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# Case study of Lidar measurements in southeast Finland – Lidar performance and wind conditions in cold climate and complex terrain

WinterWind 2015, Piteå, 3.2.2015

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# Outline

- Background
- Scope
- Measurement campaign
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- Lidar performance
- Upflow angle evaluation
- Wind shear evaluation
- Conclusions

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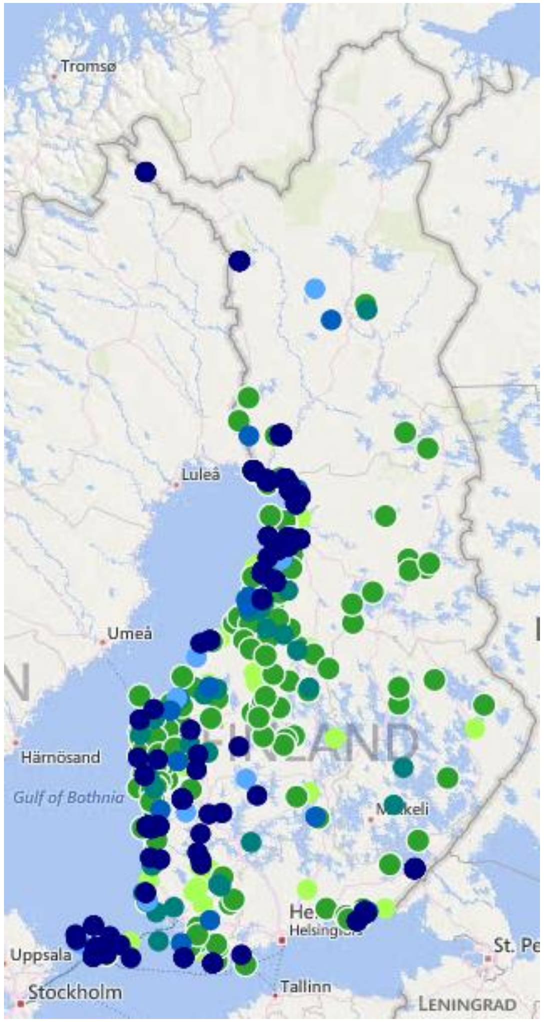
# Background

- Amount of wind power is exploding
  - Existing wind turbines (blue) and planned projects (green) in Finland can be seen in picture.
- Wind shear conditions in inlands may be challenging due to forestry environment
  - ⇒ Reduces energy production
  - ⇒ Increases turbine loads
- Wind shear along the whole rotor area can easily be determined using Lidar technology




Picture: http://www.tuulivoimayhdistys.fi/tuulivoimalaitokset

# Scope

- Scope of this study is to investigate
  - Lidar operation and availability in cold climate
  - Upflow behavior in a wind farm in southern Finland
  - Wind shear conditions in a wind farm in southern Finland

- The study is a part of a research project *’Wind power in cold climate and complex terrain*’ carrying out by
  - Lappeenranta university of technology
  - Alstom Renevables España S.L
  - TuuliMuukko and
  - TuuliSaimaa

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# Scope

| WP | | Sub. WP | Title |
|---|---|---|---|
| 1. | WP1. WIND FARM DATA ACQUISITION | 1 | Wind farm data acquisition |
| 2. | WP2. POWER & OPERATIONAL PERFORMANCE ANALYSIS AND OPTIMIZATION | 2.1 | Power performance in cold climates |
| | | 2.2 | Operational performance in cold climates |
| | | 2.3 | Evaluation of WTG loads and dynamics due to ice accretion |
| | | 2.4 | Analysis turbine control for cold climate |
| 3. | WP3. ICING SENSORS AND ICE DETECTION | 3.1 | State of the art |
| | | 3.2 | Performance analysis of ice detection sensors |

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# Measurement campaign

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- Measurement campaign was performed in a wind farm of seven **3 MW Alstom ECO110 cold climate version turbines in southeast Finland**

- Measurement period was 17.12.2013 – 30.11.2014. (Campaign is still going on.)

