Simulating the Vertical Structure of the Wind with the WRF Model

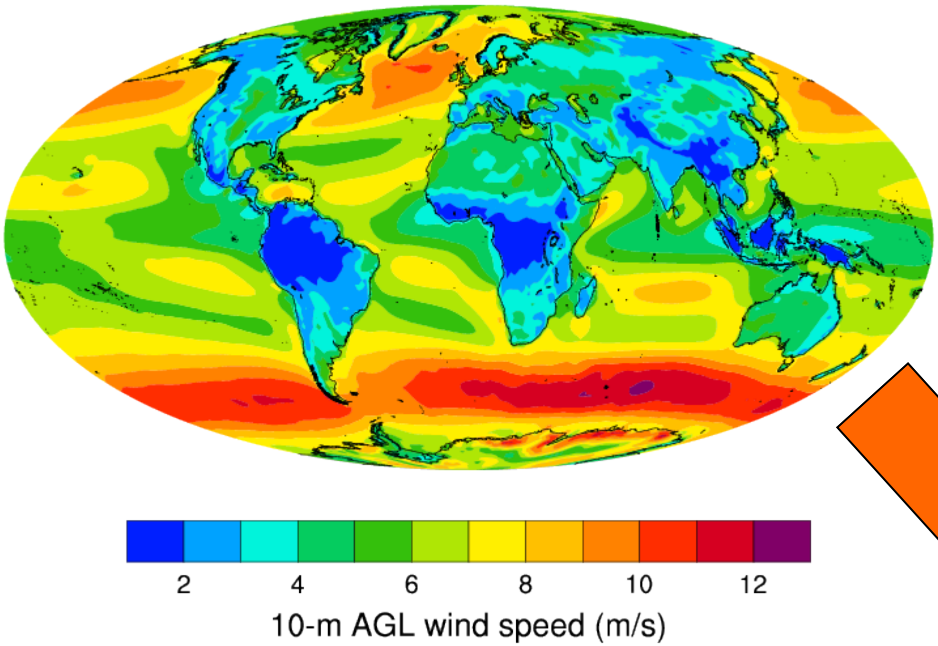
Andrea N Hahmann, Caroline Draxl, Alfredo Peña, Jake Badger, Xiaoli Lársen, and Joakim R. Nielsen

Wind Energy Division
Risø National Laboratory for Sustainable Energy
Technical University of Denmark
ahah@risoe.dtu.dk

Outline

- The problem – an introduction
- Representation of the vertical structure of the wind in WRF
- Verifying model simulated winds against measurements (brief)

ERA Interim reanalysis averaged winds (1989-2009)



Climate (Atmospheric reanalysis) Models → Resource estimation at the wind farm level

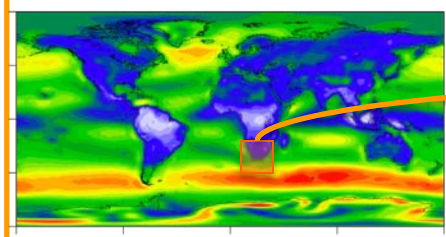
?

wind farm

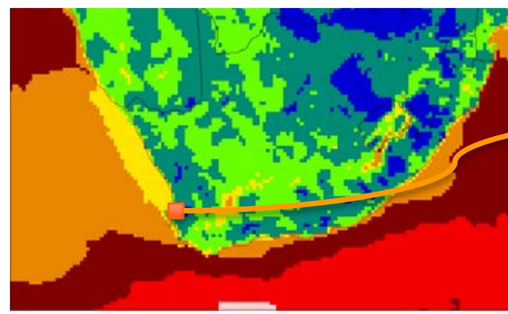
Weather (Numerical Weather Prediction - NWP) Models → Power forecast at the wind farm

Typical downscaling steps

Global



Regional



Local

Mesoscale modeling
KAMM, MM5, **WRF**, etc.

Microscale modeling
(WAsP, CFD, etc)
or statistical technique

WAsP: Wind Atlas Analysis and Application Program

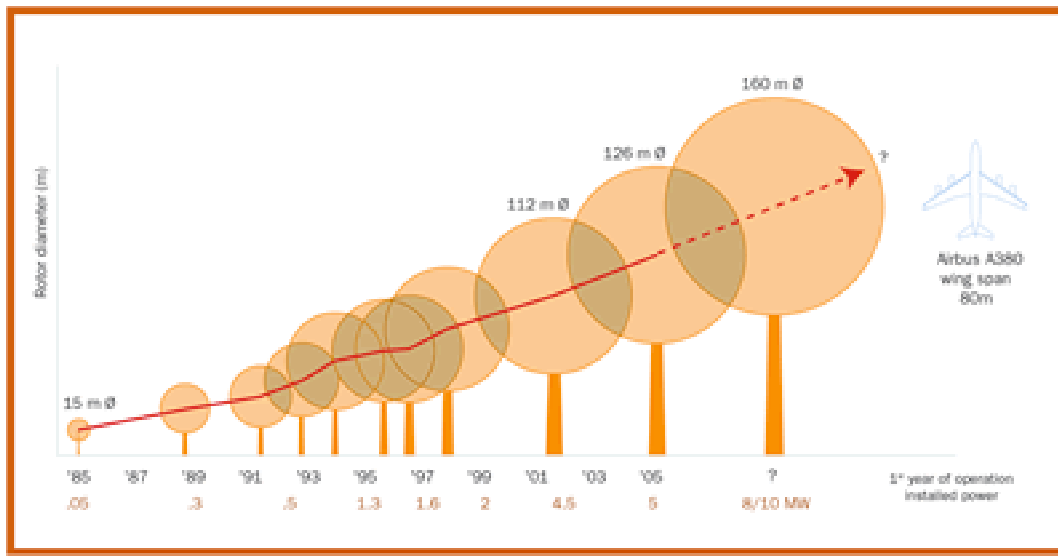
http://www.wasp.dk

What is important for wind energy applications?

