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WIND ENERGY

New European Wind Atlas

Measurement and modeling of forested areas – best practice from a NEWA benchmark

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Uppsala University Campus Gotland
Visby, Sweden

NEWA final workshop
Bilbao, April 2nd, 2019

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Learning experiences and improvements. Flow model validation case

Benchmark goal

Ryningsnäs: Compare state of the art modelling approaches. PAD inhomogeneous forest

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Ryningsnäs – What did we learn?

- Input: terrain height, PAD, fixed u_{100}
- To model 3 wind directions: 100, 240 & 290 deg

Benchmark goal

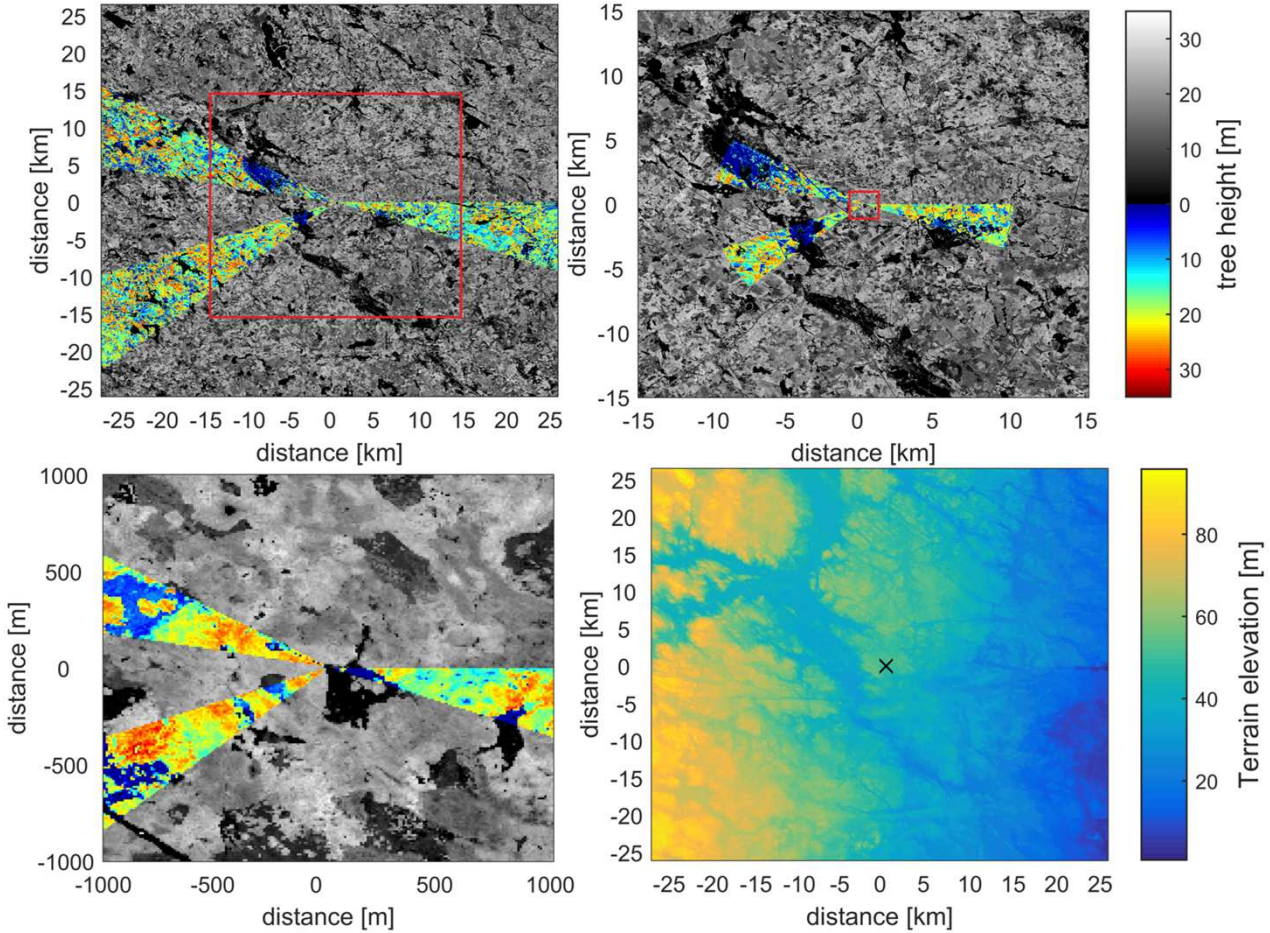
Measurement campaign

Benchmark case

Comparison strategy

Participants

Results communication



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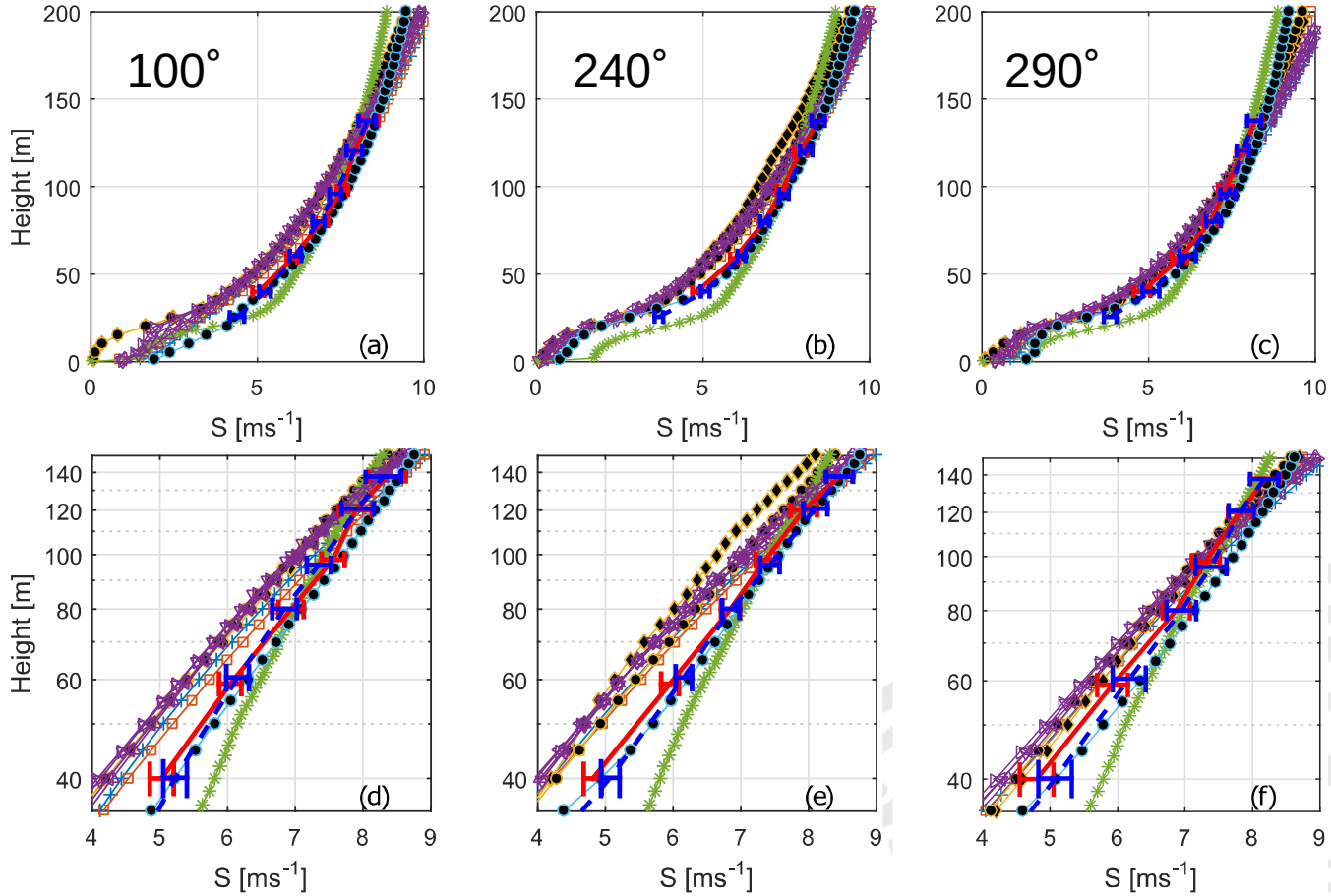
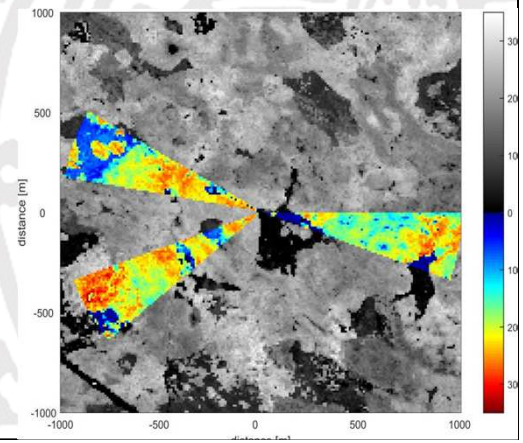


- Alya
- CFDWind
- PALM point
- PALM horizontal avg
- EllipSys 10 m
- EllipSys 50 m
- Meteodyn
- EllipSys 10 m Sogachev-const
- Ellipsys 50 m Sogachev-const
- UUCGWind LES
- Sonics
- Cups



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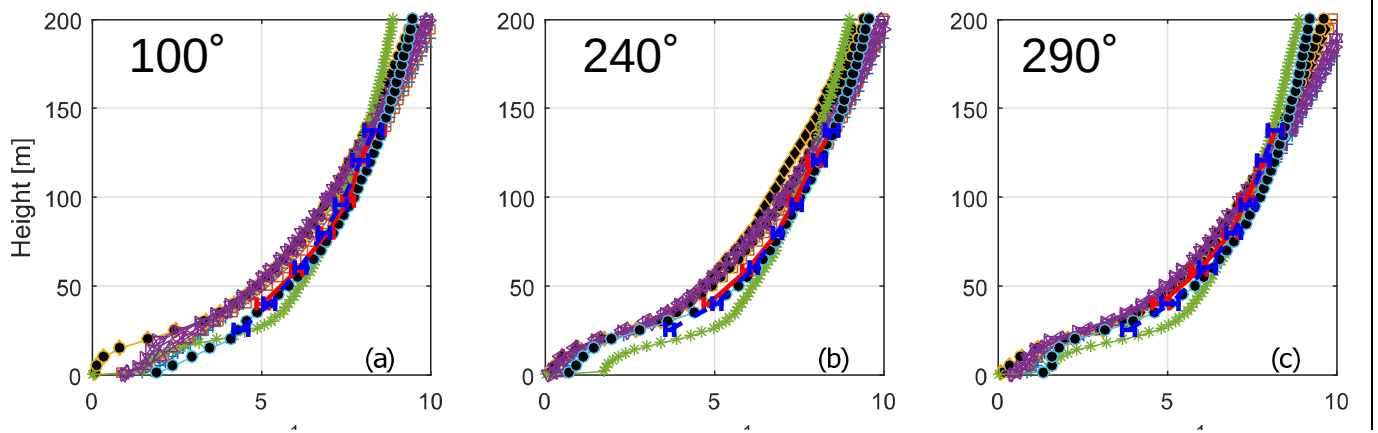

