

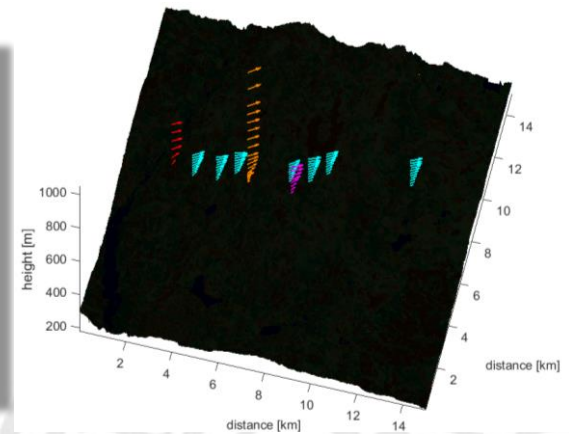
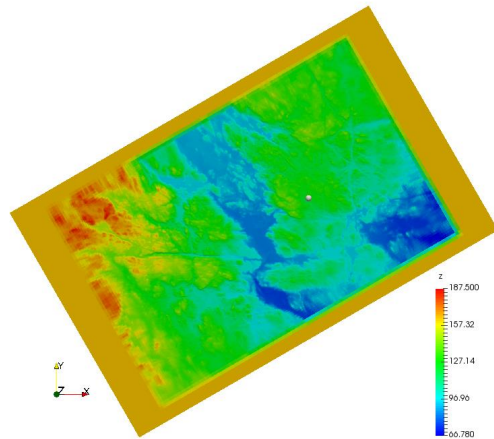


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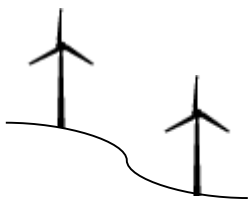
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NEW EUROPEAN WIND ATLAS
newa



Johan Arnqvist och Stefan Ivanell

Hans Bergström, Hugo Olivares, Stefan Söderberg, Matthias
Mohr, Magnus Balchevsky, Gunnar Bergström, mfl



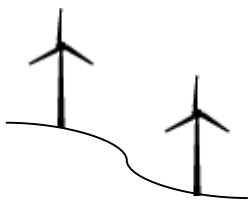


Bakgrund

Många olika typer av osäkerheter inom vindresursbedömning

- Mätningar
 - Mätosäkerheter
 - Mätfel
 - Representativitet
 - Rumsvariationer
 - Tidsvariationer
- Modellering
 - Representativitet
 - Tidsvariationer
 - Rumsvariationer
 - Approximationer

NEWA, New European Wind Atlas, bedriver forskning på dessa områden

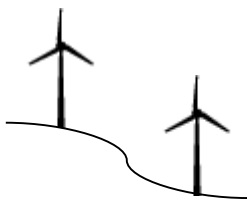




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NEWA – The New European Wind Atlas

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– Inköper Hornamossen i Sverige

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TRANSACTIONS A

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Research

This article: J. Mann et al. 2016 Complex terrain experiments in the New European Wind Atlas. *Philos. Trans. R. Soc. A* 375: 201501101. <http://dx.doi.org/10.1098/rsta.2015.01101>

Accepted: 28 November 2015

One contribution of 11 to a theme issue 'Wind energy in complex terrain'.

Subject Areas: atmospheric sciences, meteorology, energy, fluid mechanics

Keywords: complex terrain, meteorological experiment, Doppler lidar

Author for correspondence: J. Mann
email: jmann@truidk

Complex terrain experiments in the New European Wind Atlas

J. Mann¹, N. Angelou¹, J. Amqvist², D. Gallias³, E. Cantieri⁴, R. C. Álvarez Arroyo⁴, M. Courtney¹, J. Cuxart⁵, E. Dellwik¹, J. Gottschall⁶, S. Isenhardt⁷, P. Kühn⁸, G. Lea¹, J. C. Matos⁵, J. M. L. M. Palma⁶, L. Paschelet⁹, A. Peña¹, J. Sanz Rodrigo⁴, S. Söderberg⁷, N. Vasiljevic¹ and C. Veiga Rodrigues⁶

¹Technical University of Denmark, Roskilde, Denmark

²Uppsala University, Uppsala, Sweden

³Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), Germany

⁴National Renewable Energy Centre (CENER), Samoguren, Spain

⁵Instituto de Ciencia e Innovación en Ingeniería Mecánica e Gestión Industrial (INEGI), Porto, Portugal

⁶Faculdade de Engenharia da Universidade do Porto (FEUP), Porto, Portugal

⁷WeatherTech Scandinavia AB, Uppsala, Sweden

⁸Universitat de les Illes Balears, Mallorca, Spain

DOI: 10.1098/rsta.2015.01101

The New European Wind Atlas project will cover a newly accessible wind atlas covering Europe and Turkey, develop the model chain to create the atlas and perform a series of experiments on flow in and around complex terrain to validate many disparate kinds of complex terrain models. This paper describes the experiments of which some are already completed while others are in the planning stage. All experiments focus on the flow properties that are relevant for wind turbines, so the main focus is the mean flow and turbulence, so the main focus is the mean flow and turbulence at the highest between 40 and 200 m. Also

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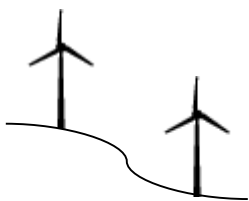
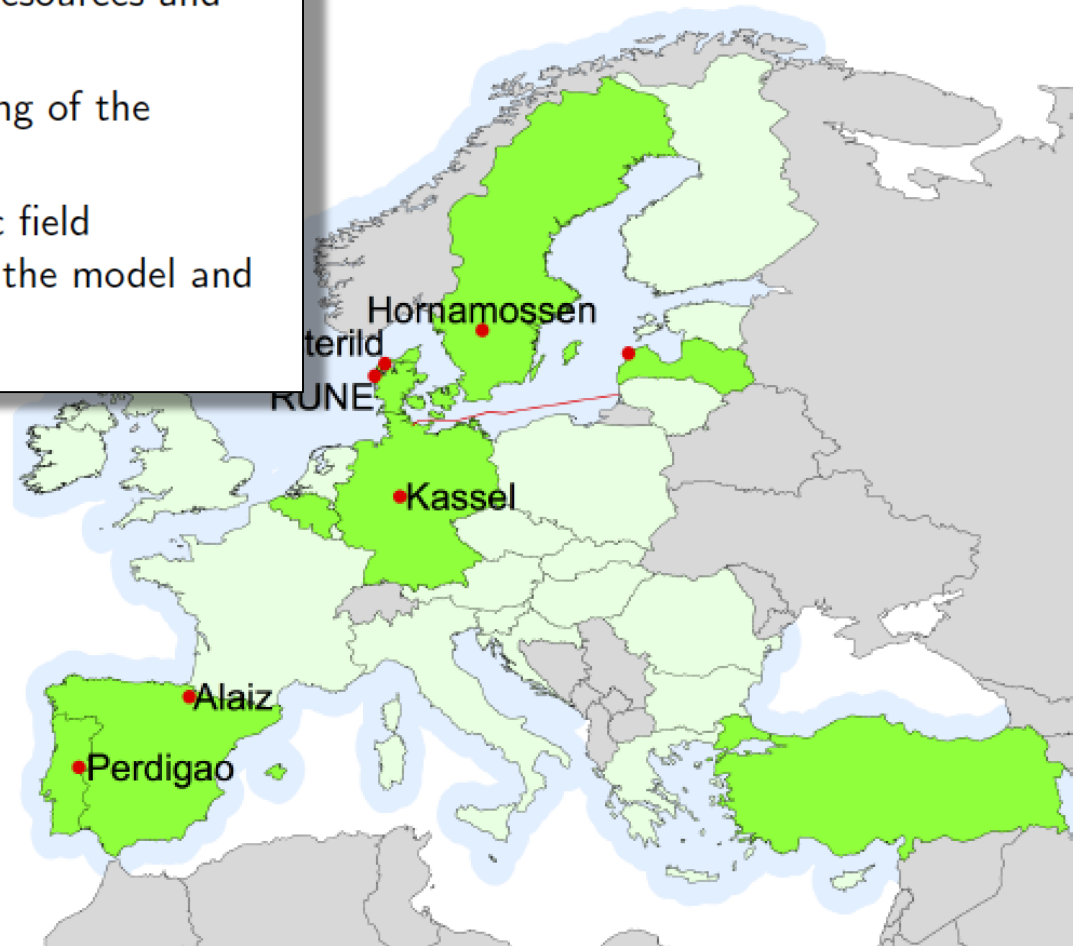
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NEWA - New European Wind Atlas

- Accurate mapping of wind conditions for the estimations of resources and loads
- Development and testing of the model chain
- A series of atmospheric field experiment to validate the model and atlas.

- EU countries
- NEWA partners
- Offshore coverage
- Experimental sites





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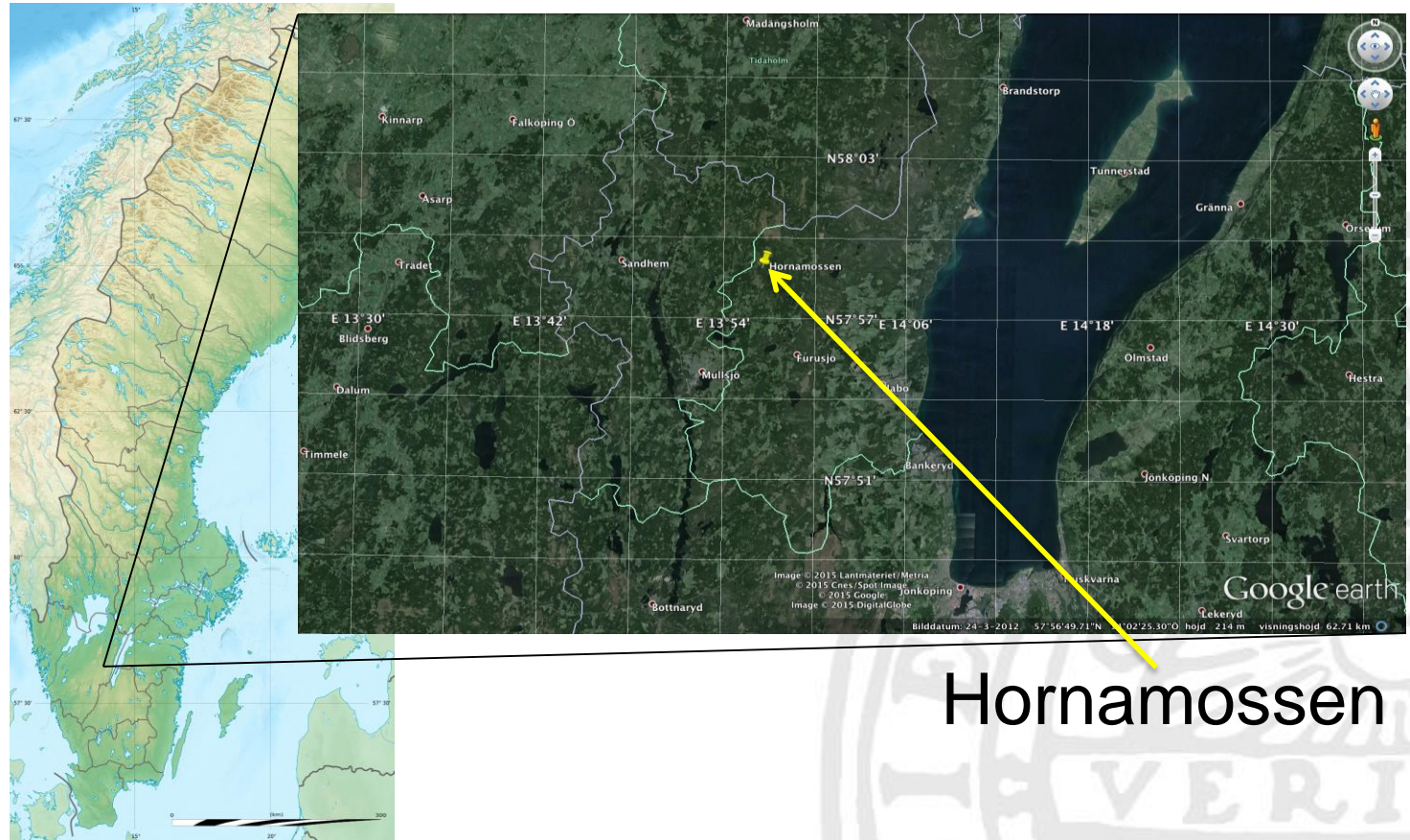
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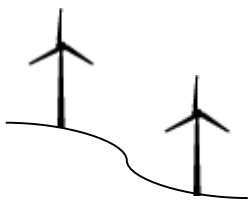
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Den svenska siten - Hornamossen



Hornamossen

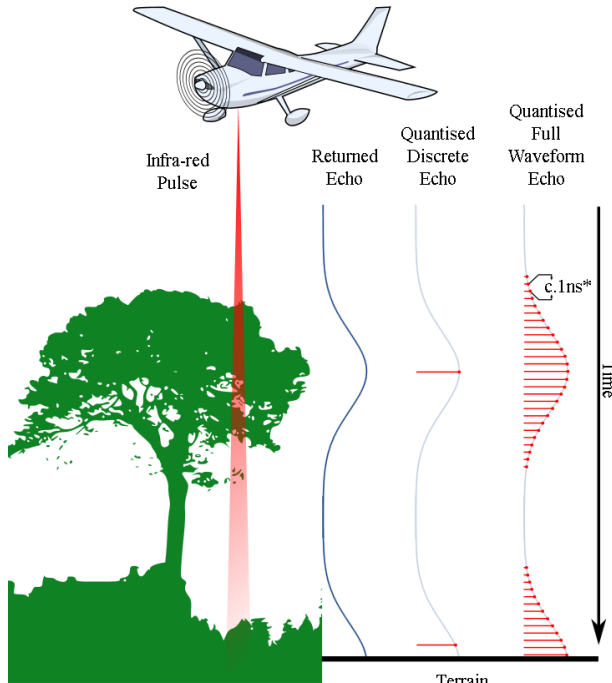




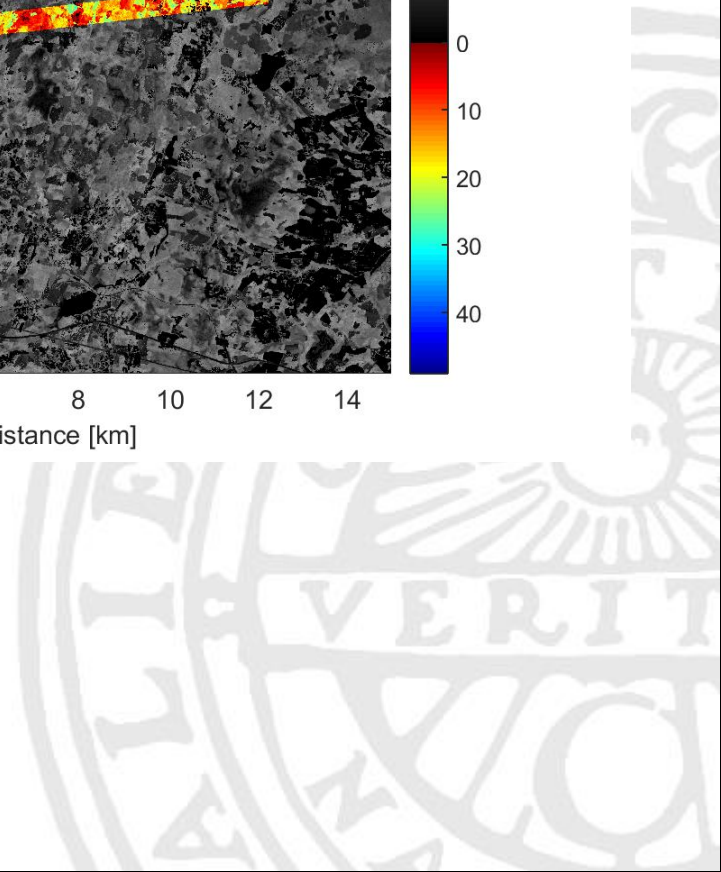
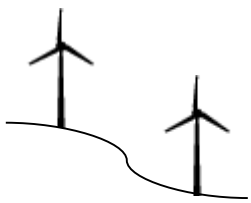
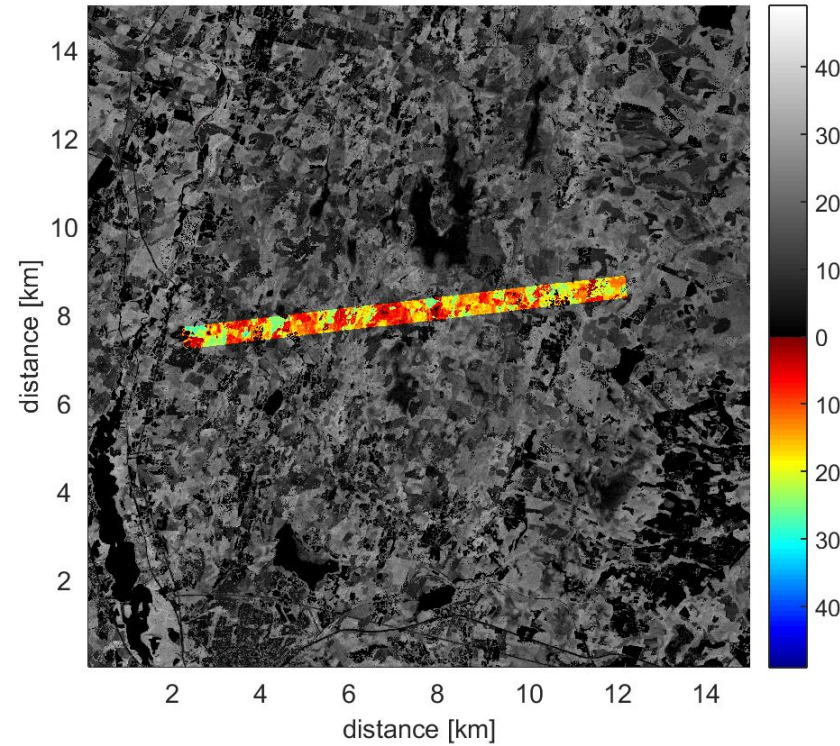
Mätningar av alla randvillkor + valideringspunkter för modellstudier

- Markhöjd, skogshöjd och skogsdensitet från laserscanningar

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* In a vacuum light will travel approximately 0.3m in 1ns

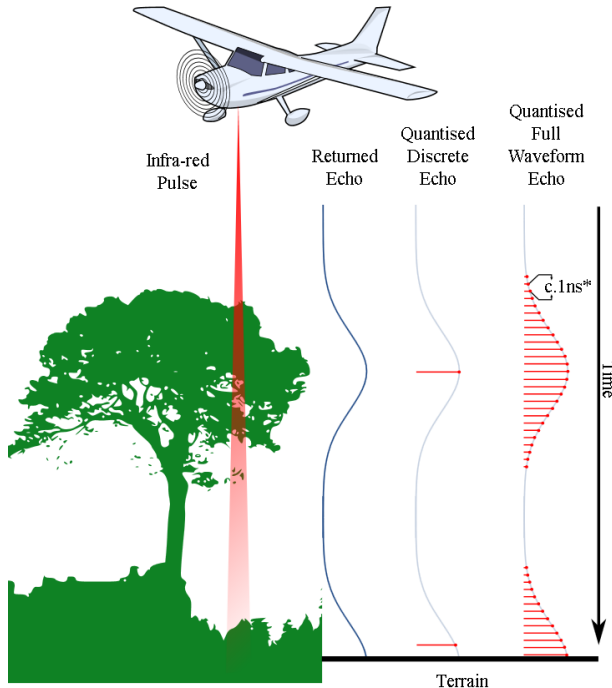




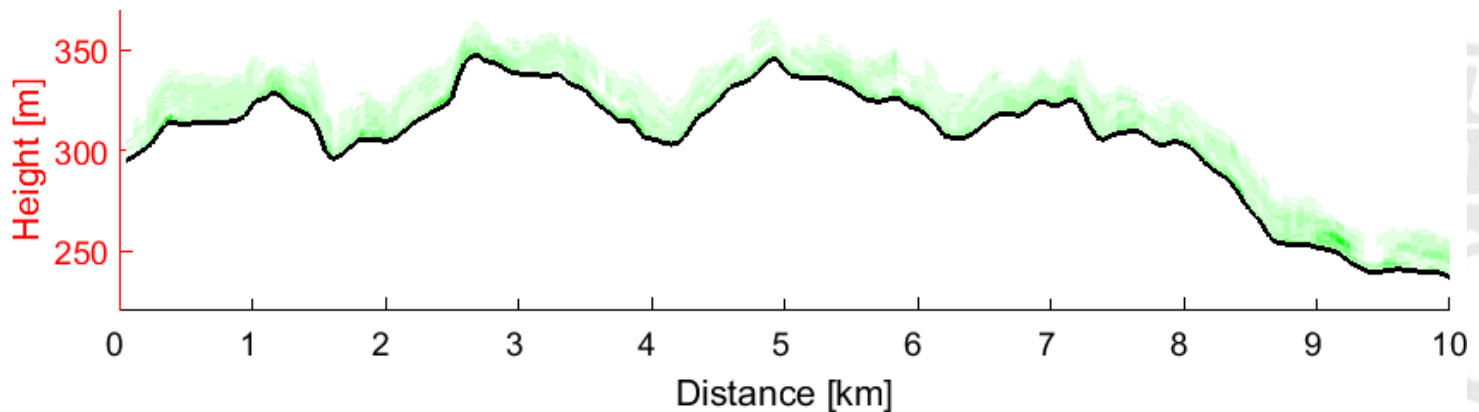
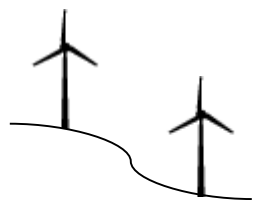
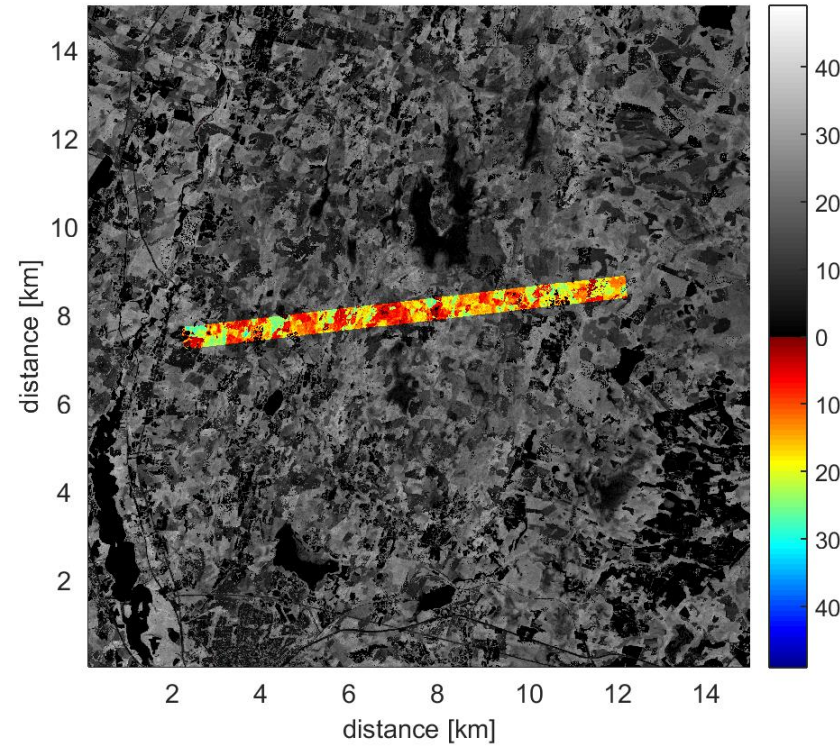
Mätningar av alla randvillkor + valideringspunkter för modellstudier

- Markhöjd, skogshöjd och skogsdensitet från laserscanningar

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* In a vacuum light will travel approximately 0.3m in 1ns





Mätningar av alla randvillkor + valideringspunkter för modellstudier

- Markhöjd, skogshöjd och skogsdensitet från laserscanningar
- Flöden (turbulens, värme, strålning) från mätmasten
- Vindprofiler (sodar)