- Accurate prediction/simulation of the wind speed and direction across the depth of the rotor blade (up to 300 meters above ground for upcoming turbine models)
- Understanding the errors characteristics of the simulated wind profile to allow for intelligent coupling to microscale models

- Wind shear impacts:
  - Direct energy extraction by the turbine (what is the mean wind?)
  - the development of the wind farm wake, and thus the overall wind farm efficiency

evolution of the size of typical wind turbines



Source: Jos Beurskens, ECN

Model Configuration – Real-time forecasting system

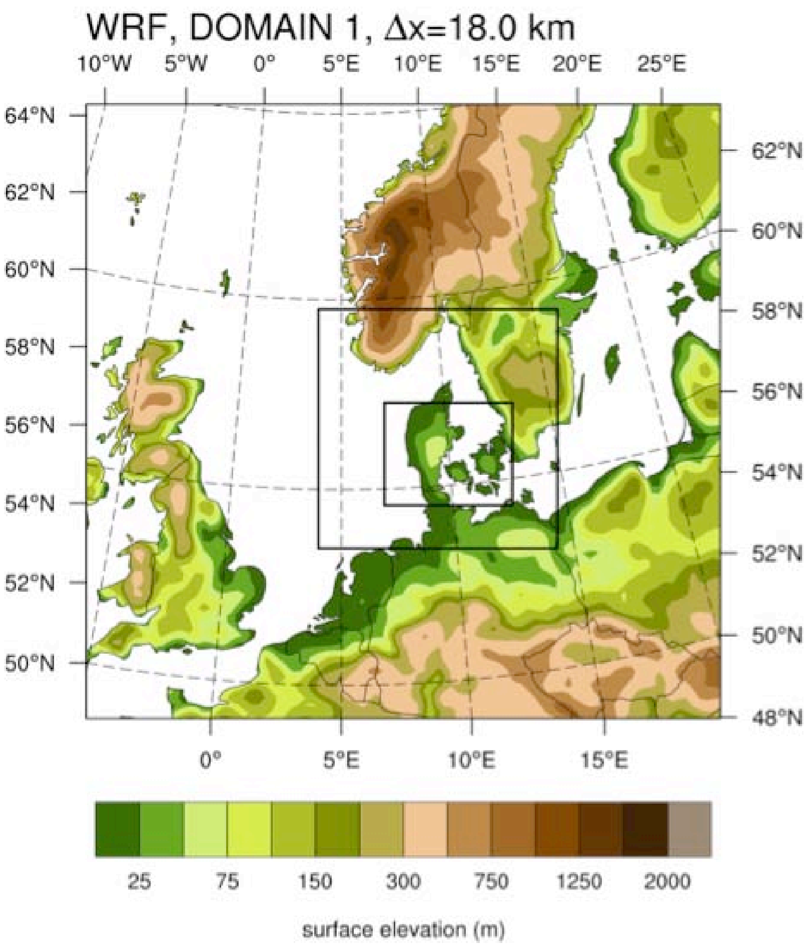


Table 1. WRF configuration
Daily runs at 12 GMT driven by GFS(1°×1°) initial and boundary conditions for the period 1-30 October 2009;
SST from NCEP at 0.5°×0.5° horizontal resolution
Each simulation lasts 30 hours; hours 0-5 are not used in the analysis
Model domain: 18 km parent domain and two nests at 6 and 2 km
37 vertical levels; lowest 4 at 14, 52, 104, and 162 meters.
No data assimilation or nudging
Besides various PBL and surface layer schemes (see Table 1), the model uses: Thompson graupel scheme, Kain-Fritsch cumulus parameterization

One month long experiment: Same everything except for the PBL + surface layer scheme (ACM2 run with PX land surface model)

Diagnosis of the wind shear

Høvsøre test center, Denmark

The parameter α is often used to diagnose the shape of the wind profile. It comes from the expression