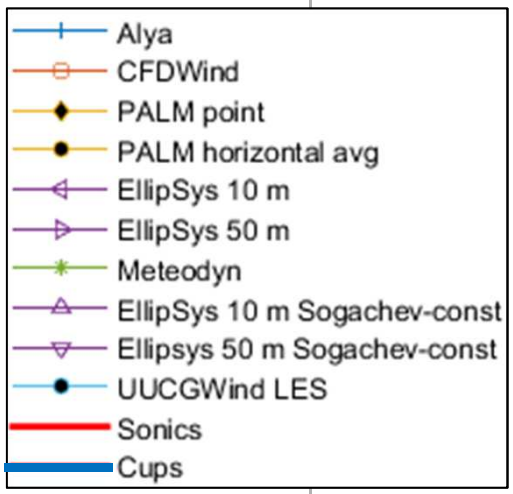

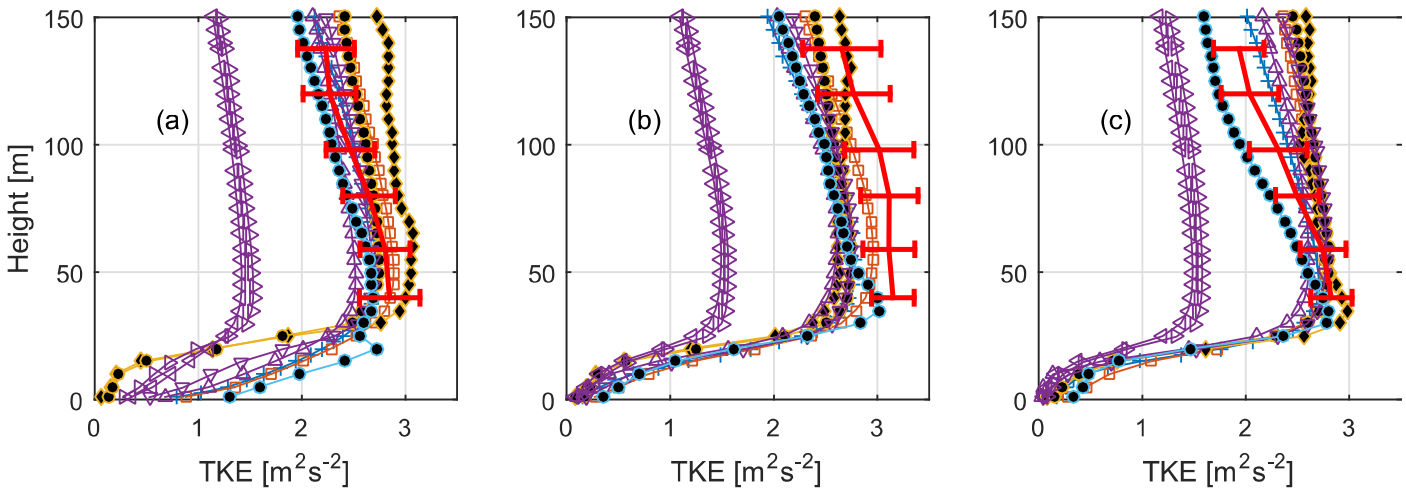

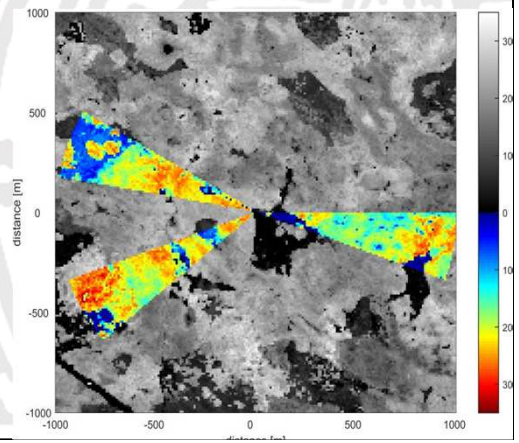

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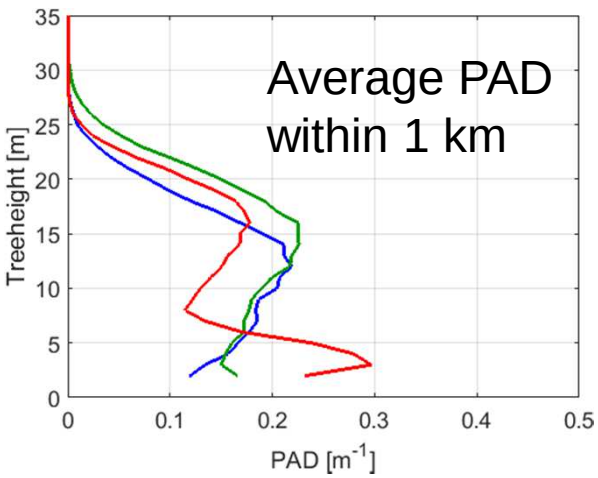
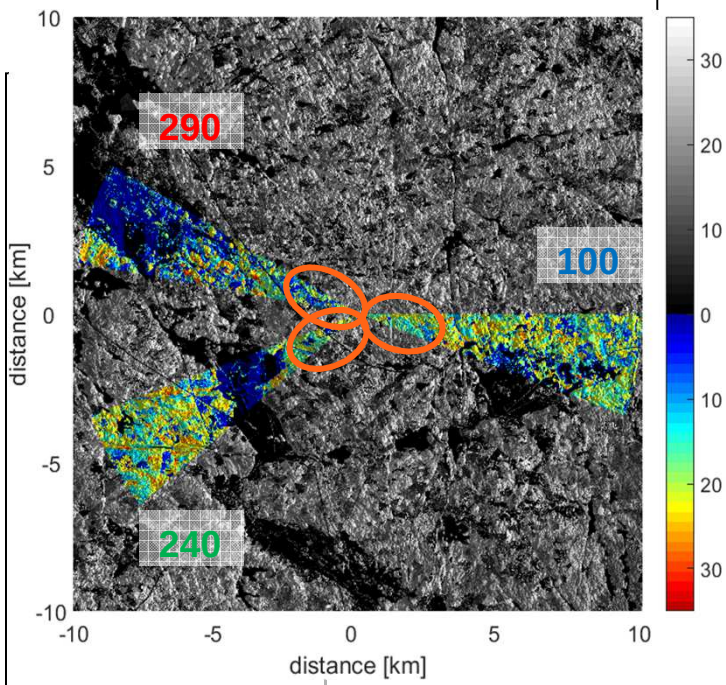
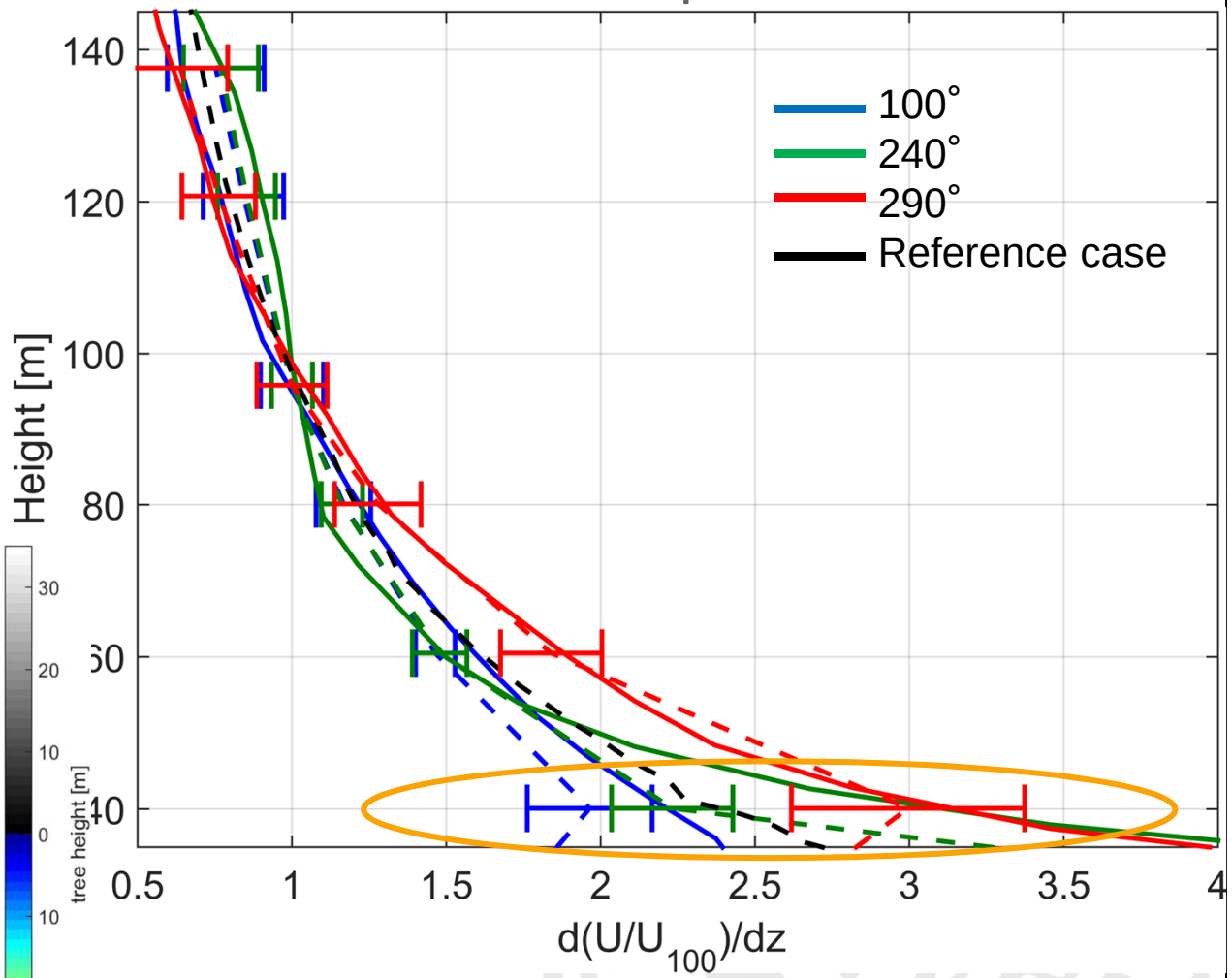
100 240 290





Benchmark Ryningsnäs – Wind shear profiles



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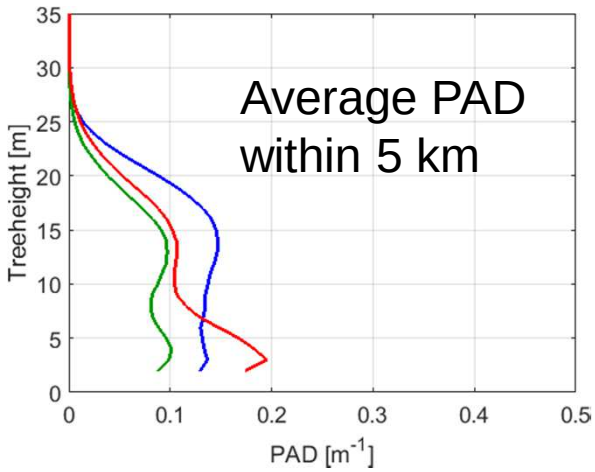

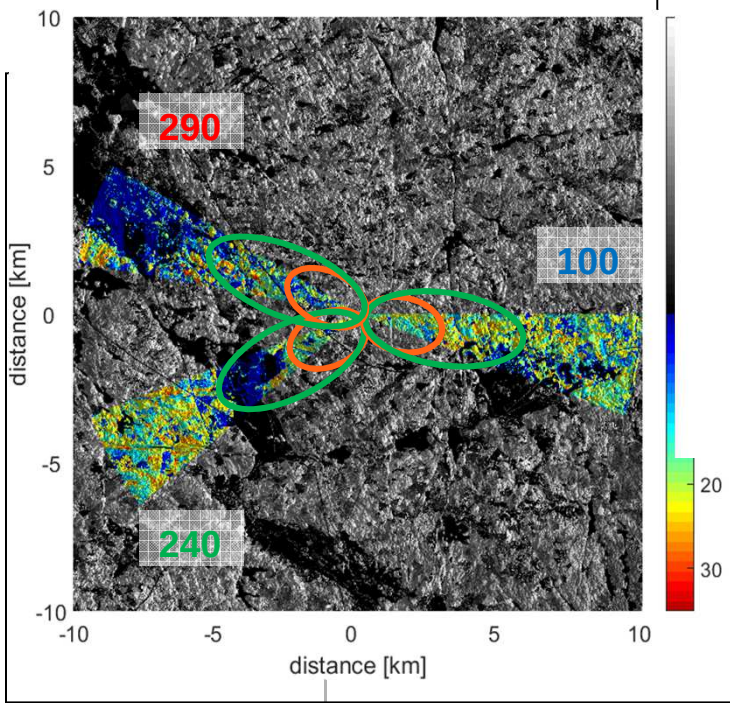

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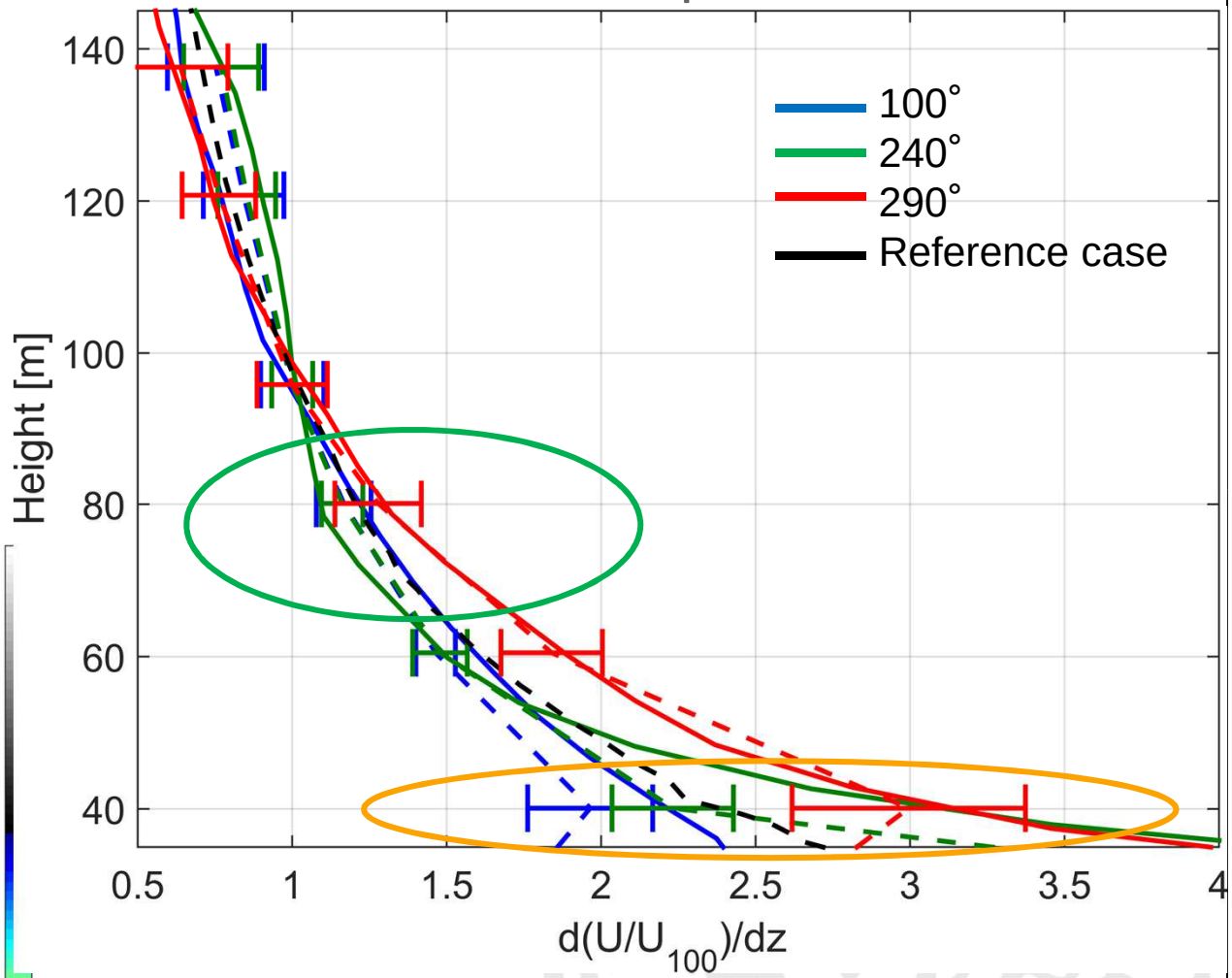

