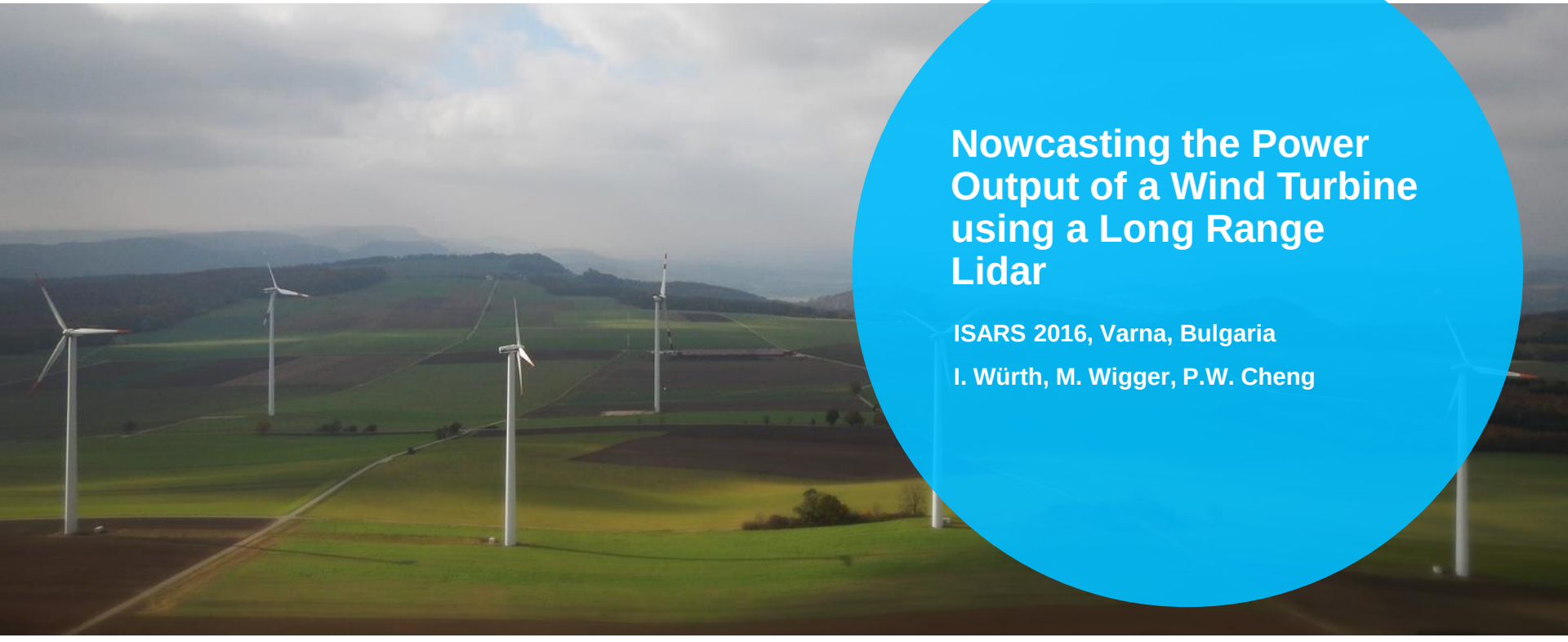
University of Stuttgart
Stuttgart Wind Energy (SWE)
@ Institute of Aircraft Design



Nowcasting the Power Output of a Wind Turbine using a Long Range Lidar

ISARS 2016, Varna, Bulgaria

I. Würth, M. Wigger, P.W. Cheng

SWE

WindForS
Wind Energy
Research Cluster

Welcome to the Energiewende

Germany goes Renewables!

Goals of the Energiewende:

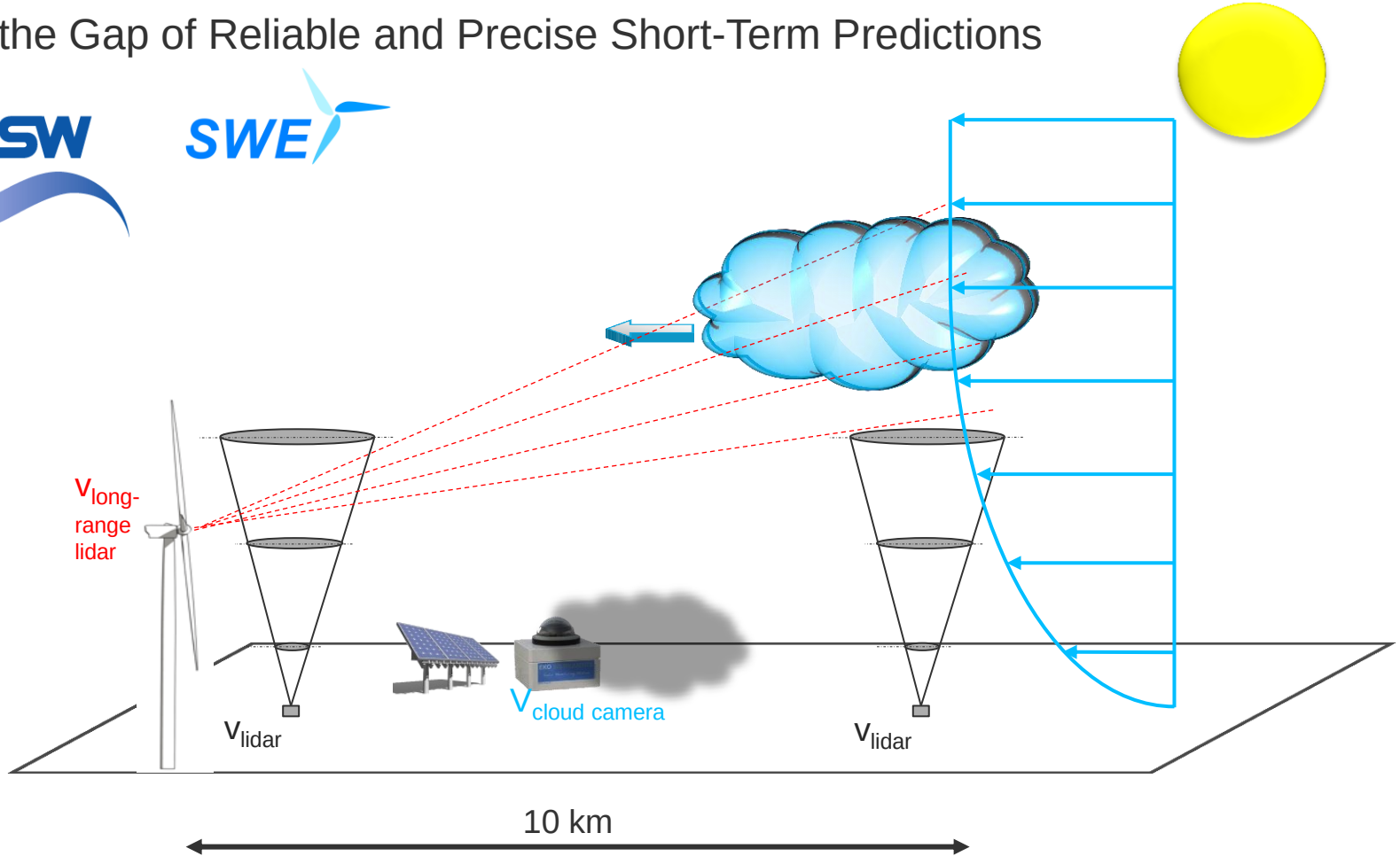
Target	2020	2050
Share of renewable energies in total electricity consumption	35%	80%
Reduction of electricity consumption (base year 2008)	−10%	−25%

