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Wake modelling combining mesoscale and microscale models

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CRES

DTU Wind Energy
Department of Wind Energy

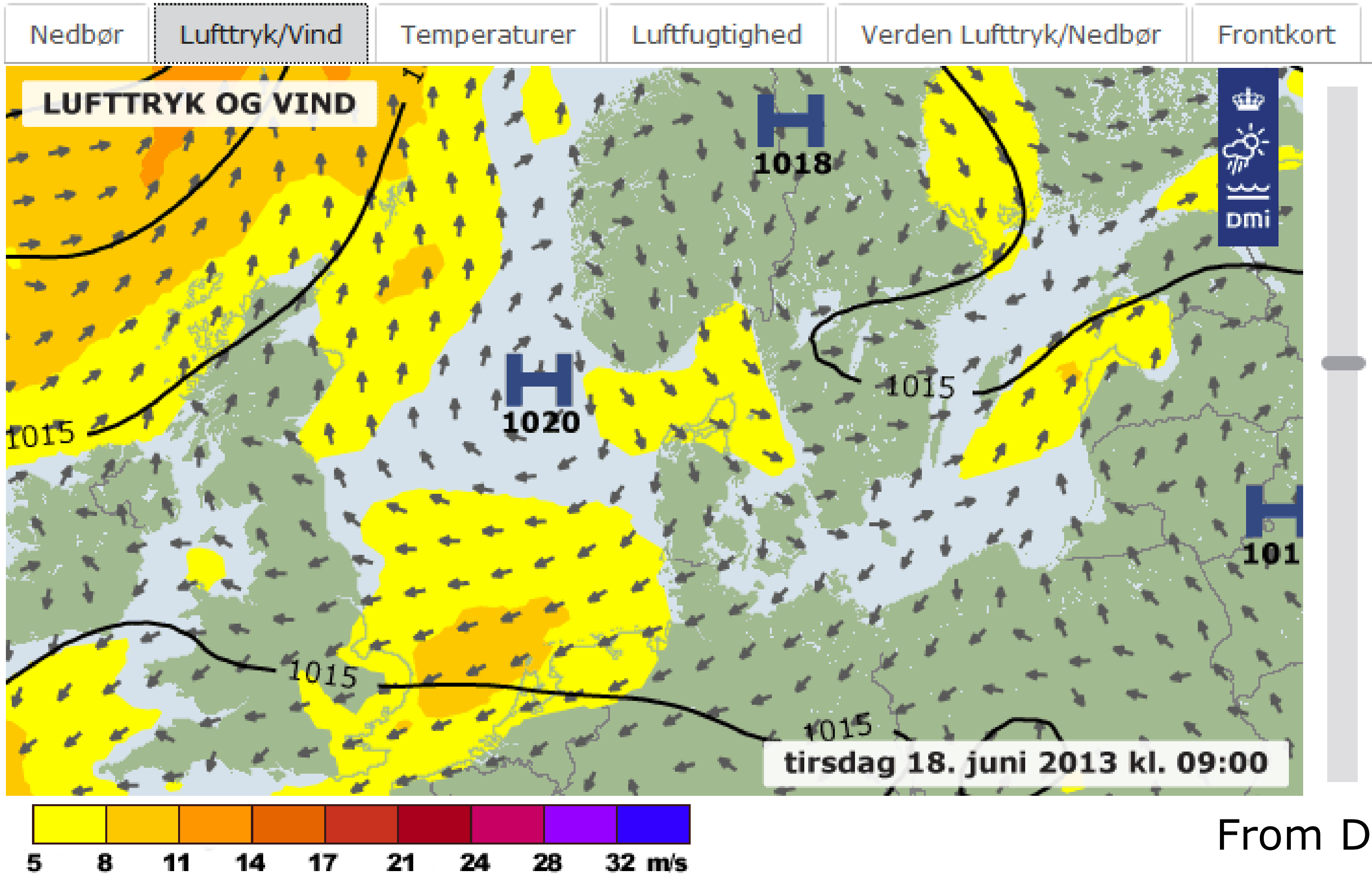
EERA DTOC

Introduction - EERA-DTOC

- European Energy Research Alliance
- **DTOC: D**esign **T**ool for **O**ffshore (wind farm) **C**lusters
- EU-FP7 funded project, 2012-2015
- Focus on designing wind farm **clusters**

EERA DTOC
THE EUROPEAN ENERGY RESEARCH ALLIANCE
DESIGN TOOLS FOR OFFSHORE WIND FARM CLUSTER
Support by
SEVENTH FRAMEWORK PROGRAMME

Mesoscale models – ubiquitous, we see them everyday



From DMI.dk

Typical model resolutions and extent:

Horizontal: between 2 km and 20 km, extend 100 – 1000s km

Vertical: between 10 m and 30 m near to the surface, extend to several km in height

Mesoscale covers atmospheric processes with horizontal scales from ~1 km to ~100 km