$$\frac{u(z_1)}{u(z_2)} = \left(\frac{z_1}{z_2}\right)^{\alpha}$$

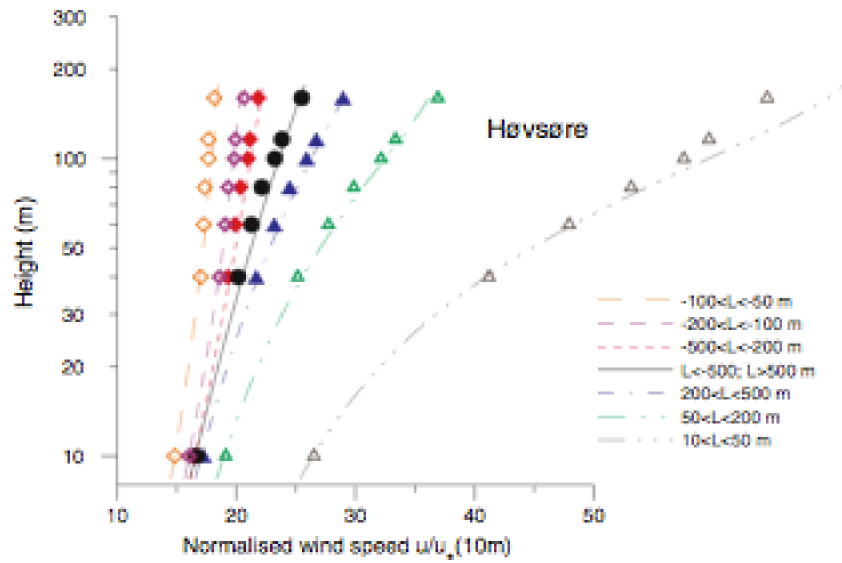
where $u(z_1)$ and $u(z_2)$ are the wind speeds at heights z_1 and z_2, respectively. α varies with height, surface roughness length, and atmospheric stability. Using similarity theory, for neutral conditions, surface roughness length of 5 cm, and z_1=10 and z_2=60 m, α=0.162. Smaller (larger) values represent unstable (stable) atmospheric BL conditions.

Boundary-Layer Meteorol (2007) 124:251–268
DOI 10.1007/s10546-007-9166-9

ORIGINAL PAPER

On the extension of the wind profile over homogeneous terrain beyond the surface boundary layer

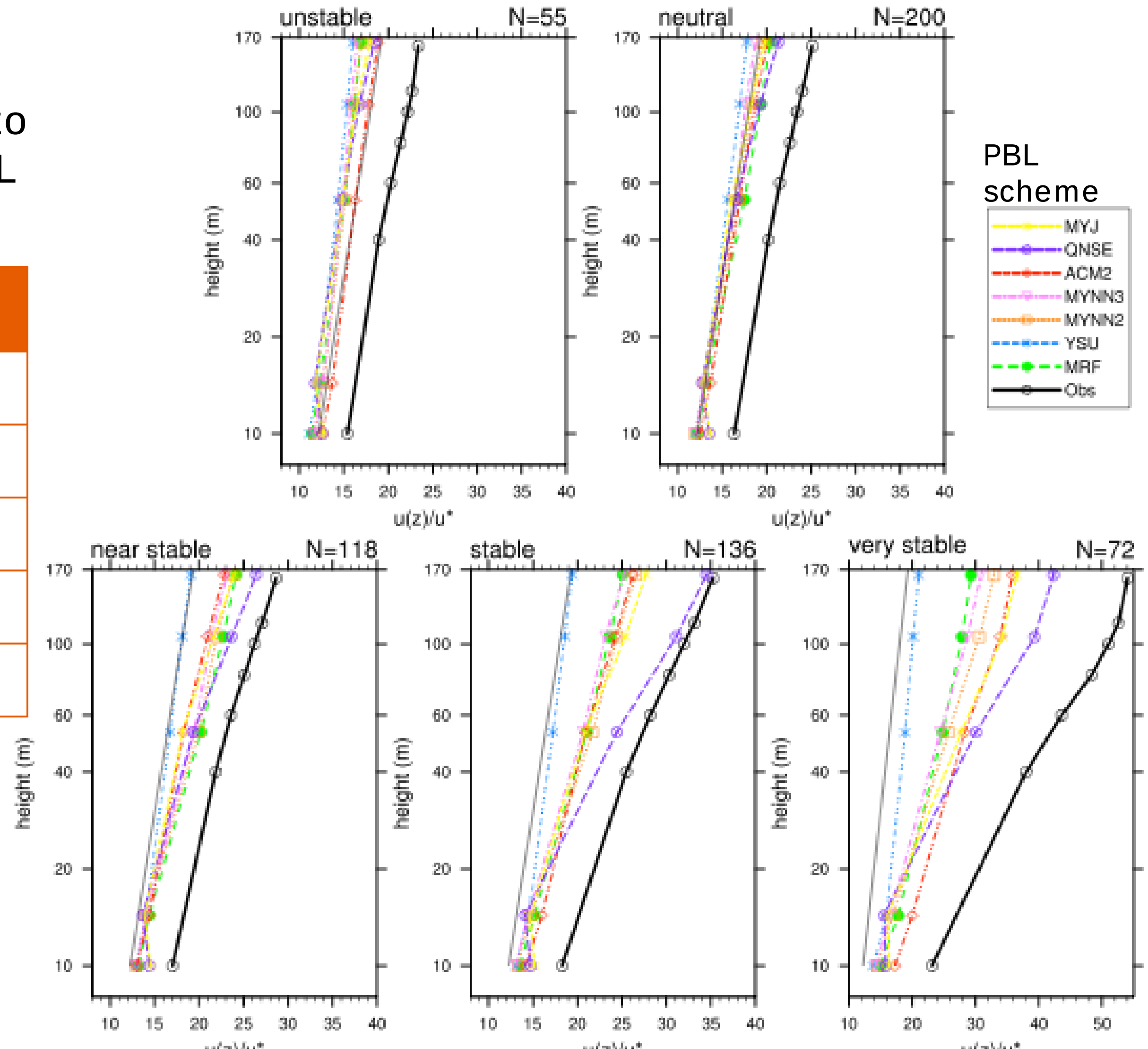
Sven-Erik Gryning · Ekaterina Batchvarova · Burghard Brümmer · Hans Jørgensen · Søren Larsen