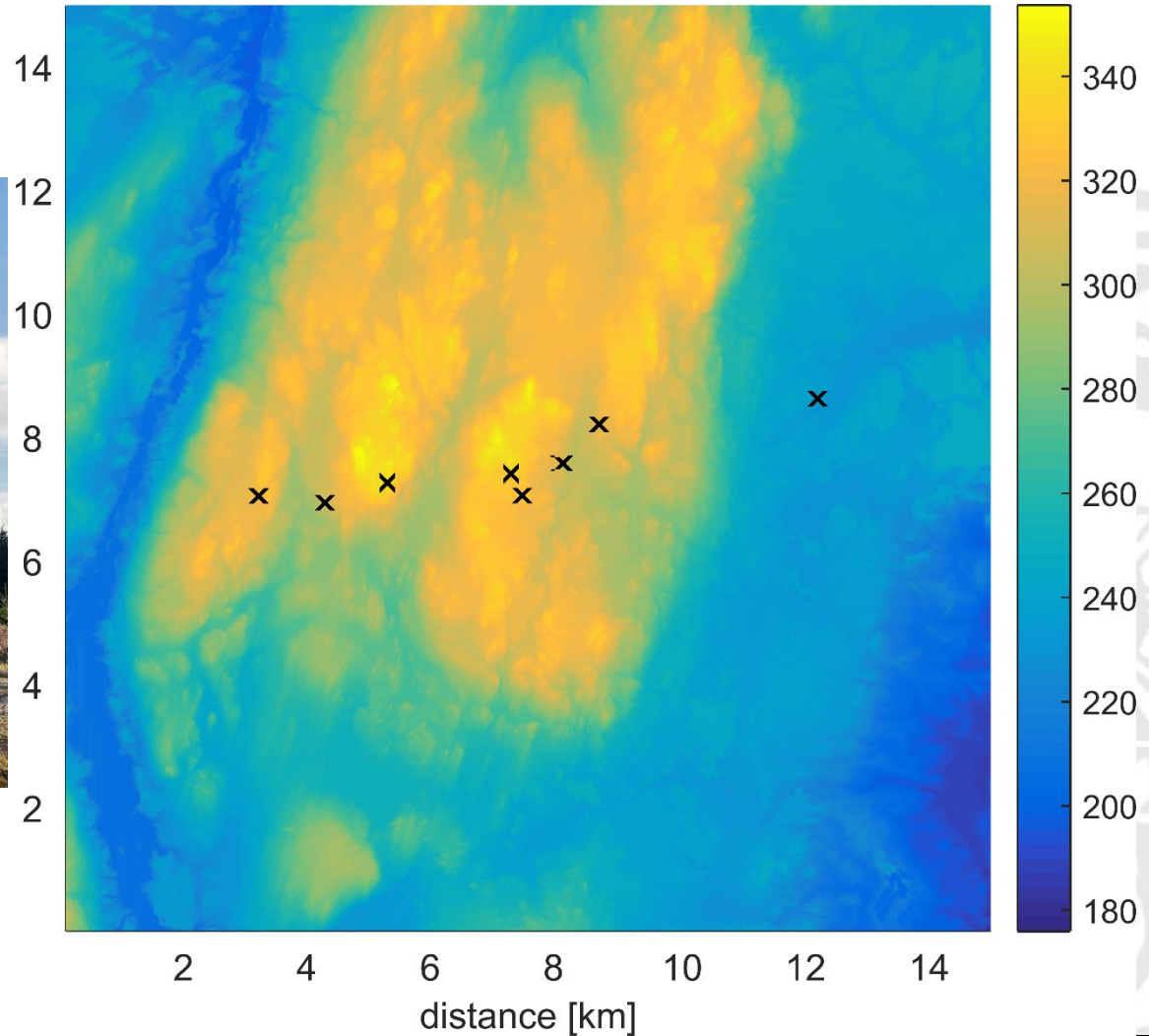
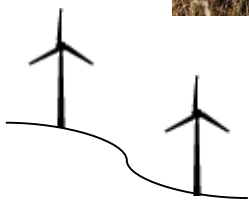
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Mätningar av alla randvillkor + valideringspunkter för modellstudier

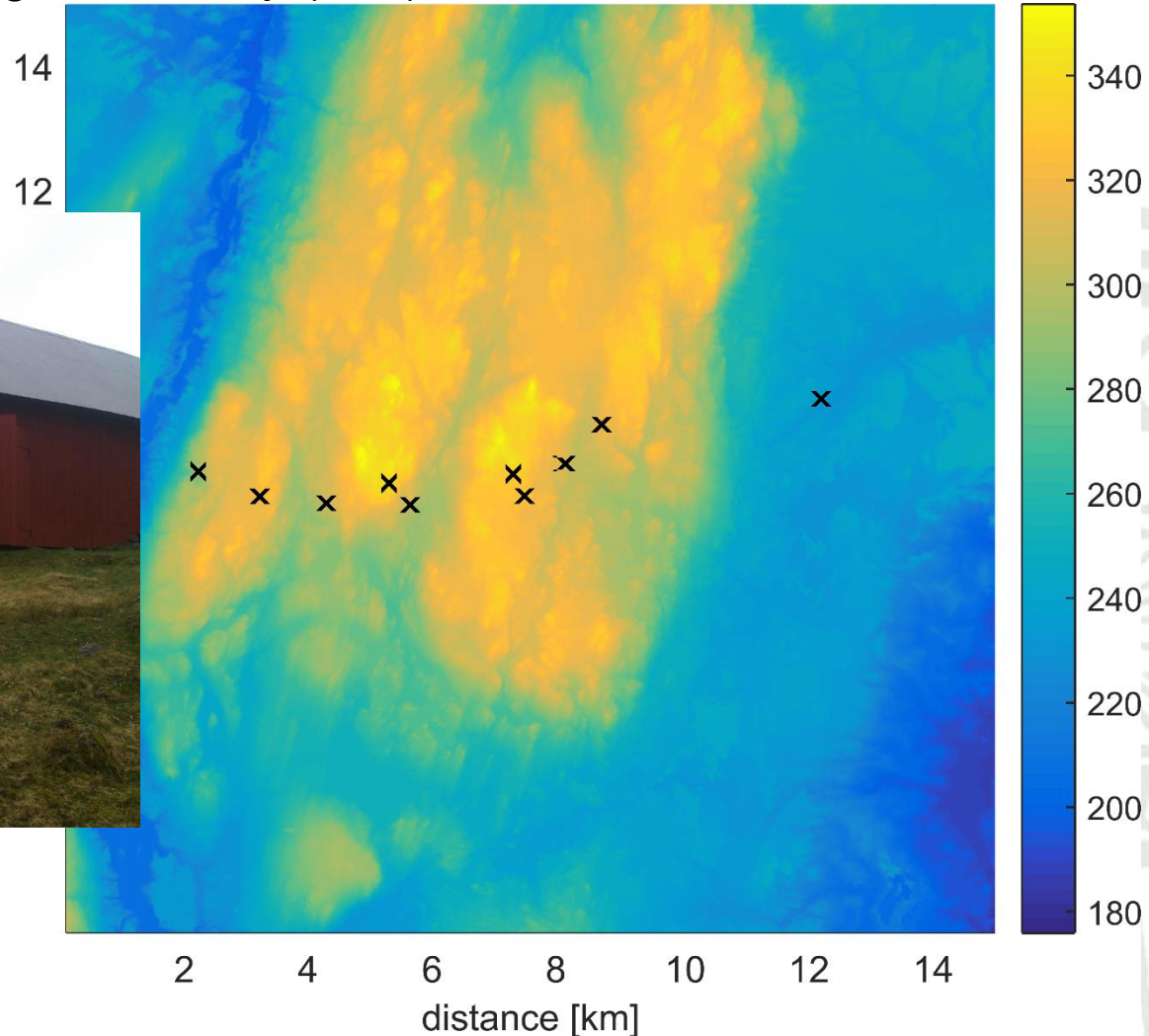
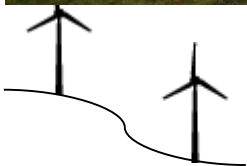
- Markhöjd, skogshöjd och skogsdensitet från laserscanningar
- Flöden (turbulens, värme, strålning) från mätmasten
- Vindprofiler (sodar)
- Vindprofiler och gränsskiktsöjd(lidar)

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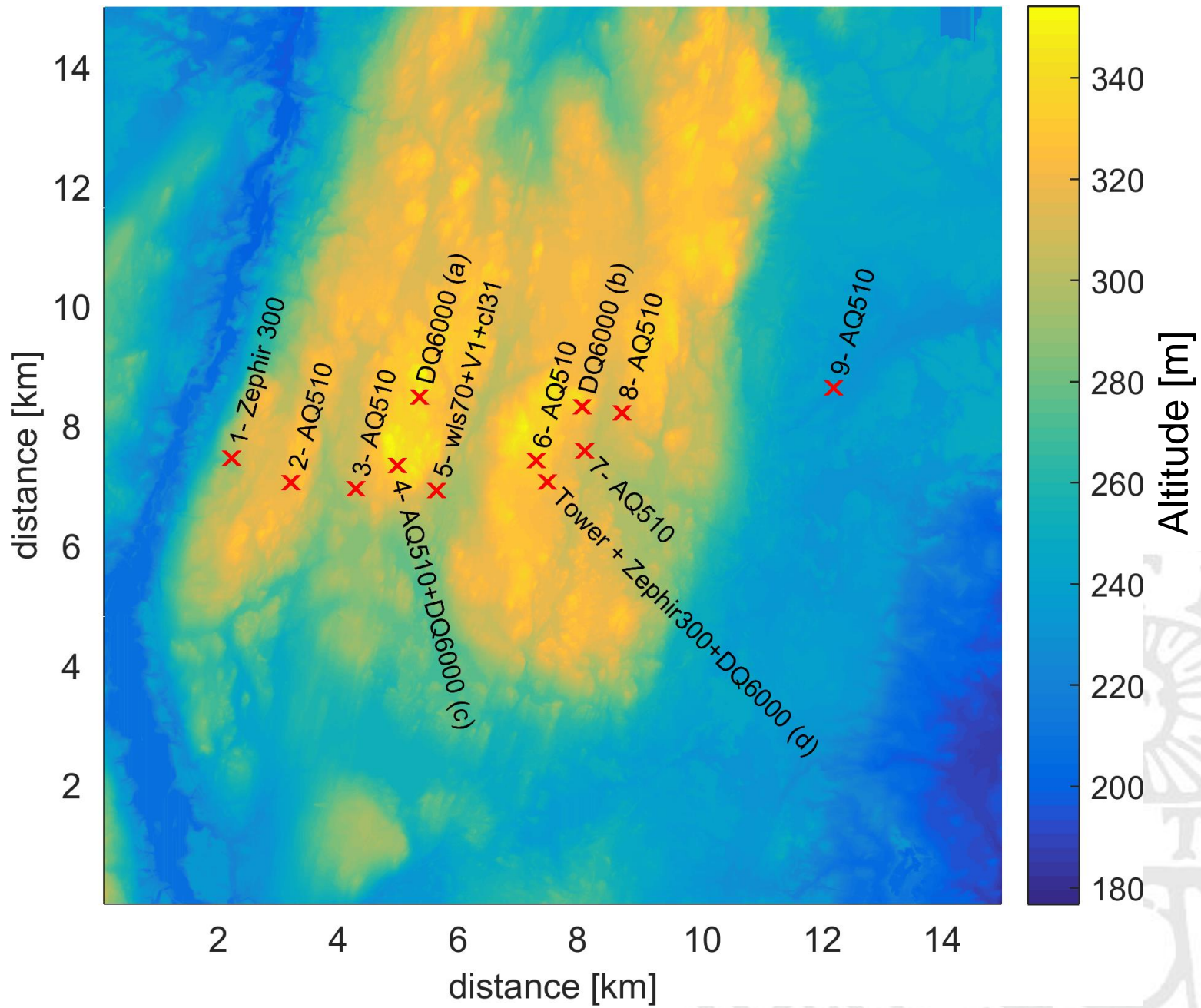
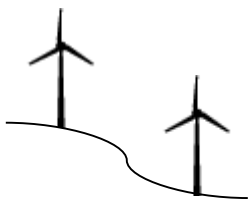




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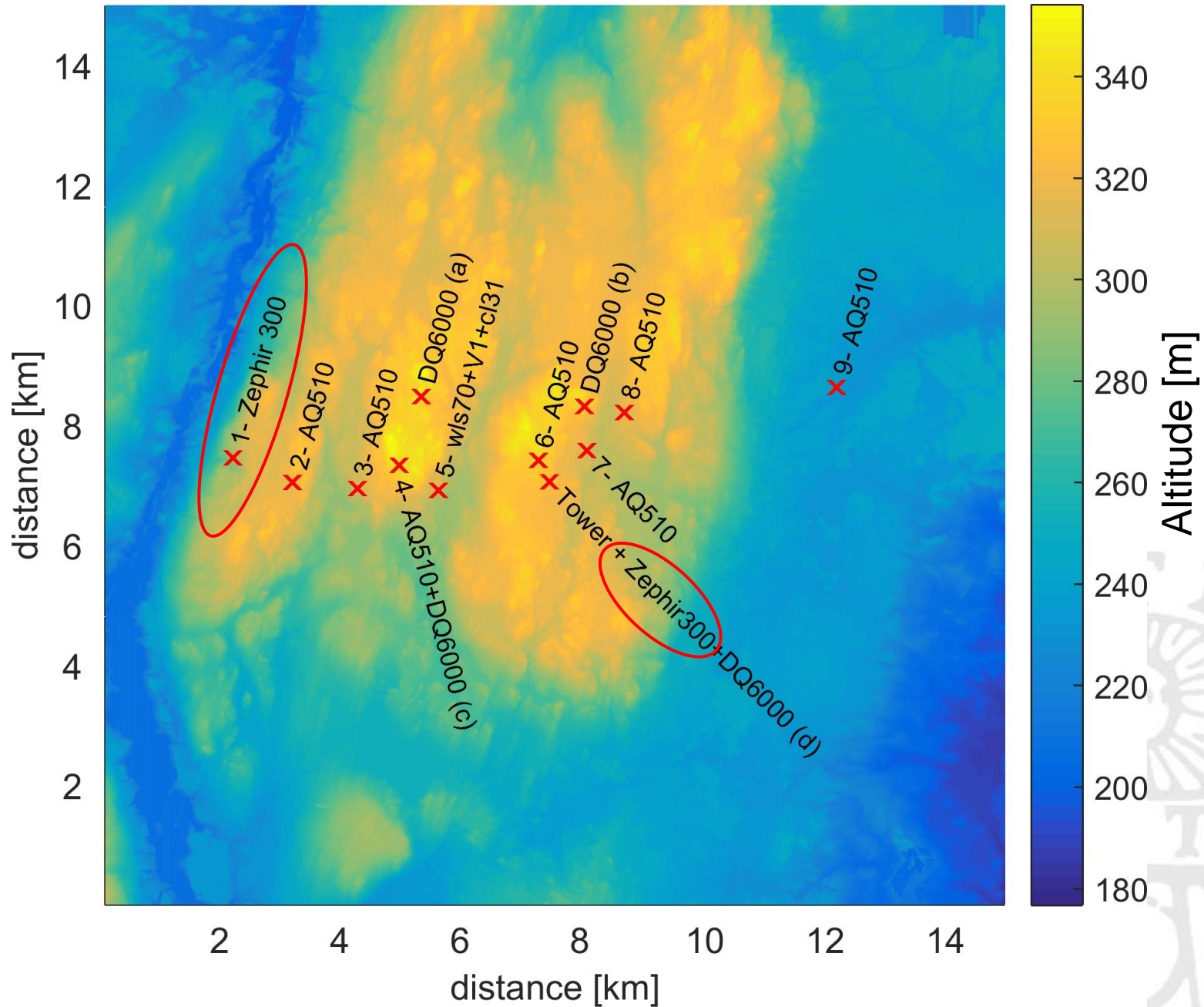
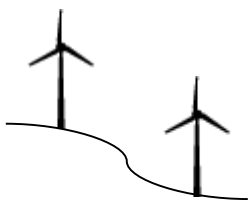




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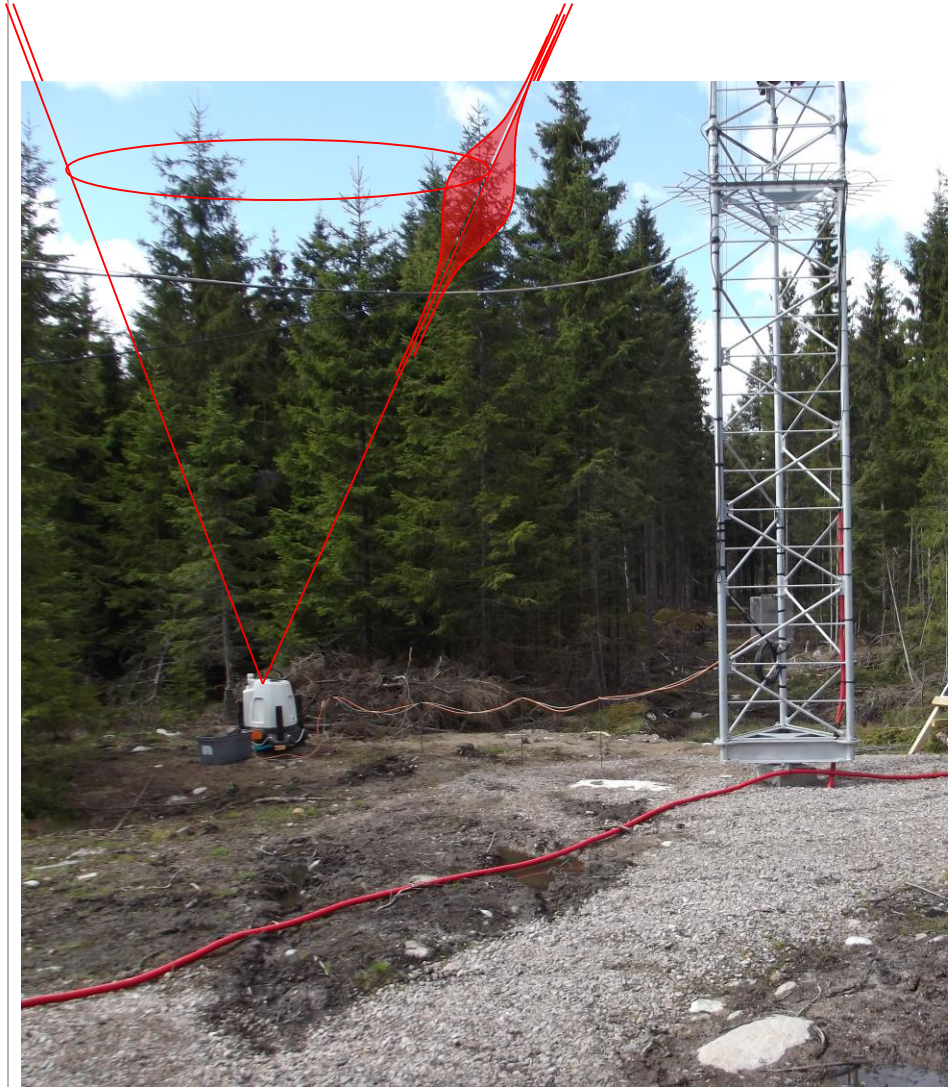
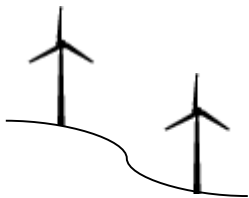
Zephyr 300 lidar

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2 locations,
Mean and raw data
collected for 4 resp 7
months.

Over all:
Worked well

Main problem:

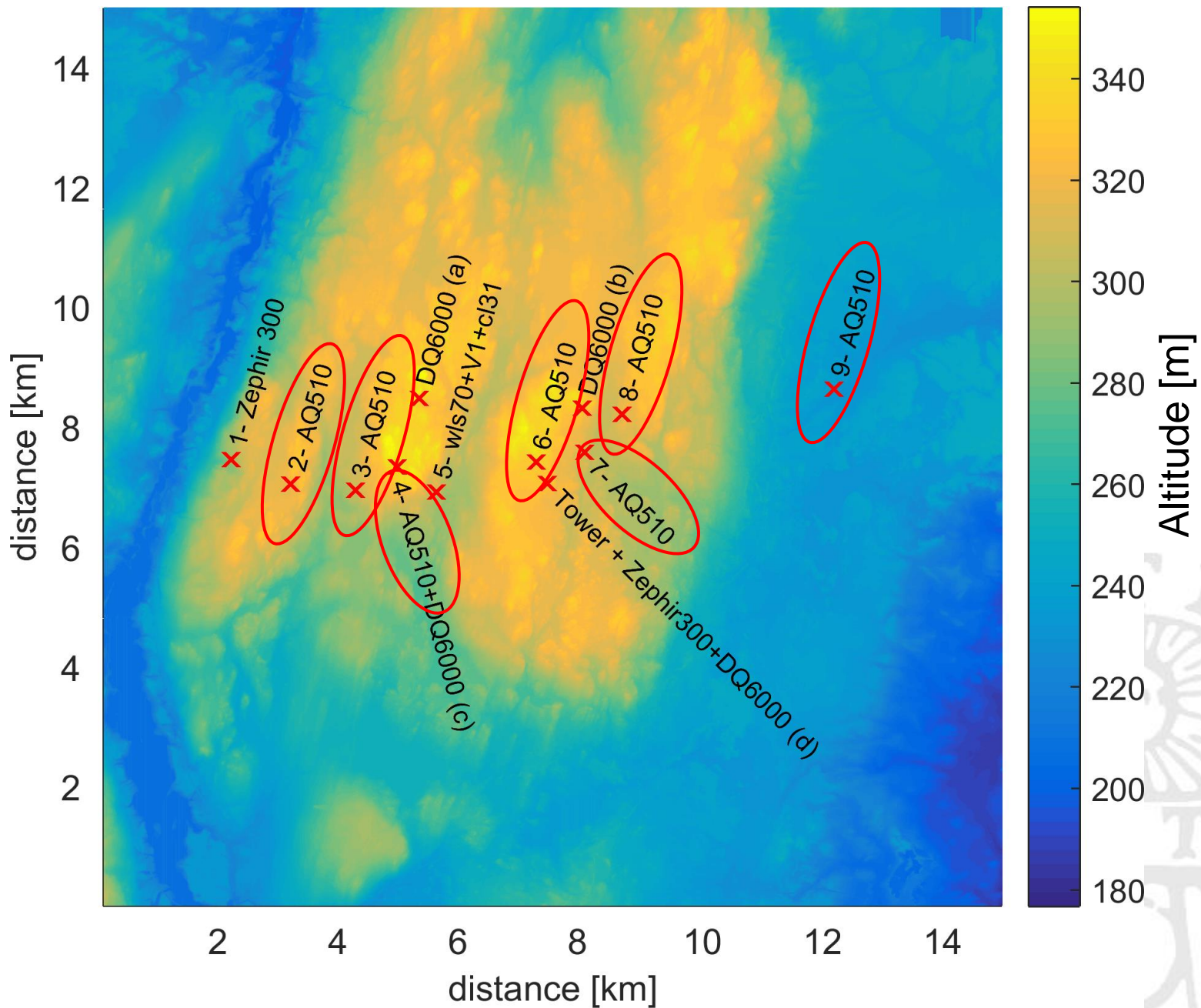
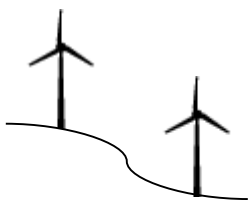
- Signal to noise ratio
- measurement volume (upper heights)
- Wind direction



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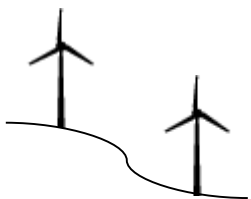




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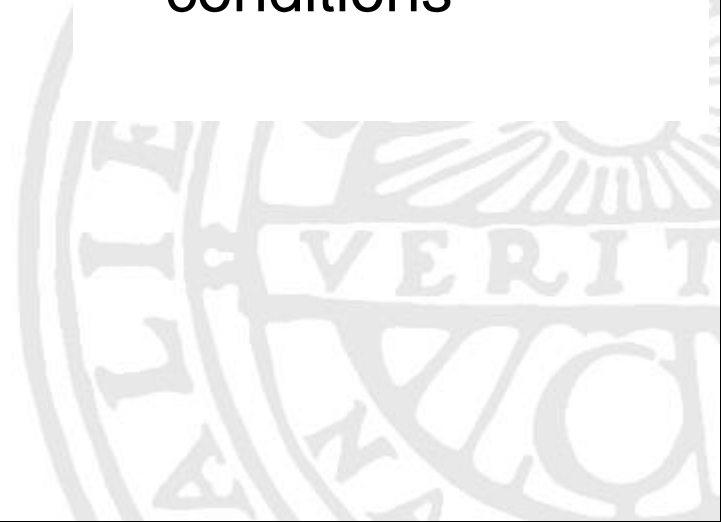
AQ510 Sodar



7 locations,
Mean and raw data
collected for 6 resp 8
months.