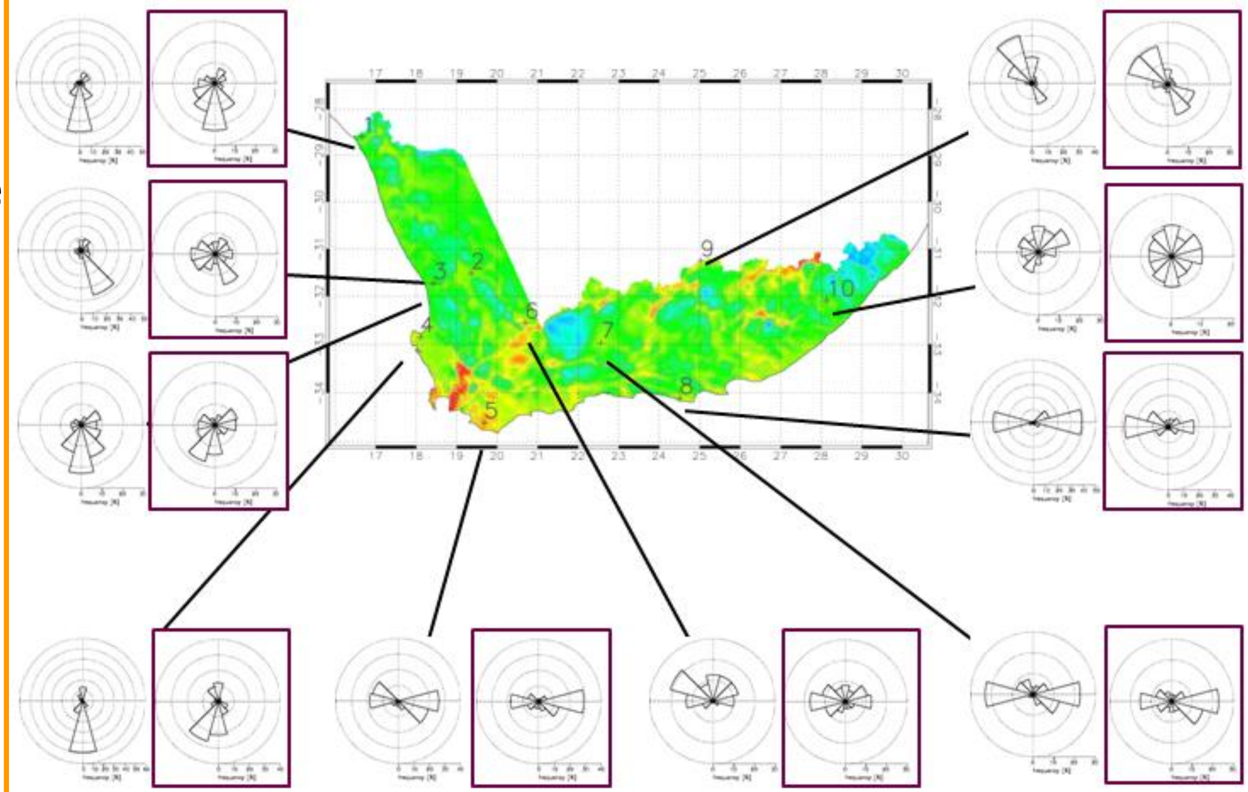
Mesoscale models - well established in wind energy

DTU Wind Energy has developed:

KAMM/WAsP
WRF/WAsP

methodologies for resource estimation.

unboxed mesoscale modelling, boxed from measurements
Wind Atlas for South Africa http://www.wasaproject.info/



Mesoscale models used extensively for wind power forecasting....

Motivation

Microscale models
- wind farm scale
- analytical or semi-analytical
- CFD

Mesoscale model
- cluster scale
- WRF community model
- idealized or realistic modes

Motivation

Detail of how turbine wake interact
Individual turbine thrust
Potential for detail of wake expansion

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Stability conditions
Mesoscale phenomena included
- terrain induced
- synoptically induced

Spatially inhomogeneous wind speed and direction
Temporally unsteady wind fields
Very far extension of farm wakes
Long range farm wake recovery

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By means of look-up table

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A new mesoscale wind farm wake parameterization

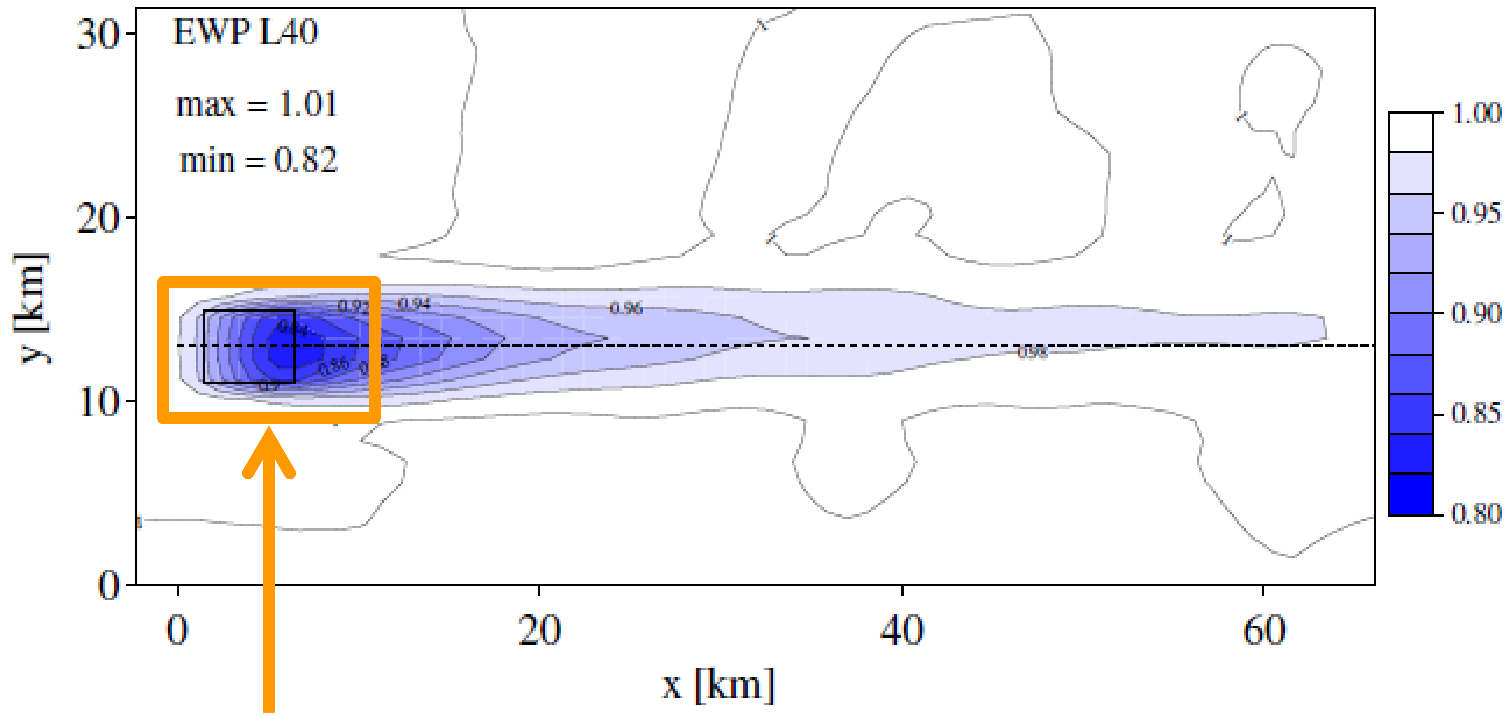
Advert: June 19 9:15-9:35

Patrick Volker

Technical University of Denmark

"Wind farm parameterizations in mesoscale models"