- Wind measurements were performed using WindCube v2 ground-based Lidar


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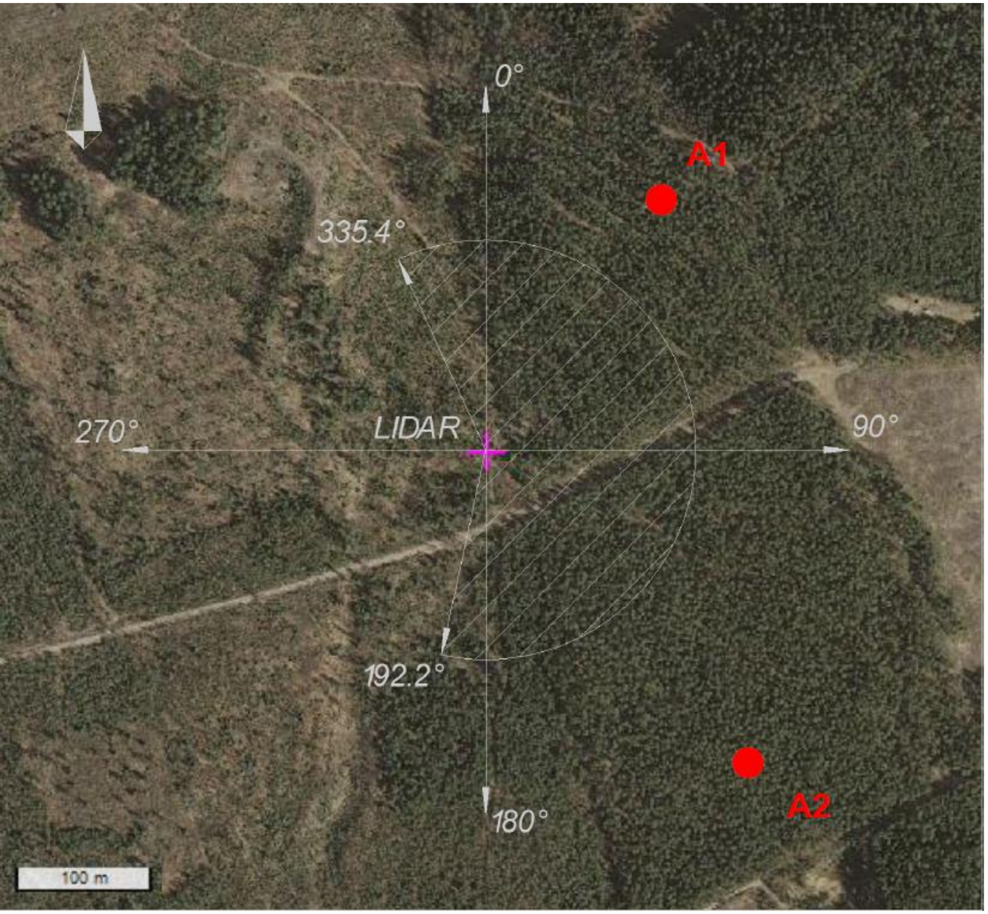
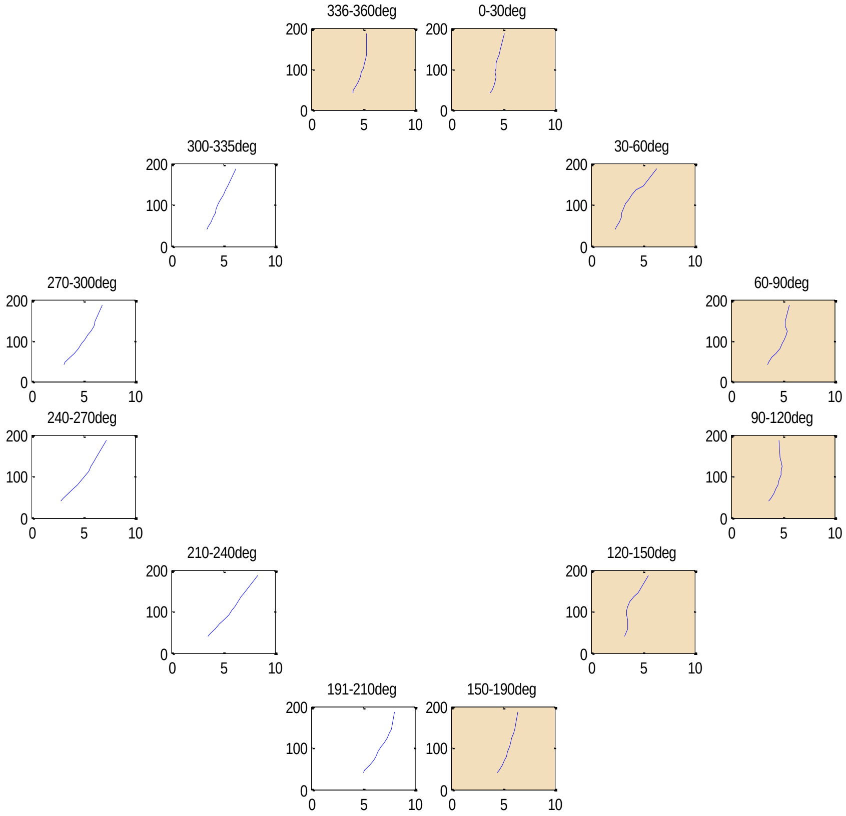
# Site assessment

- Wind farm is situated in variable terrain with mostly forest and industrial area.
- Research turbine and lidar location are surrounded by similar terrain.
- Lidar is situated 250 m (2.3*D) from the research turbine on the direction of predominant upwind.
- 11 measurement heights were chosen along the rotor area 40-146 m + 12th height 186 m

# Site assessment
# Free flow checking – Shear rose



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# Lidar measurements

- Windcube v2 ground-base lidar was used
- 12 heights from the range 40 – 184 m
- Installed on a pedestal and inside fences is order to keep people and animals away.
- Power is obtained from the grid.
- Additional water tank required for wiper operation.
- Windcube equipped with Flow Complexity Recognition (FCR) module

# Lidar performance

- Operates without problems in all temperatures, the minimum temperature reached in January 2014 was -23.5 °C.
- Tolerates well snowing.
- Clean atmosphere in Finland sets challenges to Lidar operation.
- Lidar performance was improved decreasing CNR threshold from -22 dB to -25 dB and later to -26 dB.
- The following analyses were performed in order to investigate the lidar performance:
  - Recovery rate in different heights and availabilities
  - Availability in different weather conditions. Weather data was obtained from Finnish meteorological institute (FMI)