- Decentralized energy system with many interconnected power generating units
- Challenge: match a given electric load profile to the short-term power fluctuations

www.erneuerbare-jetzt.de

The VORKAST Project

Closing the Gap of Reliable and Precise Short-Term Predictions



Measurement Setup on the Swabian Alb

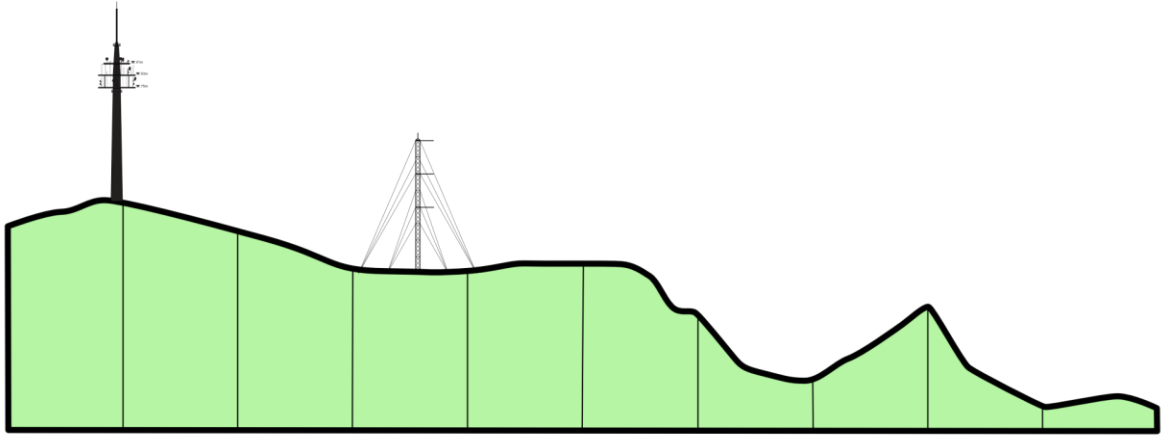
Stream Line XR

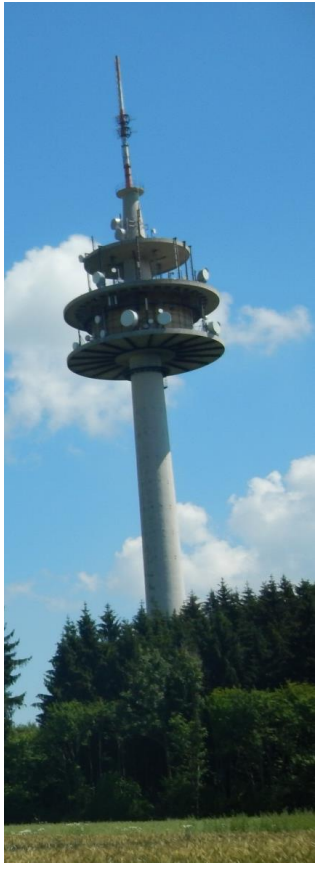
Lidar facts

- Maximum range: 10 km
- Pulse length: 410ns
- Measurement volume: ~80m
- Standard no. range gates: 167
- Trajectories: staring, DBS, VAD, RHI, custom, +wind direction dependent

Measurement Setup on the Swabian Alb

An unobstructed view





Which Answers need to be found?

1. Filter algorithms

   How can the radial velocities be filtered?

2. Device alignment

   How can the exact position of the device and the measurement point be determined?

3. Correlation with met mast

   Are the lidar measurement comparable with conventional measurement techniques?

4. Wind field reconstruction

   How do I have to measure to be able to reconstruct the wind field precisely in great distances?

5. Wind evolution/ -prediction

   How does the wind field evolve over great distance and which influence does that have on the prediction?