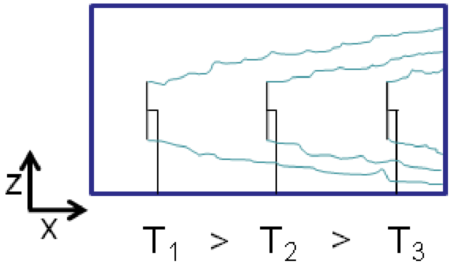
Explicit Wake Parameterization **EWP**



Typical domain for microscale wake modelling

How to include turbine wake in mesoscale models?

Sub-grid scale detail



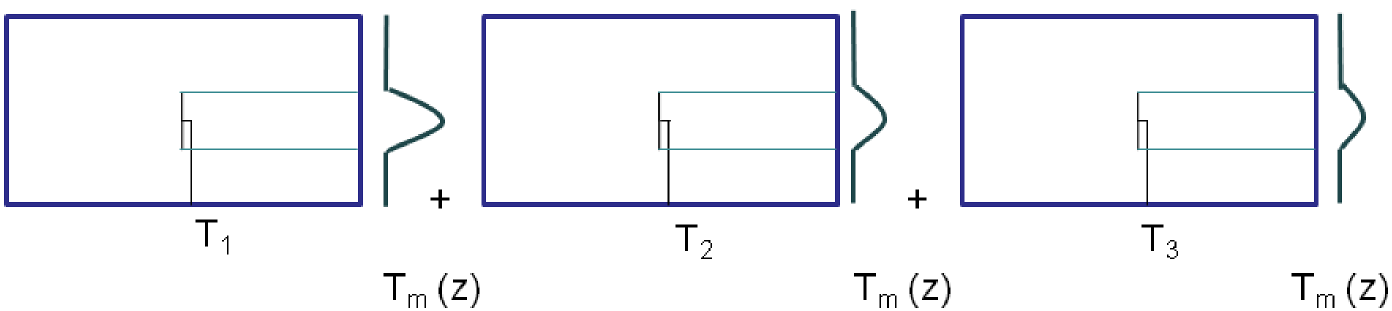
Thrusts, T_i, not equal

Will consider turbine as drag devices.

Where does thrust calculation come from?

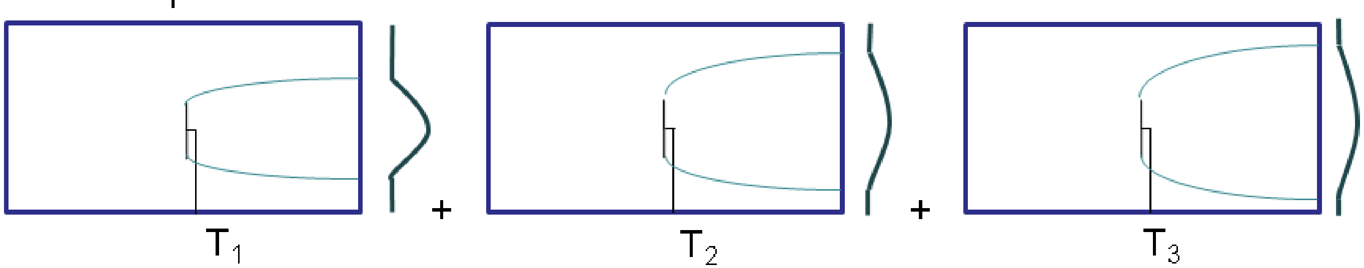
How will velocity deficit be
- distributed vertically?
- distributed horizontally?

Rotor distribution



No sub-grid scale wake expansion

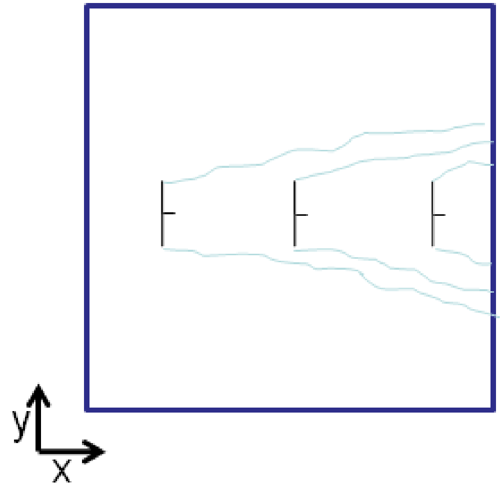
Wake expansion



model sub-grid scale wake expansion

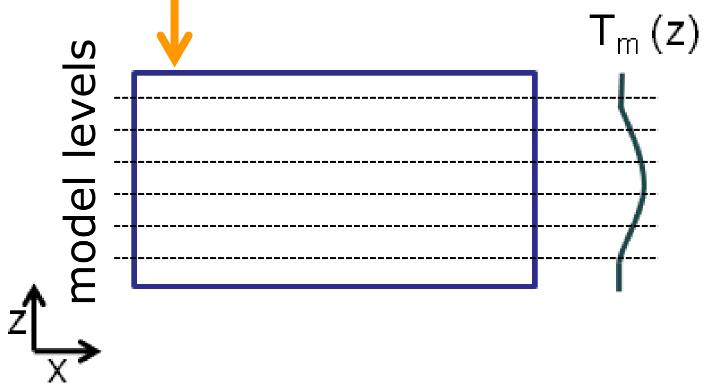
How to include turbine wake in mesoscale models?