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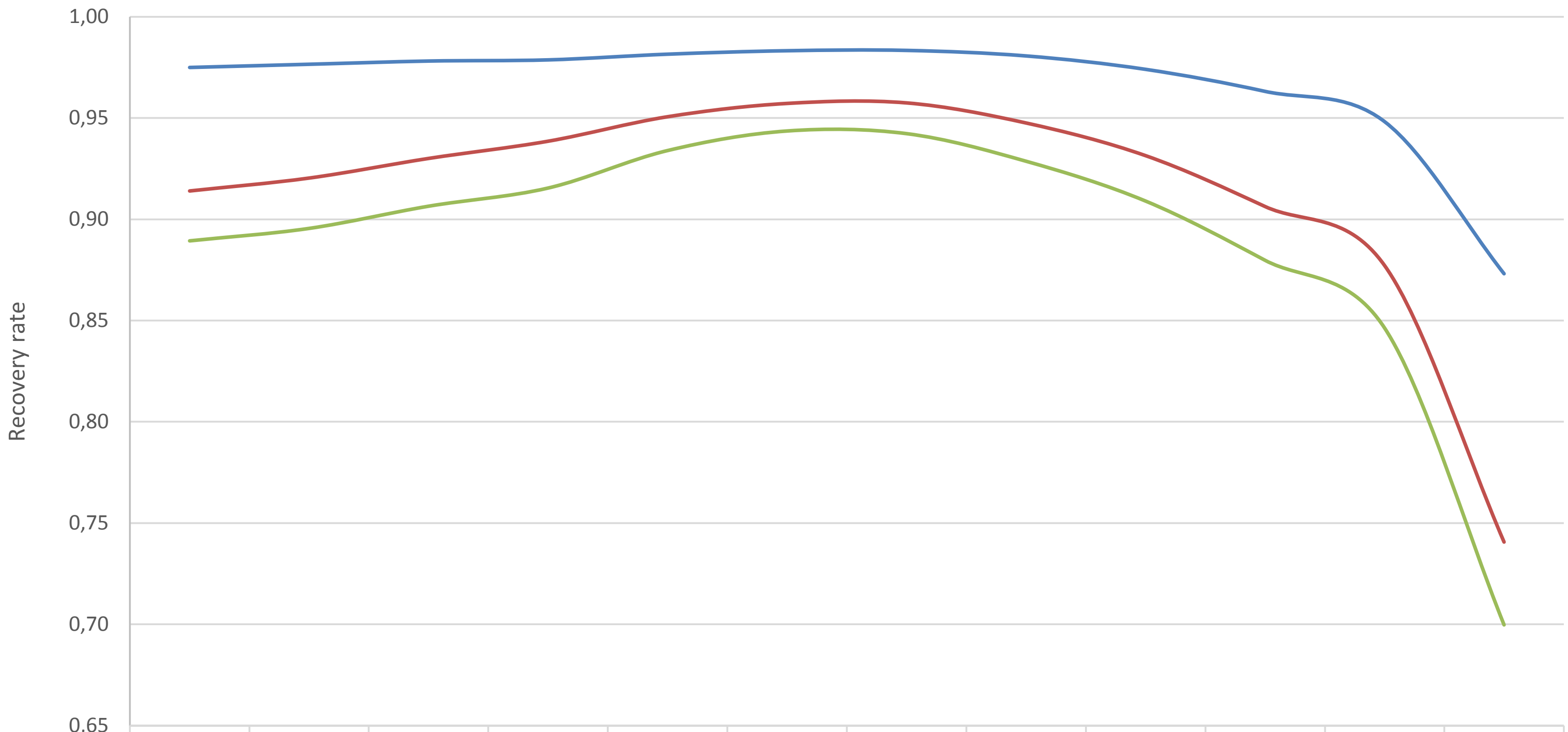
# Lidar performance:

## Recovery rate vs.height and availability




| | 40 | 47 | 58 | 69 | 80 | 91 | 102 | 113 | 124 | 135 | 146 | 186 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| >0% | 0,98 | 0,98 | 0,98 | 0,98 | 0,98 | 0,98 | 0,98 | 0,98 | 0,97 | 0,96 | 0,95 | 0,87 |
| >60% | 0,91 | 0,92 | 0,93 | 0,94 | 0,95 | 0,96 | 0,96 | 0,95 | 0,93 | 0,91 | 0,88 | 0,74 |
| >80% | 0,89 | 0,90 | 0,91 | 0,92 | 0,93 | 0,94 | 0,94 | 0,93 | 0,91 | 0,88 | 0,85 | 0,70 |