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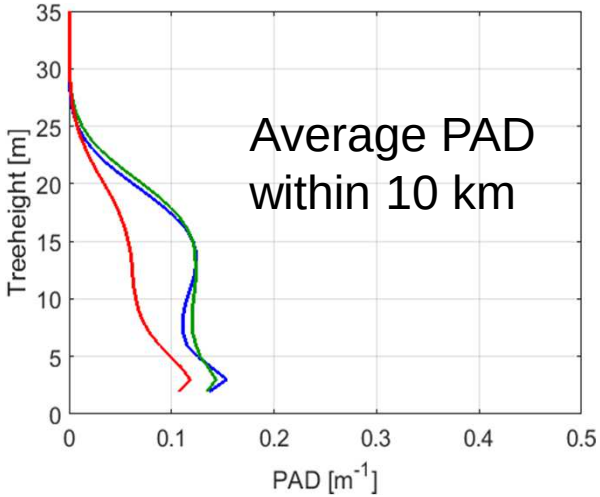

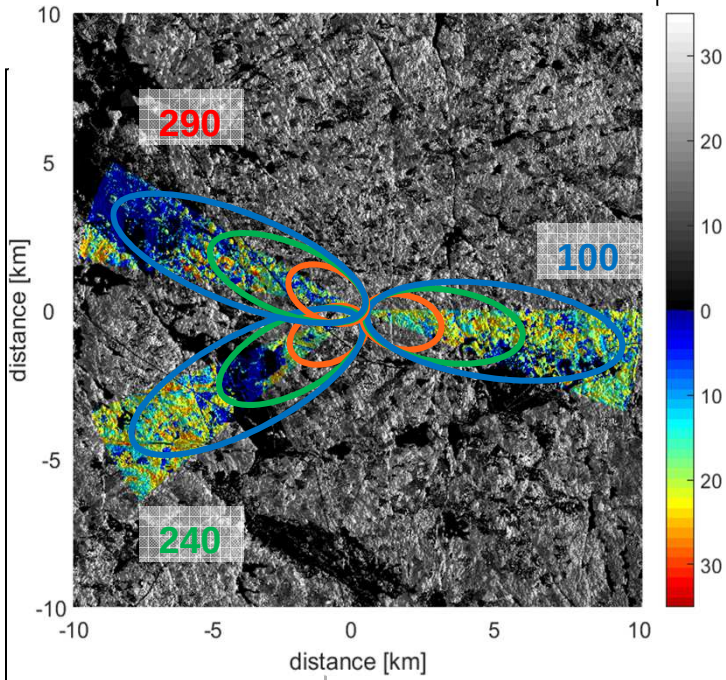

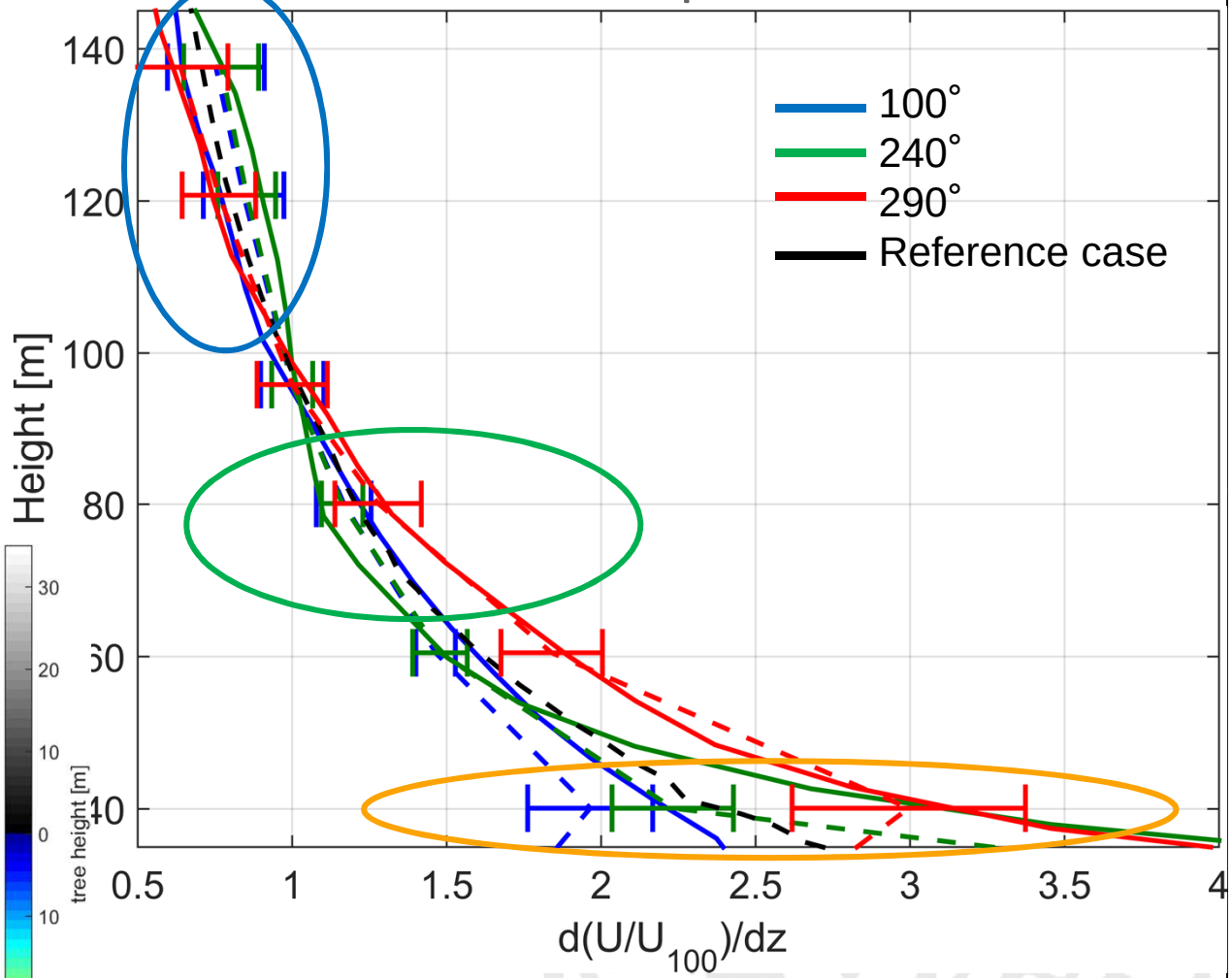

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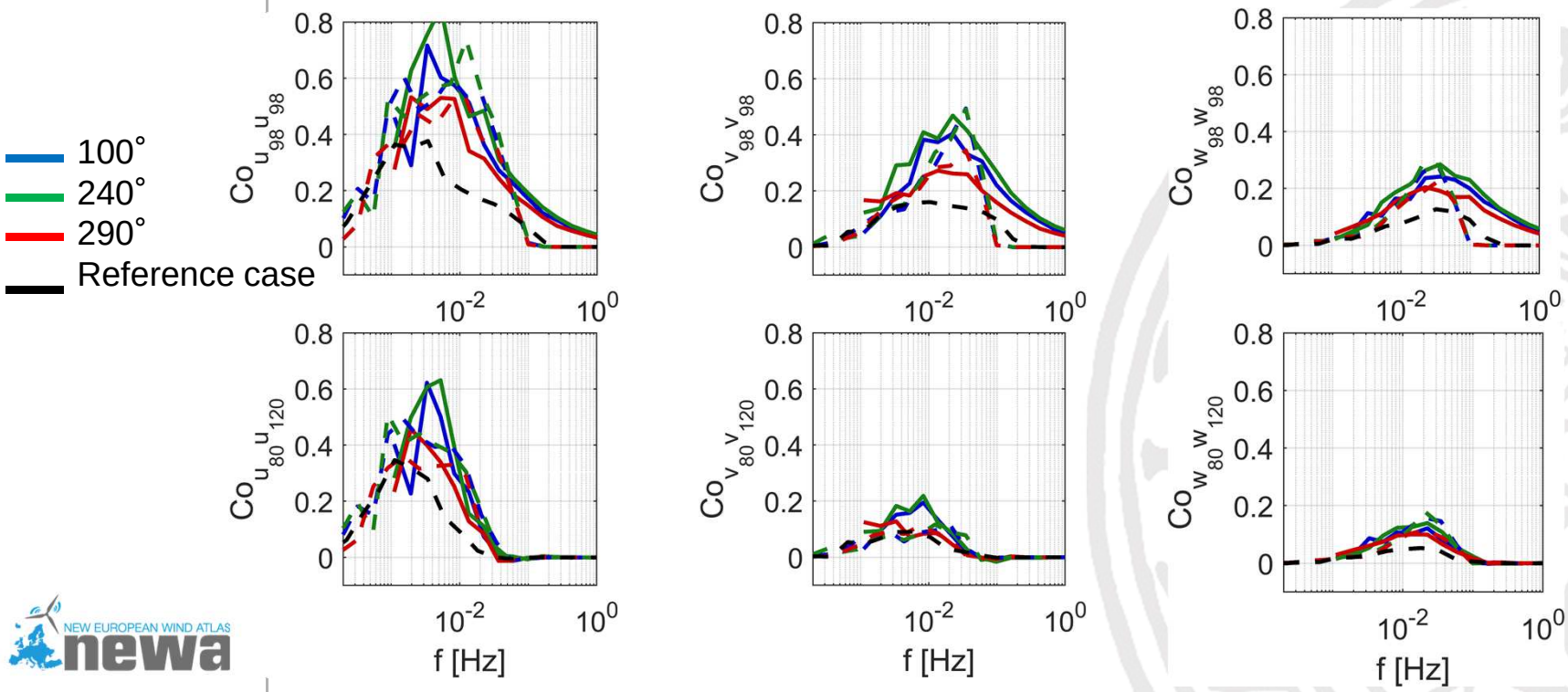
Ryningsnäs – What did we learn?

Our modelling approach:

- Large upstream coverage limits cell refinement
- Footprint from mean values is captured, *but* …
- One-point spectra reveal constrained high-freq resolution
- Two-point spectra shows relevant size structures well resolved



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Ryningsnäs – What did we learn?

- PAD data obtained from laser scans data permits to model the forest drag with a good accuracy and to represent the *inhomogeneities* of the canopy
- Forest inhomogeneities yield a footprint in the flow that is visible in the wind profiles
  - The use of average-PAD erases marks of footprint
  - Upstream coverage should be *large* in simulations
- RANS shows less variability with direction than LES and measurements

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Learning experiences and improvements. Flow model validation case

Benchmark goal

Ryningsnäs: Compare state of the art modelling approaches. PAD inhomogeneous forest
Hornamossen: Forested, complex terrain over varying stratification.

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Measurement campaign

Ryningsnäs: Single tower. Airborne laser scans.

Benchmark goal

Measurement campaign

Benchmark case

Comparison strategy

Participants

Results communication

Foto: Hans Blomberg

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Ryningsnäs – What did we learn?