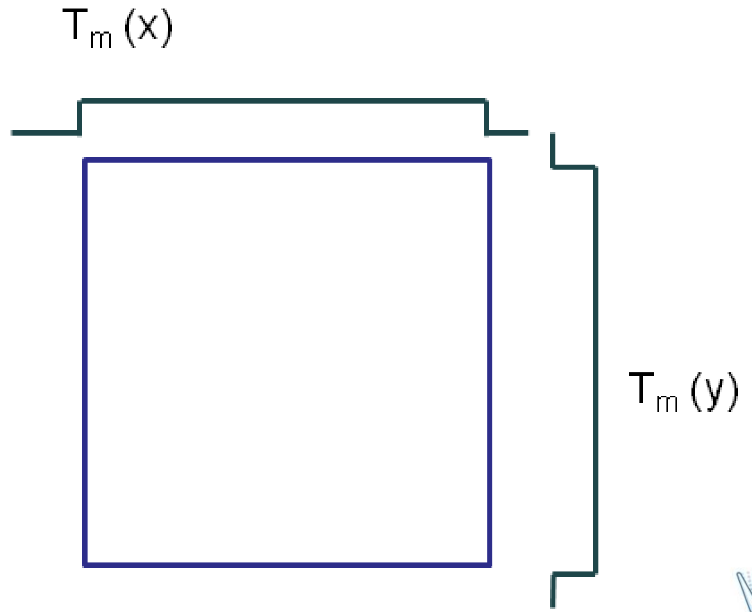
Sub-grid scale detail



Vertical distribution of velocity deficit is resolvable

Horizontal distribution of velocity deficit is not resolvable





Strategies for modelling wakes in a mesoscale model

Thrust calculation from within EWP parameterization (Volker 2013)
OR
From CRESflow-NS (or other microscale or wind farm scale model)

Neglect sub-grid scale vertical wake expansion
OR
Model sub-grid scale vertical wake expansion

Aggregate thrust over mesoscale grid cell
OR
Aggregate thrust over entire wind farm extent

"Why aggregate over wind farm extent?"

Use momentum theory applied to volume containing wind farm to get effective thrust distribution including wake expansion effects.