Filter algorithms

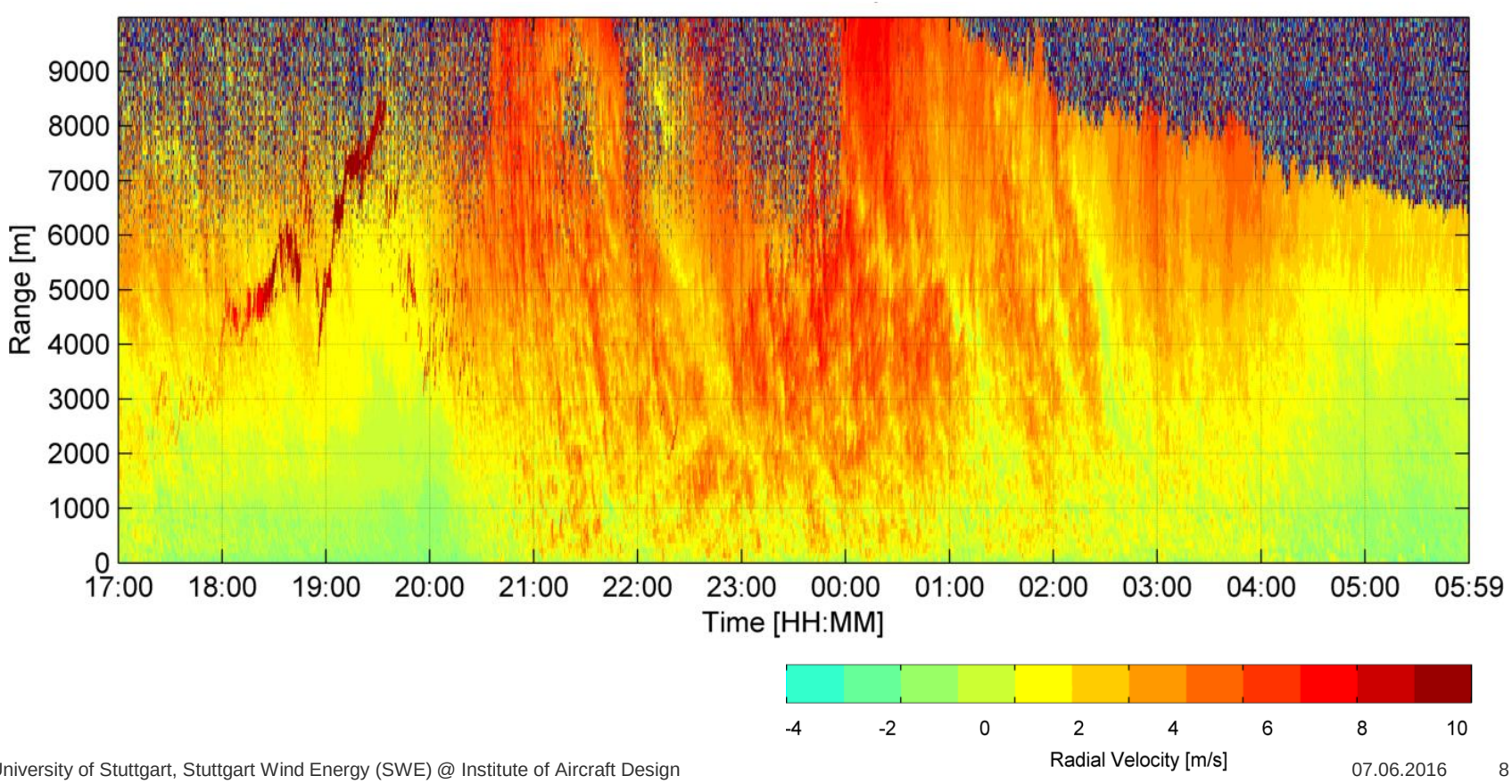
How can the radial velocitiy be filtered?

- Input Parameter: CNR, Radial velocity
- Filter techniques: CNR threshold, Velocity estimation
- Filter requirements:
  - Conservative filtering with least possible data loss
  - Working for all environmental conditions
  - Near real-time capability