- The use of laser scans provide good surface data
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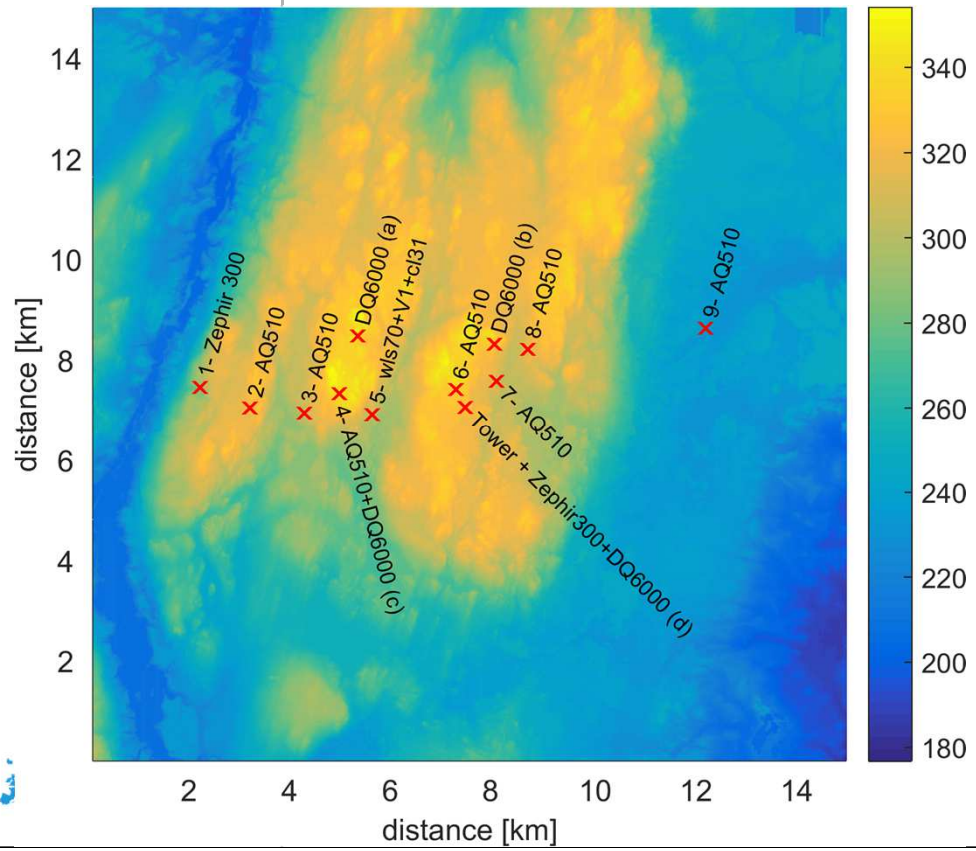

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Benchmark case

Ryningsnäs: Neutral stationary. Stable stratification stationary. Three different directions

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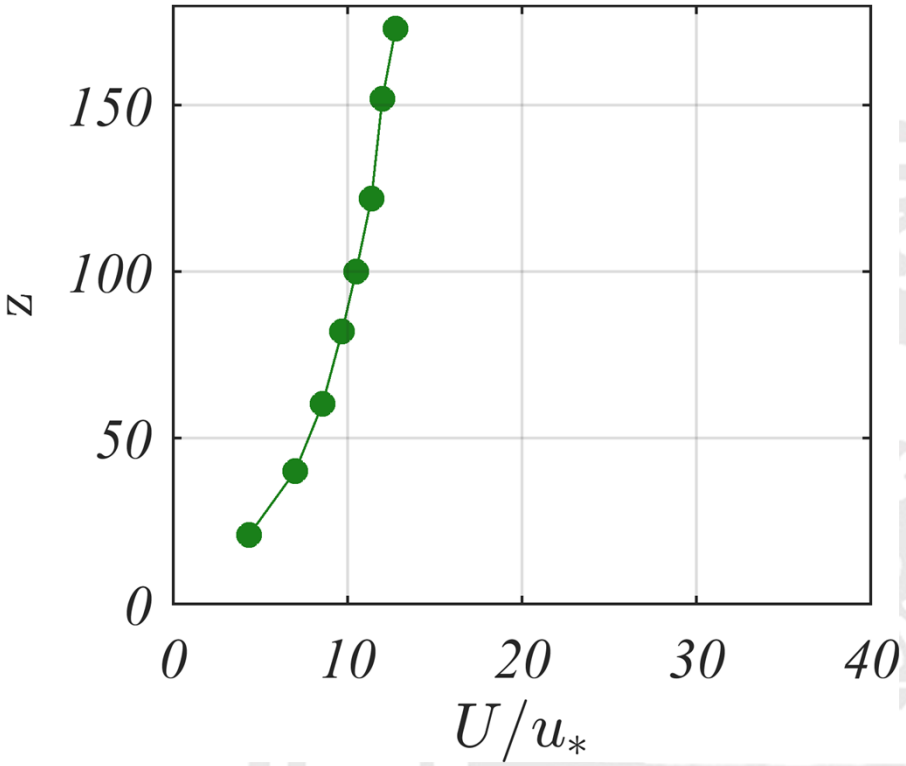
Representativity, stationarity and scaling



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Benchmark goal

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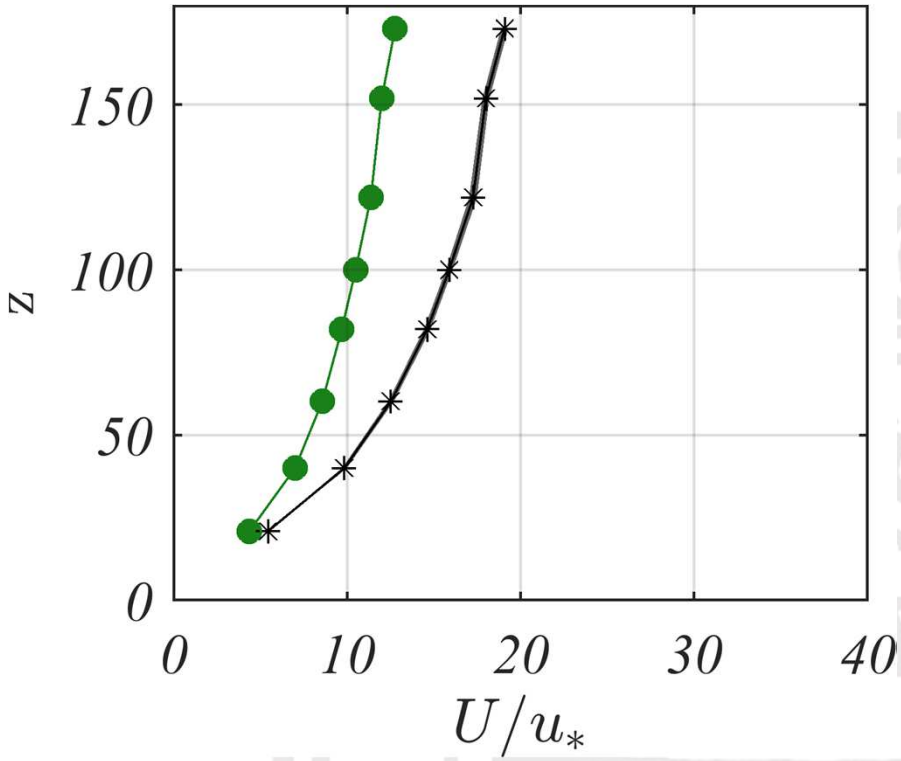
Comparison strategy

Participants

Results communication

Strictly neutral
All data



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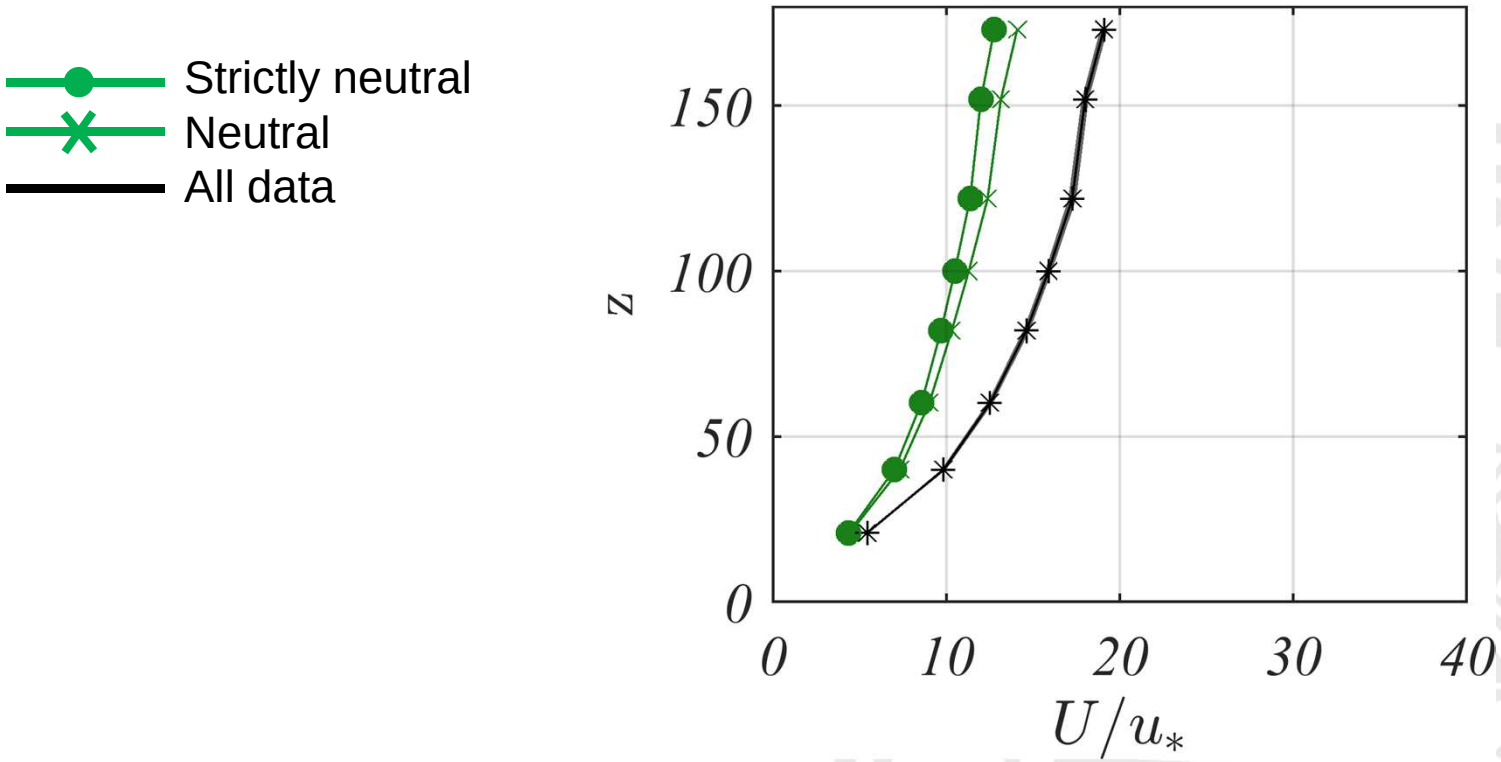

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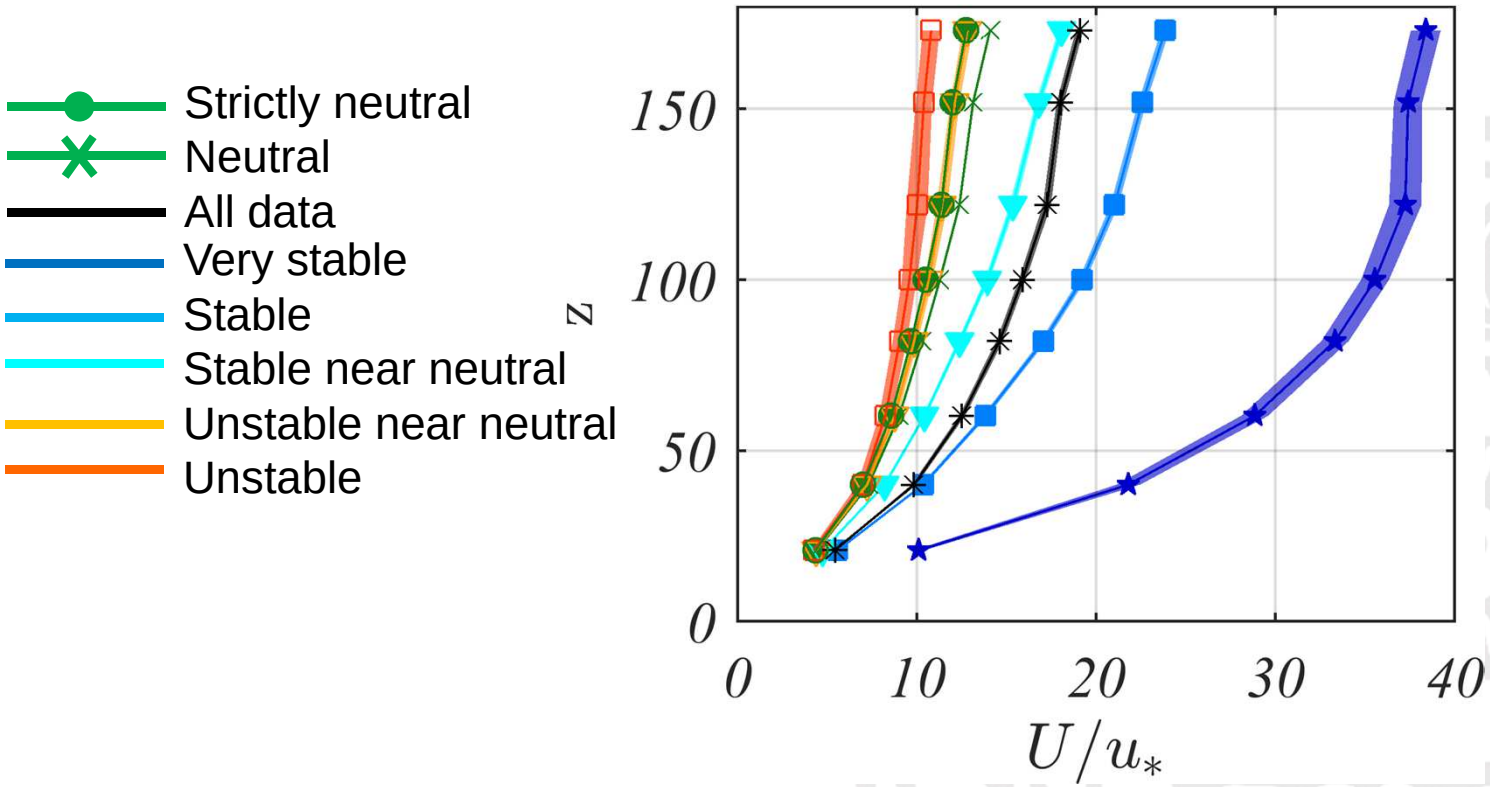

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A fair comparison in non neutral conditions

Problem: How to model stable and unstable stratification in stationary conditions

Solution: Model a full diurnal cycle

Problem: In case of non-stationary flow, how to avoid phase difference issues?