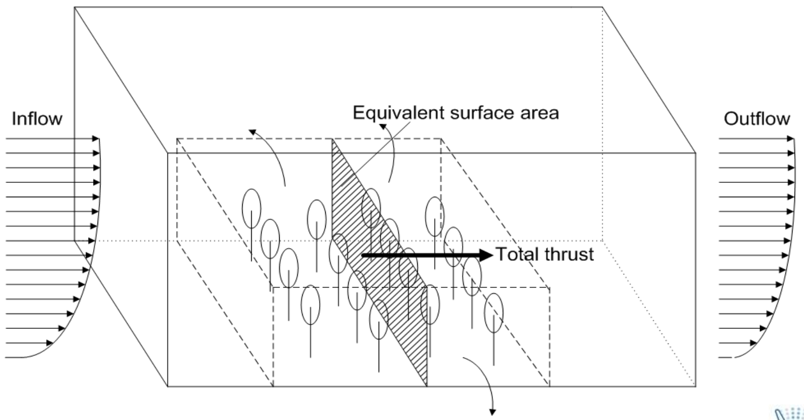


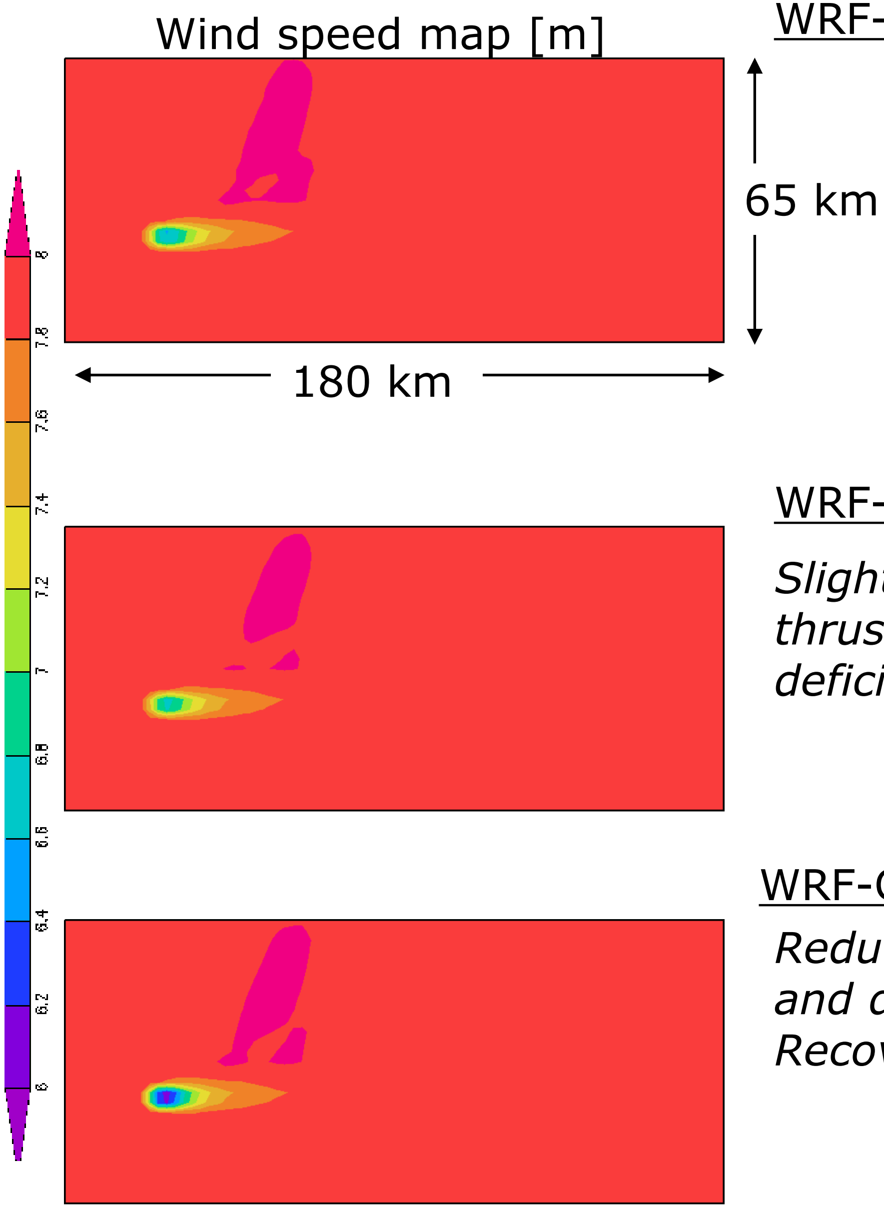
Figure from J. Prospathospoulos, 2013

Microscale wake model output -> mesoscale modelling

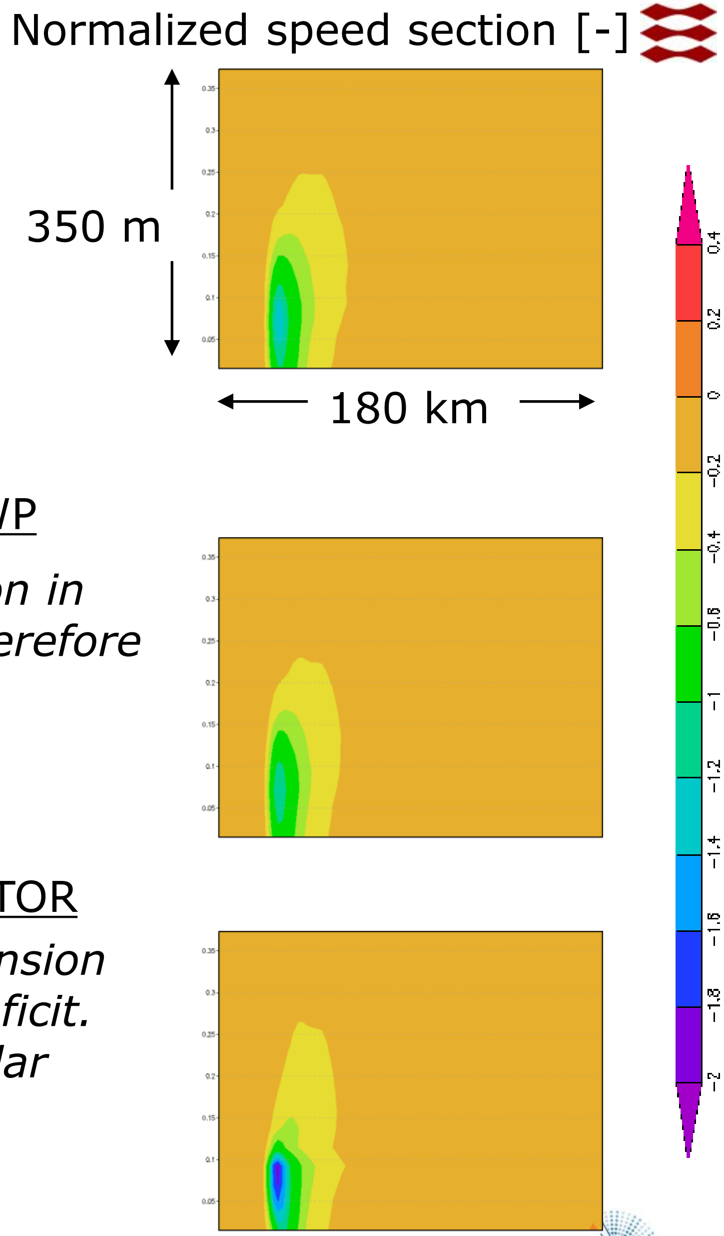
- WRF-EWP
  - EWP Wake parameterization as in Volker et al (2013)
  - Turbines' thrust from turbine thrust curve
  - Vertical wake extent evolves according to diffusive process model
- WRF-CRES-EWP
  - Turbines' thrust from CRESflow-NS
  - Vertical wake extent evolves according to diffusive process model
- WRF-CRES-ROTOR
  - Turbines' thrust from CRESflow-NS
  - Vertical wake extent according to rotor swept area (as in Fitch et al, 2012)
- WRF-CRES-ROTOR-FA
  - Turbines' thrust from CRESflow-NS
  - Vertical wake extent according to rotor swept area (as in Fitch et al, 2012)
  - Single wind farm thrust applied in single "effective wind farm plane"

Parameterization	thrust calculation	vertical thrust distribution	aggregation
WRF-EWP	turbine thrust curve	diffusive wake expansion	meso grid aggr.
WRF-CRES-EWP	CRES	diffusive wake expansion	meso grid aggr.
WRF-CRES-ROTOR	CRES	proportional to rotor swept area per level	meso grid aggr.
WRF-CRES-ROTOR-FA	CRES	proportional to rotor swept area per level	wind farm aggr.