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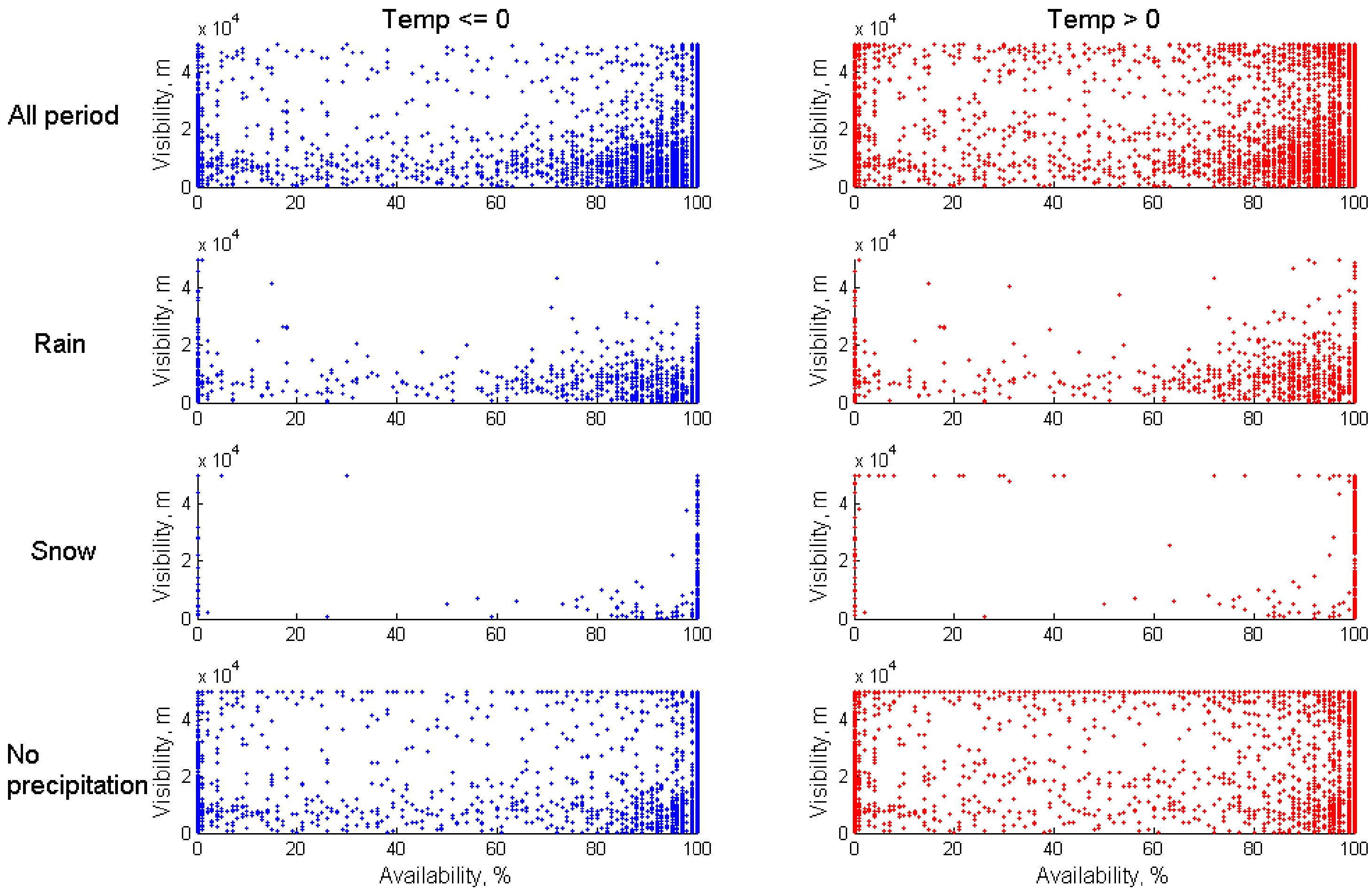
# Lidar performance
## Recovery rate monthly

| | Availability >0% for all heights | Availability >60% for all heights | Availability >80% for all heights | Notes |
|---|---|---|---|---|
| December 2013 | 0.57 | 0.38 | 0.35 | Wiper broke |
| January 2014 | 0.80 | 0.70 | 0.67 | Problems with wiper |
| February 2014 | 0.80 | 0.69 | 0.67 | |
| March 2014 | 0.89 | 0.75 | 0.71 | |
| April 2014 | 0.83 | 0.57 | 0.51 | |
| May 2014 | 0.96 | 0.79 | 0.72 | |
| June 2014 | 0.85 | 0.60 | 0.53 | |
| July 2014 | 0.98 | 0.89 | 0.84 | |
| August 2014 | 0.99 | 0.91 | 0.87 | |
| September 2014 | 0.98 | 0.95 | 0.93 | |
| October 2014 | 0.95 | 0.86 | 0.83 | |
| November 2014 | 0.64 (0.85 when 186 m excluded) | 0.54 | 0.52 | Poor availability at 186 m |
| Whole period | 0.87 | 0.74 | 0.69 | |
| 1.1.2014.-30.11.2014 | 0.88 | 0.75 | 0.71 | |