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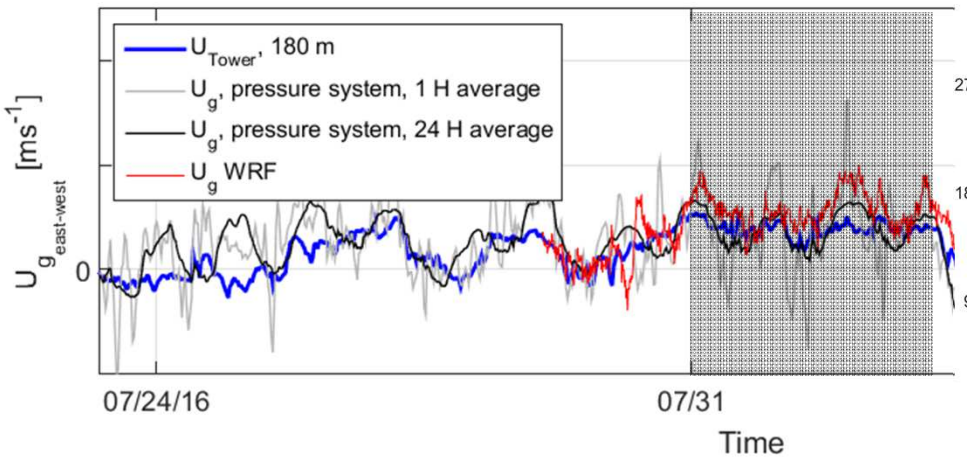

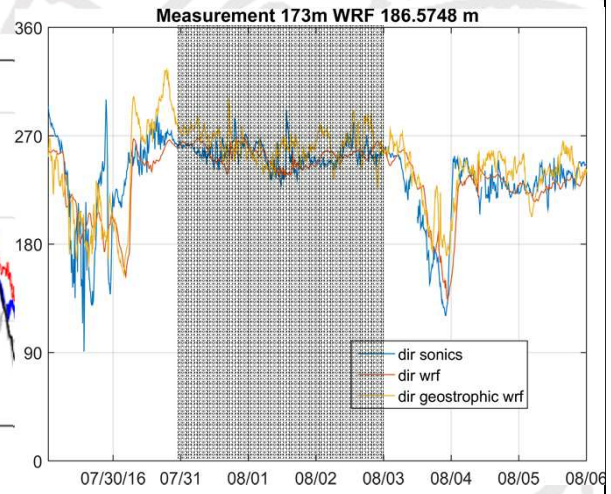

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A fair comparison in non neutral conditions

Problem: How to model stable and unstable stratification in stationary conditions

Solution: Model a full diurnal cycle

Problem: In case of non-stationary flow, how to avoid phase difference issues?

Solution: Find barotropic situations with stationary geostrophic wind speed and direction.

-If the wind speed is roughly the same, and the direction is the same, the results should be comparable

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Learning experiences and improvements. Flow model validation case

Benchmark goal

Ryningsnäs: Compare state of the art modelling approaches. PAD inhomogeneous forest
Hornamossen: Forested, complex terrain over varying stratification.

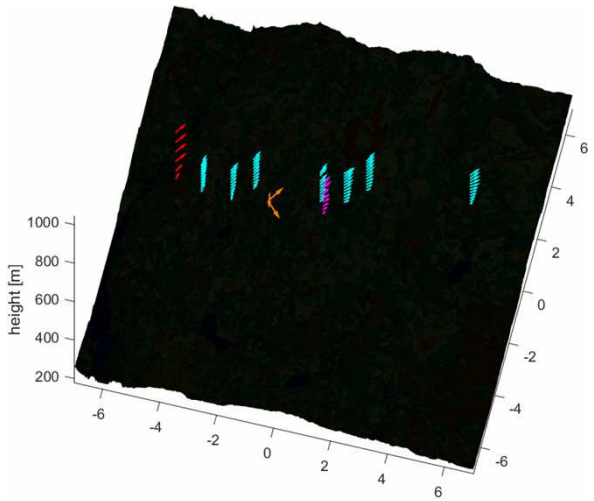
Measurement campaign

Ryningsnäs: Single tower. Airborne laser scans.
Hornamossen: Tower, profilers. Focus on both boundary conditions and validation.

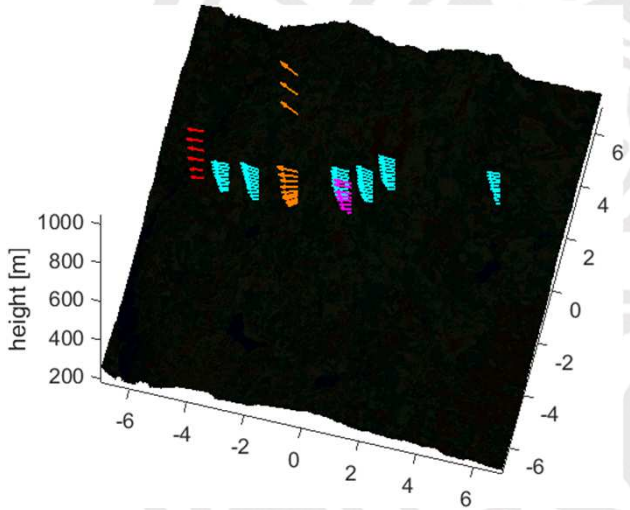
Benchmark case

Ryningsnäs: Neutral stationary. Stable stratification stationary. Three different directions
Hornamossen: Diurnal cycle. Two different, stationary, directions.

- **Case west**



- **Case east**



Benchmark goal
Measurement campaign
Benchmark case
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Results communication

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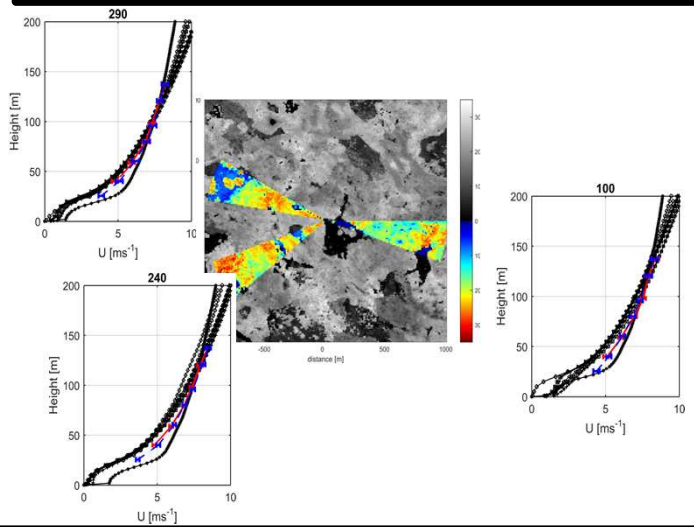
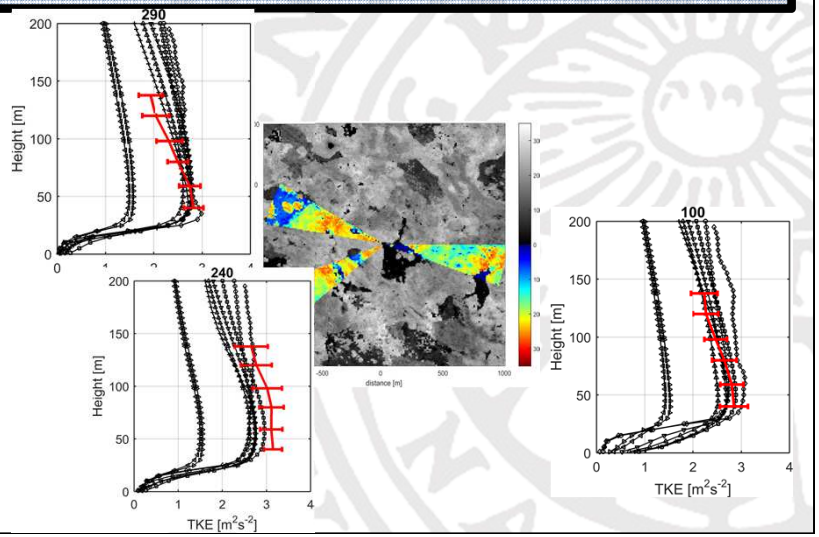
Benchmark case

Ryningsnäs: Neutral stationary. Stable stratification stationary. Three different directions
Hornamossen: Diurnal cycle. 2 directions.

Comparison strategy

Ryningsnäs: Dimensional data. 100 m target wind. Mostly quantitative comparison.





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Ryningsnäs – What did we learn?

- The use of laser scans provide good surface data
- Footprint characteristics are visible in profiles
  - Upstream coverage should be *large* in simulations
- RANS shows less variability with direction than LES and measurements
- Uncertainty of boundary conditions and few validation points hampers the analysis
- Effort needs to be made to develop models to represent <u>relevant atmospheric conditions</u>
- If a target u_{100} is asked for, adjusting u_g is very time-consuming.

Case selection

Dimensional comparison

Advantage

- Ideally the same boundary layer height, same footprint
- Statistical uncertainty of measurements is easy to estimate

Drawback

- Inconvenient for modelers
- Complicates comparison

Non-dimensional comparison

Advantage

- Easy for modelers
- Simplifies comparisons

Drawback

- Uncertainty in upper part of wind profiles since boundary layer height may not be the same.

Benchmark goal
Measurement campaign
Benchmark case
Comparison strategy
Participants
Results communication

Statistical uncertainty

- **Problem**: With short measurement periods statistical uncertainty leads to low confidence of U_i/U_{100}
  - Especially for points with large spatial separation
- **Solution**: Use as many validation points as possible. Place the sensors where you expect some difference. In addition, also compare qualitatively if flow pattern makes sense

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Hornamossen: Non dimensional data. Scaled with 100 m tower wind speed. Quantitative and qualitative

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Participants

Ryningsnäs: Mostly academia. Results are not anonymous

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- Although only a few groups participated, the open results aid the process and conclusions

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Participants

Ryningsnäs: Mostly academia. Open results
Hornamossen: Everyone is invited. Results are open.

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Results communication

Ryningsnäs: Scientific paper published

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- If a target u_{100} is asked for, adjusting u_g is very time-consuming.
- Although only a few groups participated, the open results aid the process and conclusions
- To facilitate further participation and use, find a public space for benchmark description and details

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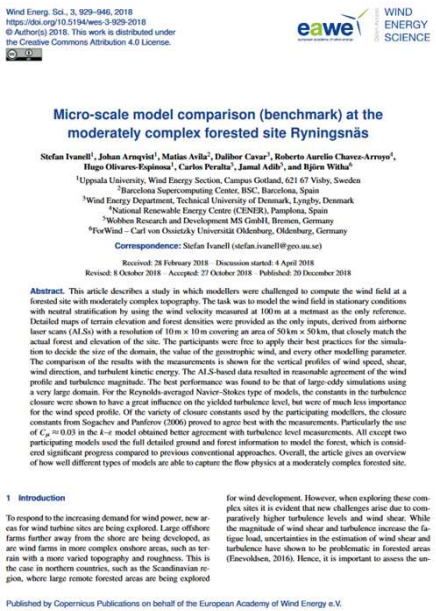

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Micro-scale model comparison (benchmark) at the moderately complex forested site Ryningsnäs

Stefan Ivanell[1], Johan Arnqvist[1], Matias Avila[2], Dalibor Cavar[3], Roberto Aurelio Chavez-Arroyo[4], Hugo Olivares-Espinosa[1], Carlos Peralta[5], Jamal Adib[5], and Björn Witha[6]
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[2]Barcelona Supercomputing Center, BSC, Barcelona, Spain
[3]Wind Energy Department, Technical University of Denmark, Lyngby, Denmark
[4]National Renewable Energy Centre (CENER), Pamplona, Spain
[5]Wobben Research and Development MS GmbH, Bremen, Germany
[6]ForWind – Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany
Correspondence: Stefan Ivanell (stefan.ivanell@geo.uu.se)

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Abstract. This article describes a study in which modellers were challenged to compute the wind field at a forested site with moderately complex topography. The task was to model the wind field in stationary conditions with neutral stratification by using the wind velocity measured at 100 m at a metmast as the only reference. Detailed maps of terrain elevation and forest densities were provided as the only inputs, derived from airborne laser scans (ALSs) with a resolution of 10 m × 10 m covering an area of 50 km × 50 km, that closely match the actual forest and elevation of the site. The participants were free to apply their best practices for the simulation to decide the size of the domain, the value of the geostrophic wind, and every other modelling parameter. The comparison of the results with the measurements is shown for the vertical profiles of wind speed, shear, wind direction, and turbulent kinetic energy. The ALS-based data resulted in reasonable agreement of the wind profile and turbulence magnitude. The best performance was found to be that of large-eddy simulations using a very large domain. For the Reynolds-averaged Navier–Stokes type of models, the constants in the turbulence closure were shown to have a great influence on the yielded turbulence level, but were of much less importance for the wind speed profile. Of the variety of closure constants used by the participating modellers, the closure constants from Sogachev and Panferov (2006) proved to agree best with the measurements. Particularly the use of $C_\mu = 0.03$ in the k–ε model obtained better agreement with turbulence level measurements. All except two participating models used the full detailed ground and forest information to model the forest, which is considered significant progress compared to previous conventional approaches. Overall, the article gives an overview of how well different types of models are able to capture the flow physics at a moderately complex forested site.