Results



WRF-EWP



WRF-CRES-EWP

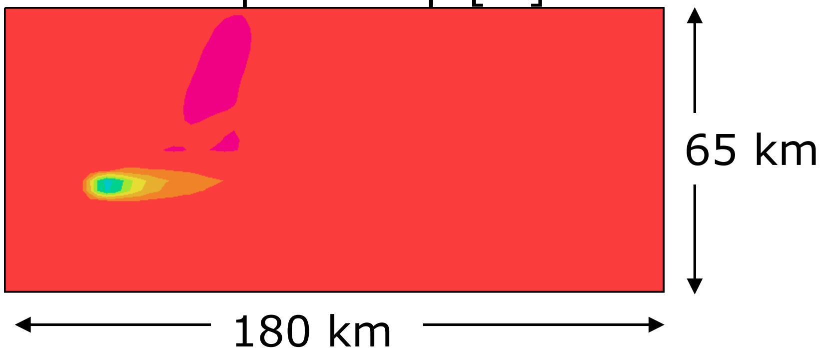
Slight reduction in thrust and therefore deficit

WRF-CRES-ROTOR

Reduced expansion and deeper deficit. Recovery similar

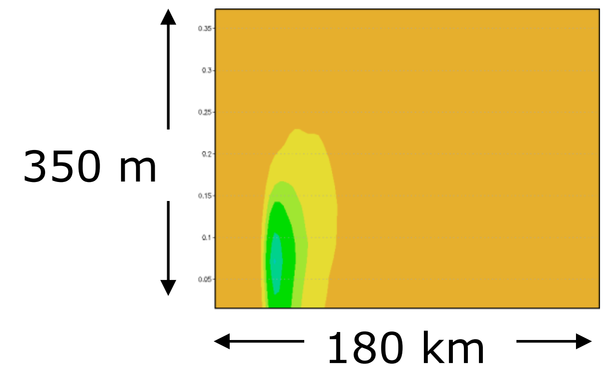
Results

Wind speed map [m]



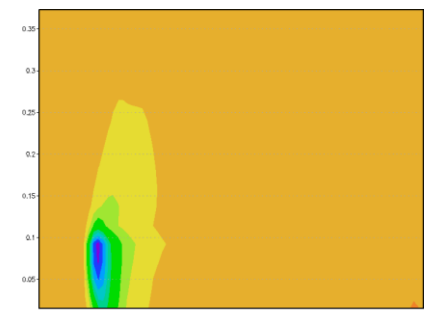
WRF-CRES

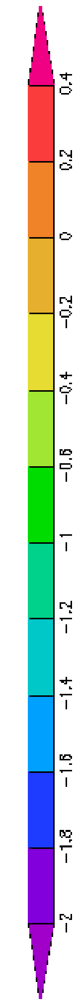
Normalized speed section [-]



WRF-CRES-ROTOR

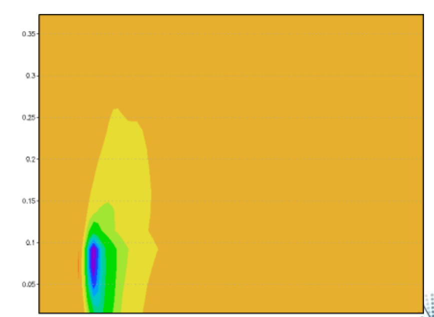
Reduced expansion and deeper deficit. Recovery similar