# Lidar performance

## Data availability vs. visibility



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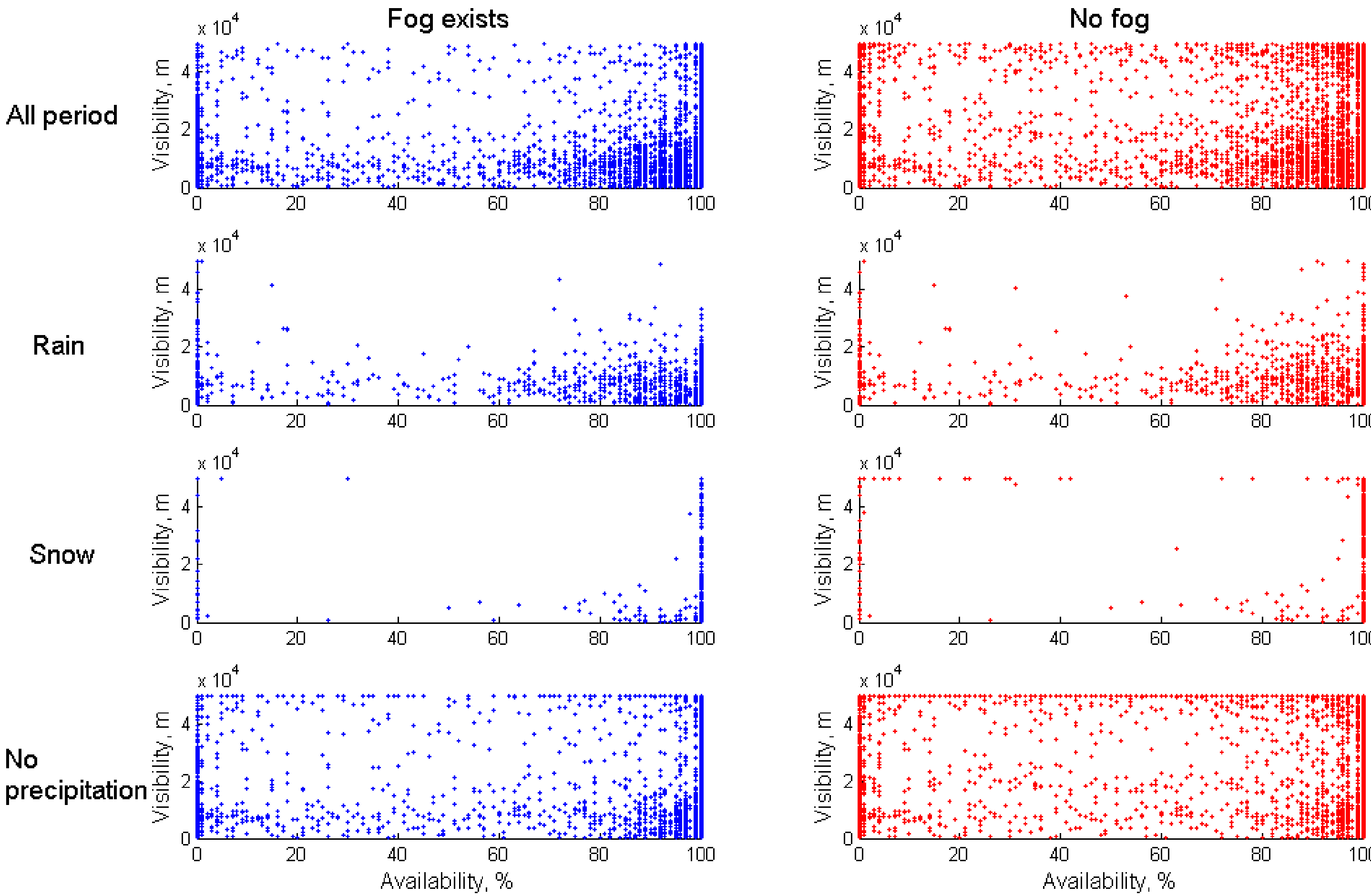
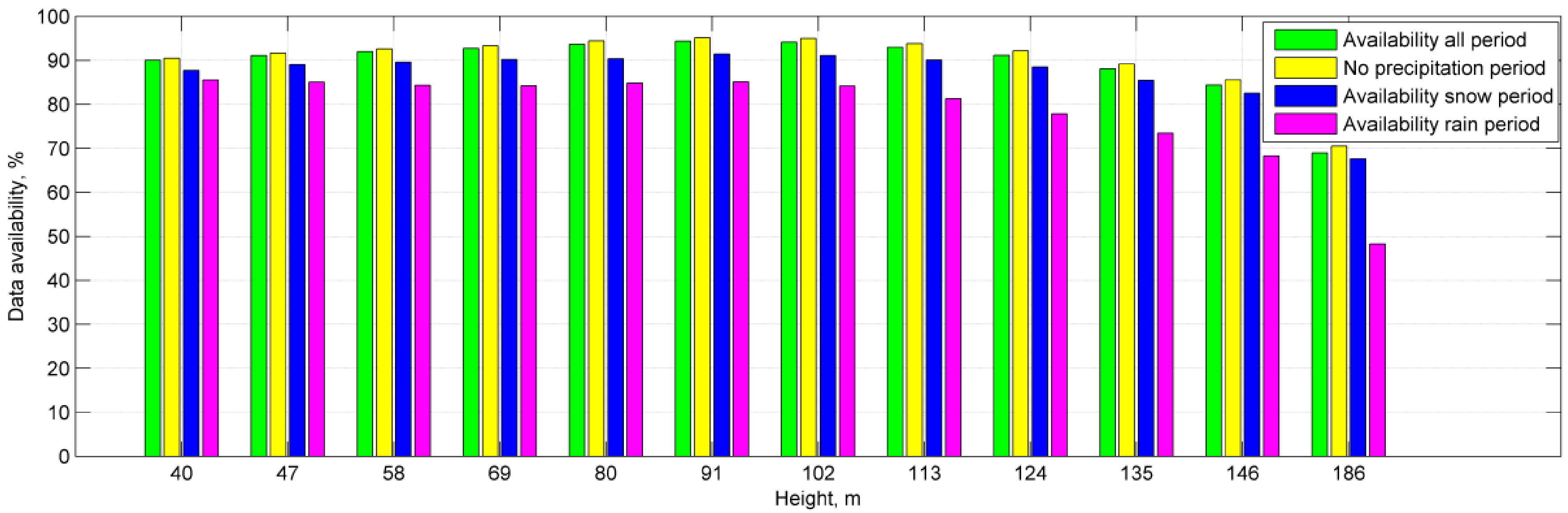
# Lidar performance
## Data availability vs. visibility during fog