Over all:
Worked well

Main problem:
• Very stable
conditions





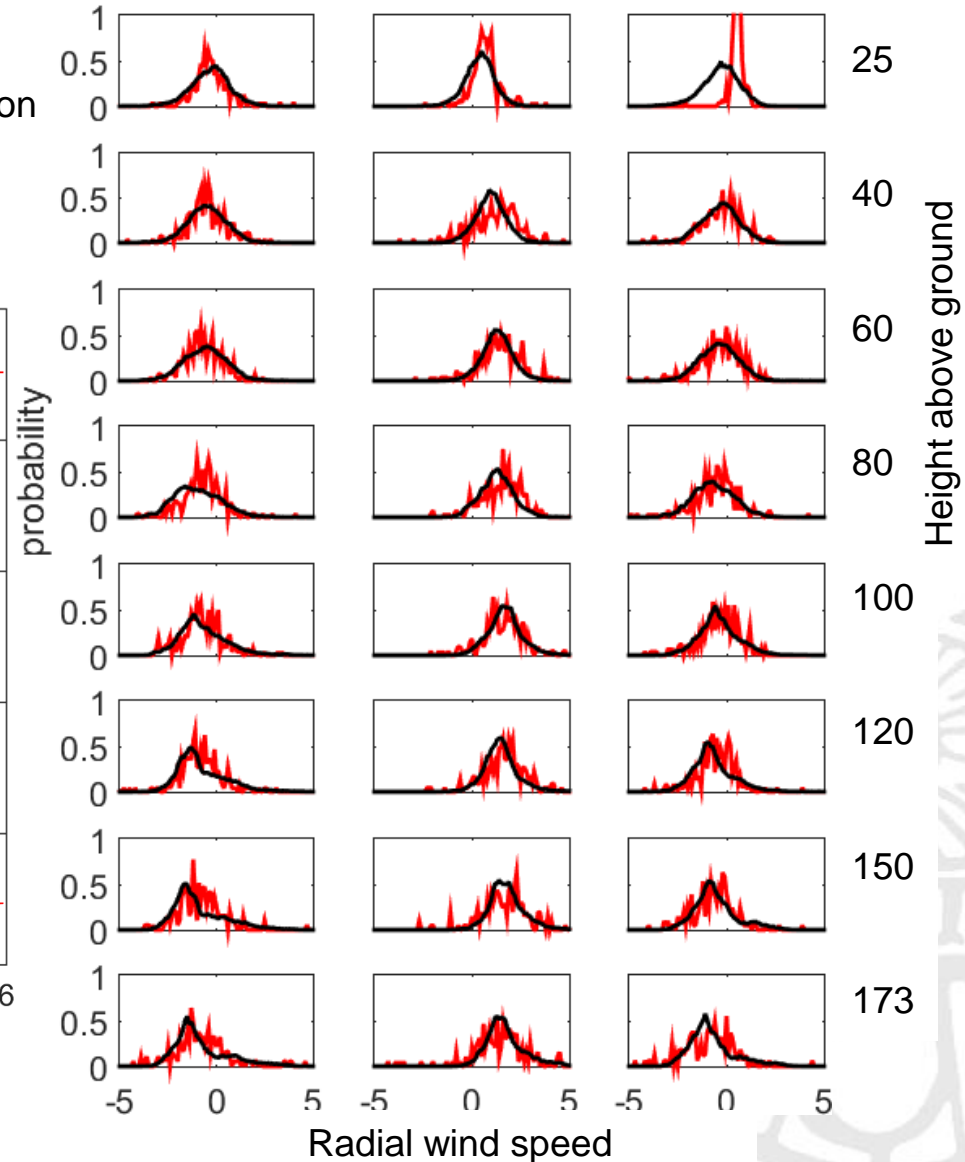
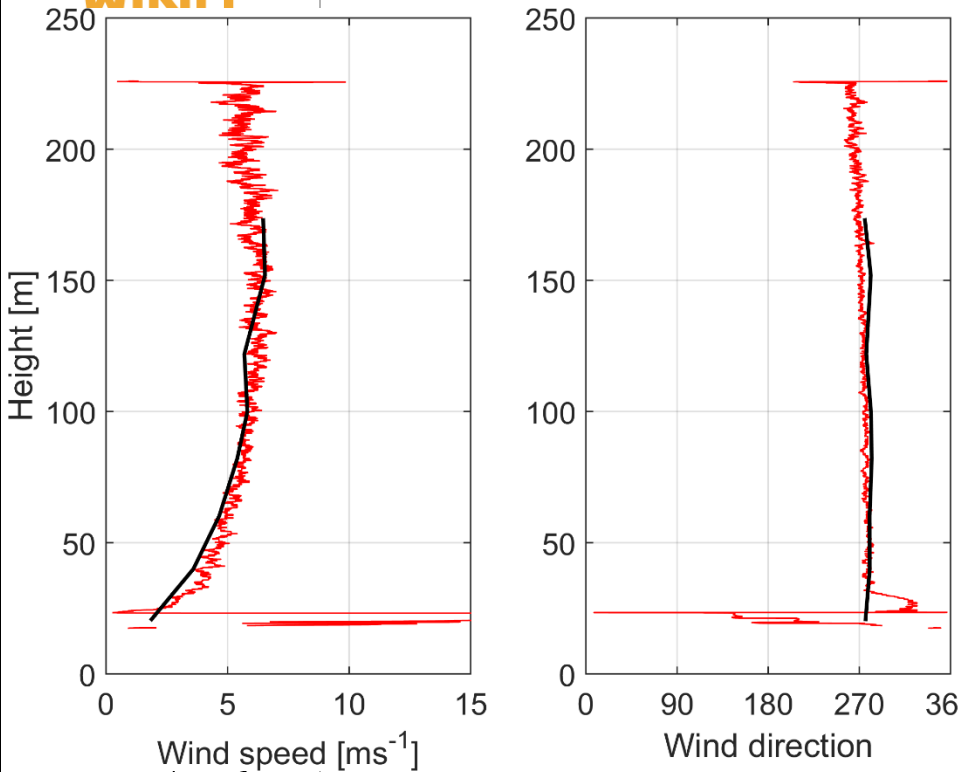
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Example of unstable atmospheric conditions

— Sodar, from wavelet transform
— Sonic projected in SODAR direction

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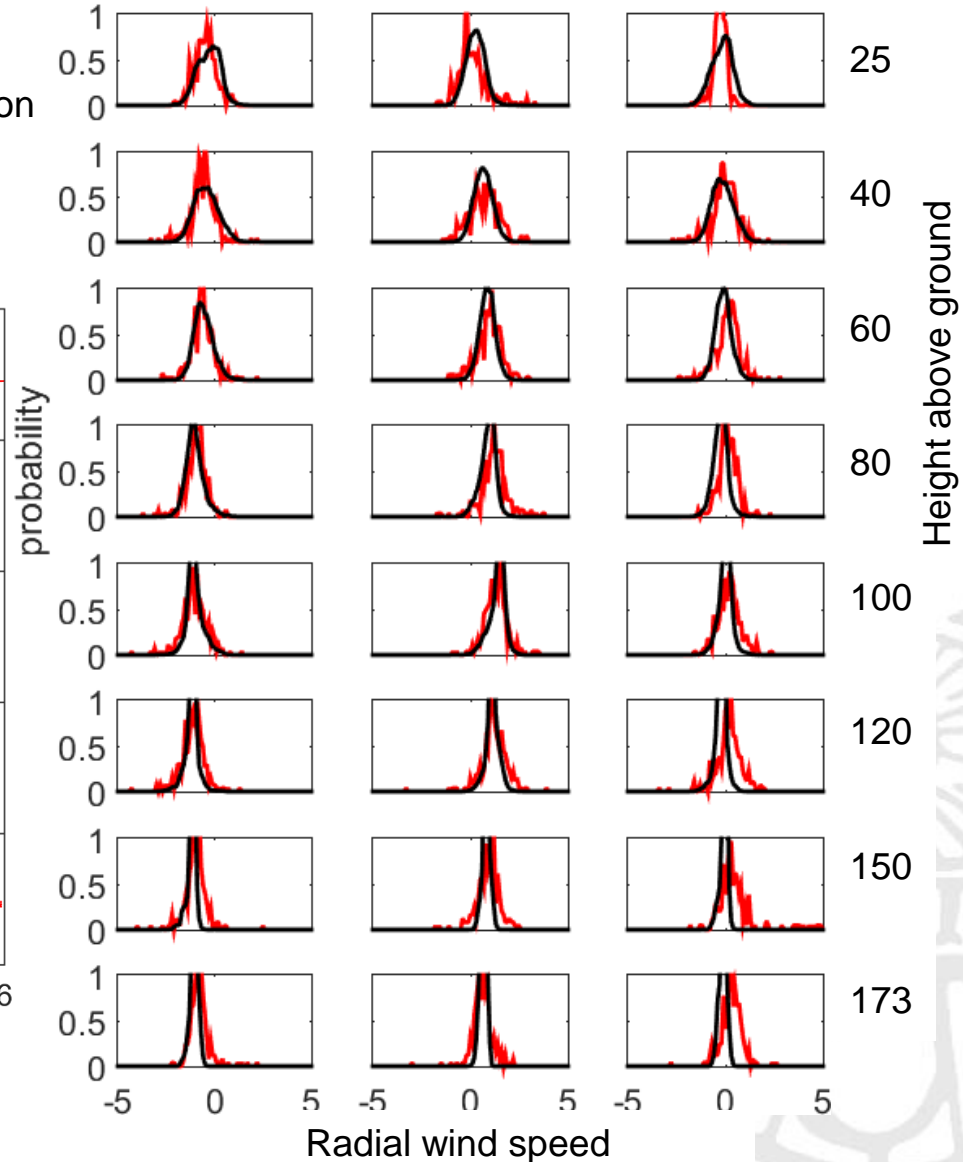
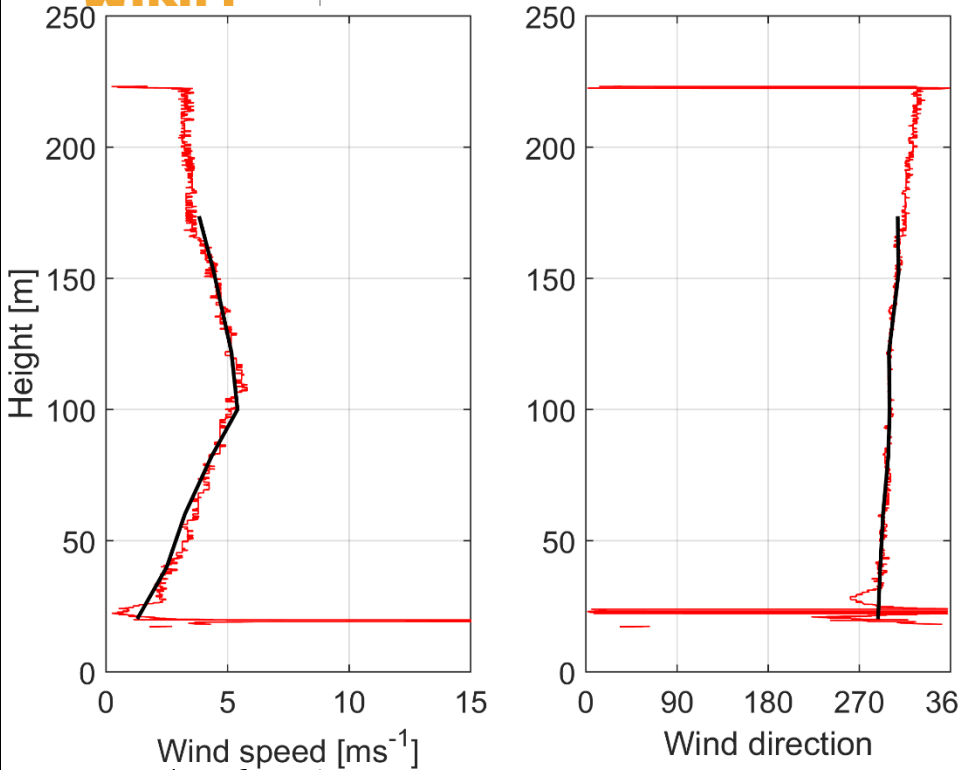
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Example of very stable atmospheric conditions

— Sodar, from wavelet transform
— Sonic projected in SODAR direction

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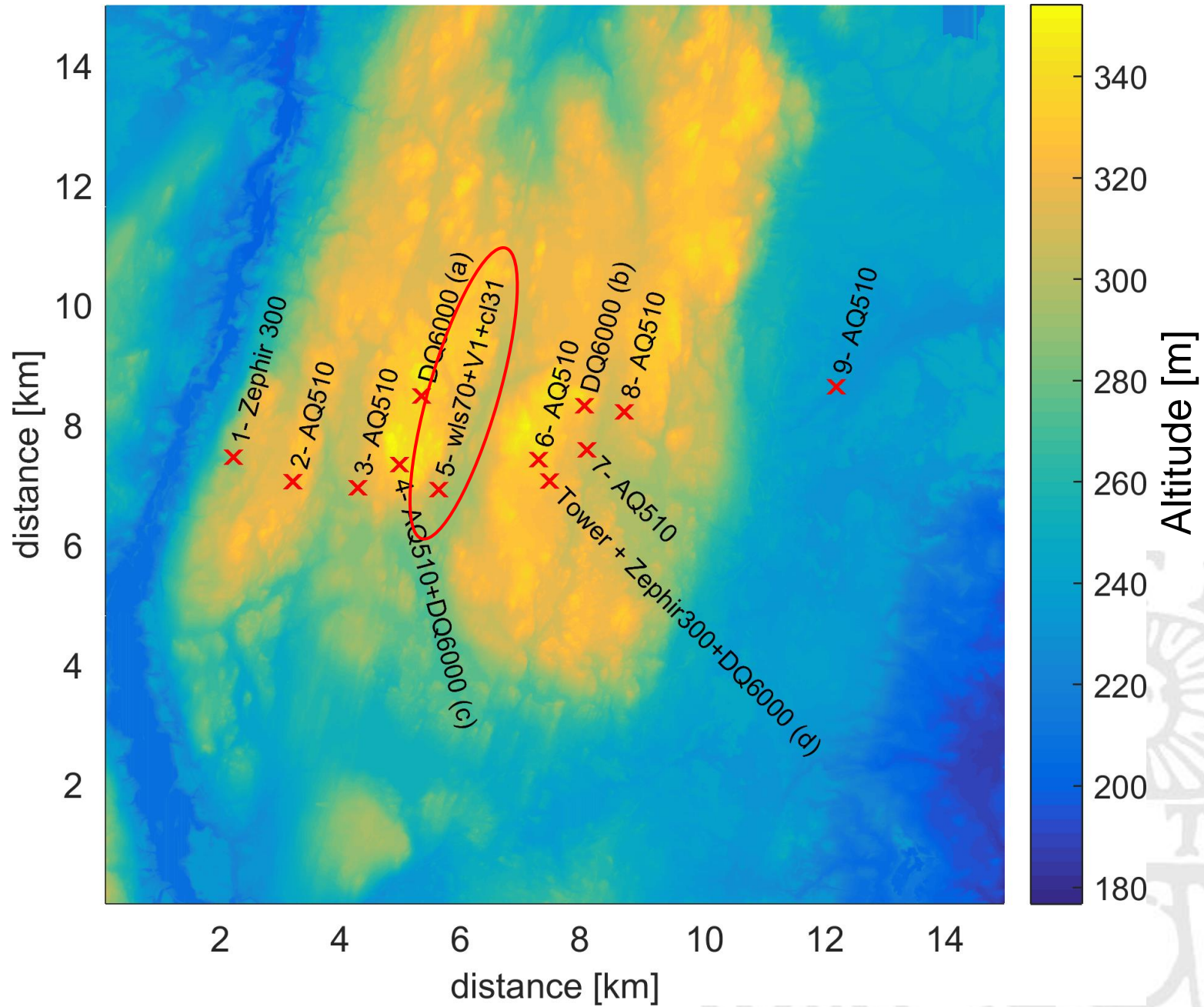
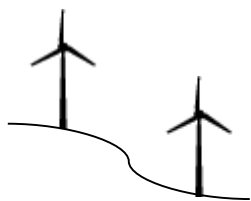




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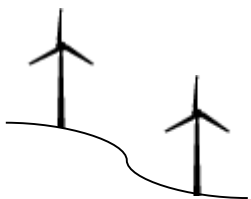




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WLS 70, V1, ceilometer

1 location,
WLS70, V1 and
Vaisala ceilometer.
Mean and 1 Hz data

Over all:
Has not worked well
(ceilometer not yet
investigated)

Main problem:

- Overheating
- Signal to noise
- Wind shield wiper
not working or
wiping the whole
time

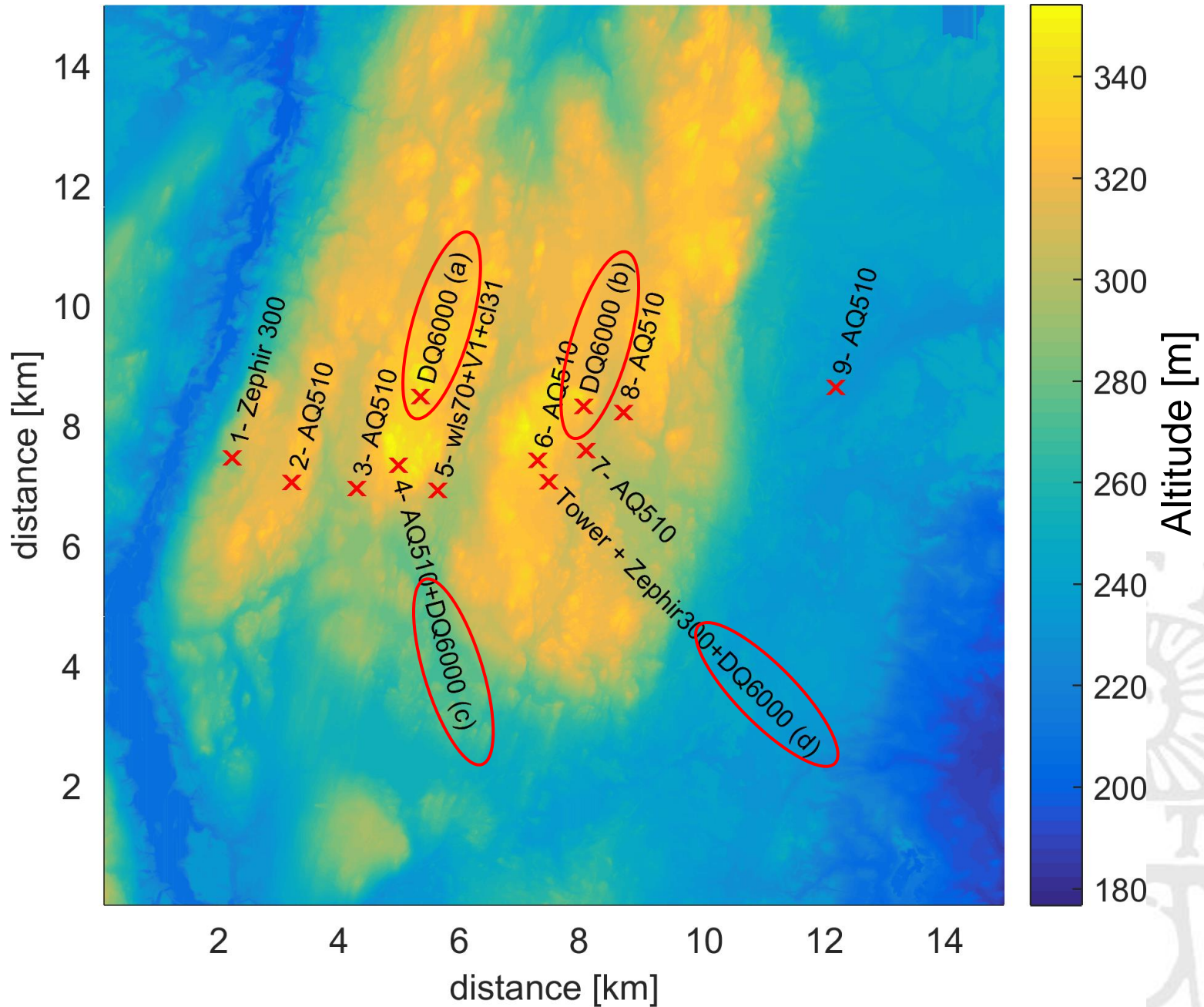
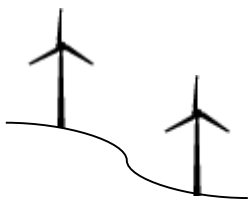




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Digiquartz micro barometers

Model 6000-16B - RS-232 and RS-485 Output Pressure Transmitters

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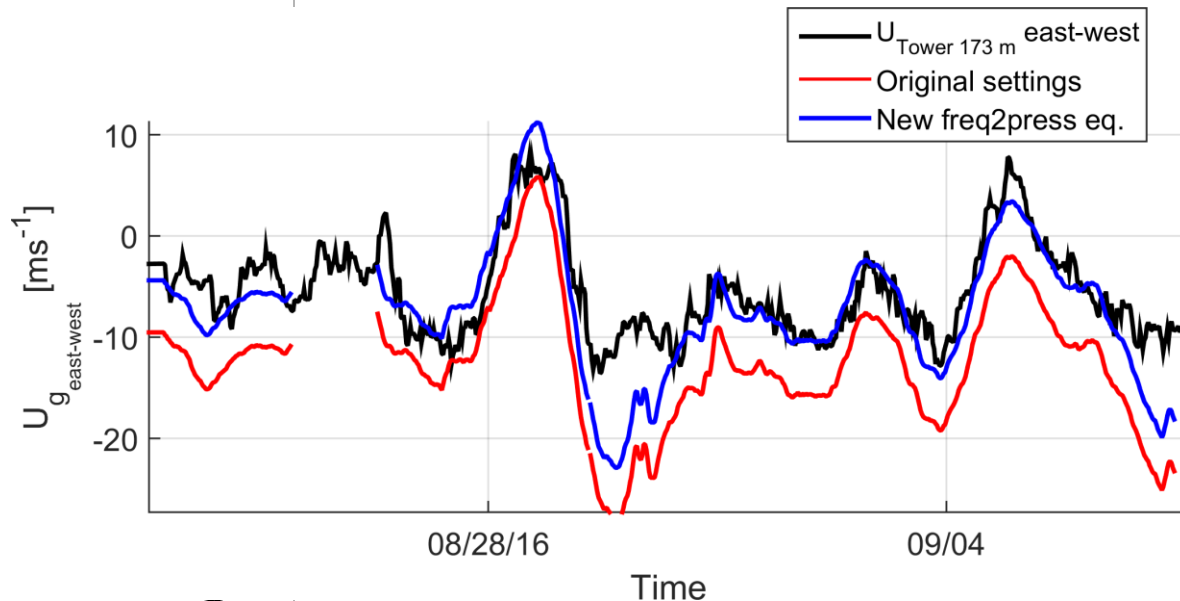
- 0.0001% Resolution
- ± 0.08 hPa Accuracy
- High Reliability and Stability better than 0.1 hPa per year
- Bi-directional RS-232 and RS-485 Serial Interface.
- User Selectable Parameters through the RS-232 interface Includes Resolution, Update Rate, Engineering Units, Sampling Commands etc. with [Supplied Software](#)
- NIST Traceable - ISO 9001:2000 Quality System
- Directly Compatible with [Model 715 Display](#)
- [Free zero adjustment](#)
- [Optional High Performance Pressure Port Available](#) (DigiPort)
- Click [here](#) for a data sheet

4 locations, one value.