Filter Algorithms

Raw data

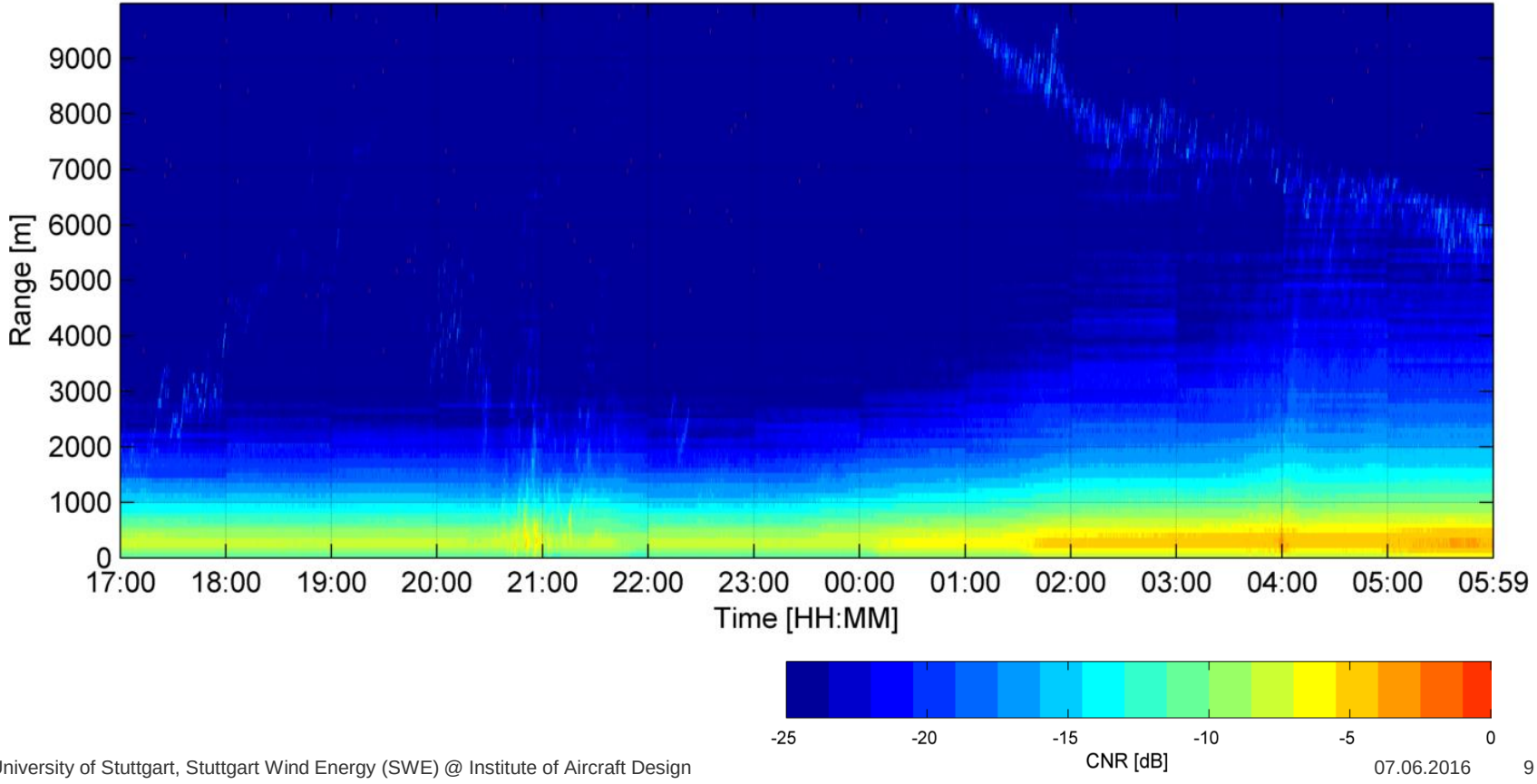
Radial velocity



Filter Algorithms

Raw data

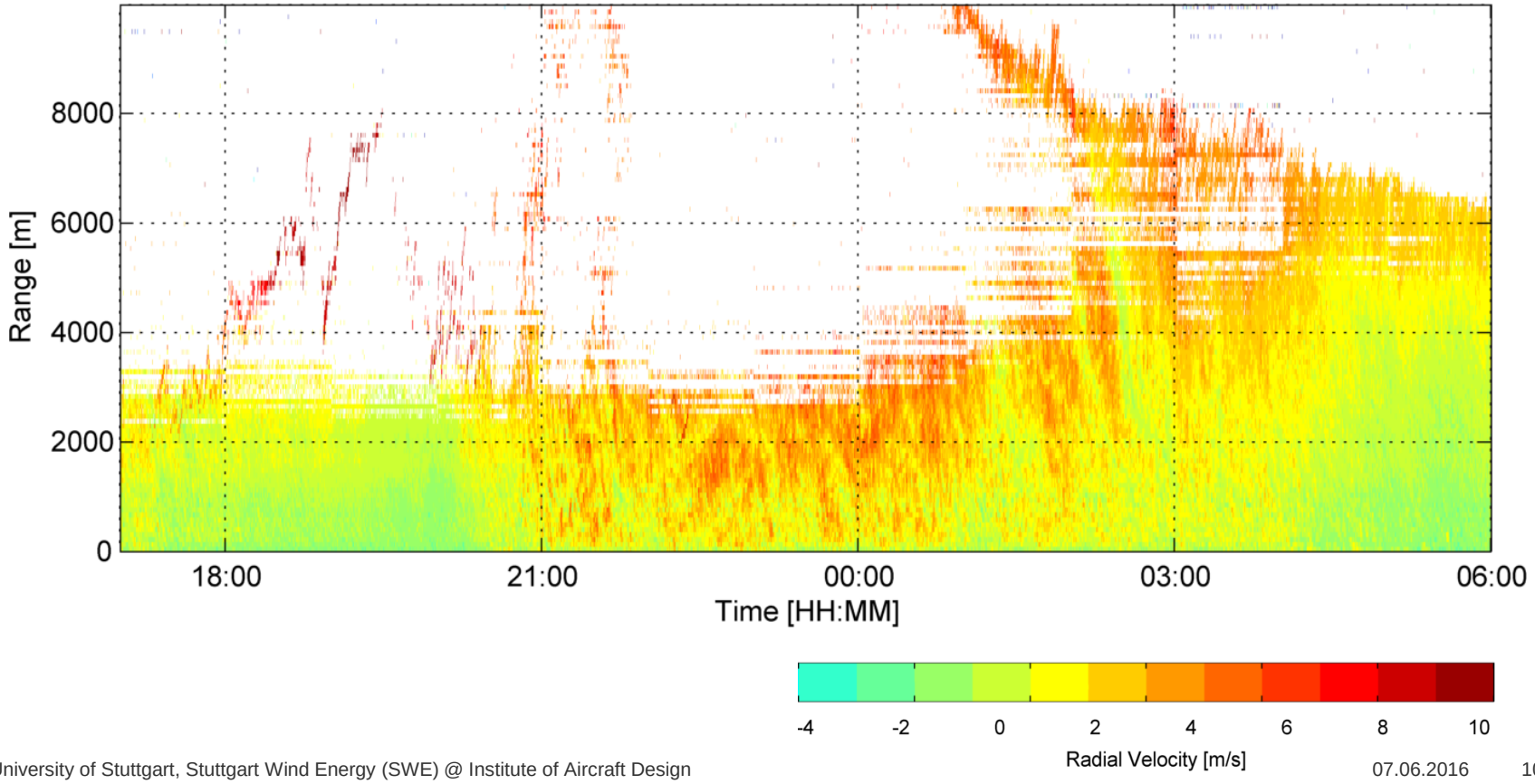
CNR



Filter Algorithms