# Lidar performance

## Data availability filtered by type of precipitation




- All type of precipitation reduce the LIDAR data availability
- Snow has less impact in reducing LIDAR data availability and is constant along the heights
- Rain has a bigger impact in LIDAR data availability and more notorious in higher altitudes

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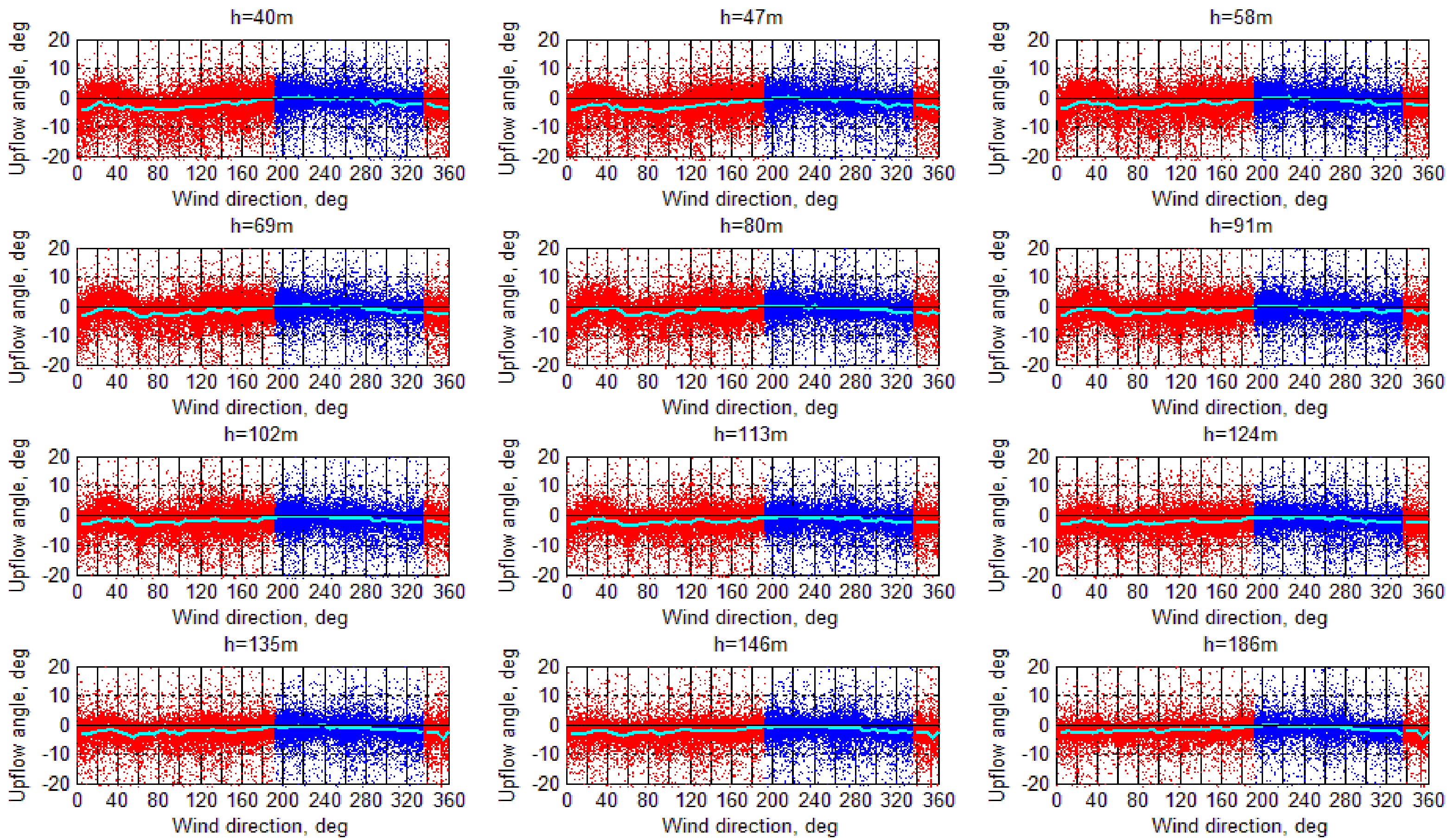
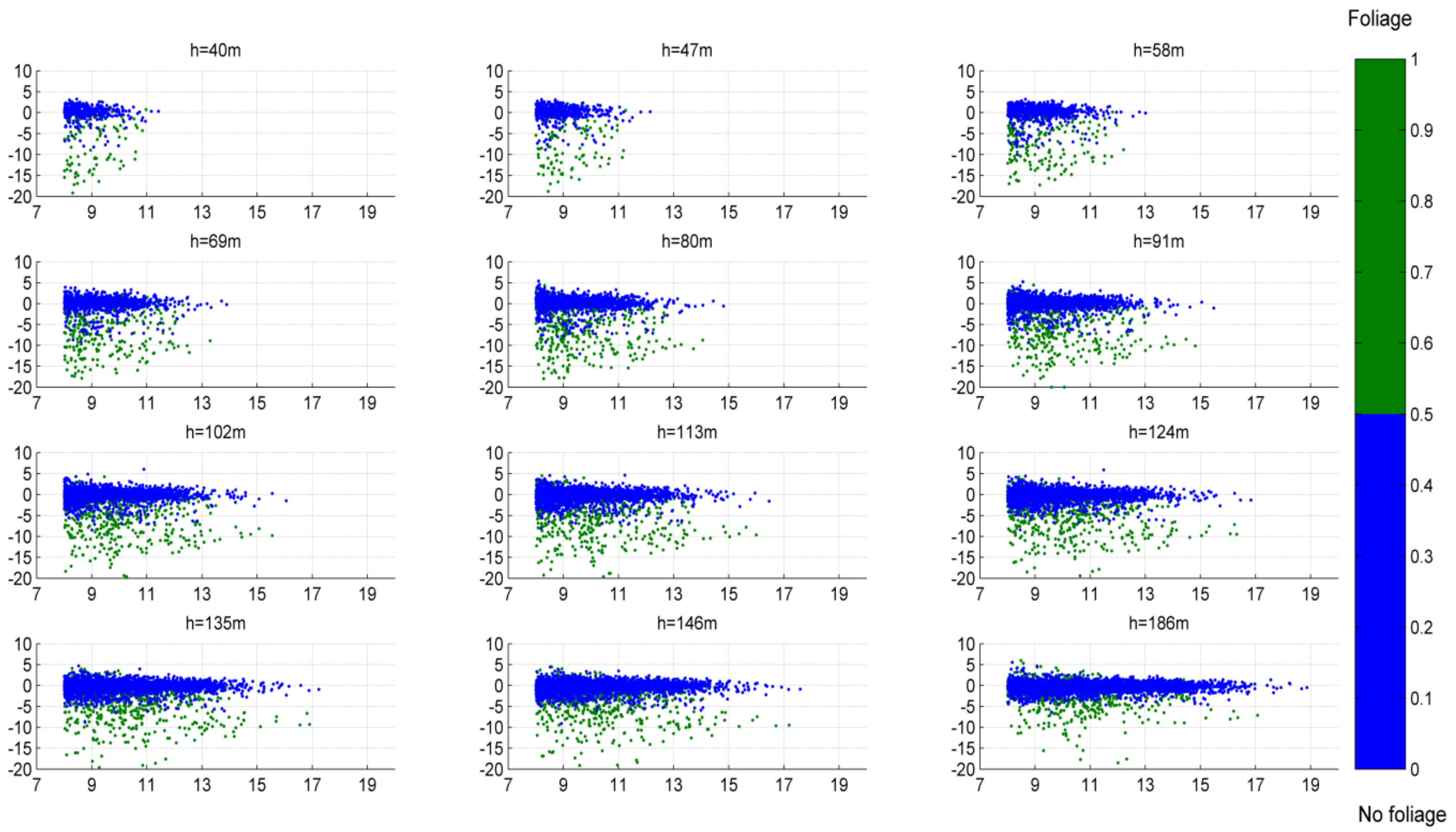
# Upflow angle vs. height