1 Introduction

To respond to the increasing demand for wind power, new areas for wind turbine sites are being explored. Large offshore farms further away from the shore are being developed, as are wind farms in more complex onshore areas, such as terrain with a more varied topography and roughness. This is the case in northern countries, such as the Scandinavian region, where large remote forested areas are being explored for wind development. However, when exploring these complex sites it is evident that new challenges arise due to comparatively higher turbulence levels and wind shear. While the magnitude of wind shear and turbulence increase the fatigue load, uncertainties in the estimation of wind shear and turbulence have shown to be problematic in forested areas (Enevoldsen, 2016). Hence, it is important to assess the un-

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Micro-scale model comparison (benchmark) at the moderately complex forested site Ryningsnäs,
Wind Energ. Sci., 3, 929-946,
https://doi.org/10.5194/wes-3-929-2018, 2018.

Although open access and discussion papers increase the communication, it is still mainly used by academia

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Thanks to the wind vane blog, the Hornamossen benchmark has a public interactive face to anyone interested

Benchmark goal

Measurement campaign

Benchmark case

Comparison strategy

Participants

Results communication

Wind Energ. Sci., 3, 929–946, 2018
https://doi.org/10.5194/wes-3-929-2018

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Micro-scale model comparison (benchmark) at the moderately complex forested site Ryningsnäs

Stefan Ivanell[1], Johan Arnqvist[1], Matias Avila[2], Dalibor Cavar[3], Roberto Aurelio Chavez-Arroyo[4], Hugo Olivares-Espinosa[1], Carlos Peralta[5], Jamal Adib[5], and Björn Witha[6]

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[6]ForWind – Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany

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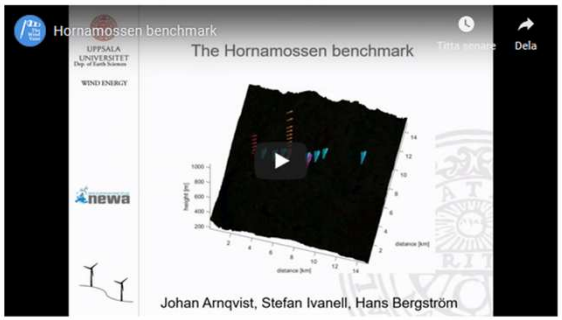
M

The Wind Vane WIND WAKES CONTRIBUTE | WEMEP

The Hornamossen diurnal-cycle benchmark for flow modeling in forested and moderately complex terrain

Johan Arnqvist
Sep 7, 2018 · 5 min read

The test challenges the models to predict the wind field during a full diurnal cycle using mesoscale input data versus traditional methods based on onsite measurements and idealized boundary conditions.



Presentation of the Hornamossen experiment and diurnal-cycle benchmark.

https://thewindvaneblog.com/the-hornamossen-diurnal-cycle-benchmark-for-abl-models-in-forested-and-moderately-complex-terrain-747b60401254

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Learning experiences and improvements. Flow model validation case

Benchmark goal

Ryningsnäs: Compare state of the art modelling approaches. PAD inhomogeneous forest
Hornamossen: Forested, complex terrain over varying stratification.

Measurement campaign

Ryningsnäs: Single tower. Airborne laser scans.
Hornamossen: Tower, profilers. Focus on both boundary conditions and validation.

Benchmark case

Ryningsnäs: Neutral stationary. Stable stratification stationary. Three different directions
Hornamossen: Diurnal cycle. 2 directions.

Comparison strategy

Ryningsnäs: Dimensional data. 100 m target wind. Mostly quantitative
Hornamossen: Non dimensional data. Scaled with 100 m tower wind speed. Quantitative and qualitative

Participants

Ryningsnäs: Mostly academia. Open results
Hornamossen: Everyone is invited. Results are open.

Results communication

Ryningsnäs: Scientific paper published
Hornamossen: Scientific publication planned. Benchmark will stay open on wind vane blog.

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Measurement and modeling of forested areas – best practice from a NEWA benchmark

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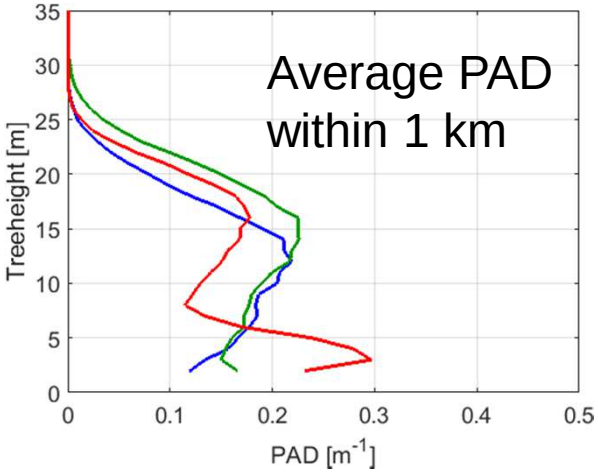
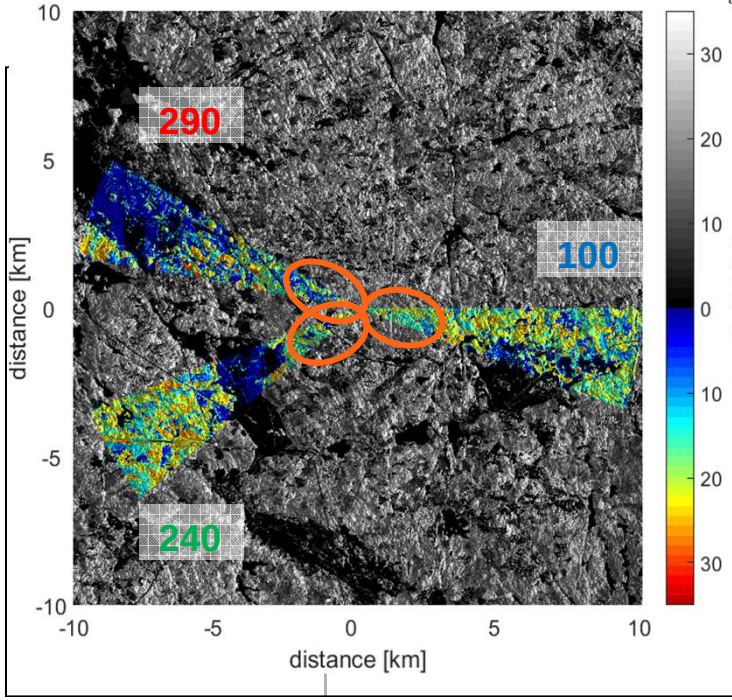
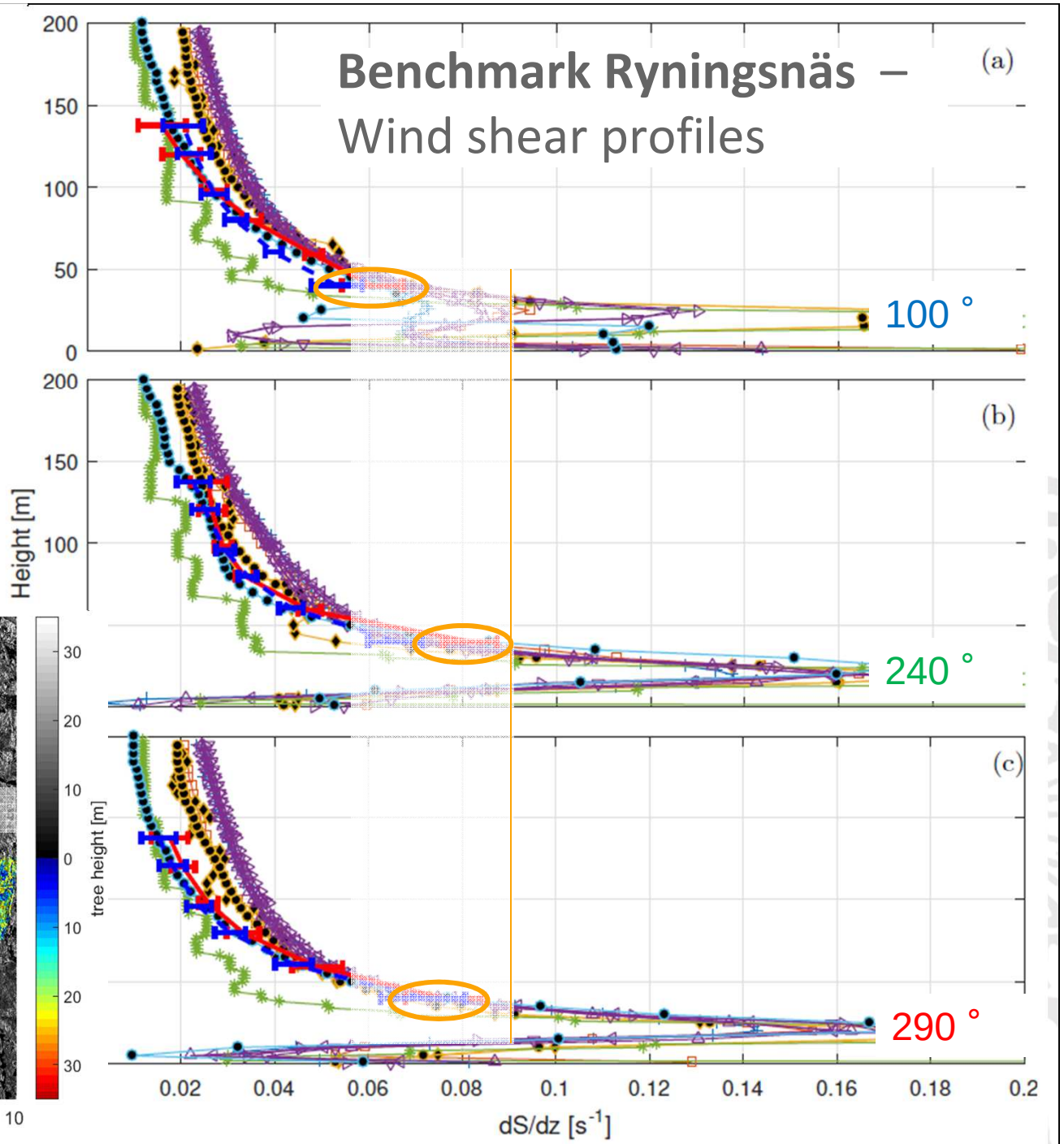
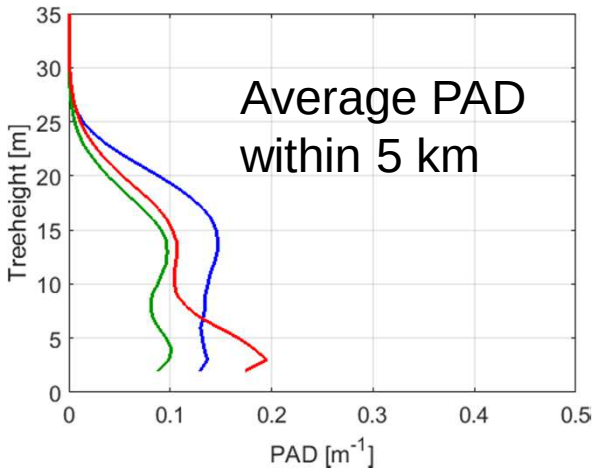
100 240 290

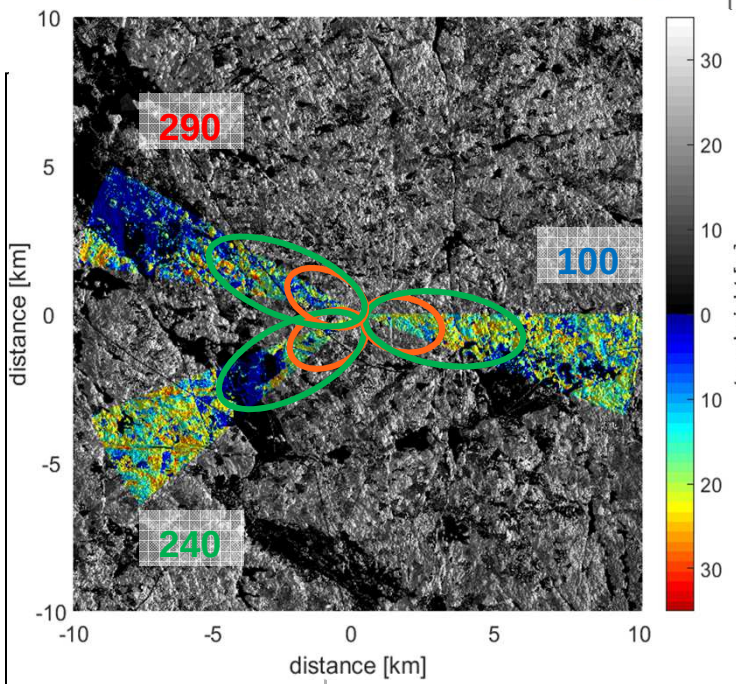

Average PAD
within 1 km
Treeheight [m]
PAD [m^{-1}]