Wind profiles grouped according to observed stability at Høvsøre, Denmark, Oct. 2009

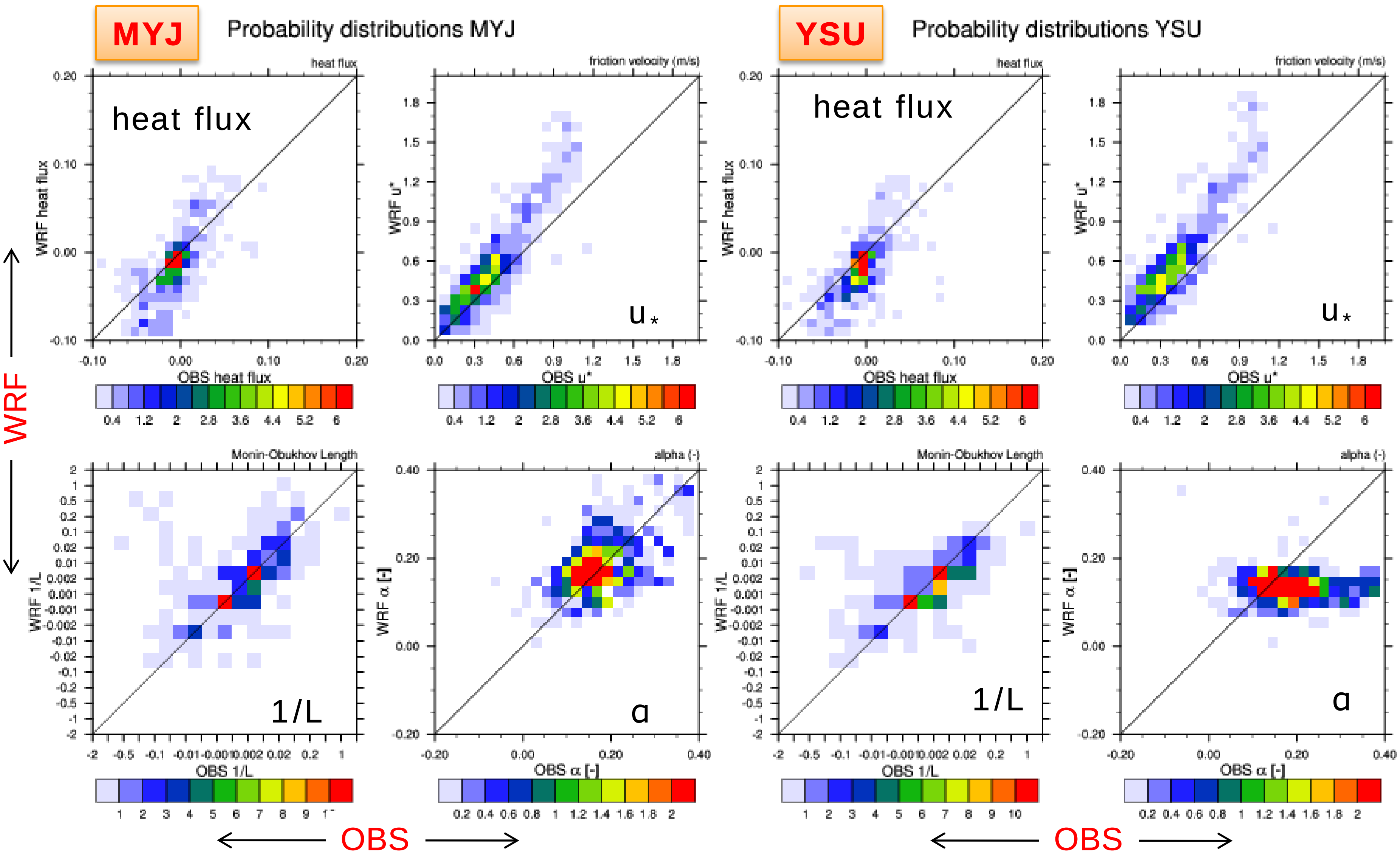
Stability classes according to the Monin-Obukhov length L (Gryning et al 2007)

Monin-Obukhov Length	stability class
-500<L<-50	unstable
L <-500; L>500	neutral
200<L<500	near-stable
50<L<200	stable
10<L<50	very stable