## Free sector (blue) vs. blocked sector (red)



# Upflow angle vs. height

## Foliage influence



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# Upflow angle evaluation
## Summary

- Free sector vs. blocked sector
  - On free sector, average values of uplow angle are close to zero.
  - Inside blocked sector, the average values in some directions go down to -3 – - 4 ° even at height of 146 m.

- Influence of foliage
  - Foliage has strong influence on upflow angle
  - During foliage period, there is obvious inclunation towards upflow angle -10 °.
  - During the period with no foliage, the forest has more porosity, and upflow angle keeps around 0 °

# Wind shear evaluation

- Three different laws to describe vertical wind profile were considered
  - Power law
  - Logarithmic law
  - Modified logarithmic law

- Complex terrain conditions were characterized by
  - Shear exponent, $\alpha$
  - Surface roughness length, $z_0$
  - Displacement height, $d$

- The parameters were fount to be out of the tabulated range, which corresponds to highly forested area

# Wind shear evaluation:
## Power law



- Each pair of 12 heights were used to find power law exponent $\alpha$

$$\alpha = \frac{\ln\left(\frac{V_{hub}}{V_i}\right)}{\ln\left(\frac{Z_{hub}}{Z_i}\right)}$$

- Vertical profile for every $\alpha$ is generated as

$$V_i = V_1 * \left(\frac{Z_i}{Z_1}\right)^{\alpha}$$

- Each generated profile was compared with averaged measured vertical profile
- Goodnes of fit between every generated profile and reference profile for each 10-min sample was determined
- As a result, wind shear calculated between 40 and 91 m gave the maximum number of occurrence.
- Thus, the best fit average wind shear exponent is $\alpha$ = 0.38.

# Wind shear evaluation:
## Logarithmic law

- Logarithmic wind profile is determined as

$$\frac{V_i}{V_r} = \frac{\ln\left(\frac{Z_i}{Z_0}\right)}{\ln\left(\frac{Z_r}{Z_o}\right)}, \rightarrow \quad V_i = V_r * \frac{\ln\left(\frac{Z_i}{Z_0}\right)}{\ln\left(\frac{Z_r}{Z_o}\right)}$$

- Determined surface roughness length using the measurements in heights 40 and 91 meters was $z_0$ = 4.6 m.