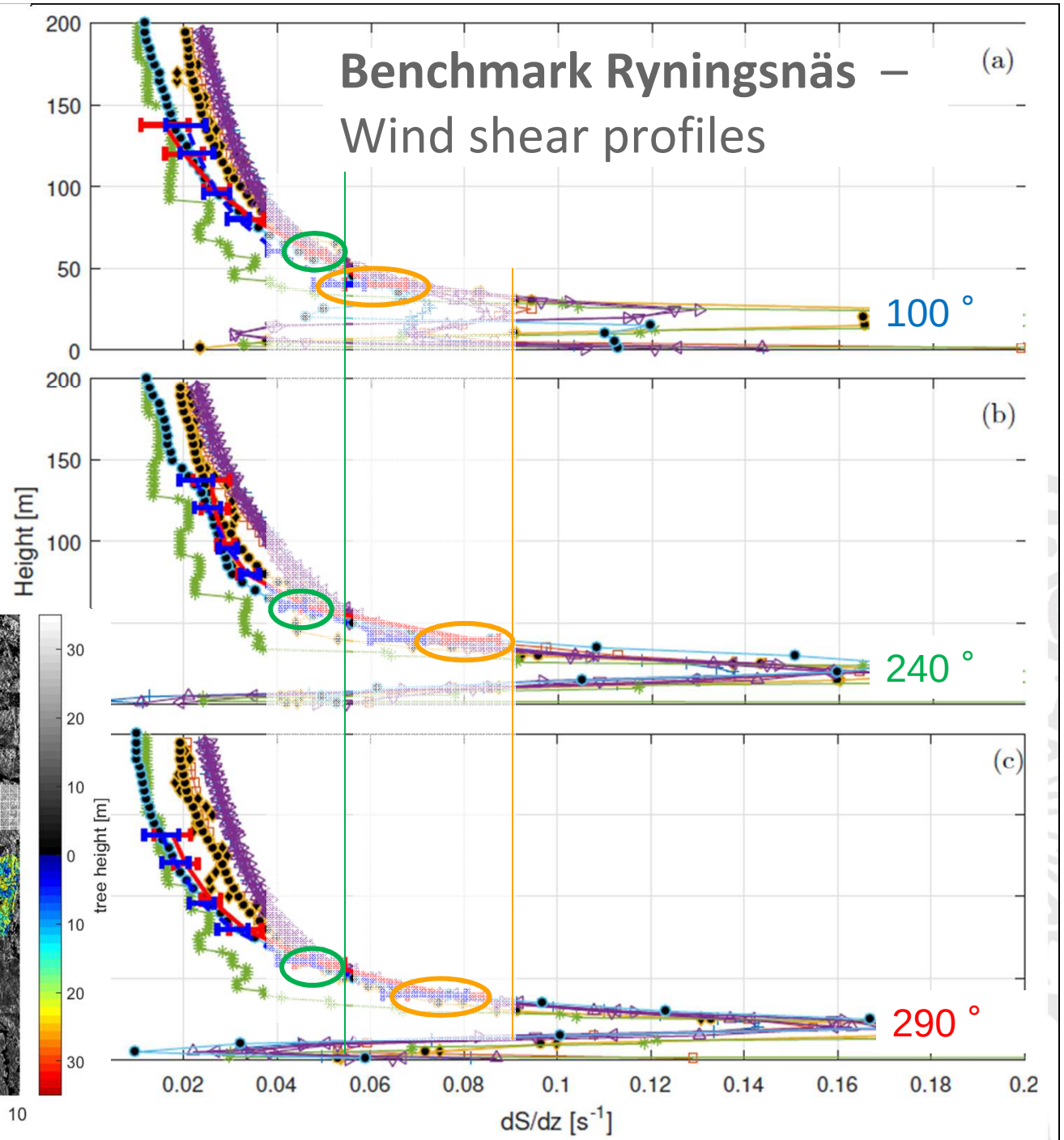

290
100
240
distance [km]
distance [km]


Benchmark Ryningsnäs –
Wind shear profiles
(a)
(b)
(c)
100 °
240 °
290 °
Height [m]
tree height [m]
dS/dz [s^{-1}]

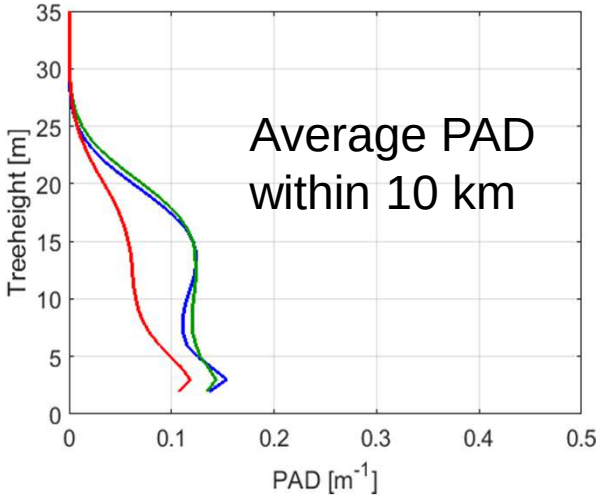
100 240 290

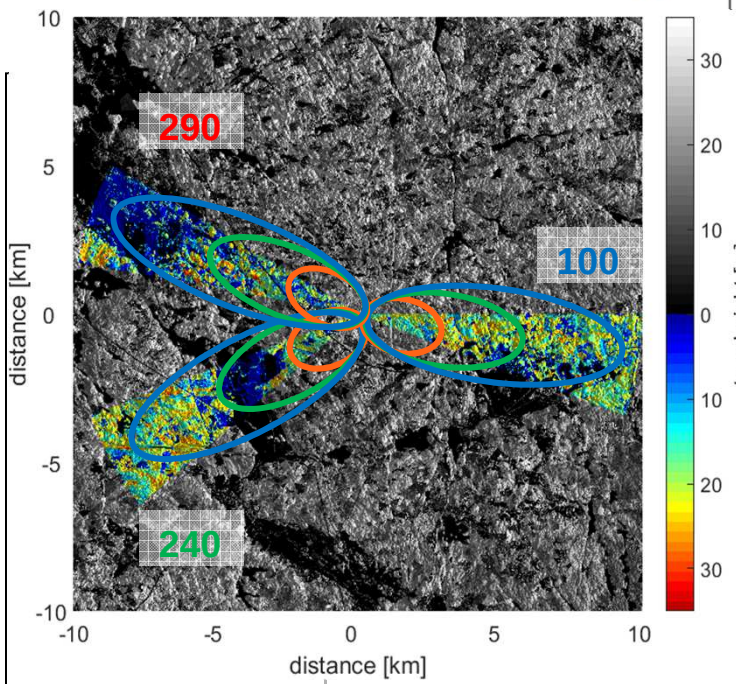

Average PAD
within 5 km
Treeheight [m]
PAD [m^{-1}]

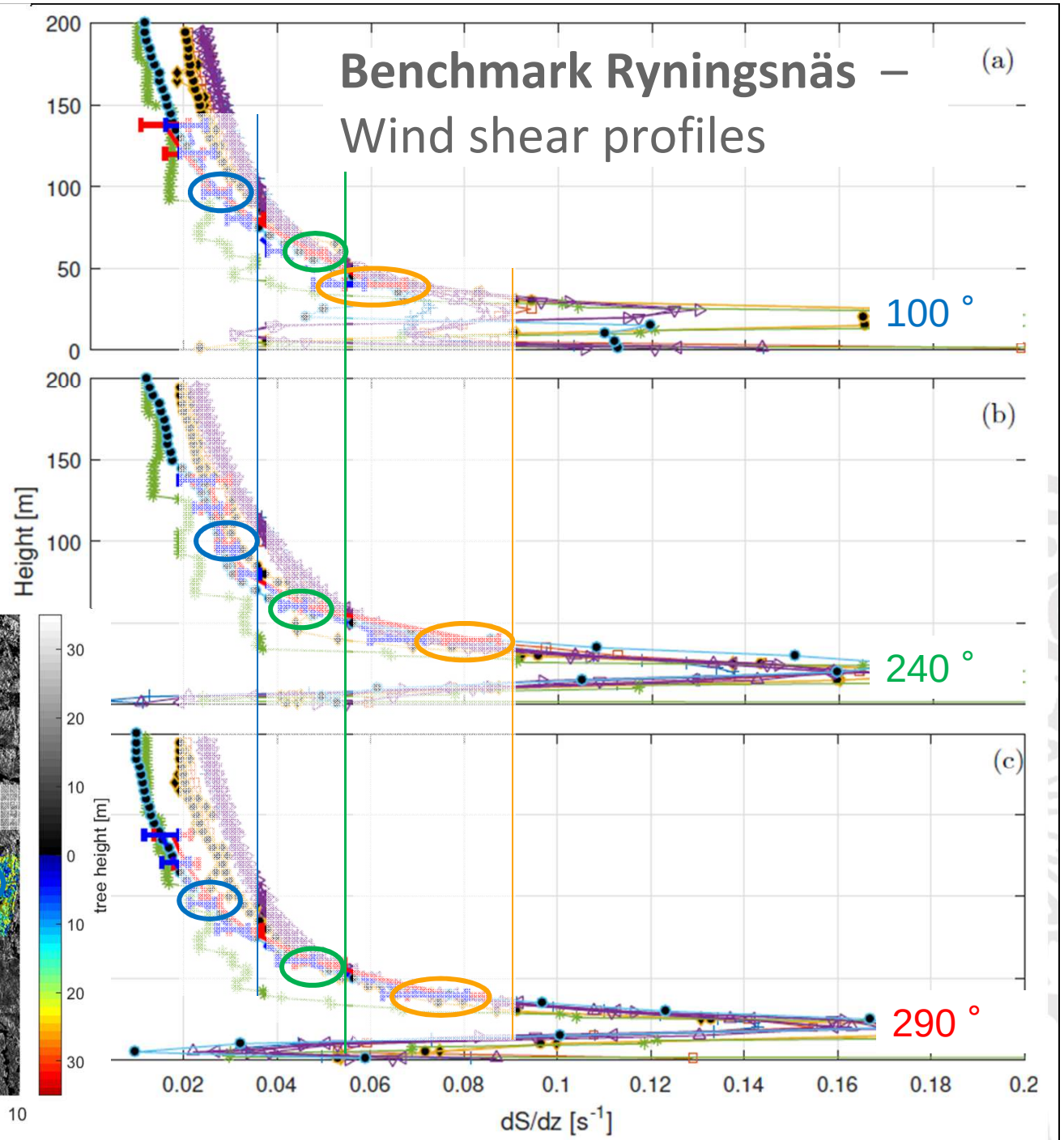

290
100
240
distance [km]
distance [km]


Benchmark Ryningsnäs –
Wind shear profiles
(a)
(b)
(c)
100 °
240 °
290 °
Height [m]
tree height [m]
dS/dz [s^{-1}]

100 240 290


Average PAD
within 10 km
Treeheight [m]
PAD [m^{-1}]


290
100
240
distance [km]
distance [km]


Benchmark Ryningsnäs –
Wind shear profiles
(a)
(b)
(c)
100 °
240 °
290 °
Height [m]
tree height [m]
dS/dz [s^{-1}]

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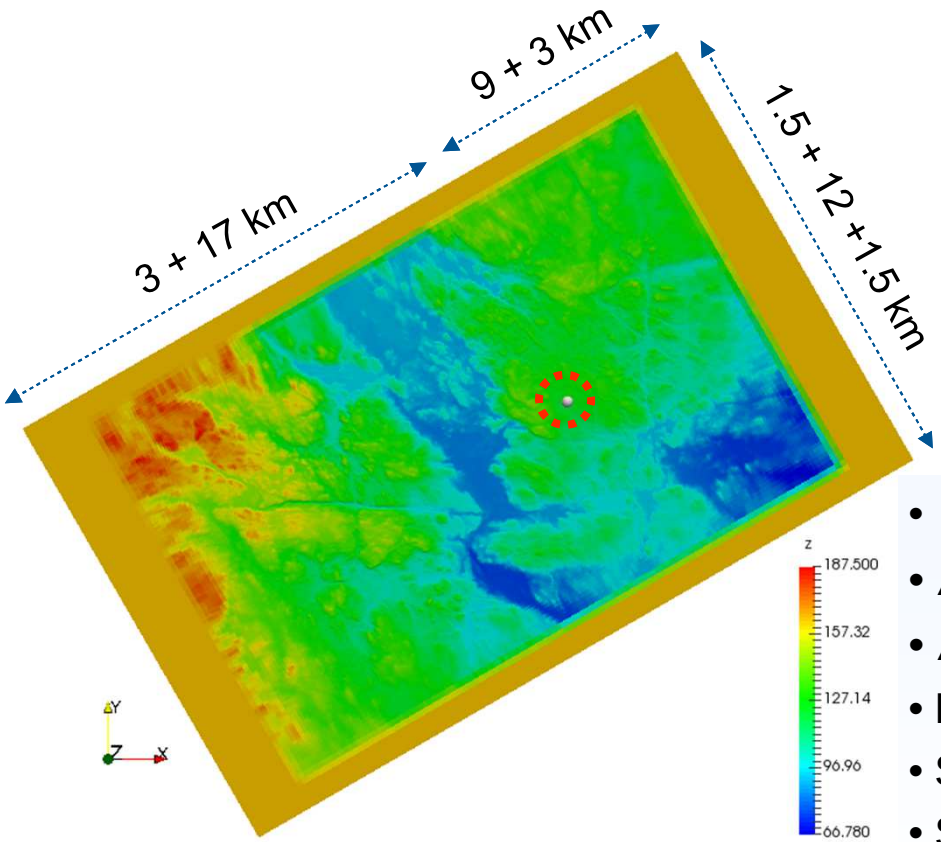
LES computations: Domain size