Over all:
Difficult, but promising

Main problem:

- Temperature dependence
- Calibration
- Set too close apart

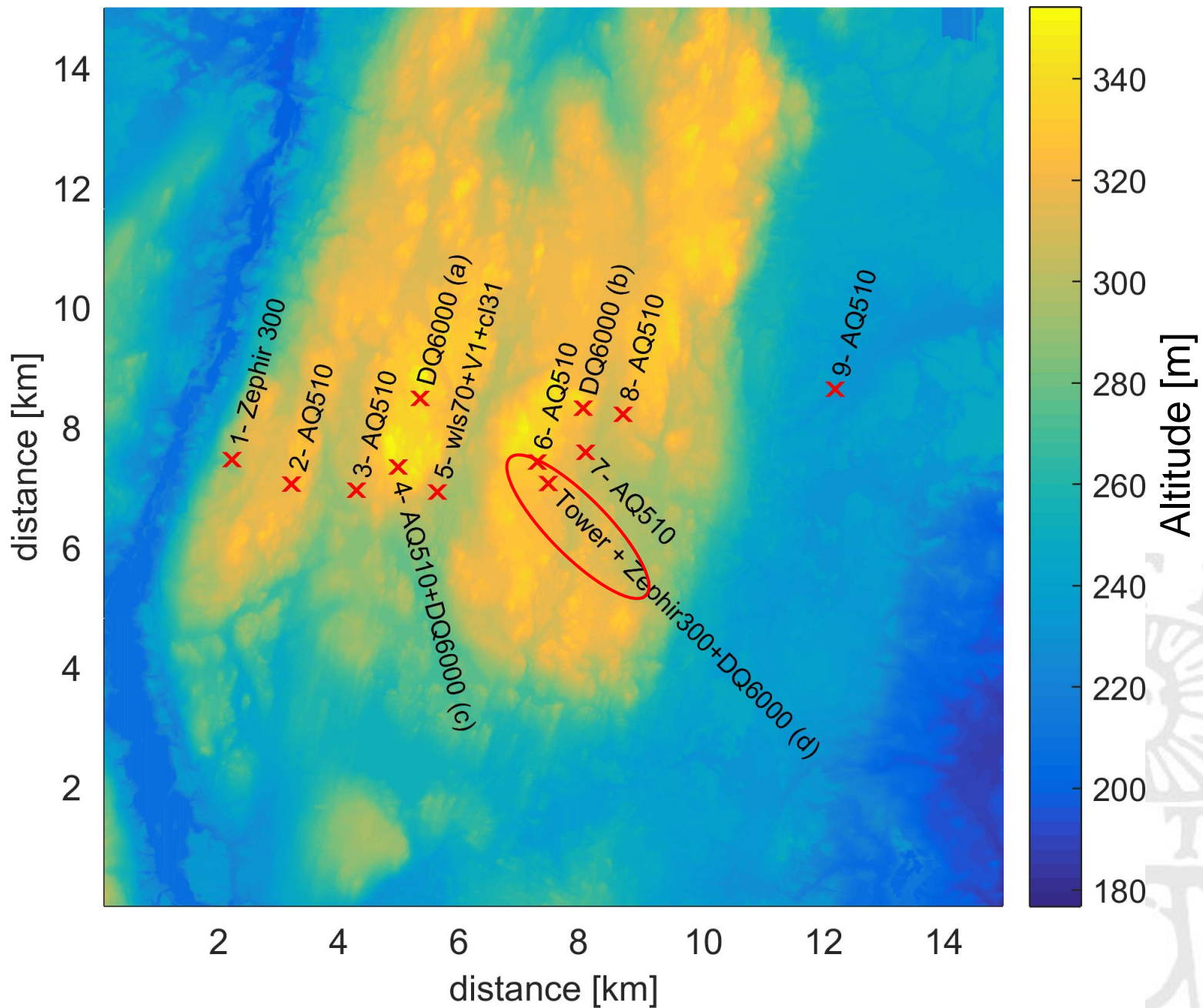
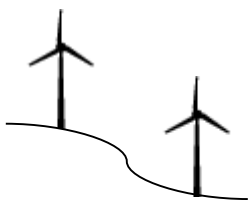




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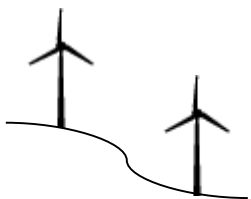
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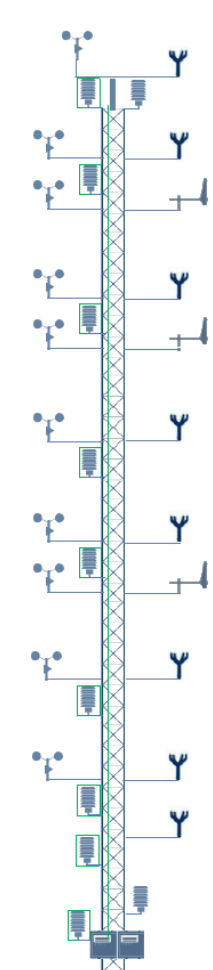


Tower

- Sonics
- Thies cups
- Vaisala cups
- Wind vanes
- Temperature profile
- Kipp & Zonen 4-way radiation sensors



Height (Meter)



- Thies first class advanced Anemometer
- Metek uSonic-3 Heated Scientific
- Thermometer including radiation shield
Thermocouple (1.78 – 7 m) w aspirated radiation shield
- Thies First Class Heated Wind vane

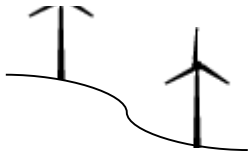
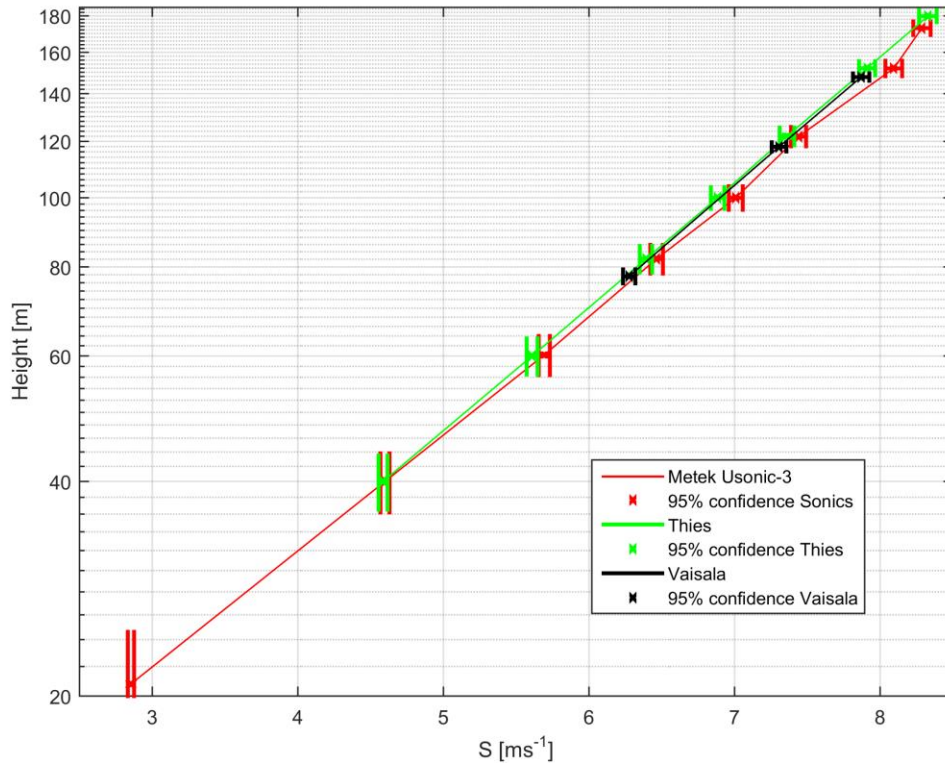




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Comparison with the three anemometers (in good, strictly neutral conditions)



Height (Meter)



- Thies first class advanced Anemometer
- Metek uSonic-3 Heated Scientific
- Thermometer including radiation shield
Thermocouple (1.78 – 7 m) w aspirated radiation shield
- Thies First Class Heated Wind vane

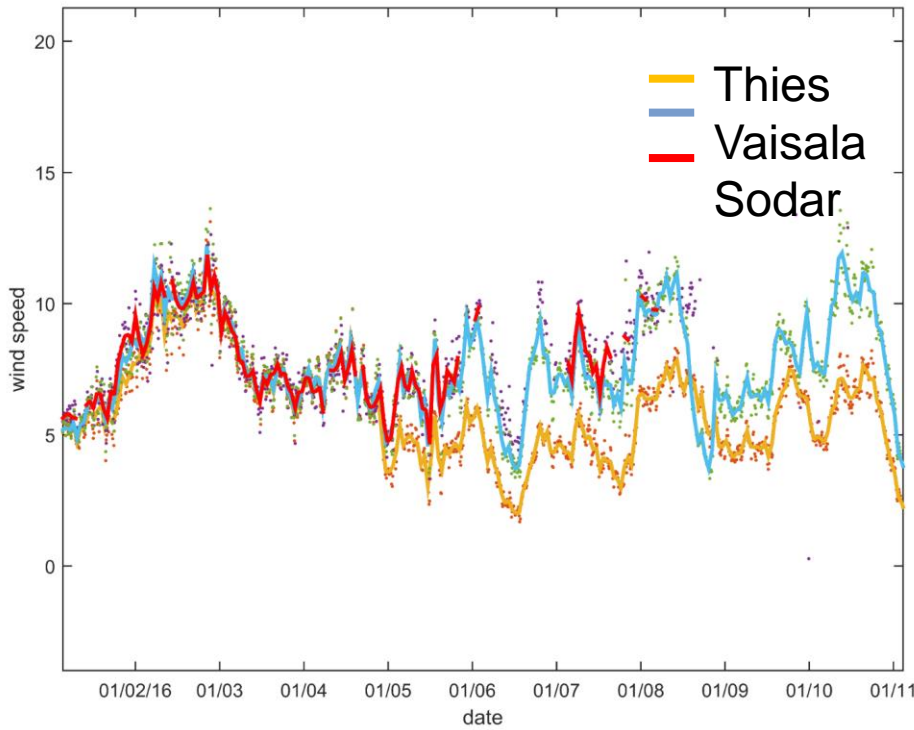




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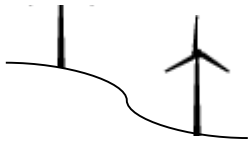
The Thies cups are unreliable in icing conditions



Height (Meter)



- Thies first class advanced Anemometer
- Metek uSonic-3 Heated Scientific
- Thermometer including radiation shield
Thermocouple (1.78 – 7 m) w aspirated radiation shield
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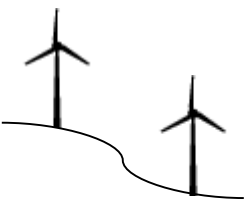
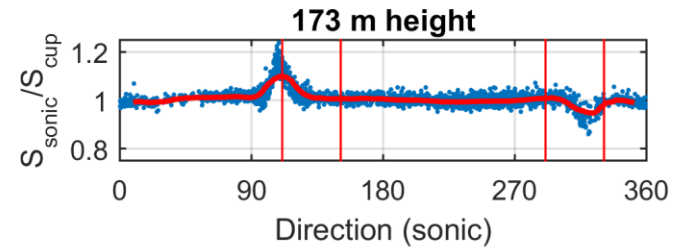
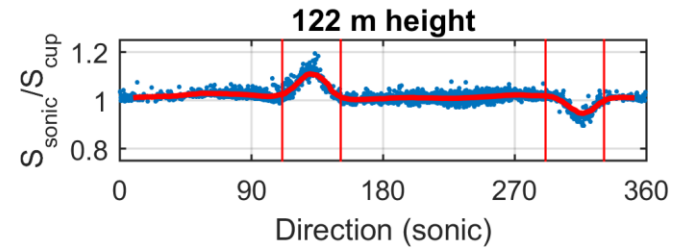
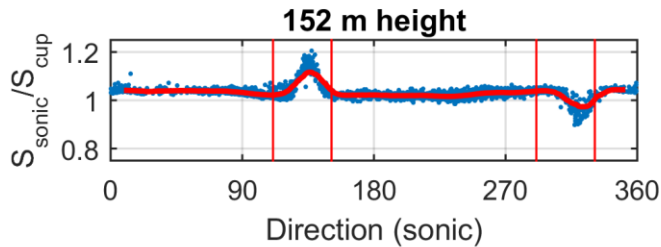
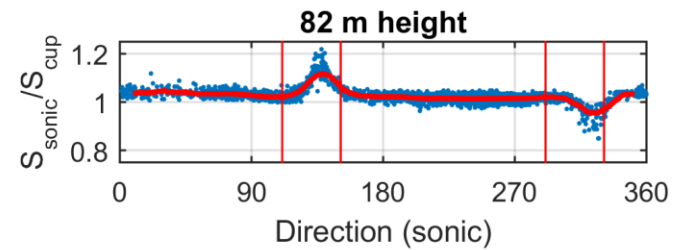
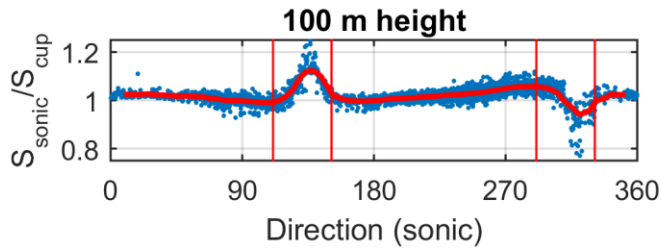
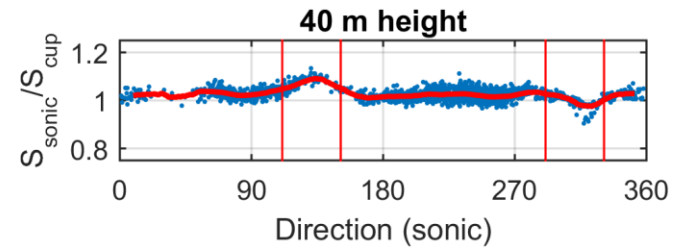
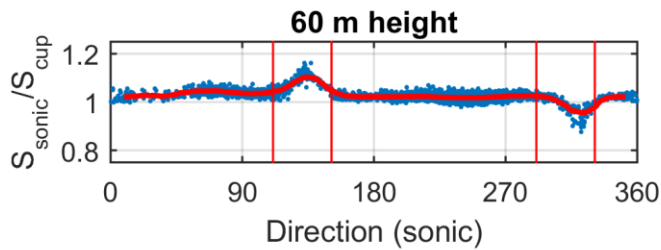
I VILKA RIKTNINGAR KAN VI FÖRVÄNTA OSS MASTSTÖRNINGAR?

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Direction analysis



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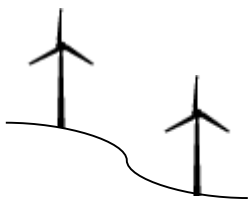
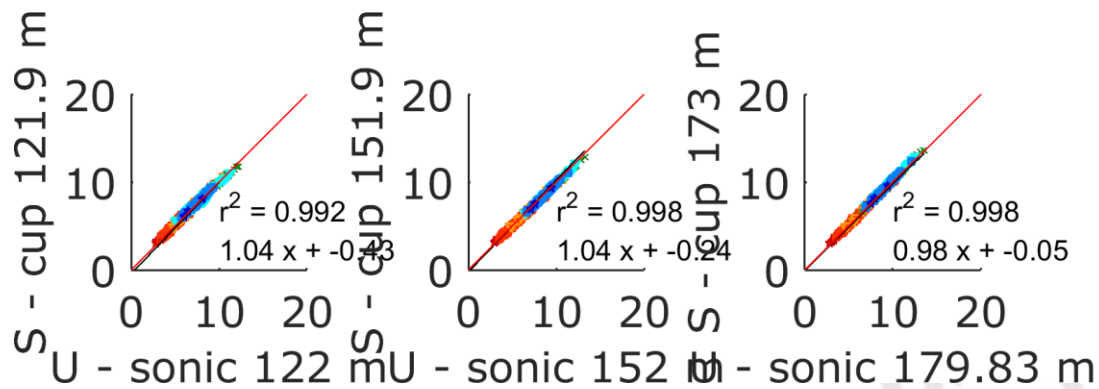
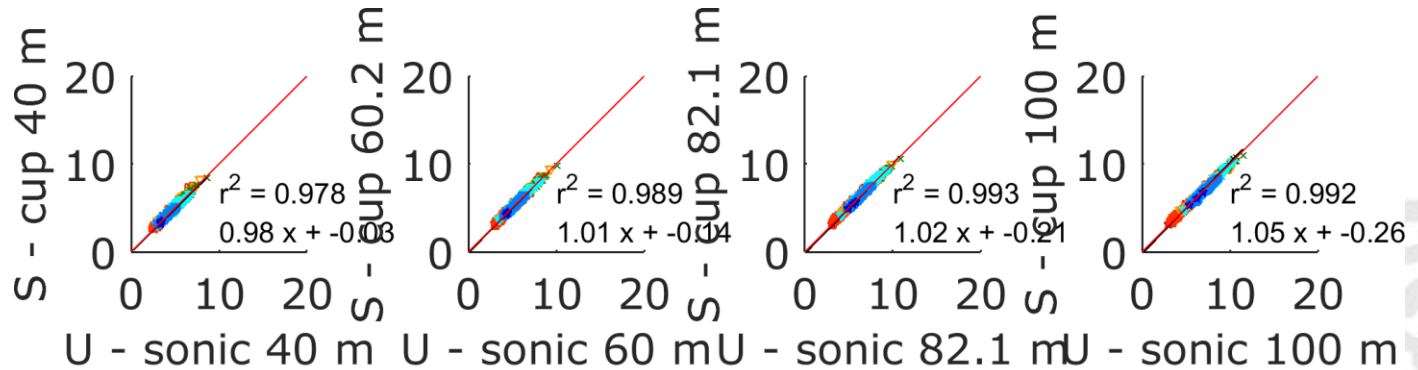
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WIND ENERGY

STandUP
for
WIND



Remote sensing instruments

Cross validation of tower instruments





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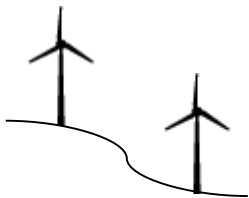
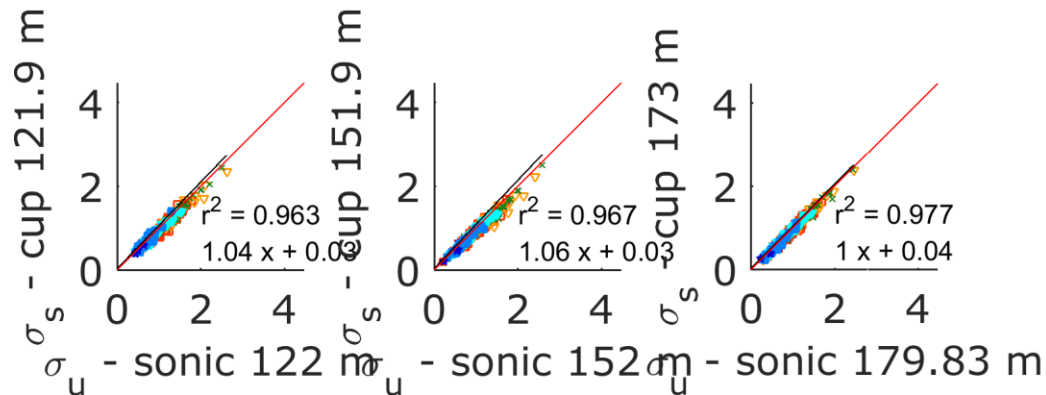
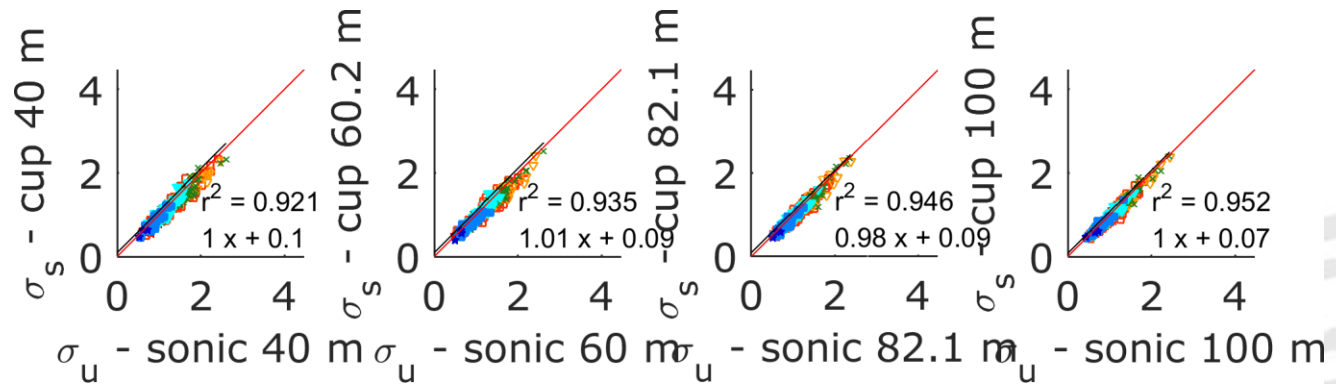
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Remote sensing instruments

Cross validation of tower instruments





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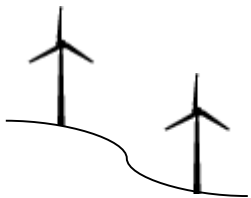
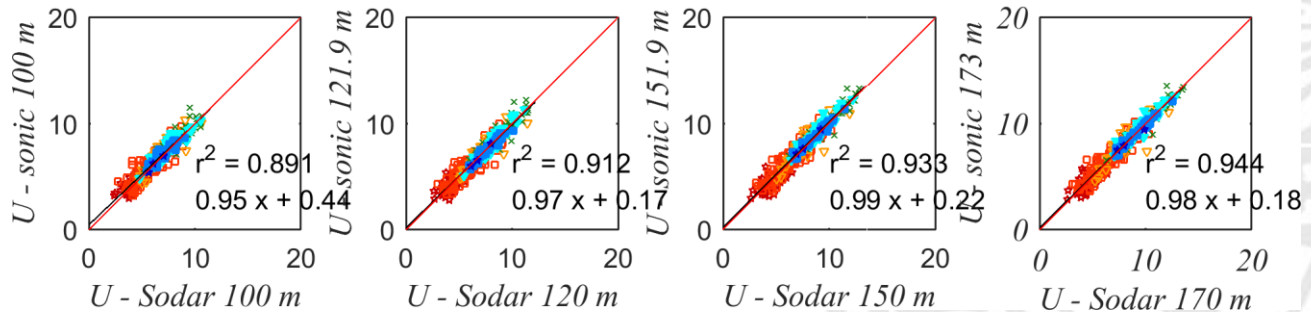
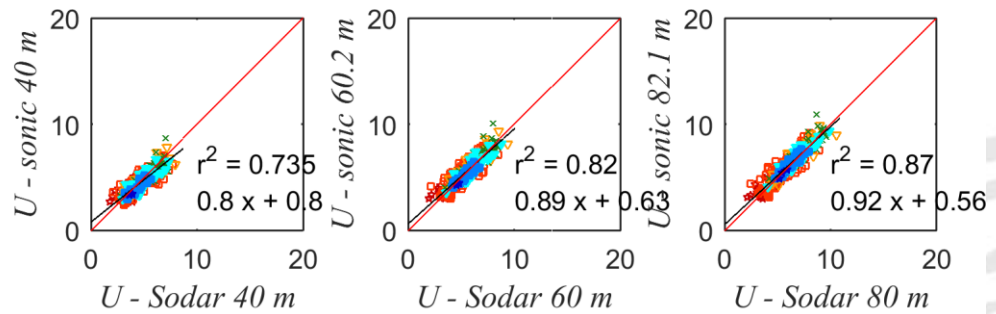
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Remote sensing instruments

SODAR





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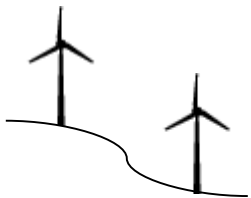
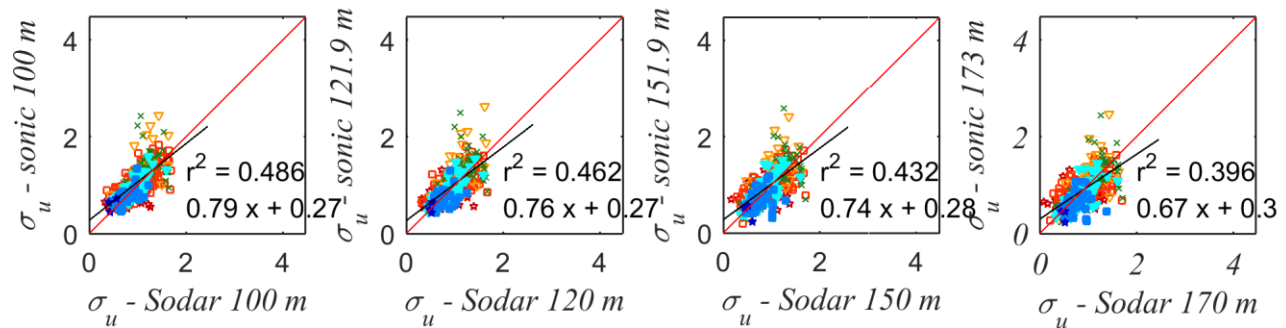
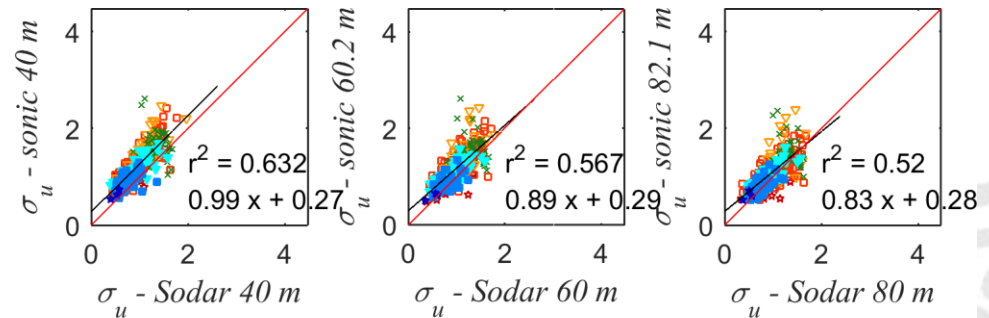
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Remote sensing instruments

SODAR

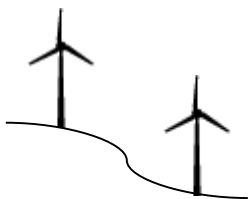




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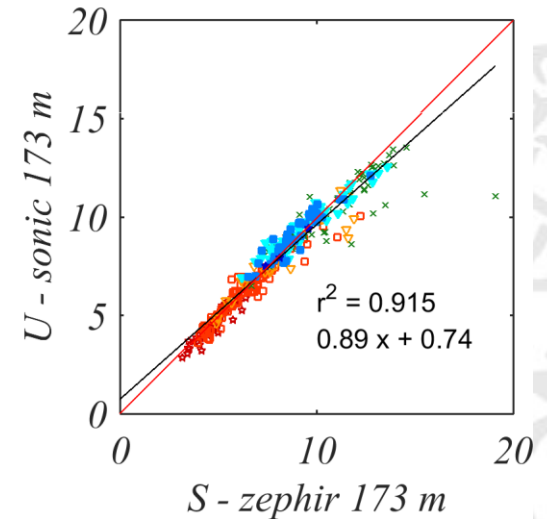
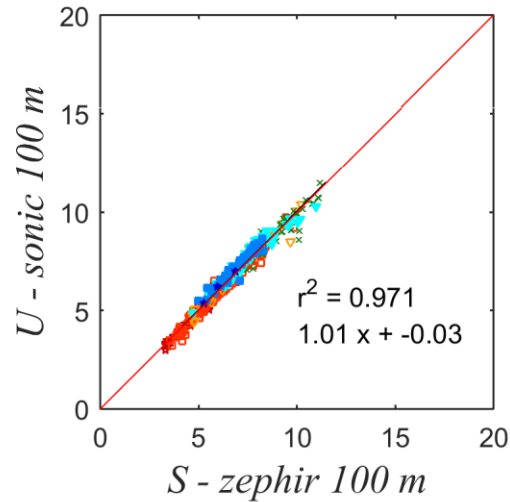
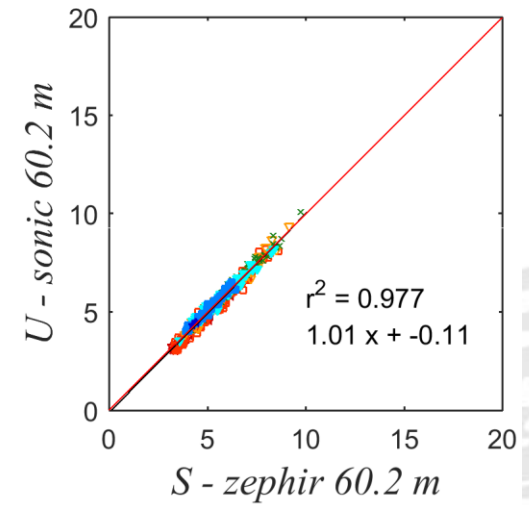
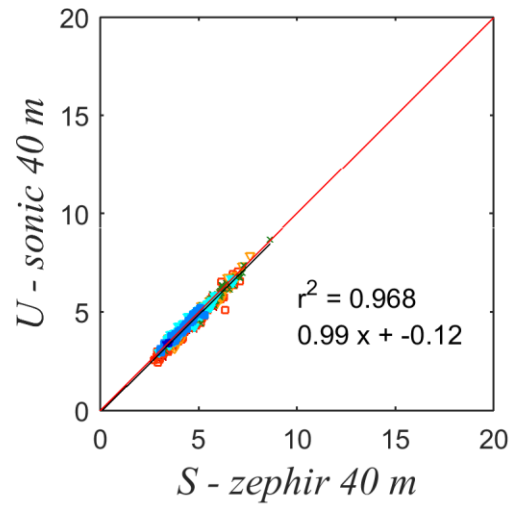
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Remote sensing instruments