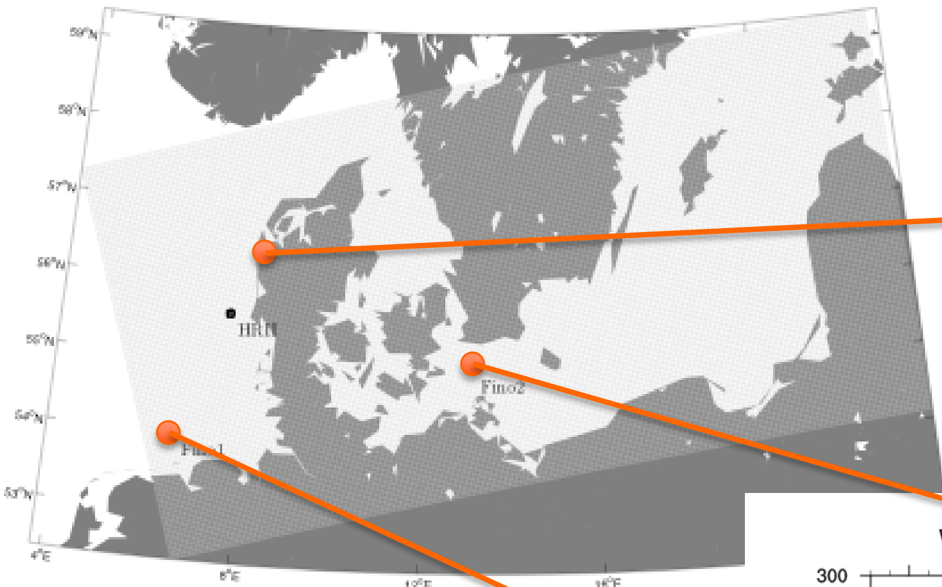


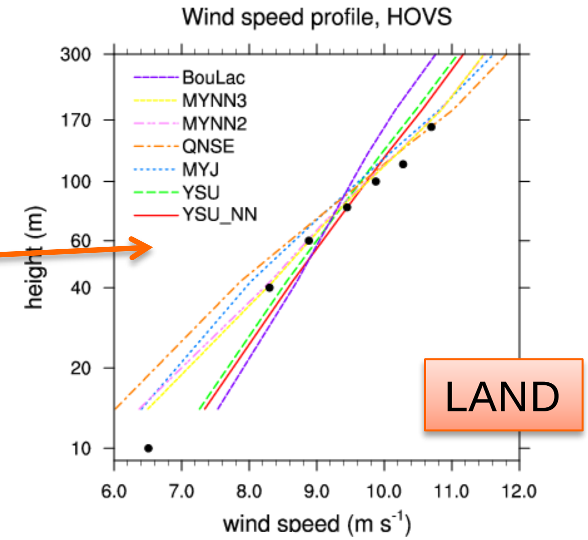
Choice of parameterizations is important

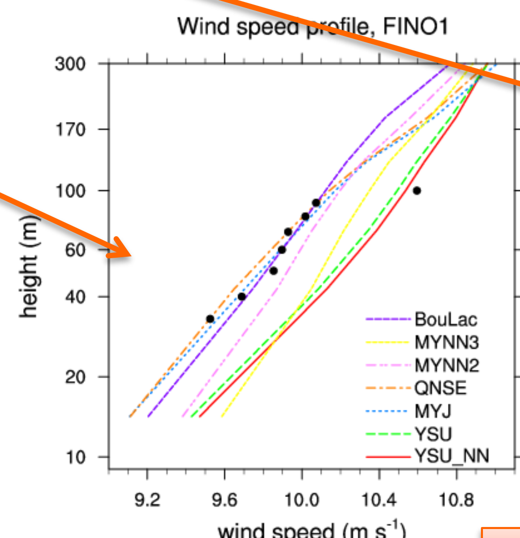
$$\frac{u_1}{u_2} = \left(\frac{z_1}{z_2}\right)^{\alpha}\text{; shear exponent; 10-60 m}$$

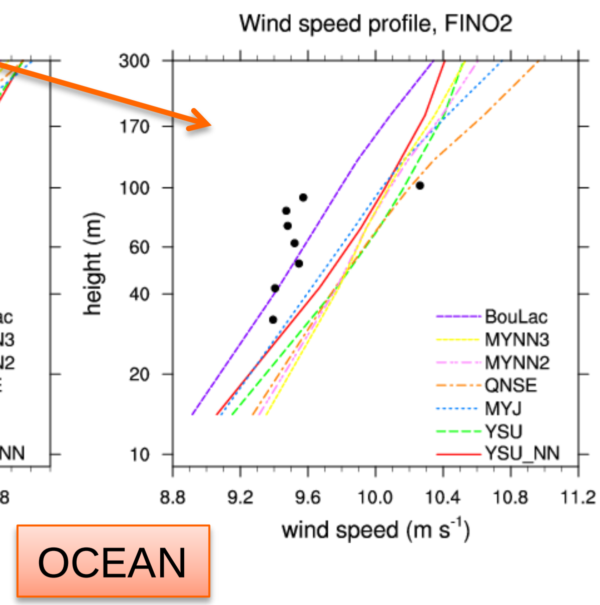


Validation of downscaling wind profiles, October 2009









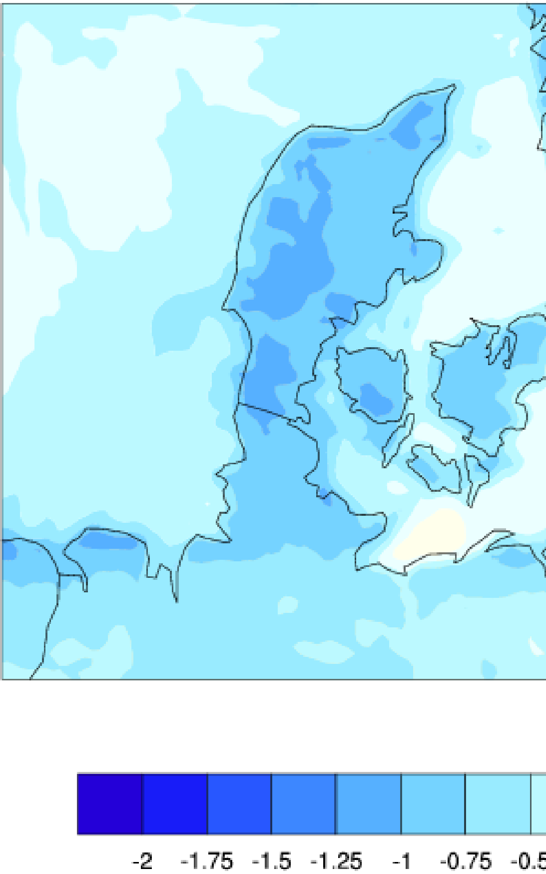
15, 5km dynamical downscaling (WRF) – CFSR reanalysis