Edges: fixed PAD
Interior: PAD from LIDAR
Z_0=0,03

- CENER's WindMesh
- $\Delta_{x,y}$ = 25 m / edges 250 m
- $\Delta_{z,min} \simeq$ 5 m, ~1.05 growth
- N_{tot} = 41.2 X 10^6 cells
- Stabilization CPUh $\simeq$ 150 000
- Sampling (physical 20 000s) $\simeq$ 19 000

L_x X L_y X L_z = 32 km X 20 km X ~ 1.2 km

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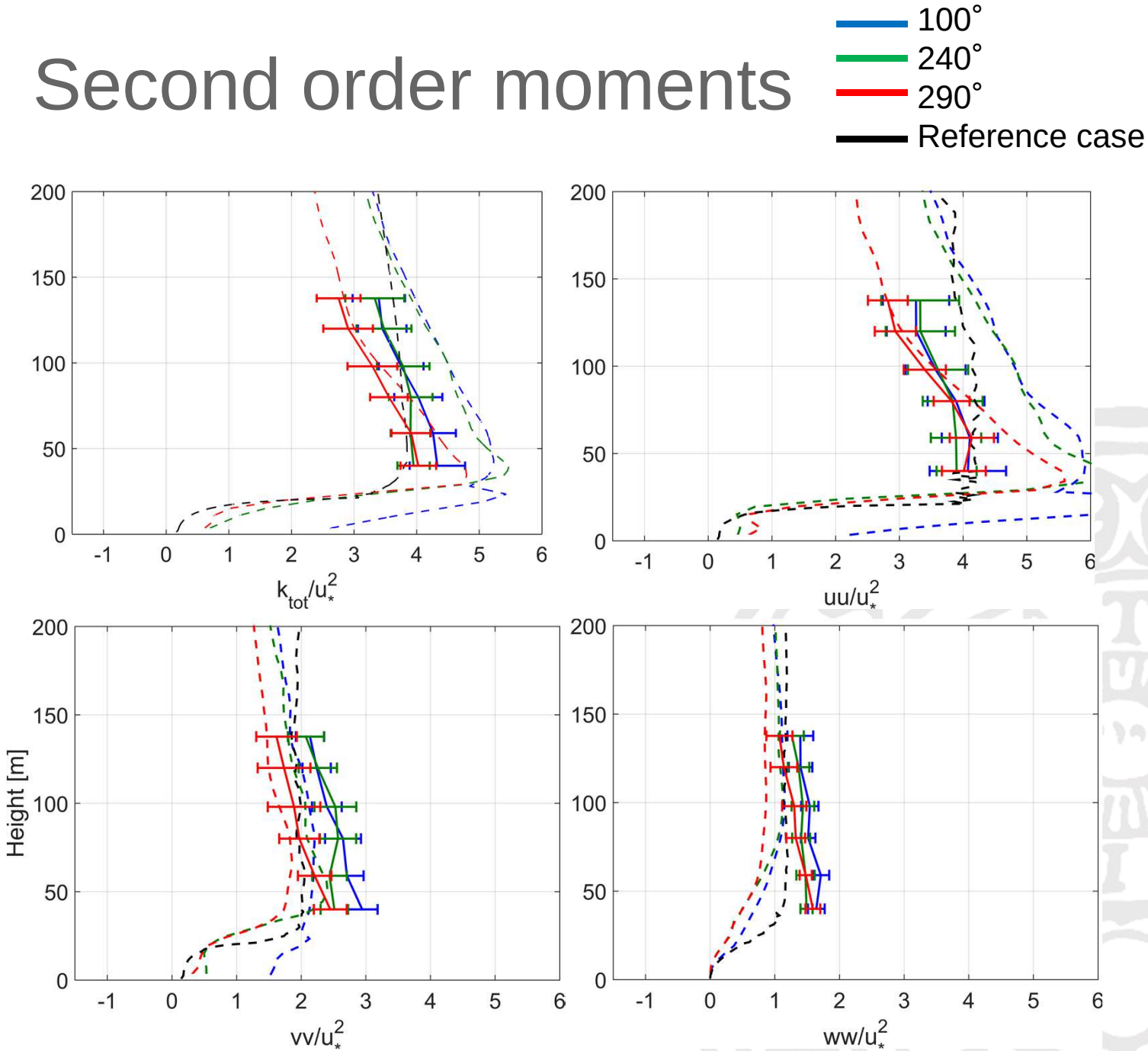
Second order moments



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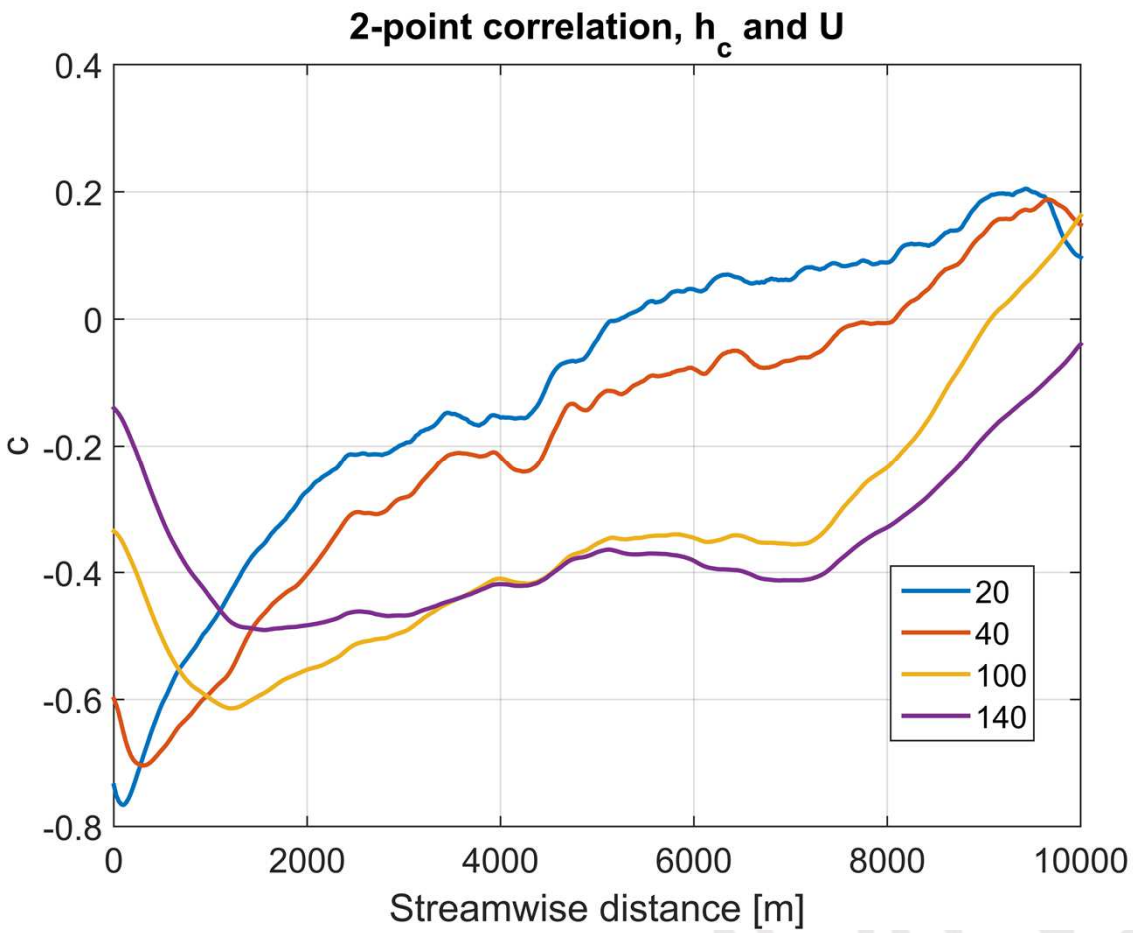
Footprint



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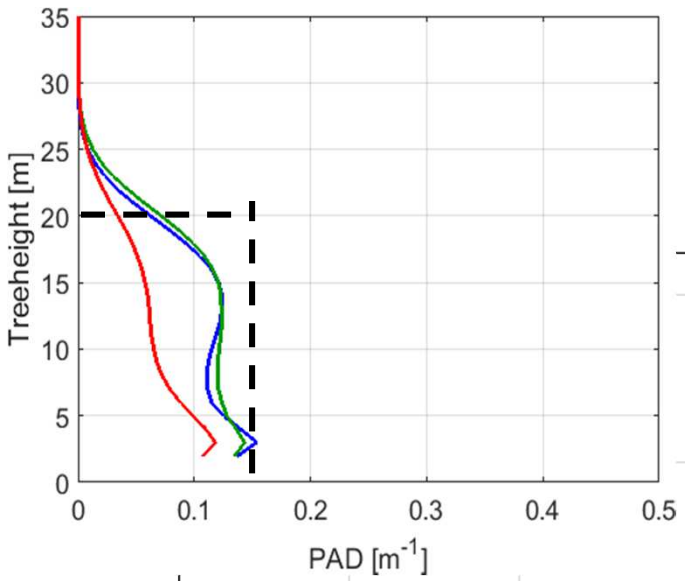
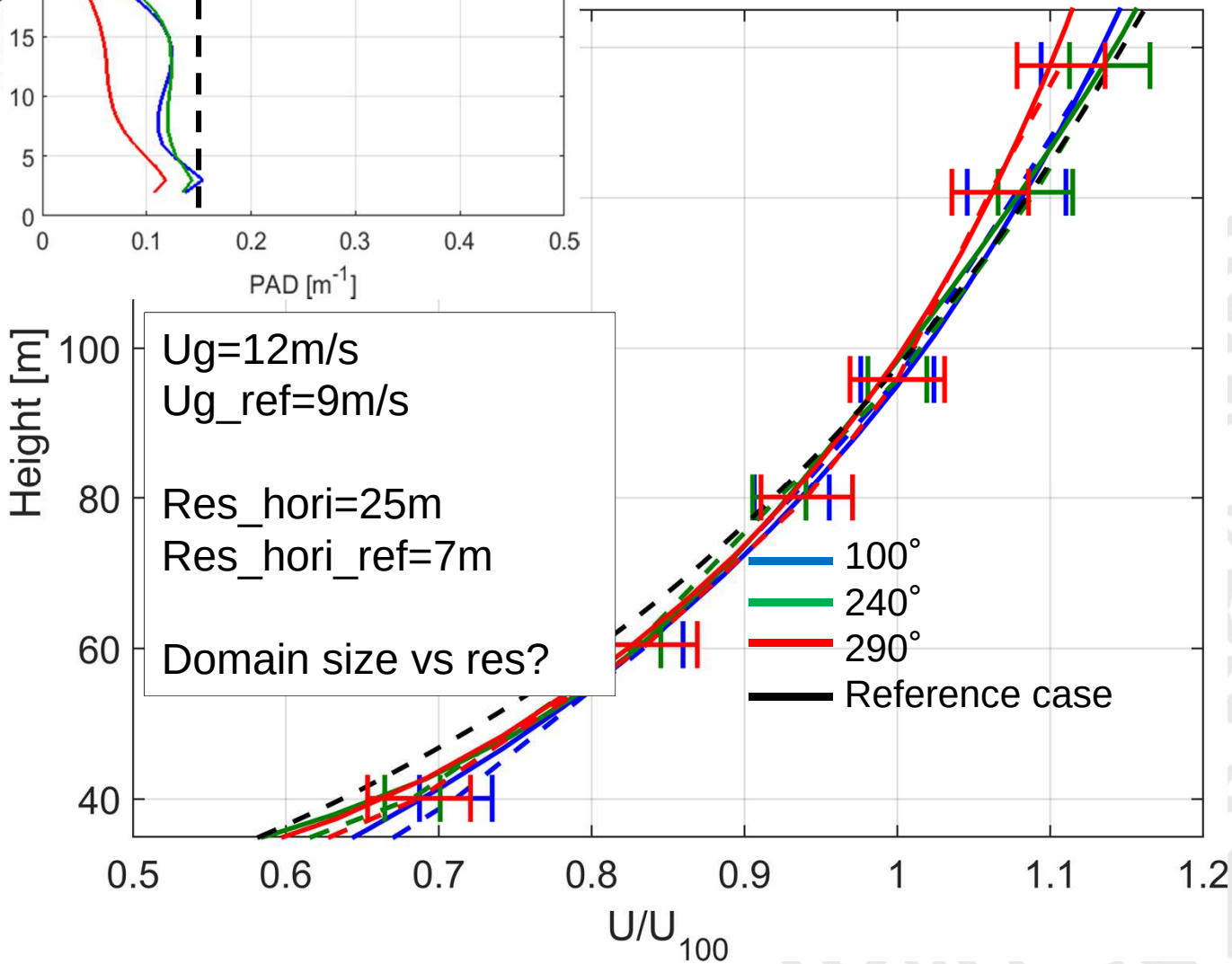
Wind speed matches the measured to a high degree





Ug=12m/s
Ug_ref=9m/s

Res_hori=25m
Res_hori_ref=7m

Domain size vs res?