CNR threshold

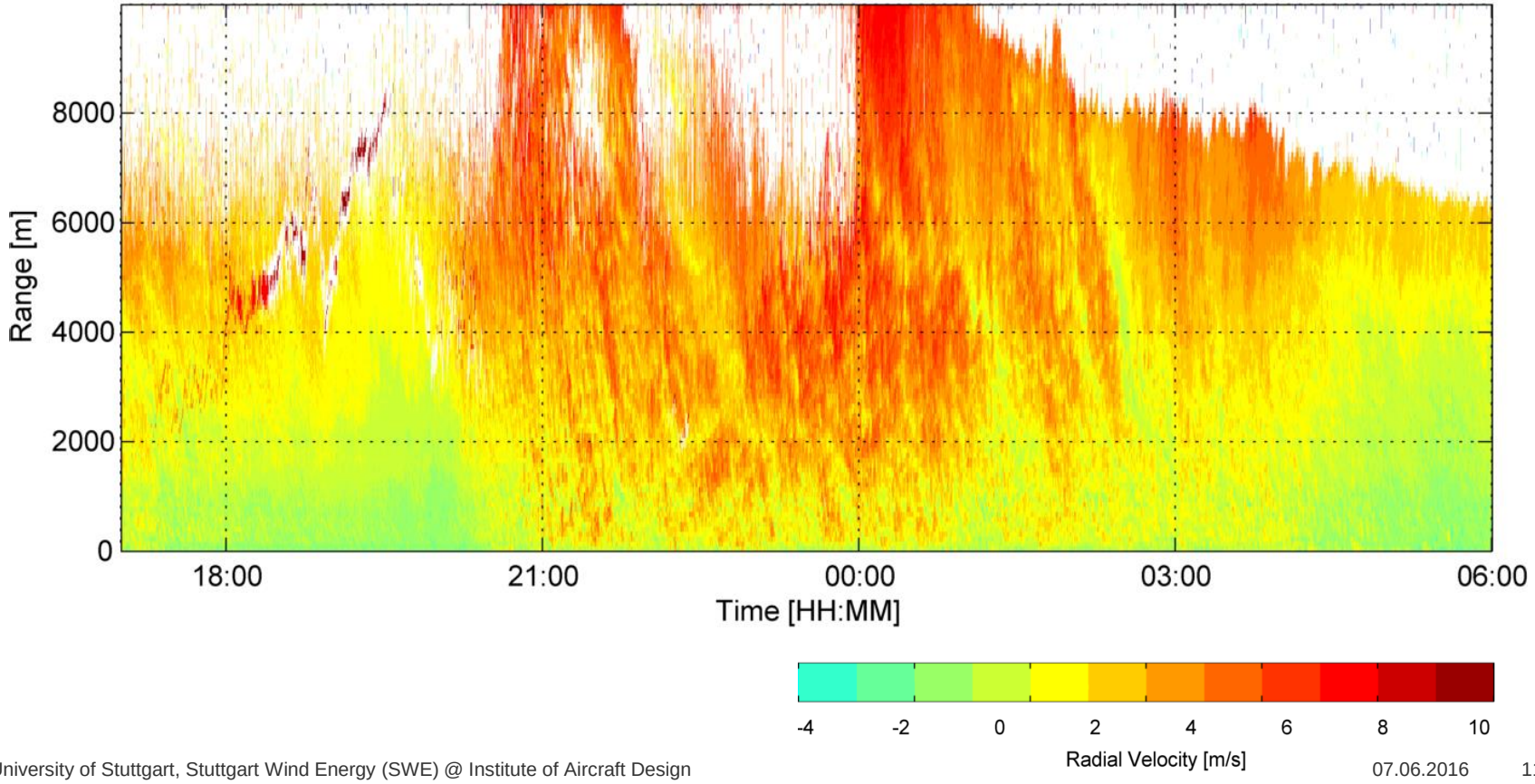
CNR threshold



Filter Algorithms

Velocity range filter

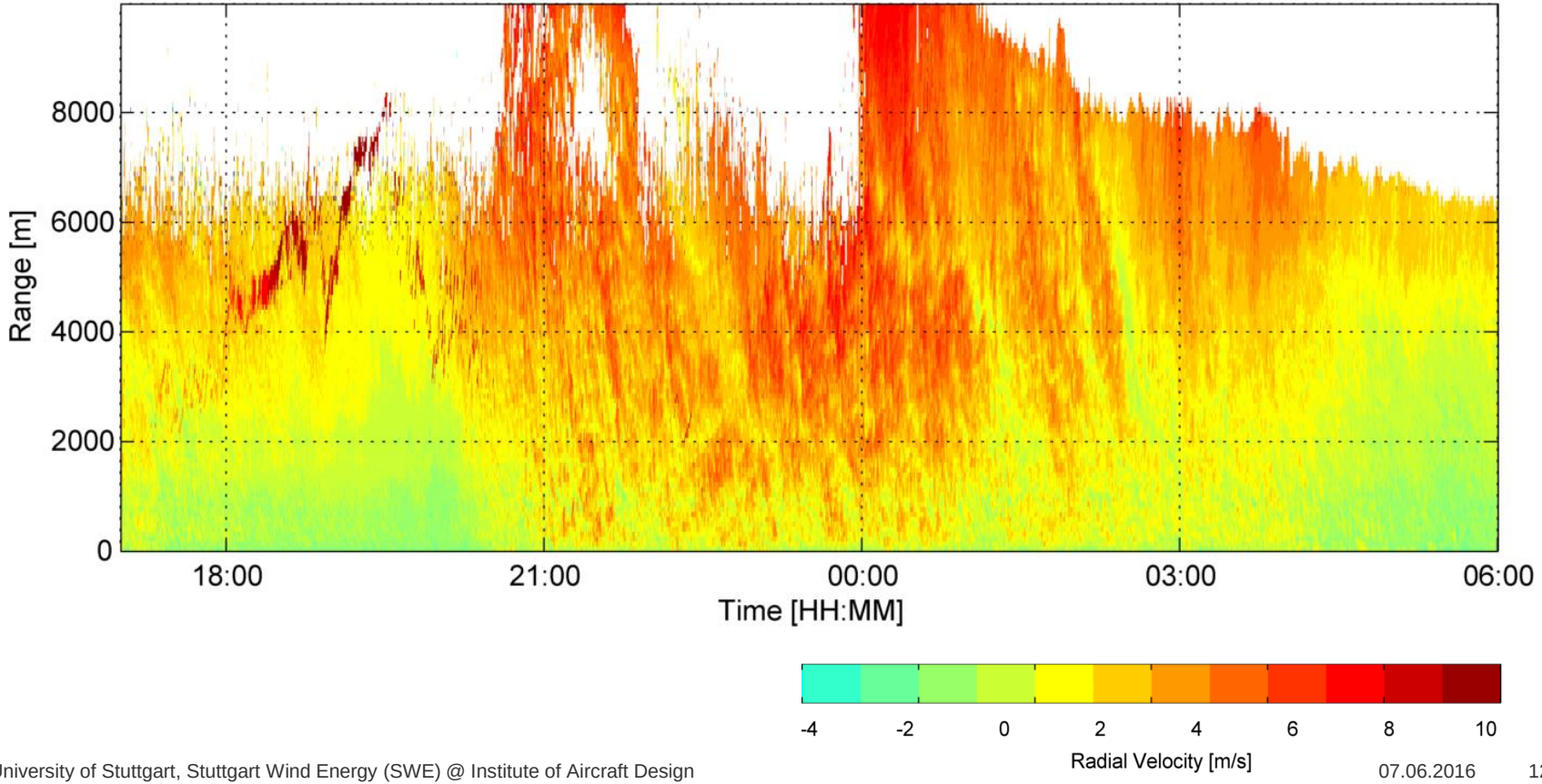
Velocity estimation



Filter Algorithms