October 2009

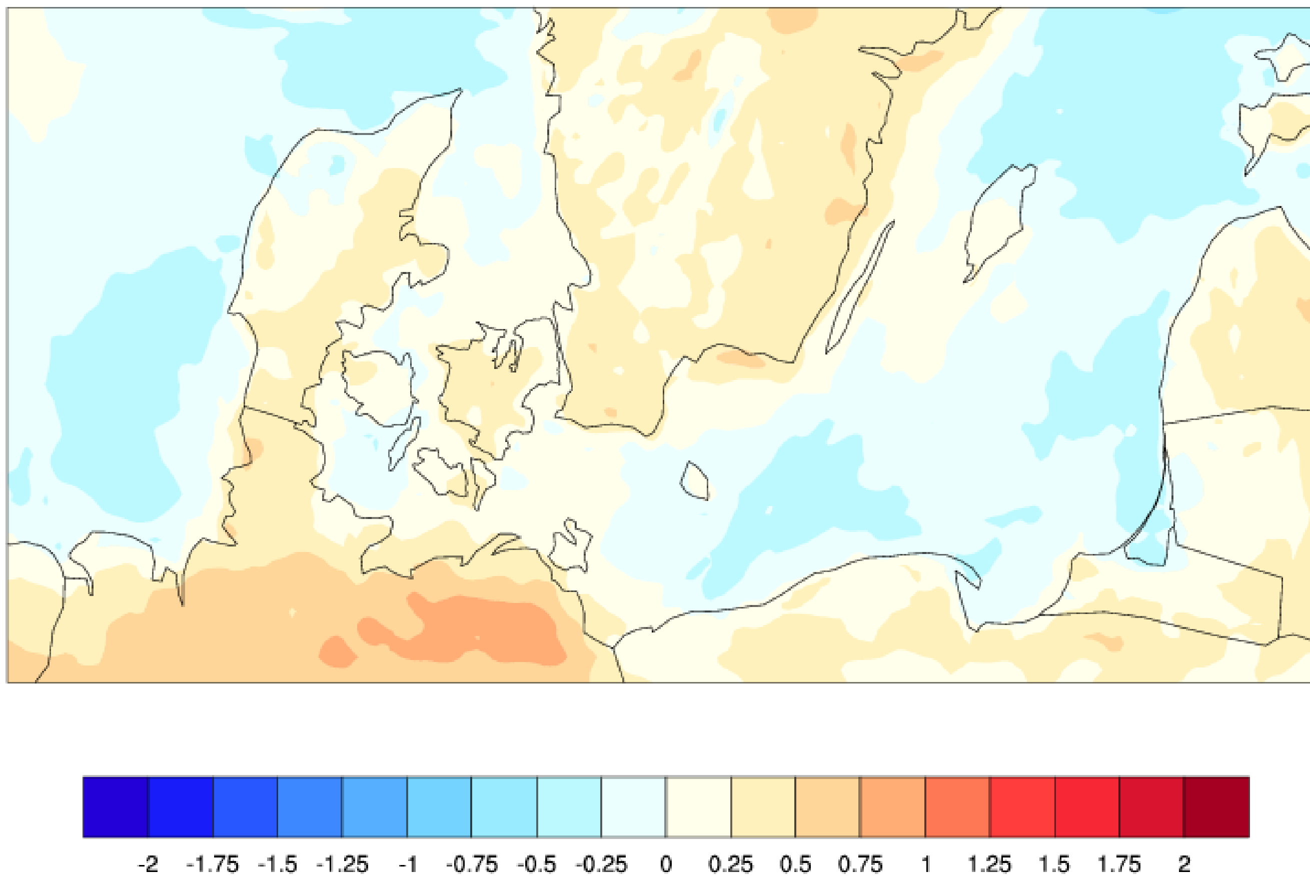
6 boundary layer schemes (MYNN2, MYNN3, MYJ, QNSE – KTE schemes, BouLac, YSU - Non-local schemes)