- Obtained roughness length is higher than any tabulated roughness values. Depending on the references, roughness lengts 1 (or 3) are used for cities with tall buildings. Values > 1 for tall forests. The forest in the are of the Lidar, however, is dense but with trees of around 5-8 m height.

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# Wind shear evaluation:
## Modified log law

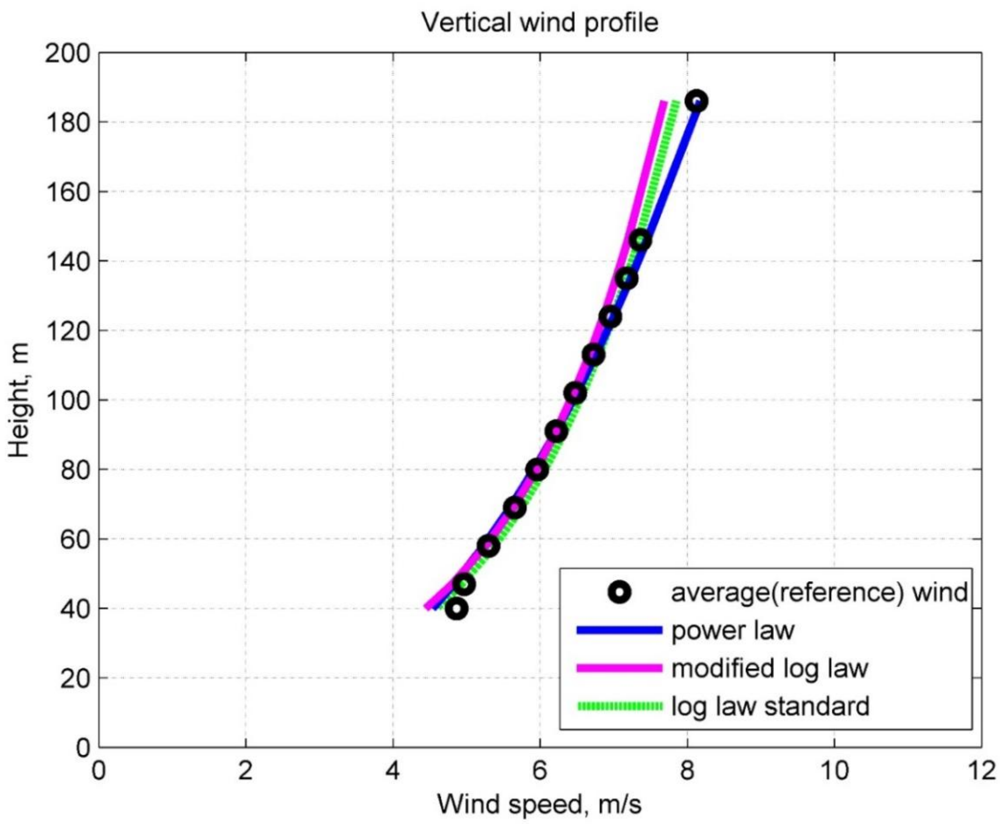
- Modified logarithmic law is used to characterize wind above a forested canopy

$$V_i = V_r * \frac{\ln\left(\frac{Z_i - d}{Z_0}\right)}{\ln\left(\frac{Z_r - d}{Z_o}\right)}$$

- Displacement height *d* is about 2/3 of the height of the trees at the site.
- With matlab fit-function, following values for surface roughness length and displacement height were determined
  - $z_0$ = 3.7 m
  - *d* = 5 m
- The parameters would apply for about 7.5 m high forest, but surface roughness lenght is still considerably high.

# Wind shear evaluation
## Comparison

- Power law
  - Best fit with exponent $\alpha = 0.38$
- Logarithmic law
  - Surface roughness lenght $z_0 = 4.6$ m.
- Modified logarithmic law
  - Surface roughness length $z_0 = 3.7$, $d = 5$ m.
- All parameters determined between heights 40 and 91 m.
- All obtained values describe tall forest or urban area with tall buildings.
- Best fit obtained with power law.



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# Conclusions

**Lidar operation** in weather conditions of **South Finland, wind shear and upflow angle in forested** environment were studied:

- Windcube Lidar tolerated well **low winter temperatures** and **snowing.**
- Due to the **clear atmosphere**, Lidar CNR threshold was set below the default value. **Lowering the CNR threashold by -1** dB increased the availabilities about **+10%**
- **Data availability** were **greater than 85%** along the heights **40-146 m (rotor area limits) .** At **hub height,** the availabilities **are greater than 94%.**
- **Data availability is good during the visibility is low**. However, all type of precipitation reduces the availability.
- **Upflow angle** is **bigger** for the **blocked sector** and it is **tree foliage dependant.**
- Best fit for the vertical wind profile was obtained using **power law** between levels: **hub height and HH-blade tip**. The mean shear exponent found was $\alpha$ **= 0.38.**

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# Next steps

- Further analysis of Lidar availability during no precipitation periods
- Further analysis of wind shear in forested terrain
- Significance of Lidar Flow Complexity Recognition in forested terrain
- Shear, upflow and temperature effect on Power Performance under IEC61400-12-1, IEC61400-12-1 ed 2. (draft) and IEC61400-12-2.

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# Thank you for the project partners:

TuuliMuukko

TuuliSaimaa