Zephyr

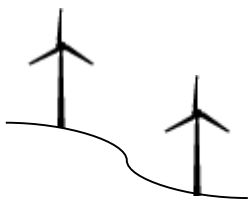




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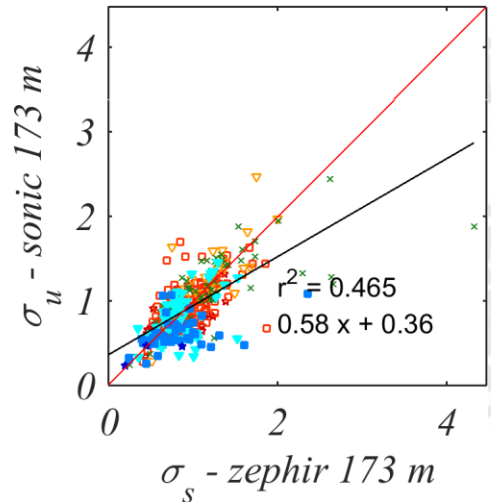
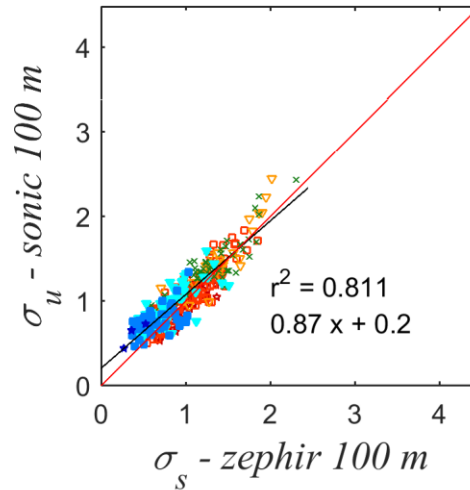
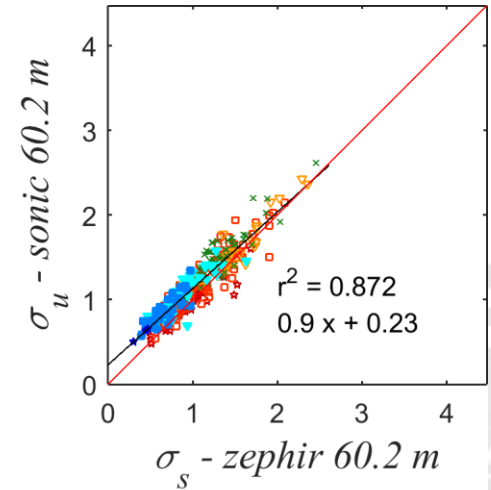
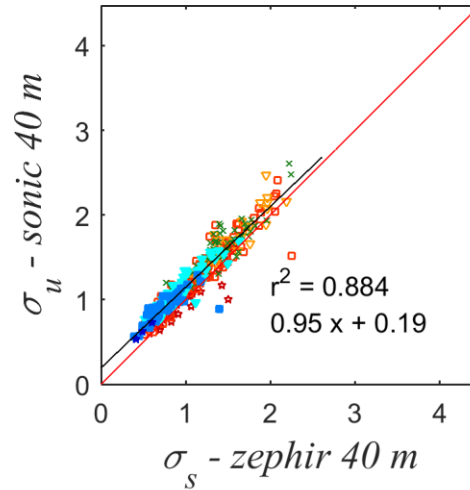
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WIND



Remote sensing instruments

Zephyr





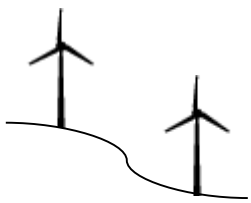
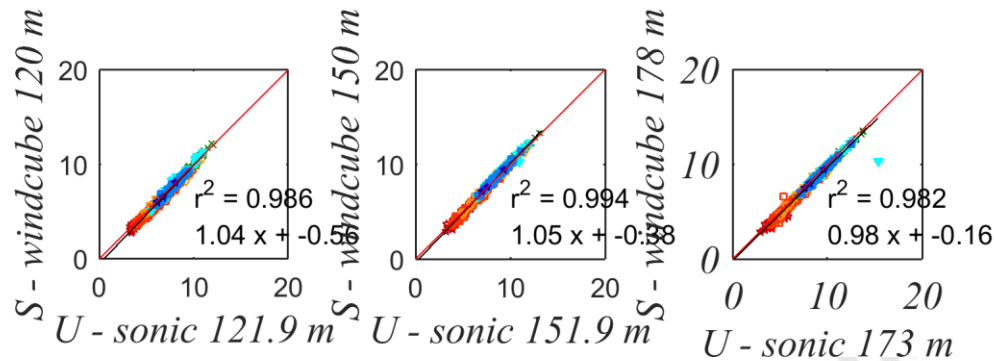
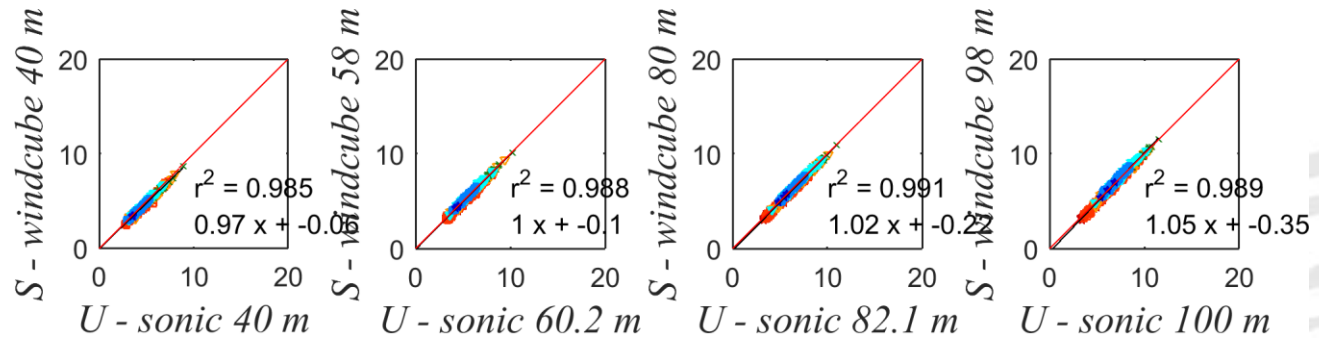
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Remote sensing instruments

WindCube (V2)

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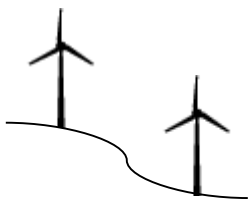
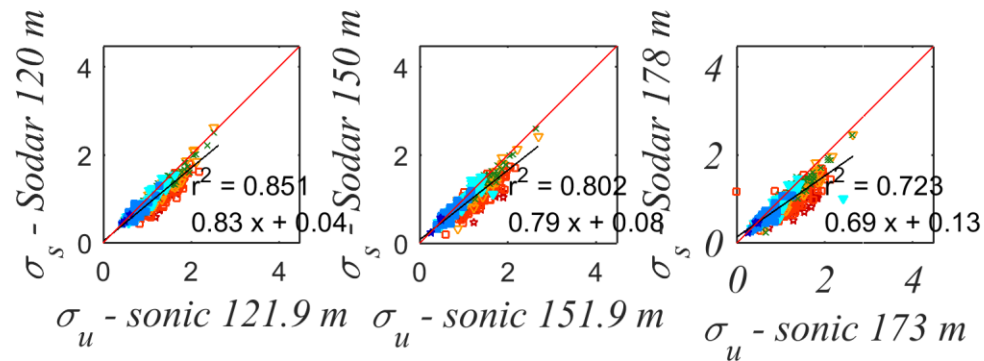
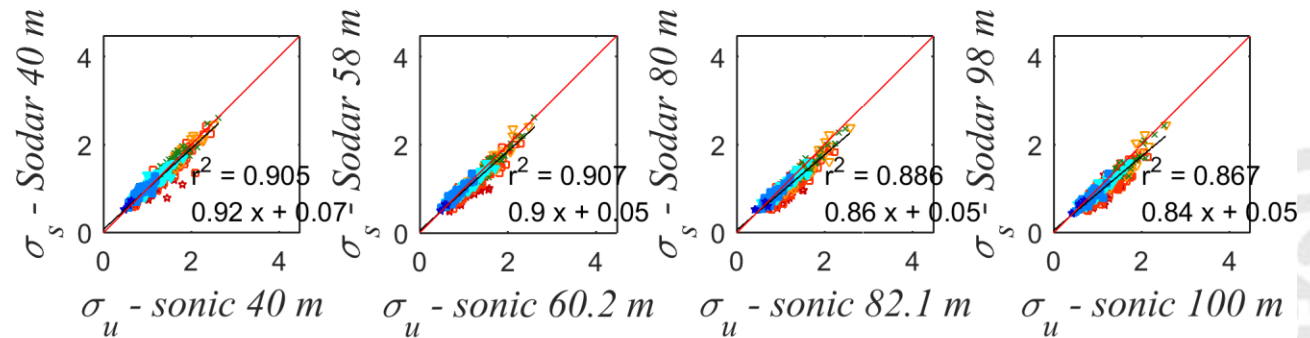
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WindCube (V2)

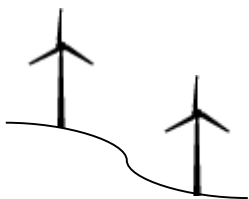




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Men!

Att använda korrelationskoefficient är ett dåligt mått på hur bra instrument är!

Det maximala r^2 som kan uppnås är en funktion av turbulensintensitet och avstånd mellan instrumenten

Fungerar bara bra om instrumenten sitter mycket nära varandra och mäter samma volym

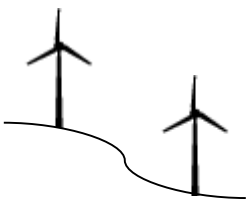


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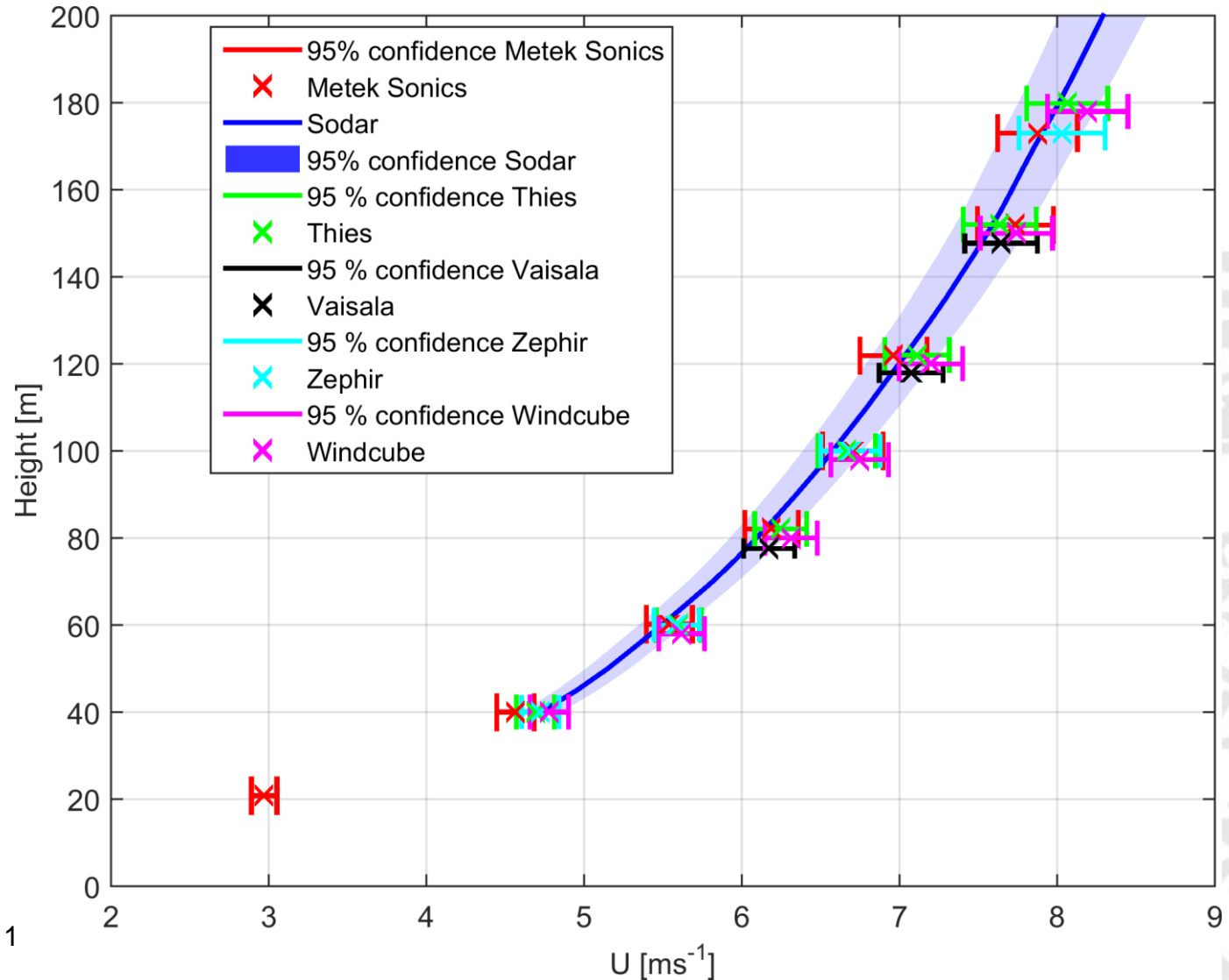
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for
WIND

NEW EUROPEAN WIND ATLAS
newa



Remote sensing instruments

Windprofile from all systems



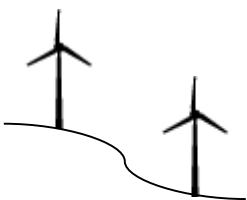


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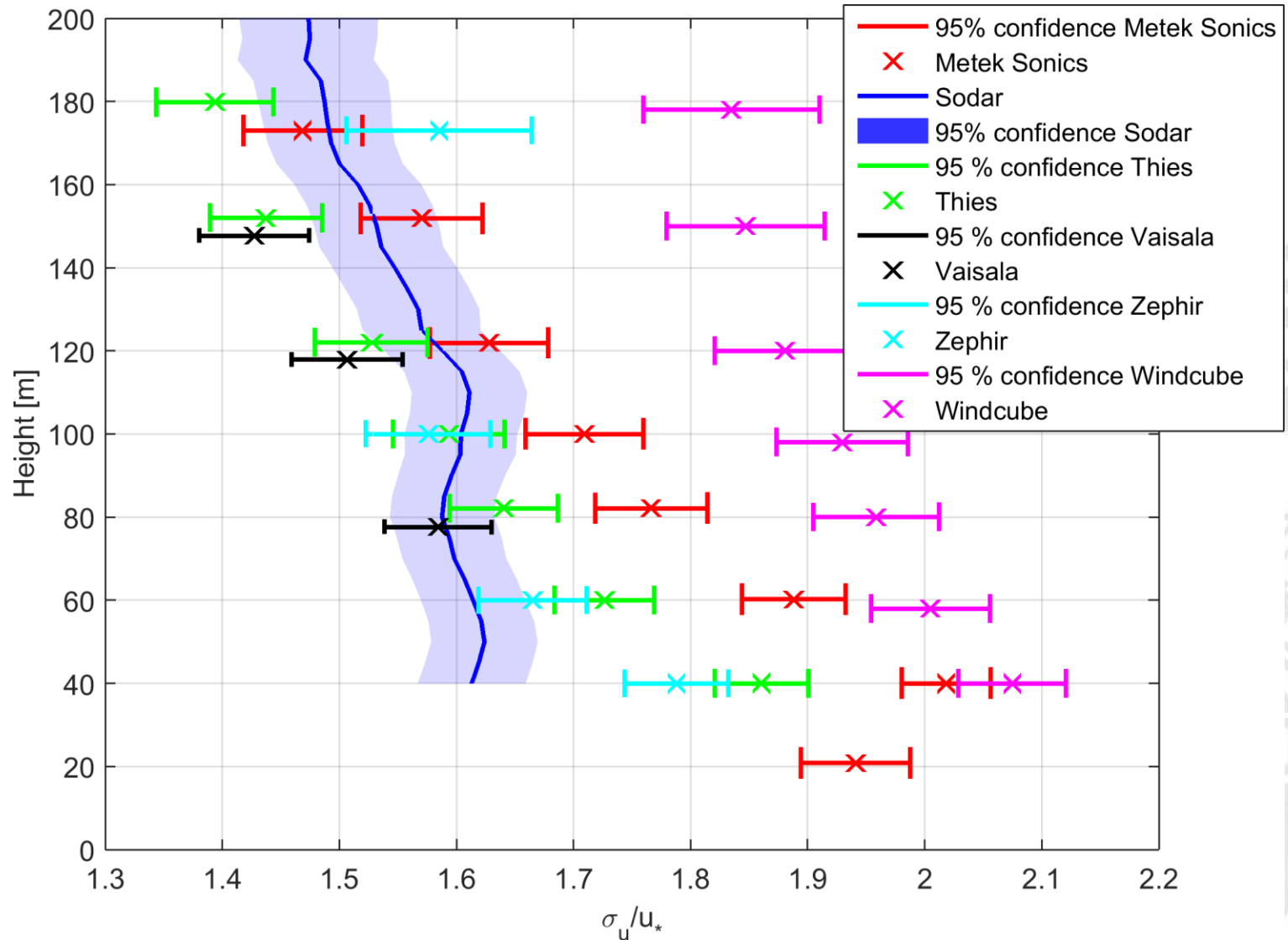
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NEW EUROPEAN WIND ATLAS
newa



Remote sensing instruments

Turbulence profile from all systems



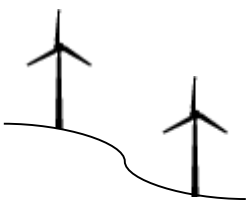


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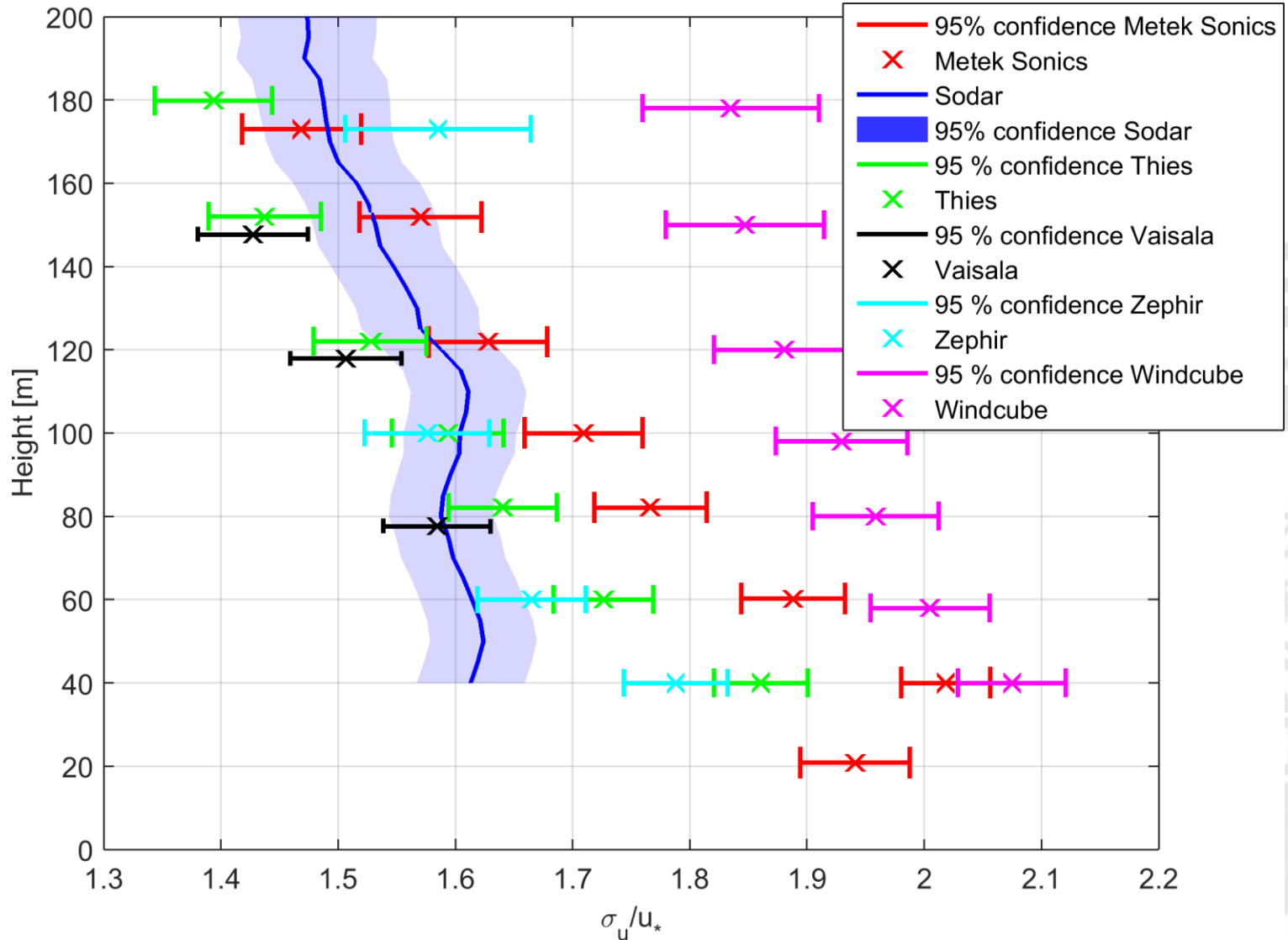
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Turbulence profile from all systems





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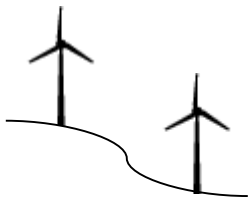
Alla instrument har fördelar och nackdelar

Cup + vane

- + Reliable
- + Cheap
- Over speeding
- Response time
- Flow distortion

Sonic anemometer

- + Temperature measurements
- + Reliable
- + Response time
- Expensive
- Flow distortion



Lidar

- + Multipoint measurements
- + No flow distortion
- + (Cheap)
- (Expensive)
- Precipitation, clear air

Sodar

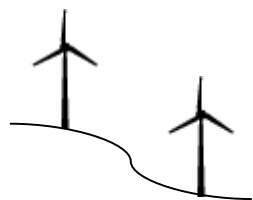
- + Multipoint measurements
- + Cheap
- + No flow distortion
- Neutral conditions and low winds
- Frequency of high altitude measurements



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STANDUP
for
WIND



Model

Wind Energy Sci. Discuss., <https://doi.org/10.5194/wes-2018-20>
Manuscript under review for journal Wind Energy Sci.
Discussion started: 4 April 2018
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Wind Energy Sci. Discuss., <https://doi.org/10.5194/wes-2018-20>
Manuscript under review for journal Wind Energy Sci.
Discussion started: 4 April 2018
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Microscale model comparison (benchmark) at the moderate complex forested site Ryningånäs

Stefan Ivaneš¹*, Johan Anagnost¹, Mathias Avall², Dalibor Cavar³, Roberto Avelino Chavez Aceroyo⁴, Hugo Chaves Espinosa¹, Carlos Peralta⁵, Jamal Aidi⁶, and Björn Wilmar⁷

- ¹Uppsala University, Wind Energy Section, Campus Gotland, 601 87 Västby, Sweden
- ²Technical University of Denmark, DTU, Denmark
- ³Wind Energy Department, Technical University of Denmark, Denmark
- ⁴National Renewable Energy Centre (CENER), Spain
- ⁵Wibler Research and Development mbH GmbH, Germany
- ⁶FuWind - Carl von Ossietzky Universität Oldenburg, Germany
- *Correspondence: Stefan Ivaneš (stefan.ivanes@wse.uu.se)

Abstract. This article describes a study where modelers were challenged to compute the wind at a forested site with moderate complex topography. The goal was to match the measured wind profile at one exact location in the forest distribution. The modelers consisted of detailed information of forest distribution and ground height derived from airborne laser scanning (ALS). All participating models except two used the full detailed ground and forest information to model the forest with a turbulence model. The ALS based data resulted in reasonable agreement of the wind profile and turbulence characteristics. The best performance was found to be of great significance for the turbulence characteristics and the wind speed profile. Overall, the article gives an overview of how well different types of models are able to capture physics at a moderate complex forested site.