Monthly-mean (Oct 2009) differences in wind speed – 2 PBL schemes

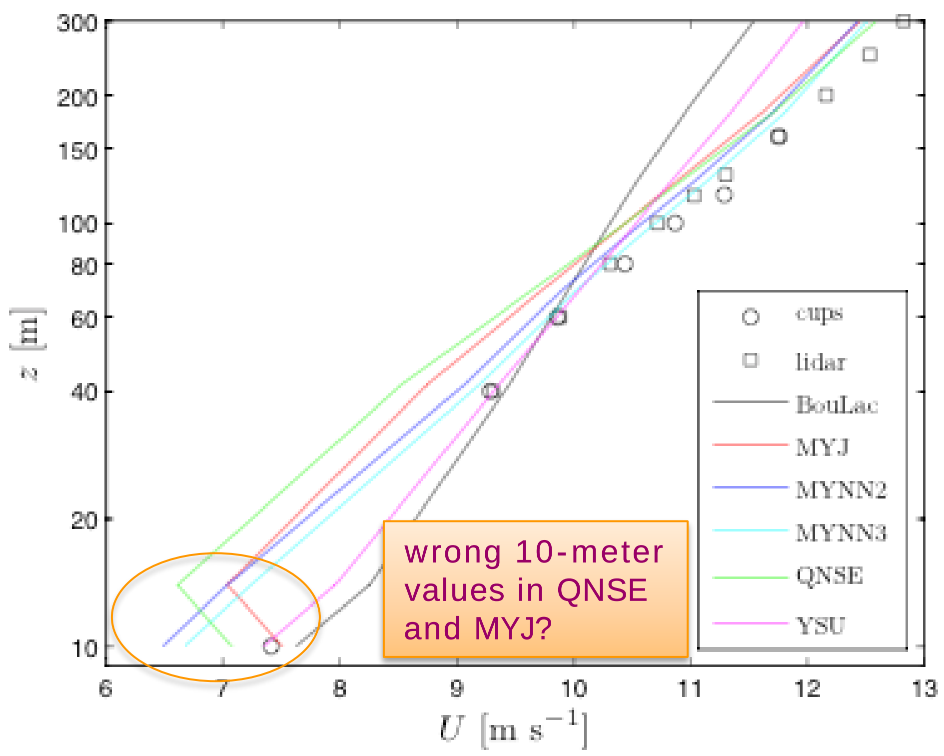
QNSE - YSU height: 42m



QNSE - YSU height: 127m



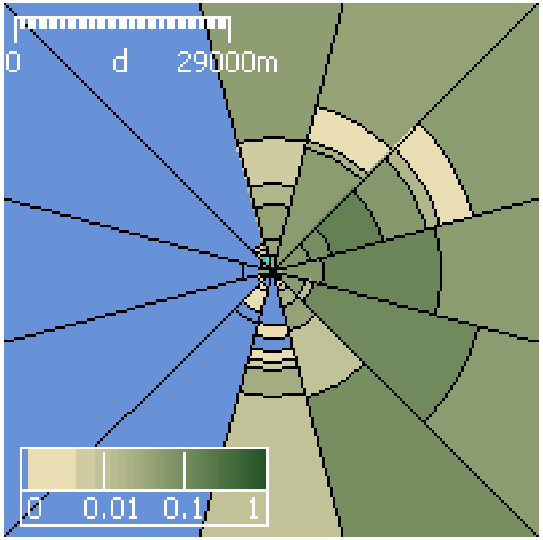
Comparison with Cups and Lidar data (Høvsøre, October 2009)



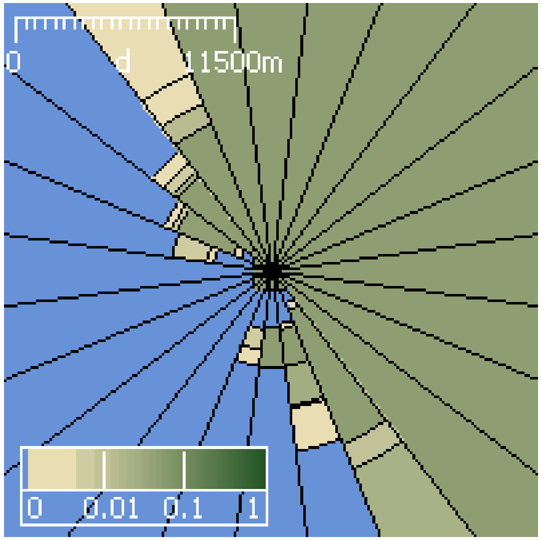
WRF versus observed wind speed measurements – all sectors

Mesoscale to microscale coupling: Need for generalization

roughness rose from high-resolution maps



roughness rose from WRF land use



To standardize measurements and model values are "corrected" using:

- WAsP speed-up factors (roughness and topography)
- Logarithmic and "geostrophic" wind laws