Standard deviation filter

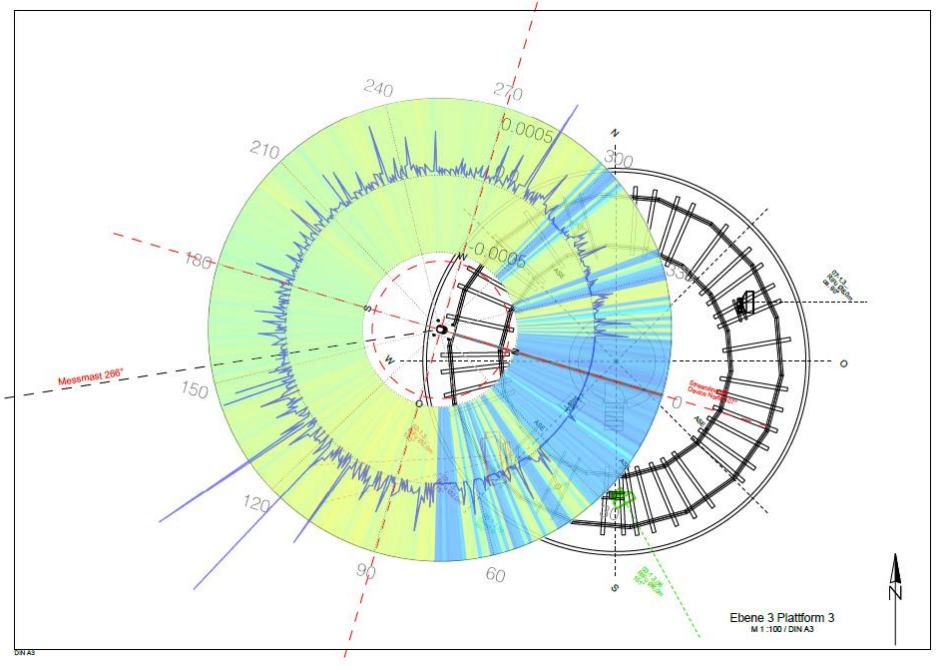
Velocity estimation



Device Alignment

How can the exact position of the device and the measurement point be determined?