Copyright statement: TEXT

1 Introduction

To counter the increasing demand of wind power, new sites are explored. Large offshore farms further away from the coast being developed as well as wind farms in more complex terrain with more complex topography. However, in mountainous areas, the example of Sweden, large complex forested sites are being explored. Exploring these complex sites is evident that new challenges arise due to turbulence level and wind shear. Evaluating these complex sites is a challenge as the difference between traditional wind energy sites and complex forested sites is that they differ from traditional sites since the exchange may be distributed at several model levels. The degree of turbulence is a choice by the modeler, going from describing Plant Area Density (PAD) in each grid cell to explicit

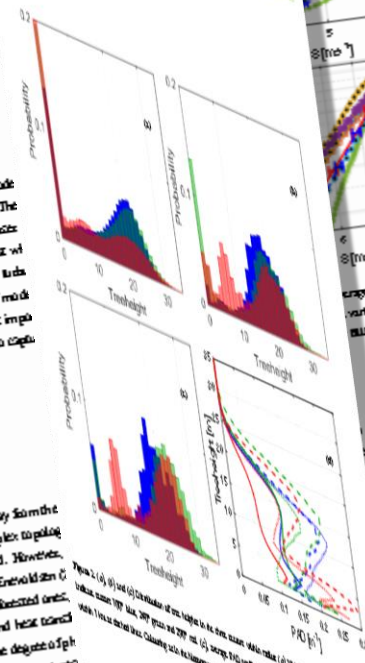


Figure 2. (a) Probability density function of wind speed. (b) Time-height profiles of wind speed. (c) Time-height profiles of turbulence intensity. (d) Time-height profiles of turbulence kinetic energy. (e) Time-height profiles of turbulence energy dissipation rate. (f) Time-height profiles of turbulence energy production rate. (g) Time-height profiles of turbulence energy dissipation rate. (h) Time-height profiles of turbulence energy production rate.

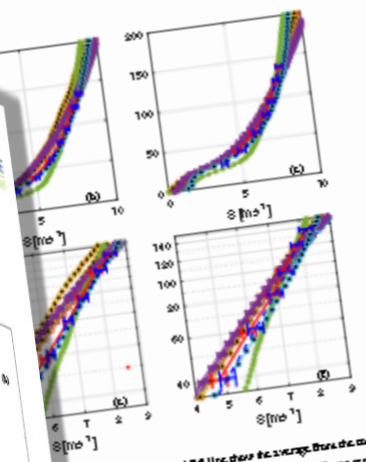


Figure 3. (a) Time-height profiles of wind speed. (b) Time-height profiles of turbulence intensity. (c) Time-height profiles of turbulence kinetic energy. (d) Time-height profiles of turbulence energy dissipation rate. (e) Time-height profiles of turbulence energy production rate.

The wind energy community is to emphasize tower measurements, vertical extrapolation (vertical profile) and then the horizontal extrapolation level and wind vector. These three quantities, in the form of wind energy $TKE = 0.5(\overline{u^2} + \overline{v^2} + \overline{w^2})$ and mean wind direction is evaluated

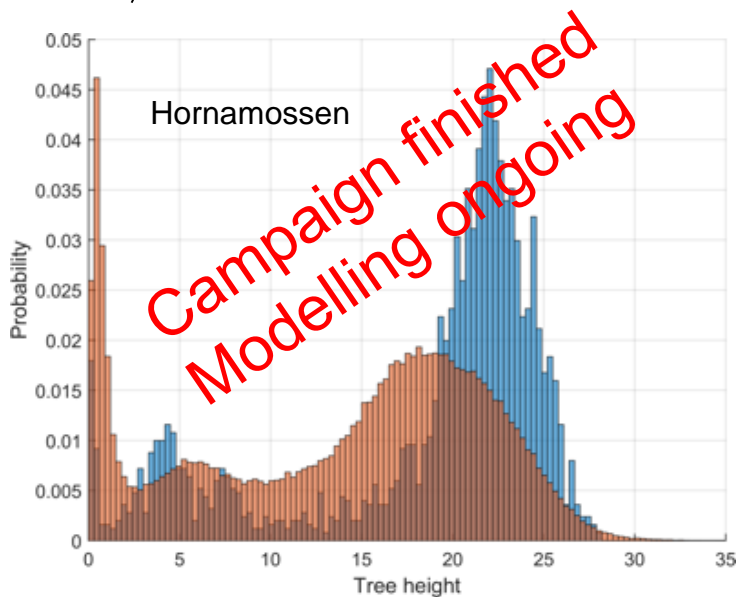
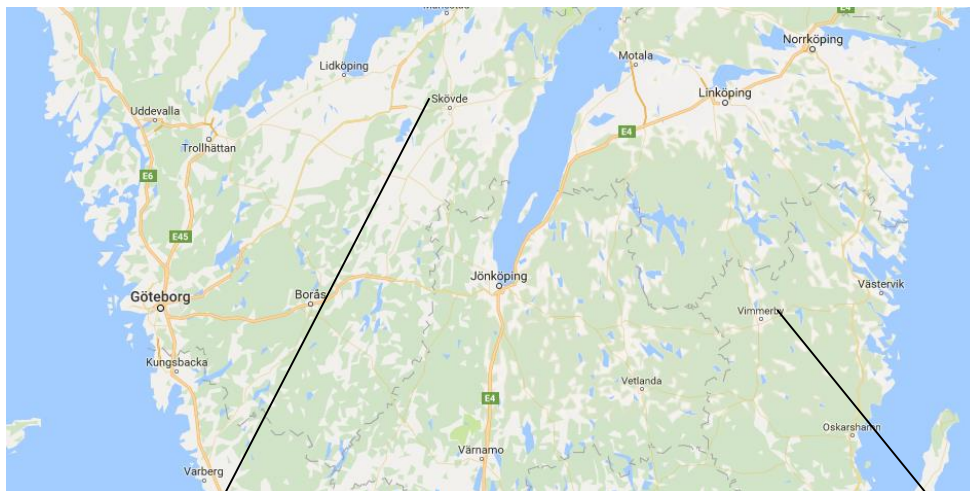
skogsterräng!



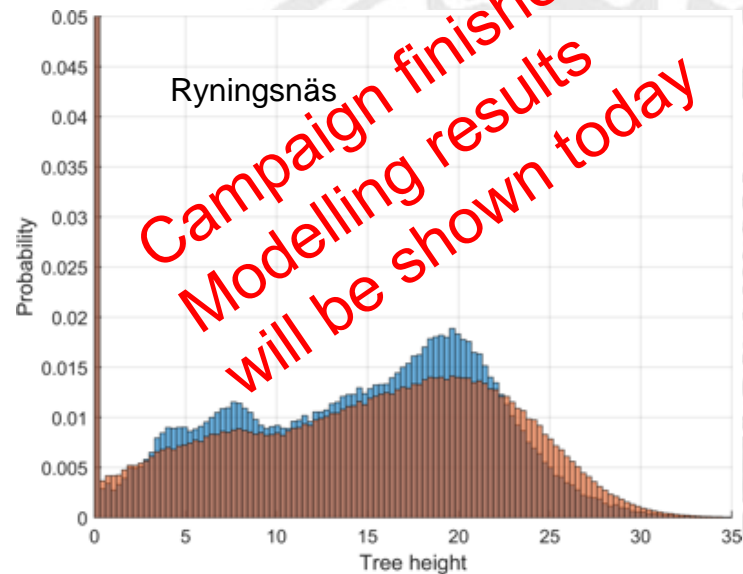
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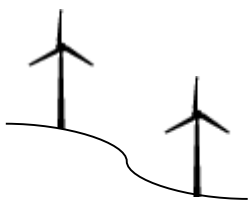


Campaign finished
Modelling ongoing



Campaign finished
Modelling results
will be shown today

Whole region (40X40 Km)
500 m closest tower





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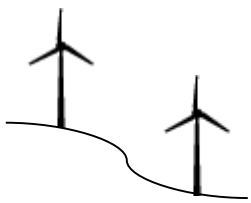
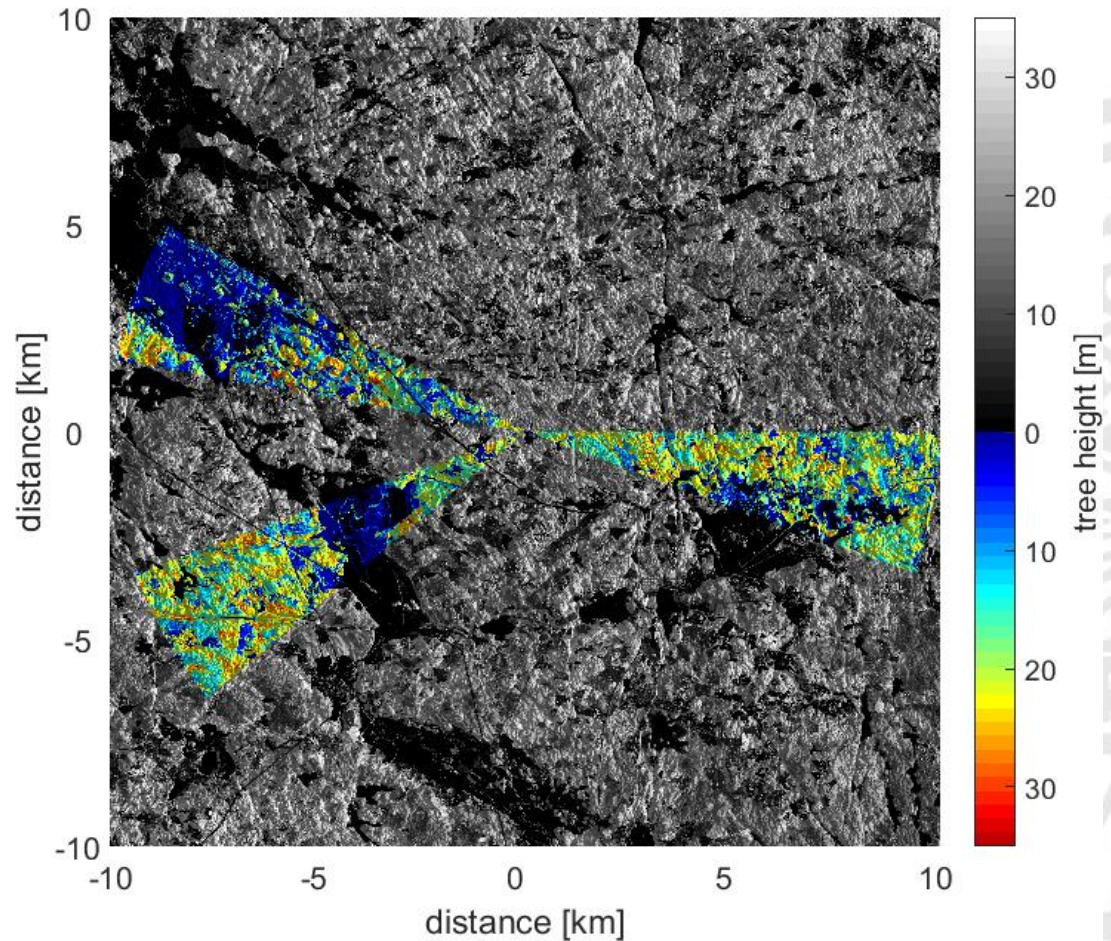
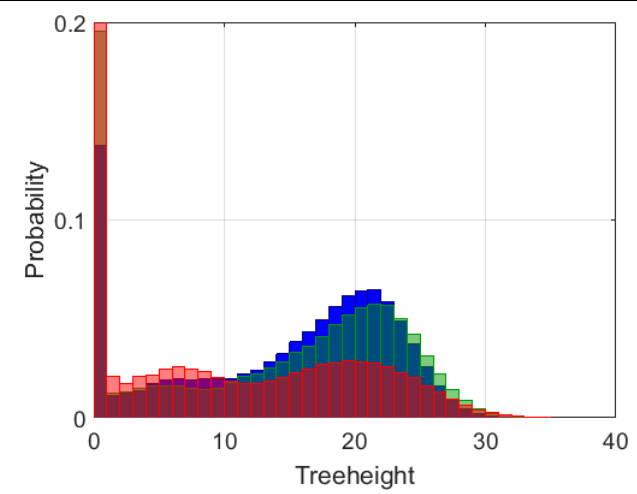
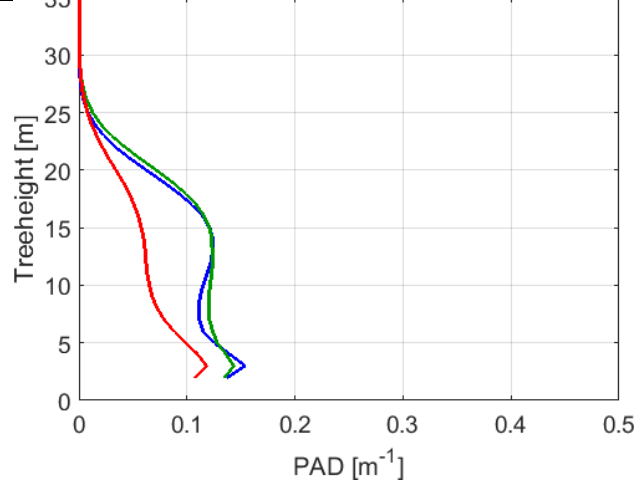
The three
directions were
selected

100, 240, 290 $\pm 10^\circ$

100

240

290



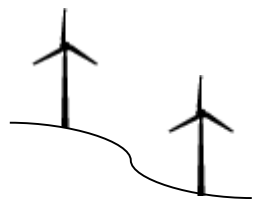
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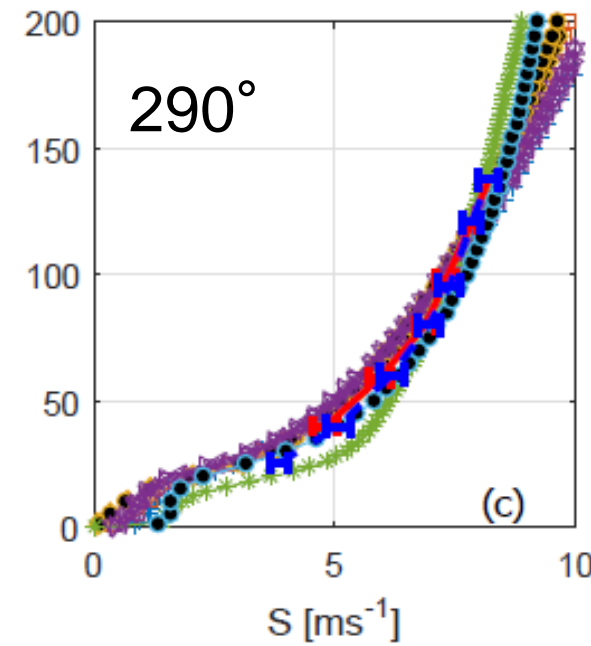
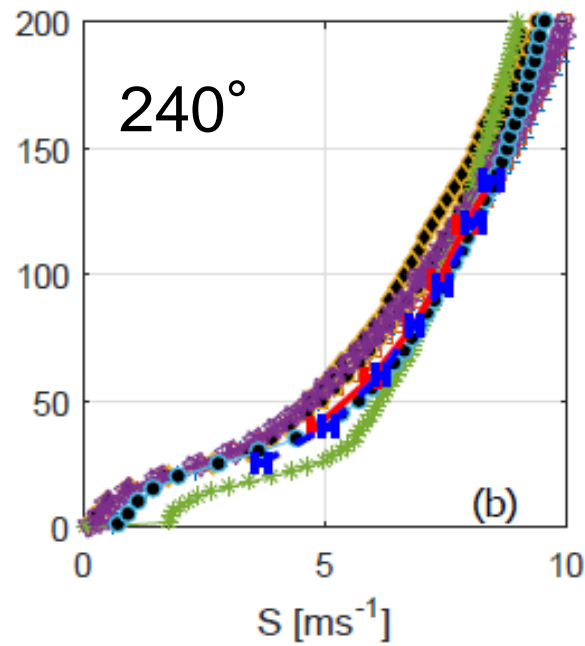
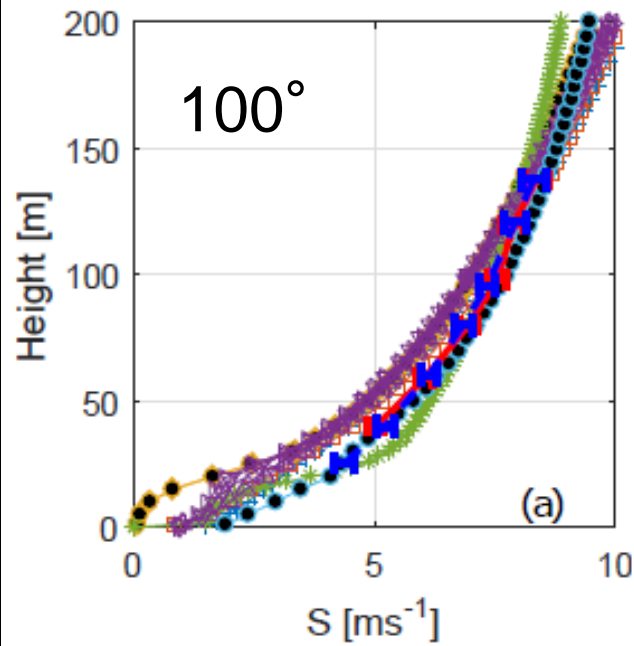
	Linear	RANS	LES	Laserscan as Input	Scale
Meteodyn (WRD)		X			PC
EllipSys3D (DTU)		X		X	Cluster
VestasFOAM (Vestas)		X			Cluster
OpenFOAM (CENER, CENAERO, Uni Uppsala)		X	X	X	Cluster
ALYA (Barcelona Supercomputing Centre)		X		X	Cluster
PALM (ForWind)			X	(X) Only average	Cluster

- **Koordinator:** Uppsala universitet, (NEWA-Partner)
Stefan Ivanell (Coordination)
Johan Arnqvist (Measurements, model comparison)
Hugo Olivares Espinosa (Modelling SE)



Vindhastighet

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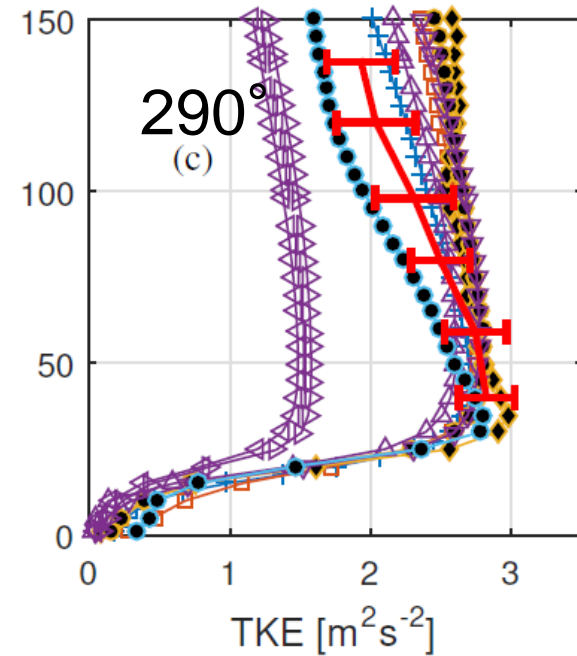
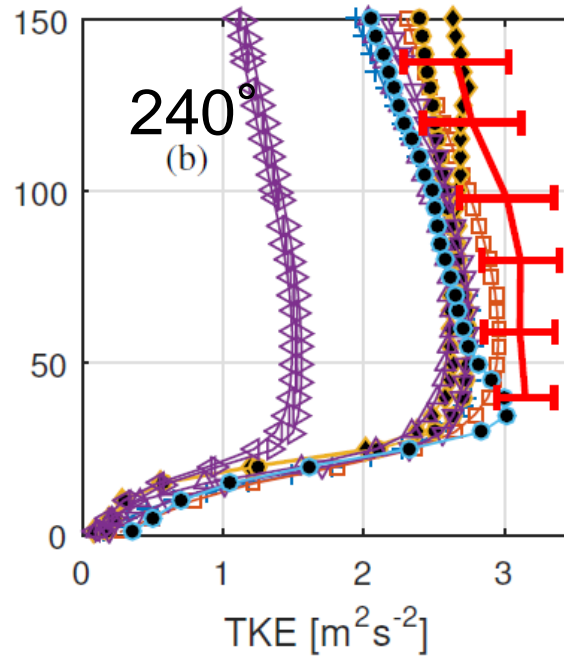
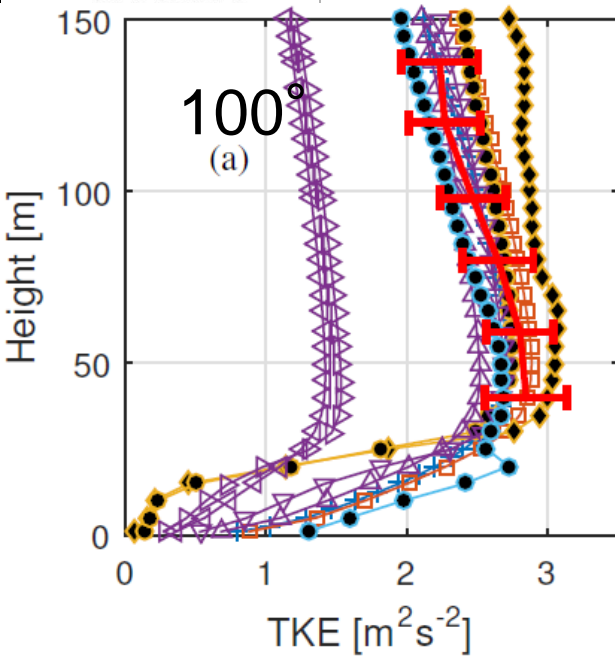
- +— Alya
- CFDWind
- ◆— PALM point
- PALM horizontal avg
- ◁— EllipSys 10 m
- ▷— EllipSys 50 m
- *— Meteodyn
- △— EllipSys 10 m Sogachev-const
- ▽— Ellipsys 50 m Sogachev-const
- UUCGWind LES
- Sonic
- Cup





Turbulent rörelseenergi

UPPSALA



- +— 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

Varför blir det inte bättre resultat?