$$u_z = u_{0z}/[(1+s_0)(1+s_r)]$$

$$u_* = \frac{\kappa}{u_z} ln(z/z_0)$$

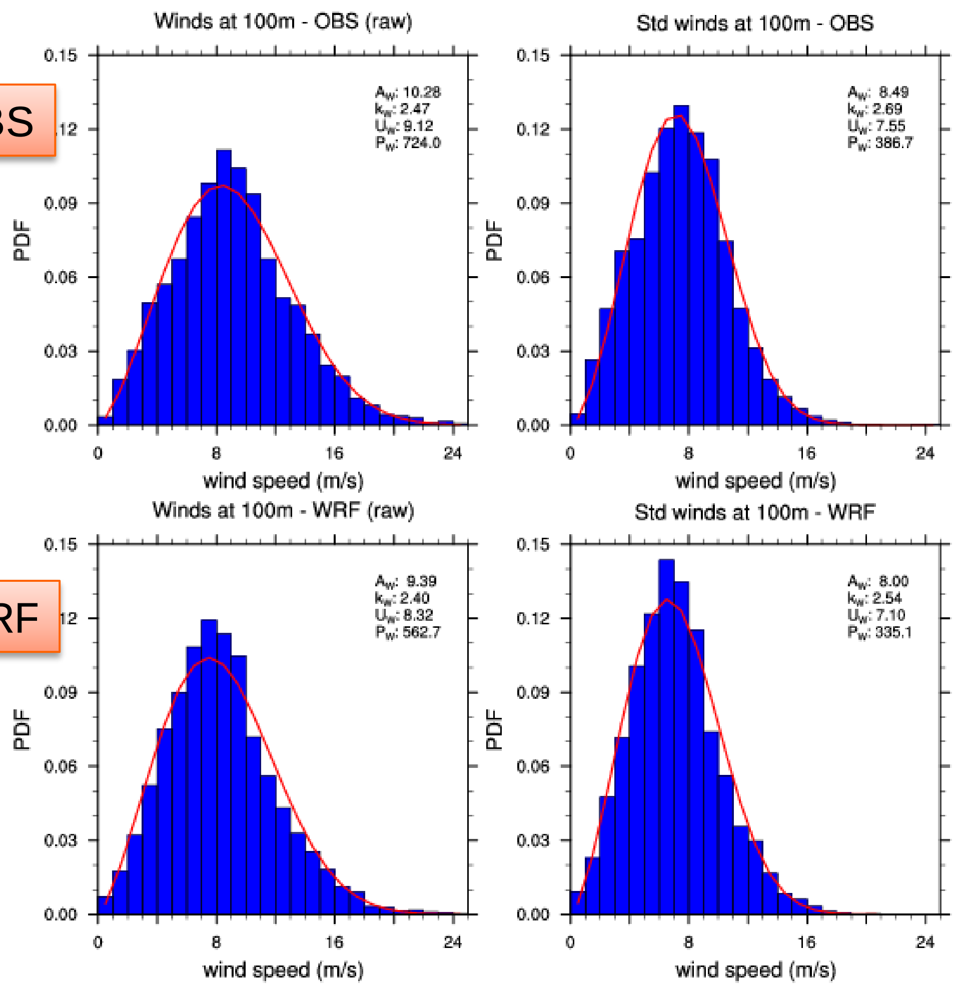
$$G = \frac{u_*}{\kappa}\sqrt{ln\left(\frac{u_*}{f z_0} - A\right)^2 + B^2}$$

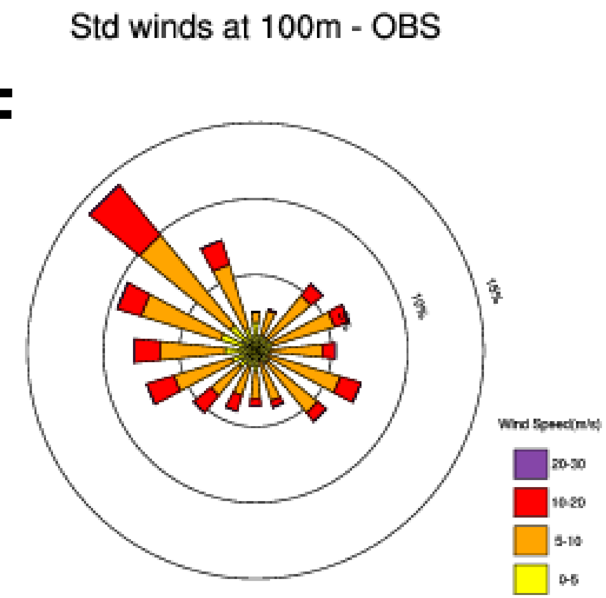
Equations are applied per sector to a standard z0 and z

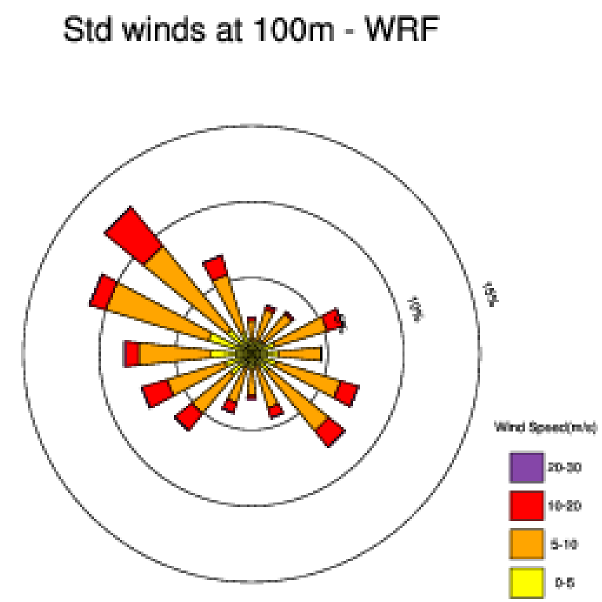
Example of wind generalization for Høvsøre mast measurements and WRF

OBS

WRF







Summary

- Atmospheric mesoscale models are used for both wind power forecasting and wind resource assessment
- Impact of choice of parameterizations (PBL, surface layer): large, will depend on climate regime and the local topography
- **Validation is a must,** especially with high quality **wind profiles**. 10-meter wind measurements should be avoided in the choice of parameterizations for wind energy applications
- How do we use the knowledge about the errors in the simulation to device a better coupling strategy?
- Generalization procedure can be used for a variety of applications:
  - Verification
  - Extreme winds (see poster **P30**)
  - Coupling to microscale models
  - Data assimilation