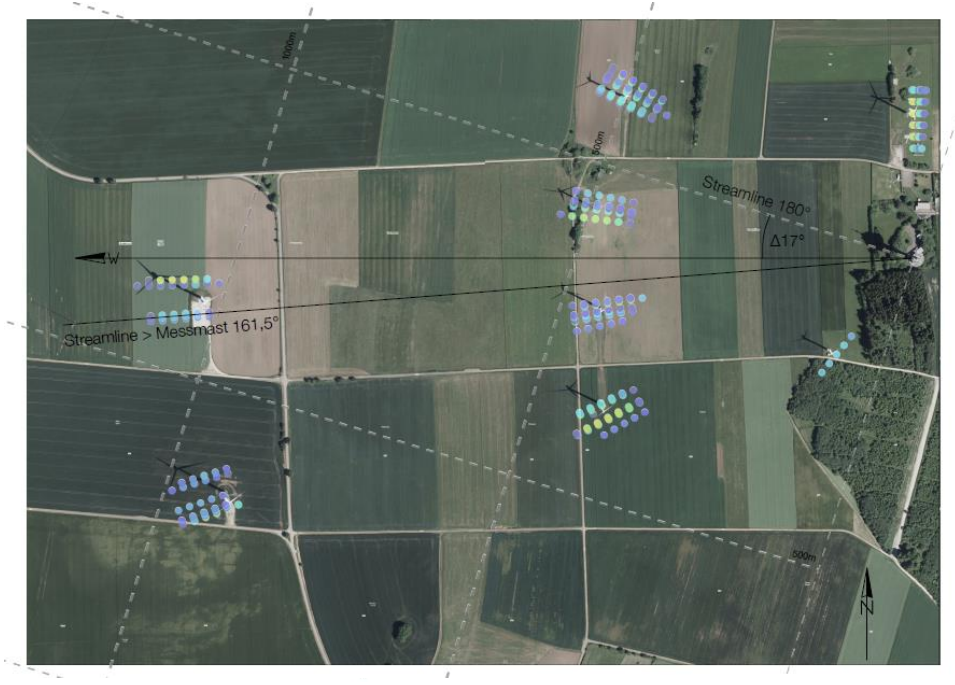
- Free sectors: 360° azimuth scan



Device Alignment

How can the exact position of the device and the measurement point be determined?

- Free sectors: 360° azimuth scan
- Rough Alignment: Hard target detection with surrounding turbines



Device Alignment

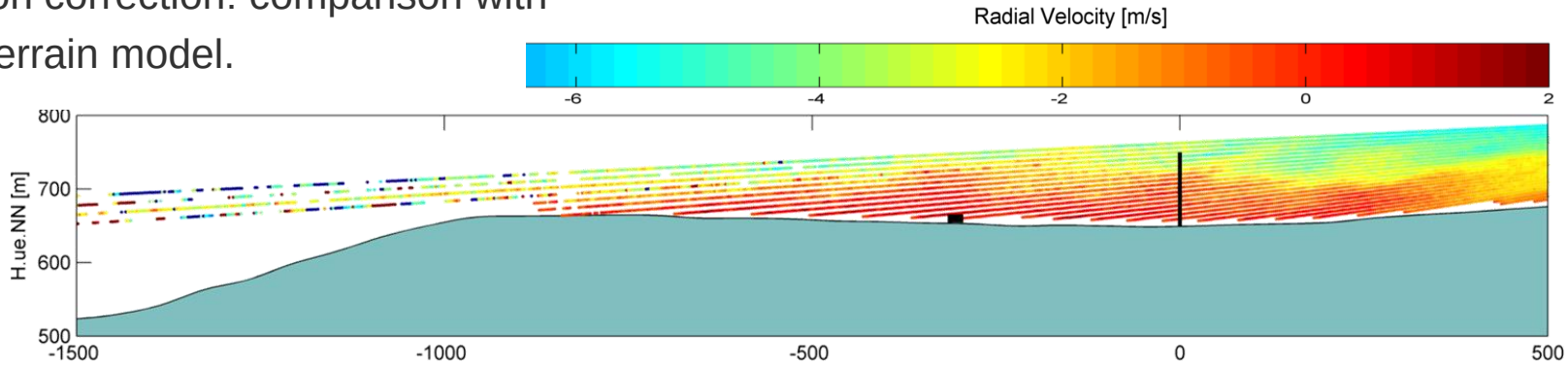
How can the exact position of the device and the measurement point be determined?

- Free sectors: 360° azimuth scan
- Rough alignment: Hard target detection with surrounding turbines
- Precise alignment: detailed scanning of single turbine

Device Alignment

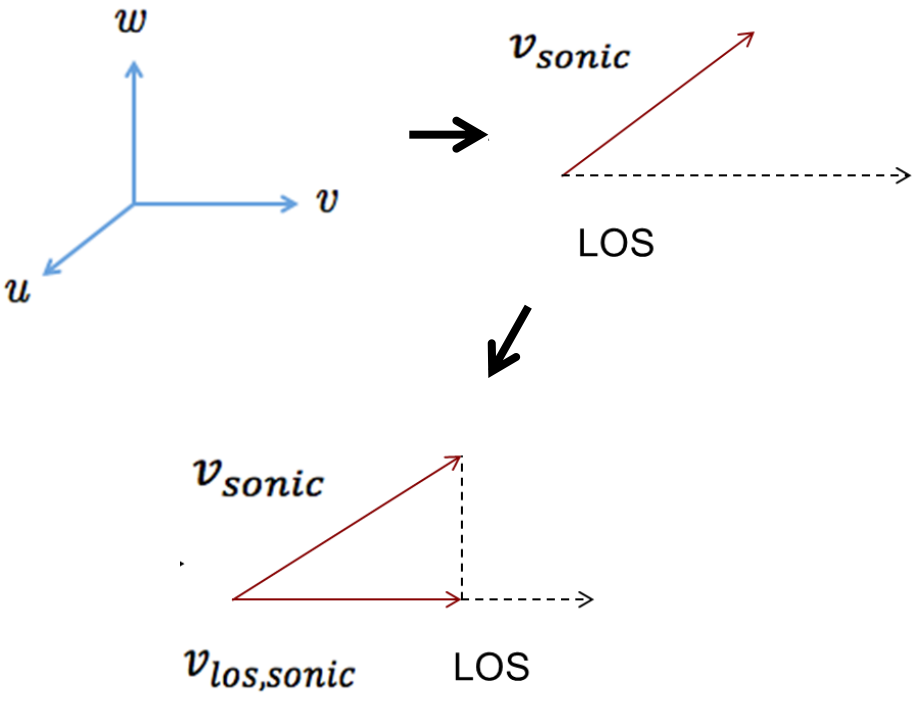
How can the exact position of the device and the measurement point be determined?