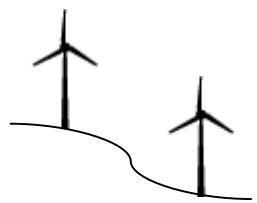
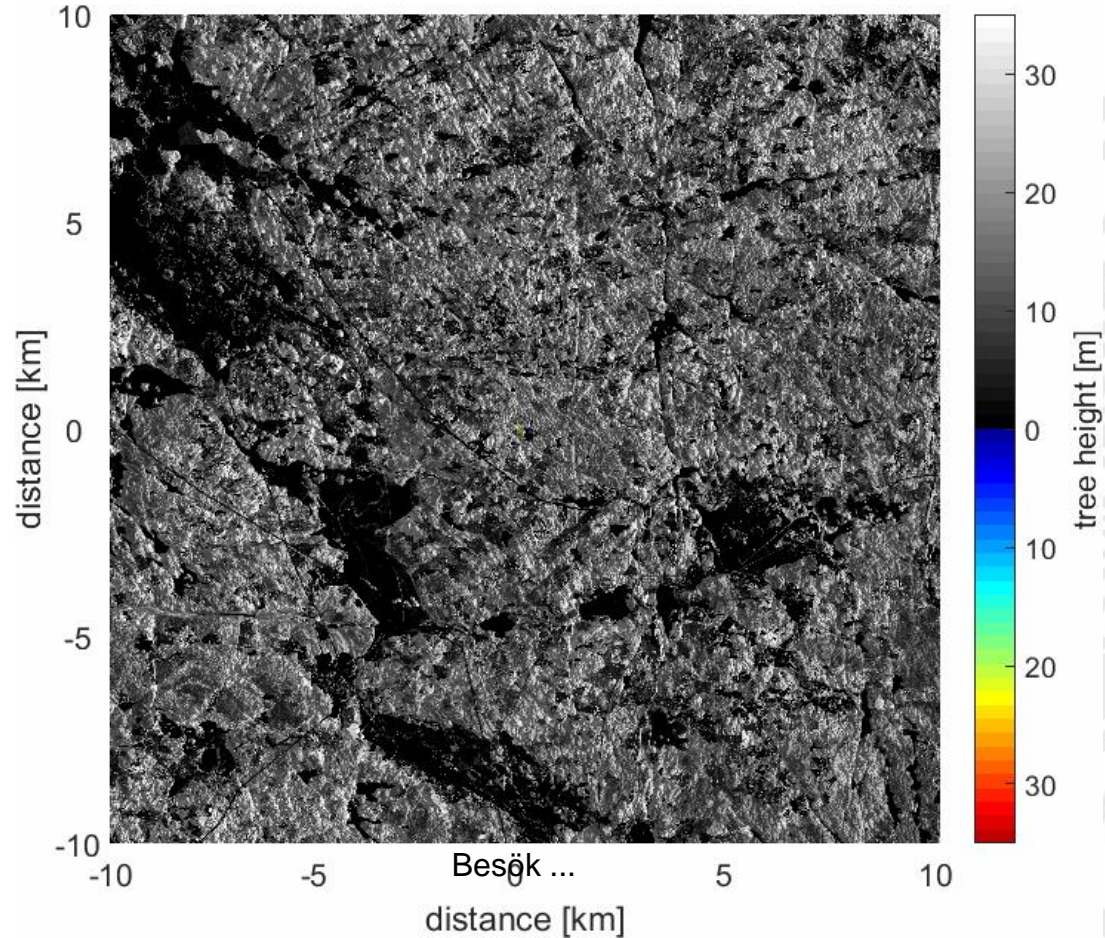
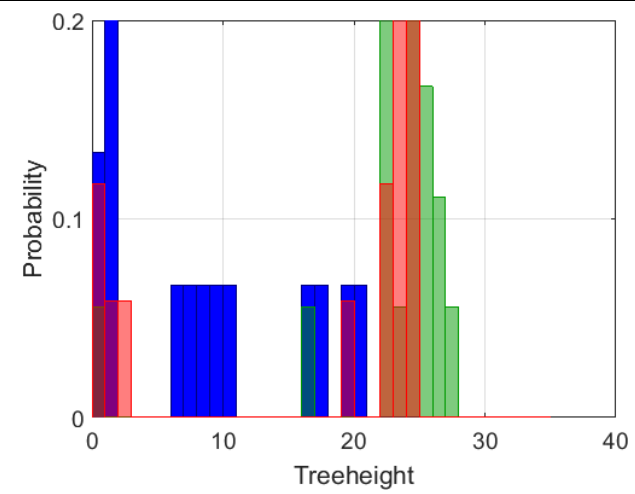
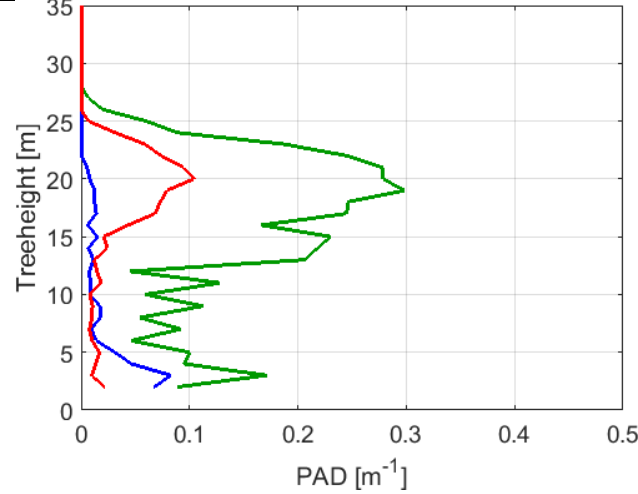
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Within 1 km
averages

100
240
290



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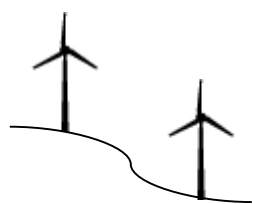
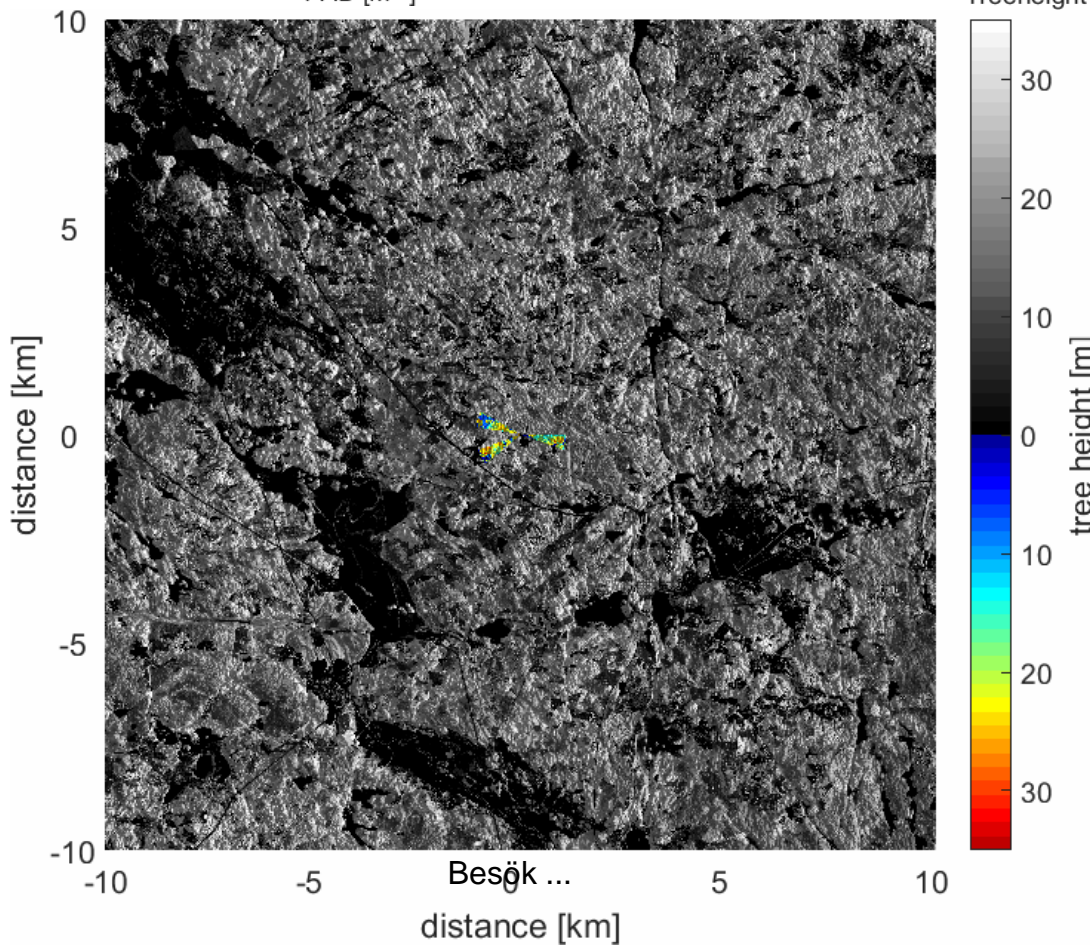
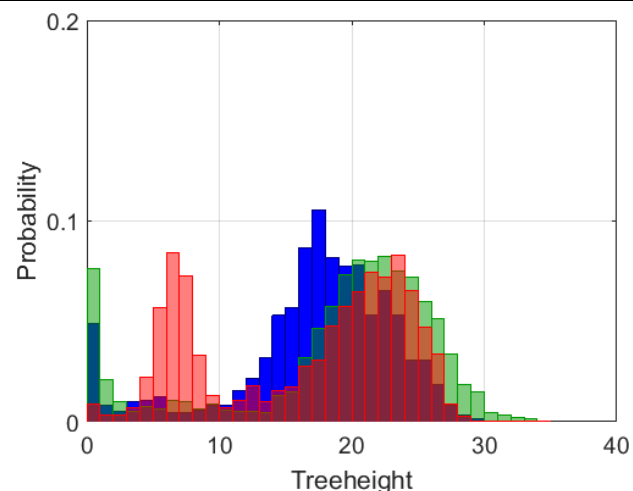
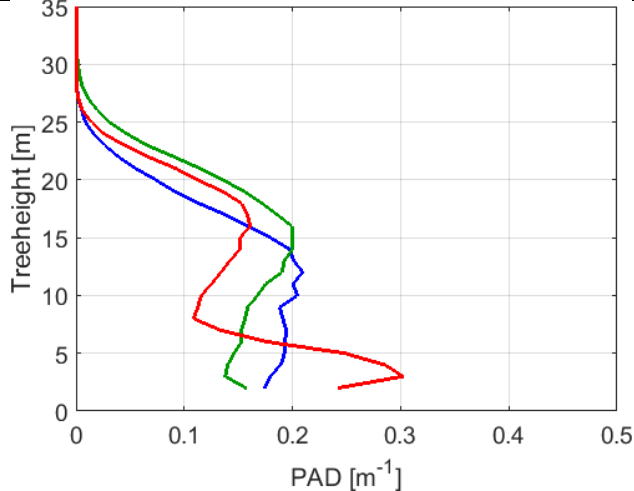
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Within 5 km
averages

100

240

290



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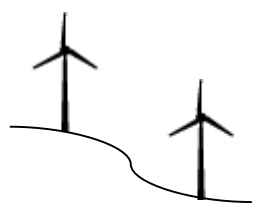


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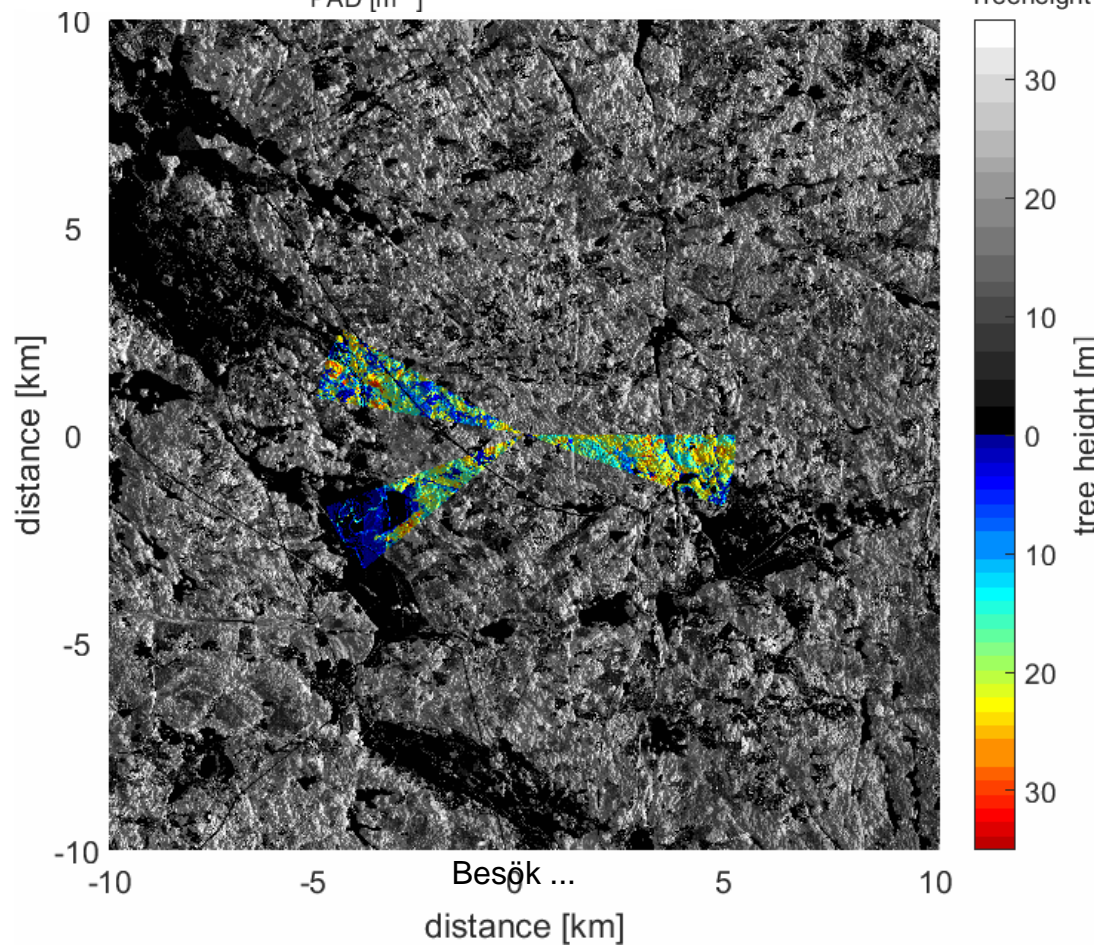
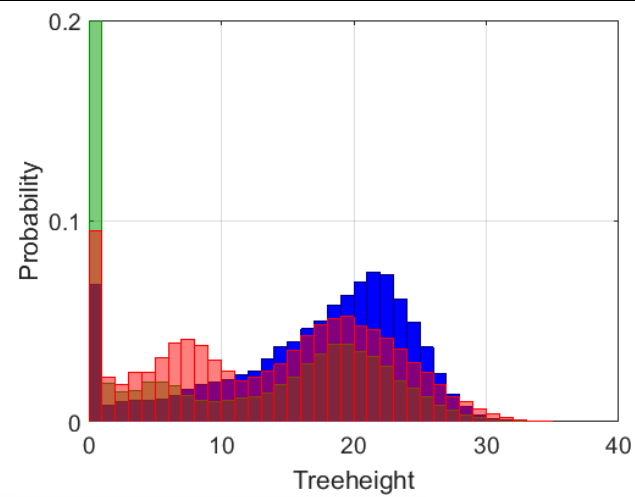
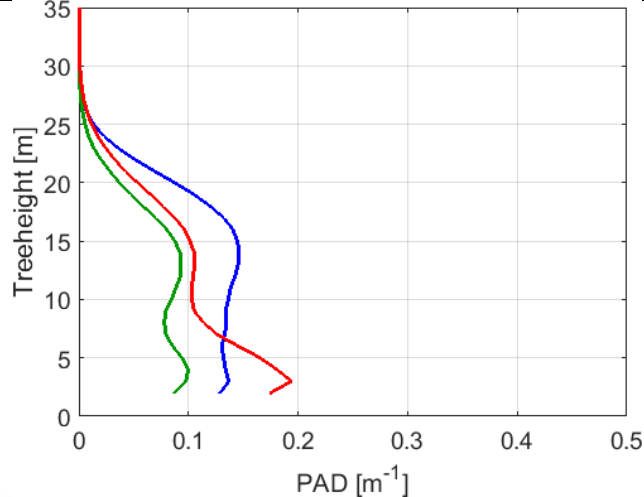
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Within 10 km
averages



2013-08-22

100
240
290



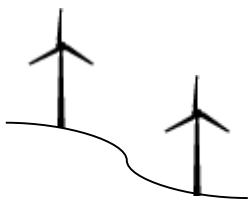
47



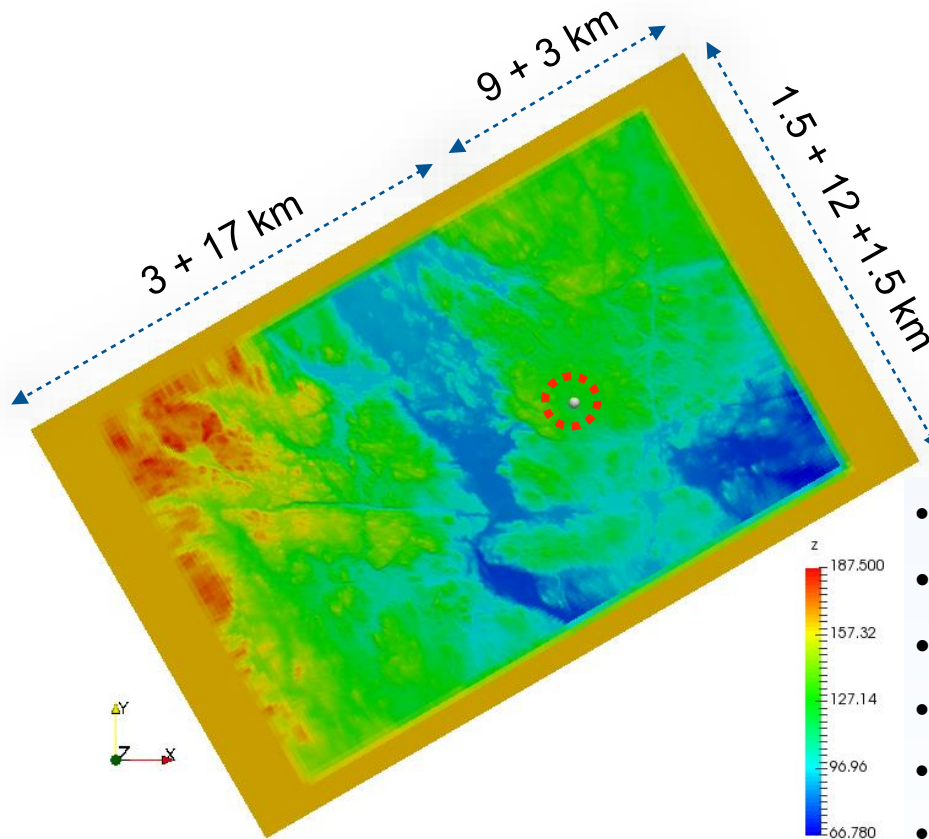
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LES computations: Domain size



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

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

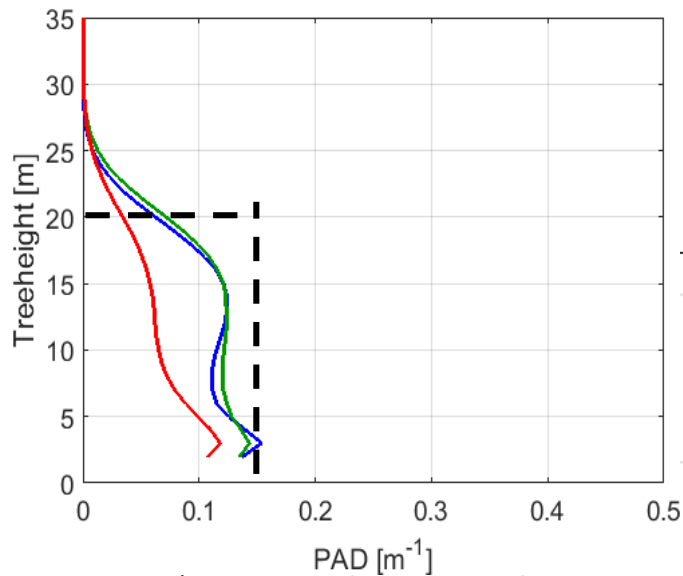
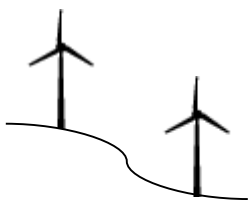
$$L_x \times L_y \times L_z = 32 \text{ km} \times 20 \text{ km} \times \sim 1.2 \text{ km}$$



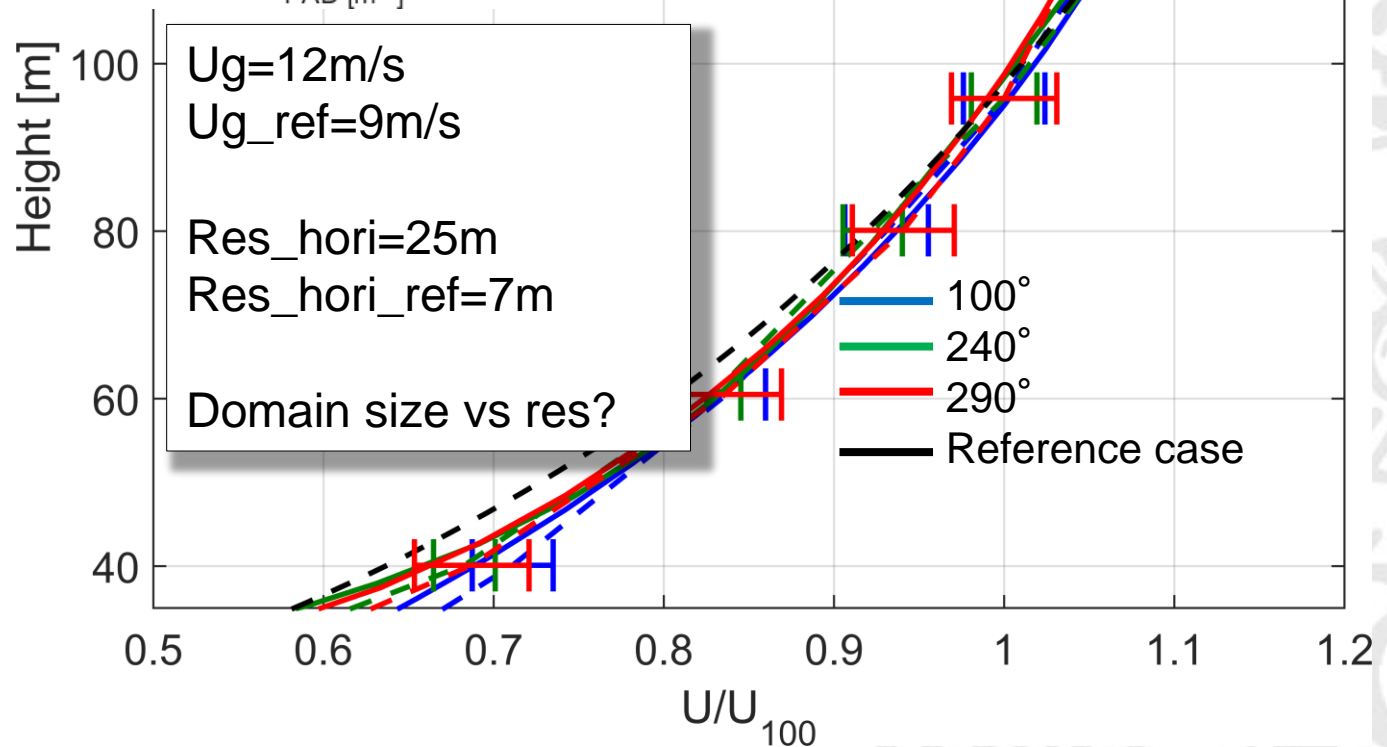
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Wind speed matches
the measured to a high
degree



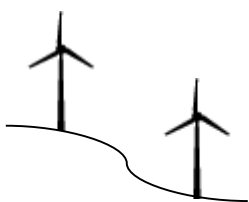


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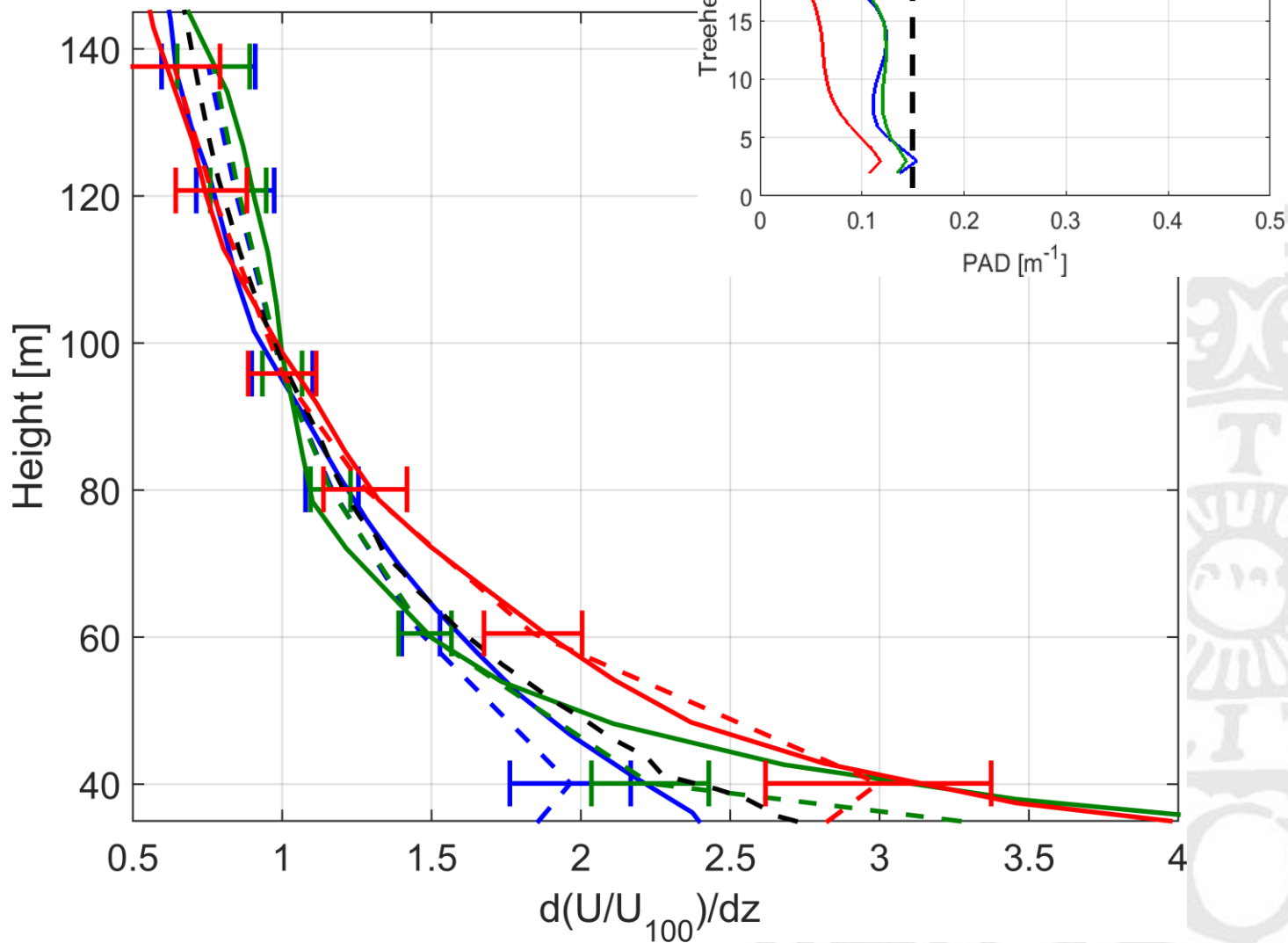
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NEW EUROPEAN WIND ATLAS
newa



To return to the question,
Resolution or domain size,
what is most important?