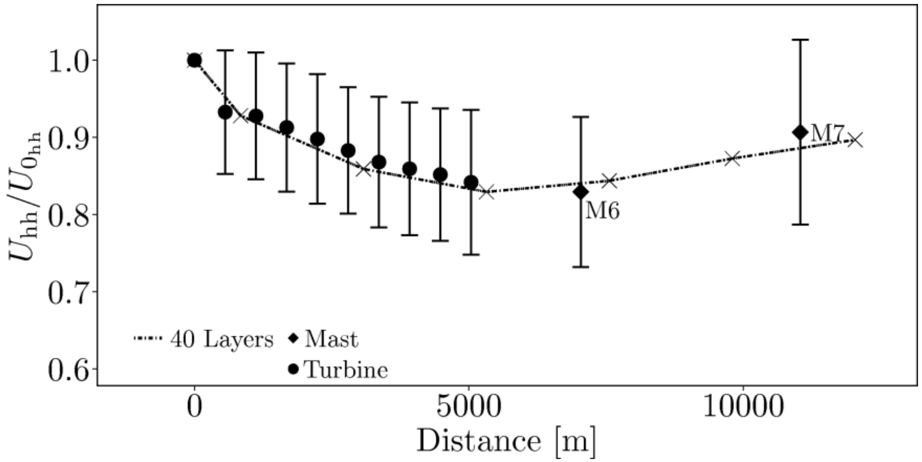
WRF-CRES-ROTOR-FA

Rapid and deep deficit. Recovery similar

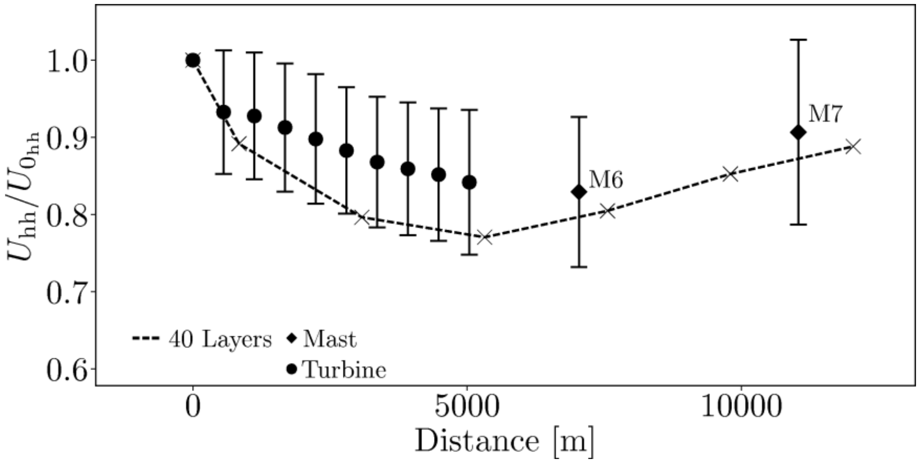


Results and validation, Horns Rev I data

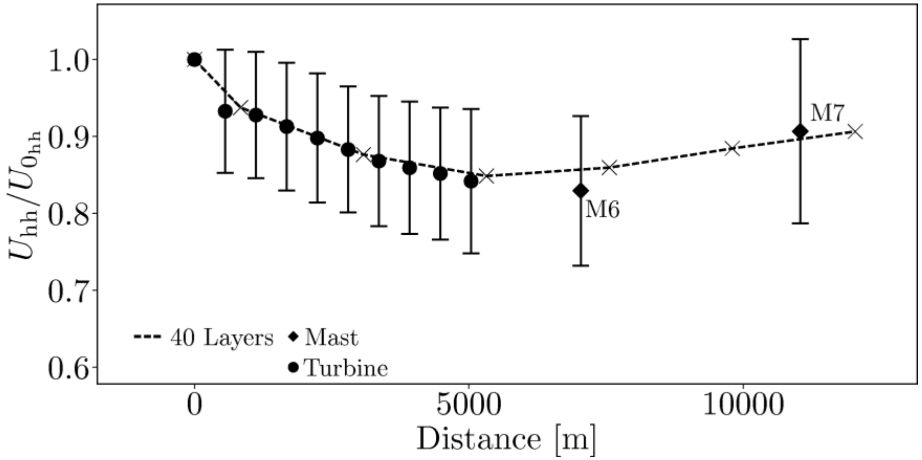
WRF-EWP



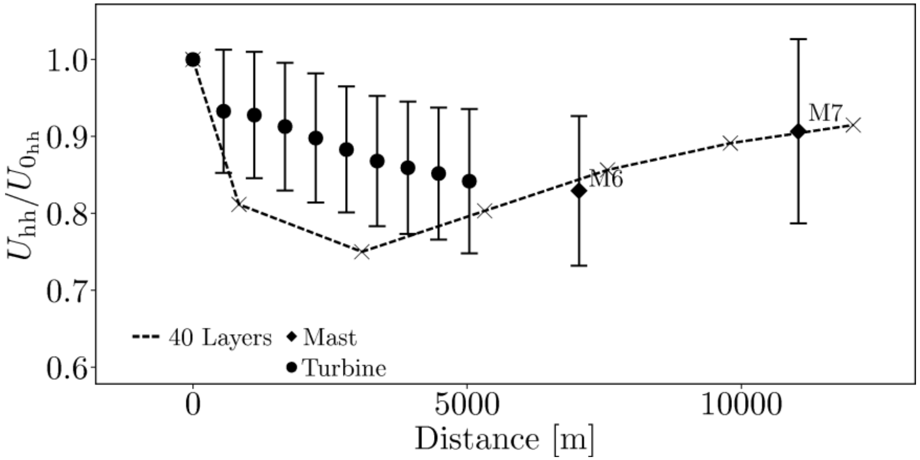
WRF-CRES-ROTOR



WRF-CRES-EWP

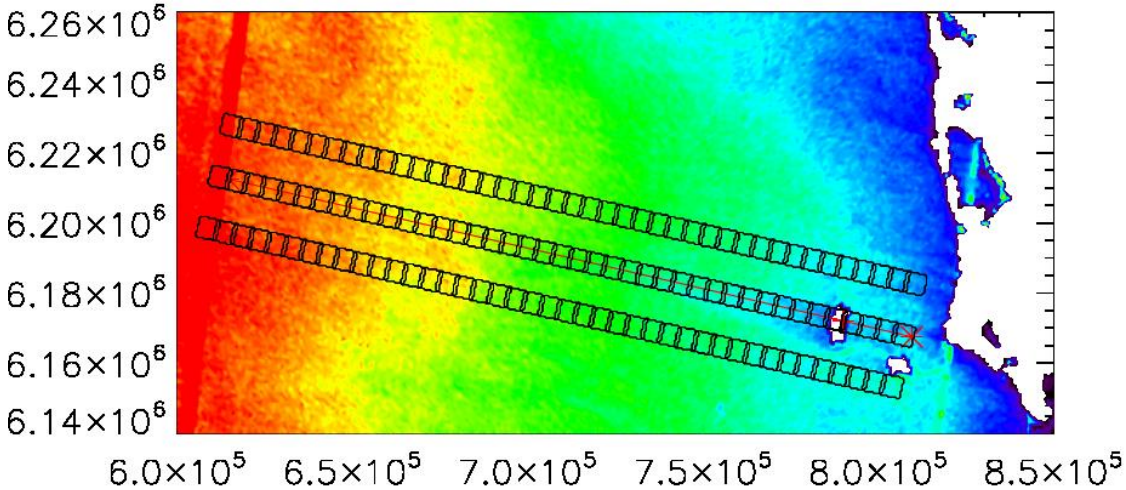


WRF-CRES-ROTOR-FA

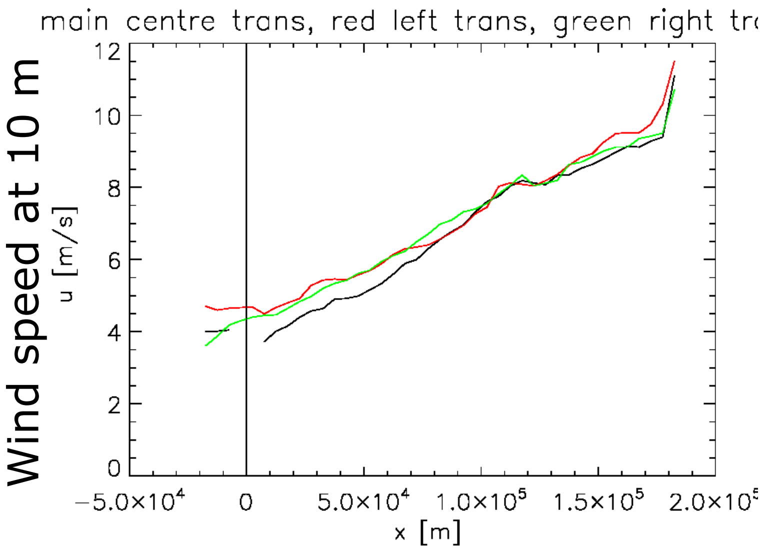


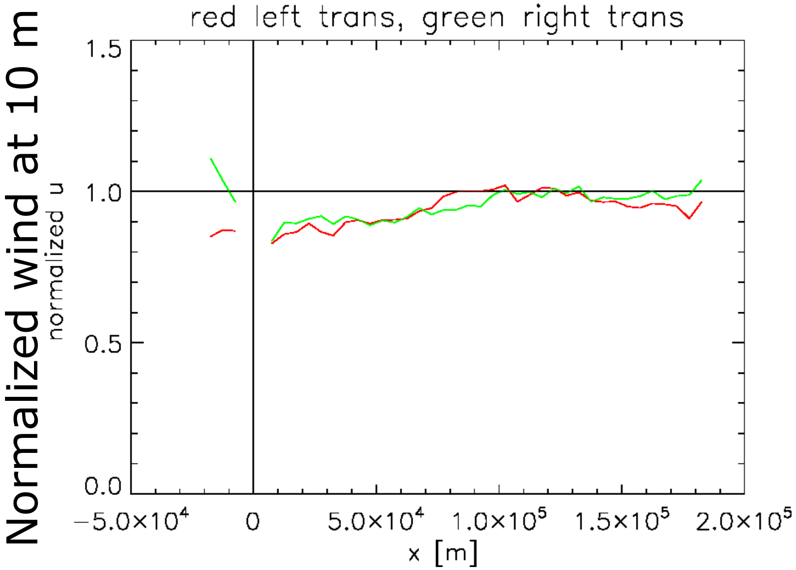
Verification against remote sensing measurements

Synthetic Aperture Radar scene derived wind speed map ("instantaneous")



SAR scene provided by Alexis Mouche, CLS, DTOC partner

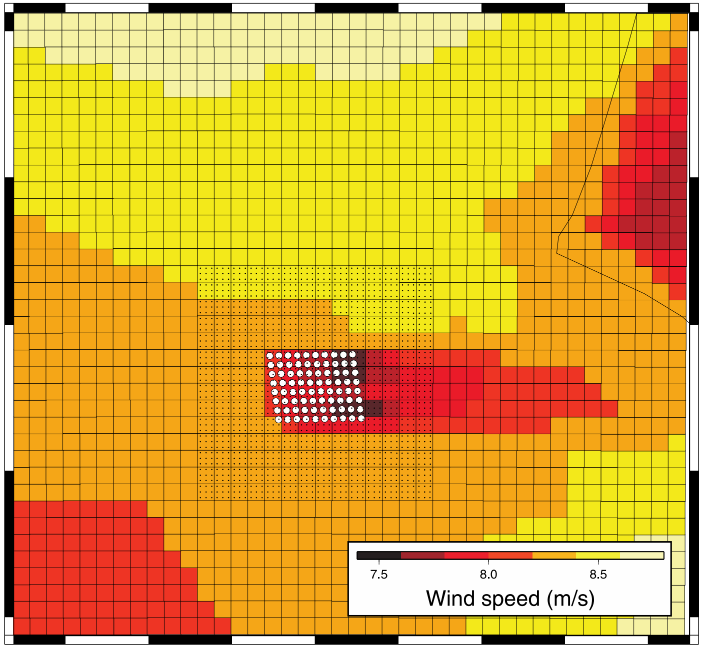




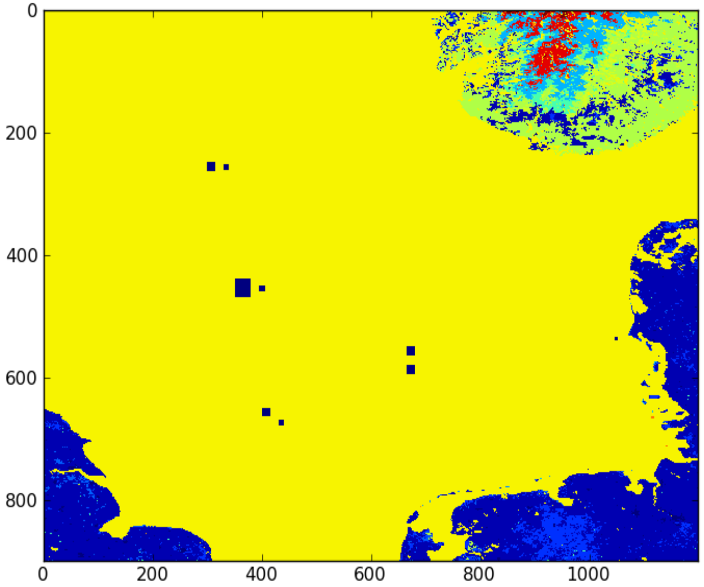
Other approaches within EERA-DTOC

CIEMAT, Spain

WRF using an already implemented wind farm wake implementation (Fitch et al, 2012) in realistic dynamical simulations



Jimenez et al. Wind Energy (under review)



CENER, Spain

SKIRON using higher aerodynamical roughness length to represent wind farm in realistic dynamical simulations

Iván Moya Mallafré et al

Conclusions

- Demonstrated application of microscale model output in mesoscale modelling of wind farm wakes; so far with CRESflow-NS.
  - The method can use output from other microscale models.
- Future work will include analysis of SAR scenes used to quantify wake deficit over a number of offshore wind farms.
- In addition the paper sets out some strategies for including microscale wake model results in mesoscale models.

Classification of mesoscale wake parameterizations

Type I, the turbine thrusts come from the mesocale parameterization itself, i.e. from turbine thrust curves

Type II, the turbine thrusts come from a microscale model, precalculcated and passed to the mesoscale parameterization in some way

Type IIA the thrust is given as a single turbine thrust value with no information about its distribution in space.

Type IIB, the whole flow field is available and via momentum theory the effective distribution of thrust for a given volume can be obtained.

Type i Aggregate on the basis of the mesoscale grid cells

Type ii Aggregate on the basis of the whole wind farm

The type II A/B ii was used in Prospathopoulos and Chaviaropoulos [EWEA Conference 2013].

Acknowledgements

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and
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Thanks for your attention

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