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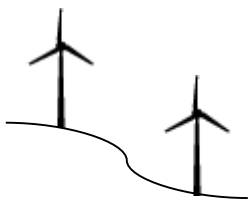
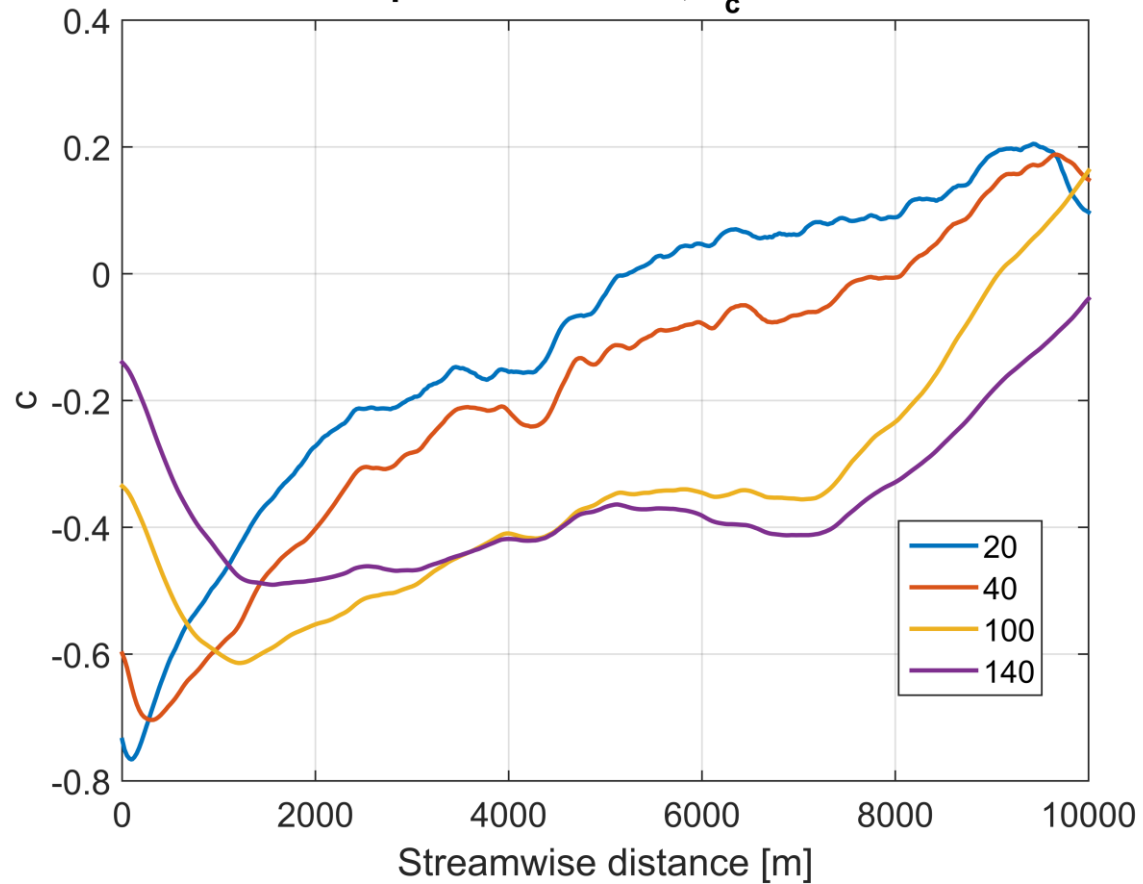
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Footprint

2-point correlation, h_c and U

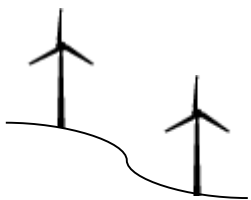




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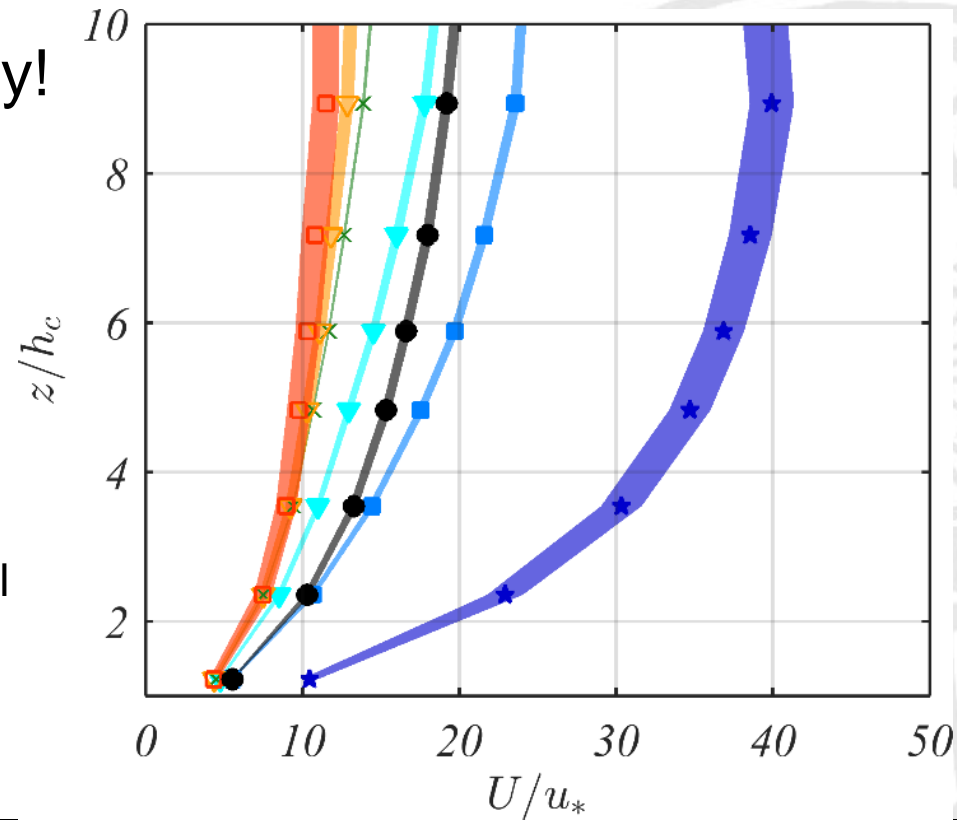
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Så LES med stor domän verkar kunna matcha mätningarna. Men.... Om skiktningen inte är neutral?

Wide effect of stability!
And the effects does not cancel out!

- Very stable
- Stable
- Stable near neutral
- Neutral
- Unstable near neutral
- Unstable
- All data





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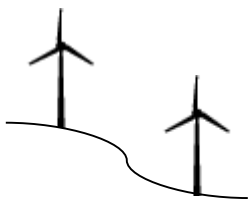
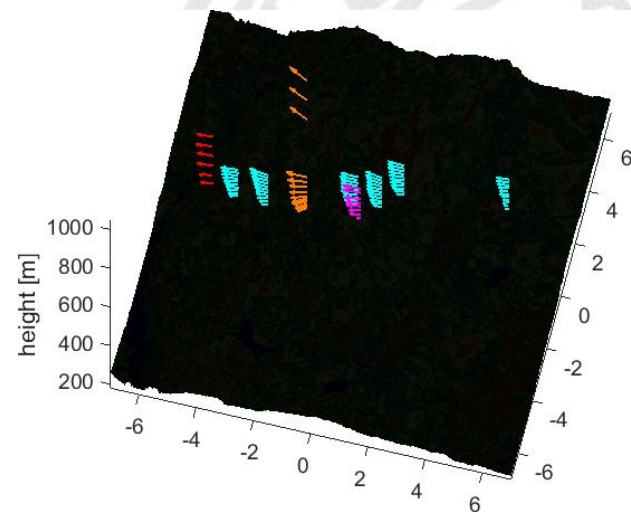
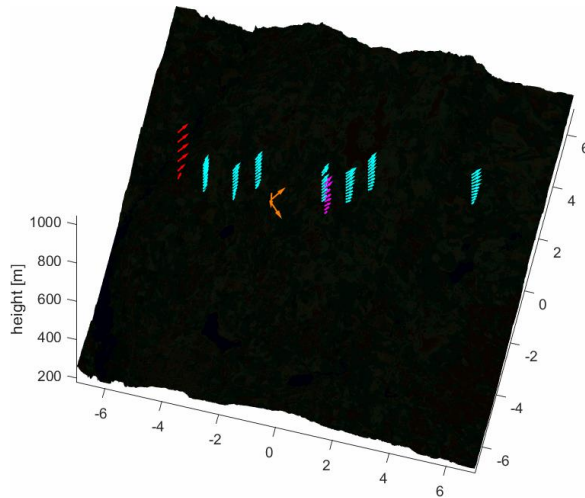
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Hornamossen dygnscykel benchmark

- **Case west**
- WD 90 deg
- $U_g \sim 12$ m/s
- Barotropic, stationary conditions for 72 hours
- Varying cloud cover

- **Case east**
- WD 270 deg
- $U_g \sim 12$ m/s
- Barotropic, stationary conditions for 72 hours
- Mostly clear sky



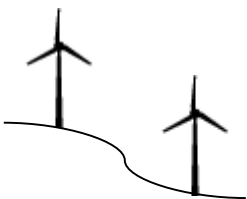


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Vad händer nu?

Benchmark Hornamossen öppnar

- Testet kommer att utvärdera hela modellkedjan

The screenshot shows a Medium article page. At the top, there is a navigation bar with 'HOME WIND WAKES CONTRIBUTE | WEMEP' and a search icon. The article is by Johan Arnqvist, posted on Sep 7, and is 5 minutes read. The title is 'The Hornamossen diurnal-cycle benchmark for flow modeling in forested and moderately complex terrain'. The abstract reads: '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.' Below the text is a video player titled 'The Hornamossen benchmark' showing a 3D terrain model. The video player has a play button, a progress bar, and a 'Dela' button. Below the video player, there is a 'GET UPDATES' button and a 'Never miss a story from The Wind Vane, when you sign up for Medium. Learn more' link.

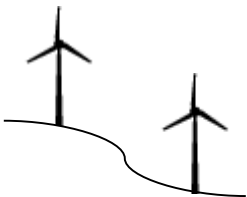


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Vad händer nu?

Benchmark Hornamossen är öppnat

- Testet kommer att utvärdera hela modellkedjan

Produktionsberäkningarna färdigställs

- Färdigställande av databas.

Mikroskaleberäkningar startar

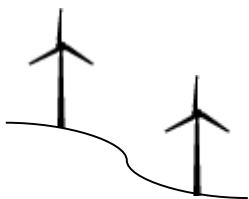
- Baserat på modellvalidering i flera Benchmarks

Atlasen sammanställs och publiceras



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Sammanfattning/slutsatser

- Laserdata gör det möjligt att i detalj modellera den faktiska skogen
- Skjuvning och turbulens kan kopplas samman med uppströms topografi och råhet
- LES med stor domän och riktig skog verkar kunna reproducera mätningarna, RANS är troligen för diffusiv
- Det verkar viktigare att ha stor domän än hög upplösning
- Modeller måste kunna reproducera ickeneutral skiktning!



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Tack för att ni lyssnat!

Frågor?

Kommentarer?

Johan Arnqvist och Stefan Ivanell

Johan.arnqvist@geo.uu.se

Stefan.ivanell@geo.uu.se



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Announcement:



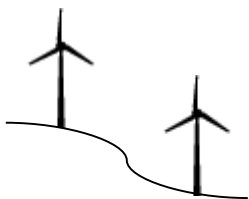
May 22-24, 2019, Visby, Sweden

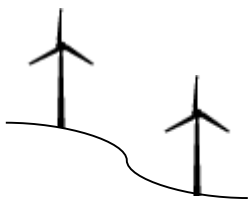
Welcome to Visby!

Stefan Ivanell & Jens Nørkær Sørensen



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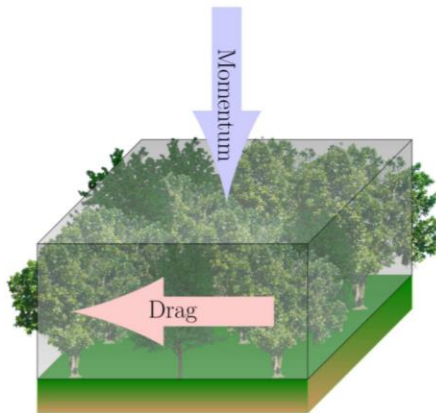


Forest model

- We wish to model the heterogeneities of the forest, obtained with LiDAR
- Drag force of the forest is implemented through the addition of sources in the momentum equation

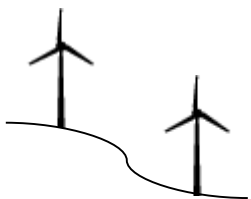
$$\frac{D \langle \bar{u}_i \rangle}{Dt} = \text{Pressure} + \text{Viscosity} + F_{ABL,i} + F_{WT,i} + F_{D,i}$$

$$F_{D,i} = -C_D a |\bar{u}| \bar{u}_i$$



L.-E. Boudreault (2015)

- $F_{D,i}$ Net effect of the plant drag
- a Frontal Area Density, unif./non-unif.
- C_D Drag of the forest
- $F_{ABL,i}$ ABL-driving volume forces
(pGrad & Coriolis)
- $F_{WT,i}$ AD/AL volume (sink) forces



Forest model

- The SGS model also needs to be modified, to account for the “destruction” of TKE by the forest
- Another source term is introduced in the transport equation of TKE

$$\frac{\partial k}{\partial t} = \textit{Advection} + \textit{Dissipation} + \textit{Diffusion} + \textit{Production} - \varepsilon_{sgs}$$

$$\varepsilon_{sgs} = -\frac{8}{3} C_{Da} |\bar{u}| k$$

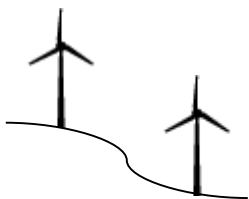
- Neutral conditions: This modification is implemented to a SGS model (Yoshikawa, 1986) that is available in the standard distribution of OF
- Non-neutral: A different model will be used, like that of Deardorff (1980)



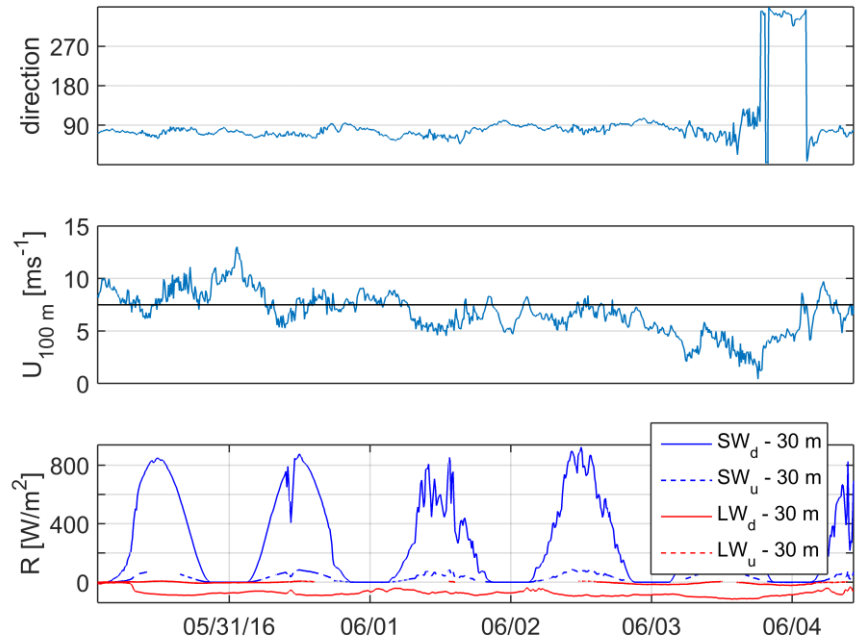
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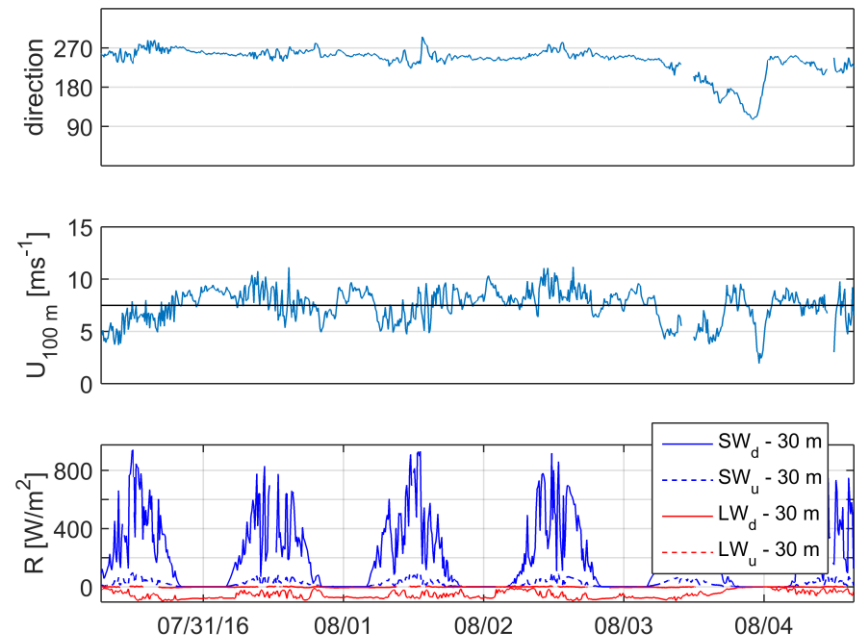
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East case



West case

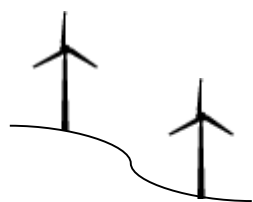




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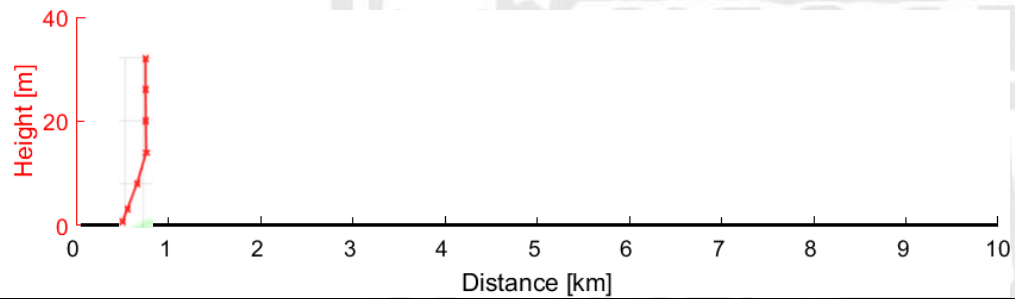
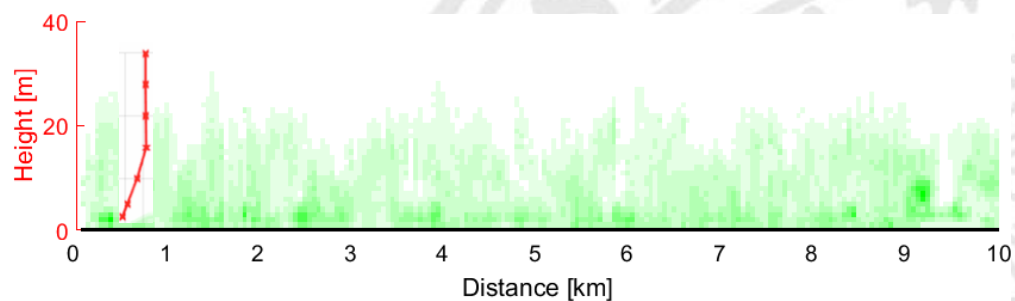
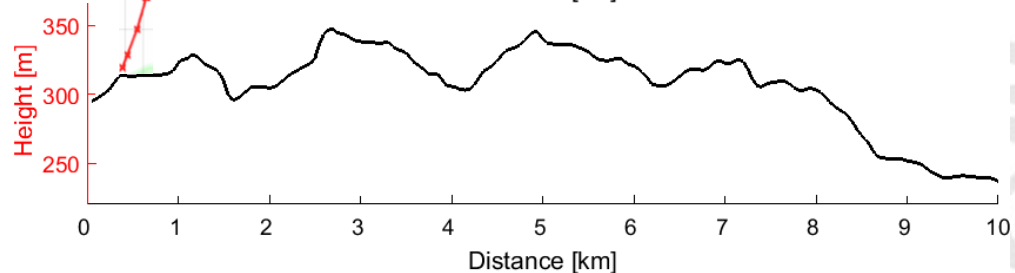
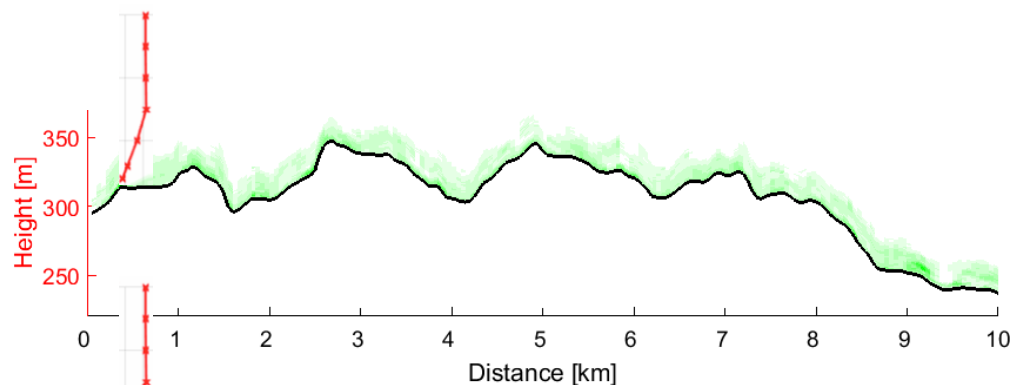
Level 4

Neutral-> Stable, Diurnal

Level 3

Level 2

Level 1

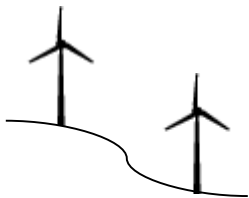




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- PAD – Plant Area Density (often called LAD – Leaf Area Density)
 - The frontal area of the forest in the wind direction

- PAI – Plant Area Index (Often LAI – Leaf Area Index)
 - The vertically integrated PAD

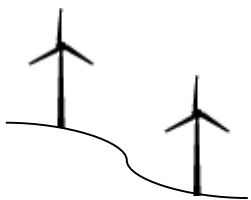
Calculation of PAD from Airborne Laser Scans

- We use the Beer-Lambert law to determine the density based on the difference between incoming and transmitted intensity of the laser beam (I) between two canopy layers

PAD = $-2 \cos \theta_l \ln \frac{I_2}{I_1}$, Where θ_l is the angle of the beam.

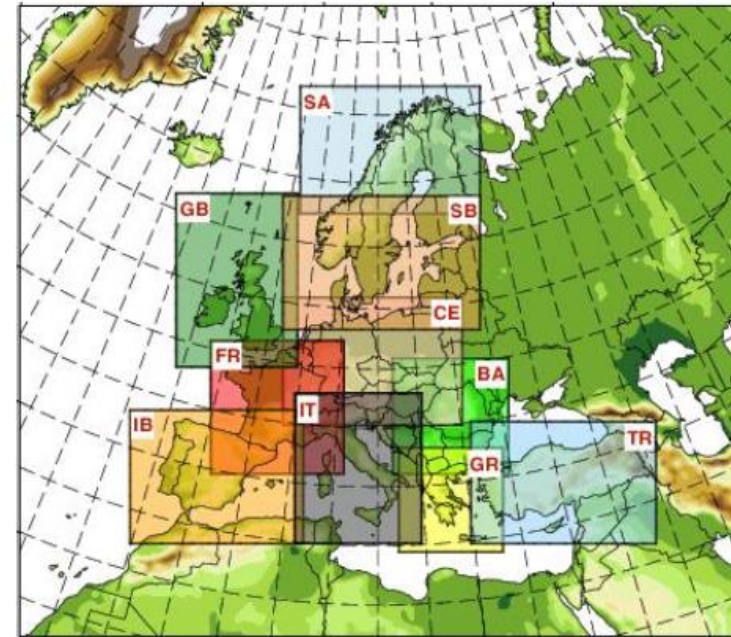
- The intensity is calculated by:
$$I_k = 1 - \sum_{i=1}^k r_{s_k} / r_{s_0}$$

Where r_{s_k} is the (scaled) number of returns in the grid cell at a certain vertical level and r_{s_0} is the (scaled) total number of returns in the grid cell.



Mesoscale Production Runs – Final Setup

- WRF version: **modified v3.8.1** (PBL, icing)
- Grid: 27 km → 9 km → 3 km; 61 vertical levels
- **10 regions**
- **8-day runs** incl. 24 h spin-up, spectral nudging in D1
- **MYNN PBL scheme** (modified) + MO surface layer
- Forcing: ERA5 reanalysis (0.3°)
- **OSTIA SST** and sea-ice (1/12°)
- Adaptive time step (where working)
- **CORINE 100 m land use data**, USGS where CORINE not available
- NOAH land surface model
- Icing (WSM5 + icing code + sum of qcloud and qice)
- Radiation time step = 12 minutes
- 480 cores, IO Quilting (1 node used for output)





Hornamossen

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