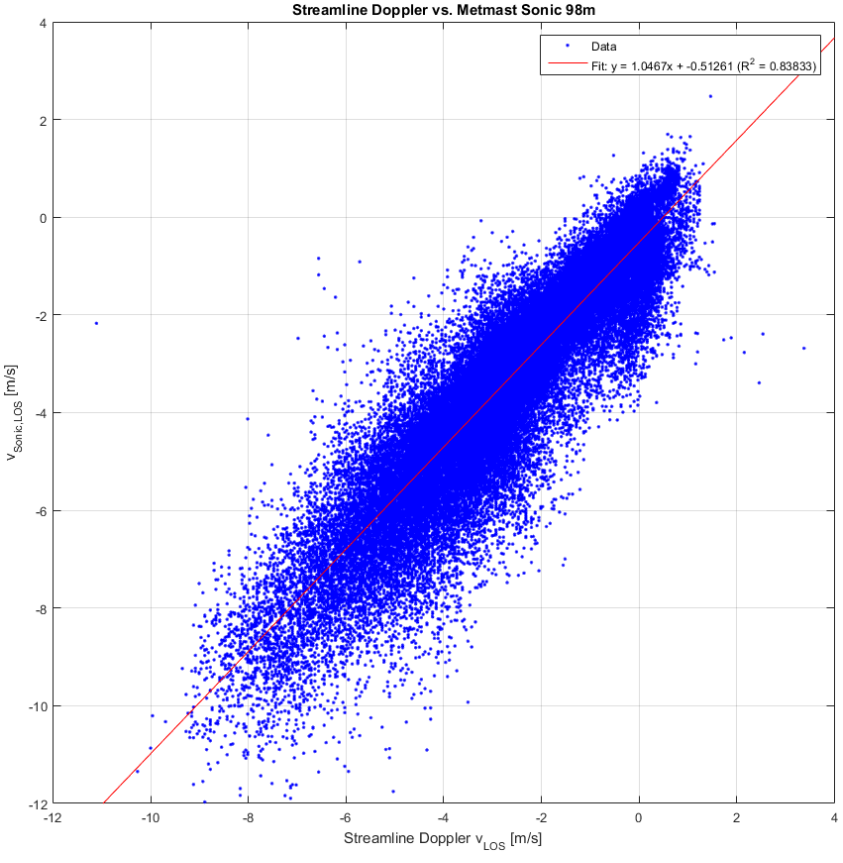
- Free sectors: 360° azimuth scan
- Rough alignment: Hard target detection with surrounding turbines
- Precise alignment: detailed scanning of single turbine
- Elevation correction: comparison with digital terrain model.



Correlation with met mast

Are the lidar measurements comparable with conventional measurement techniques?





Wind Field Reconstruction

How do we have to measure to be able to reconstruct the wind field correctly in great distances?

$$u_i = v_0 + \delta_H y_i + \delta_V z_i$$
$$v_i = w_i = 0$$

- very simple **wind model** (assuming no tilted inflow or misalignment)

$$v_{los,i} = \frac{x_i}{f_i} u_i + \frac{y_i}{f_i} v_i + \frac{z_i}{f_i} w_i$$

- lidar measurement equation

$$\underbrace{\begin{bmatrix} v_{los,1} \\ \vdots \\ v_{los,n} \end{bmatrix}}_{m} = \underbrace{\begin{bmatrix} \frac{x_1}{f_1} & \frac{x_1}{f_1} y_1 & \frac{x_1}{f_1} z_1 \\ \vdots & \vdots & \vdots \\ \frac{x_n}{f_n} & \frac{x_n}{f_n} y_n & \frac{x_n}{f_n} z_n \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} v_0 \\ \delta_H \\ \delta_V \end{bmatrix}}_{s}$$

$$\begin{bmatrix} v_0 \\ \delta_H \\ \delta_V \end{bmatrix} = A^{-1} \begin{bmatrix} v_{los,1} \\ v_{los,2} \\ v_{los,3} \end{bmatrix}$$

- solution for $n = 3$ measurements with **inverse A^{-1}**, else with **Moore-Penrose pseudoinverse A^{+}**

Wind Field Reconstruction

How do we have to measure to be able to reconstruct the wind field correctly in great distances?

Questions to answer:

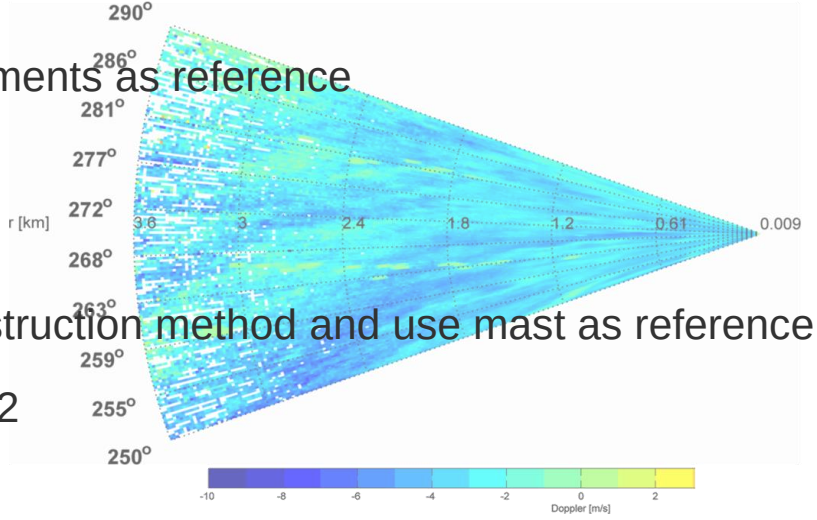
- Trajectory of lidar measurements
- How many measurements points to use for the reconstruction

Challenge:

- Only in-situ point measurements as reference
- Complex terrain

Solution:

- ➢ Apply model based reconstruction method and use mast as reference
- ➢ Schlipf et all. DEWEK 2012



Wind Evolution/ -prediction

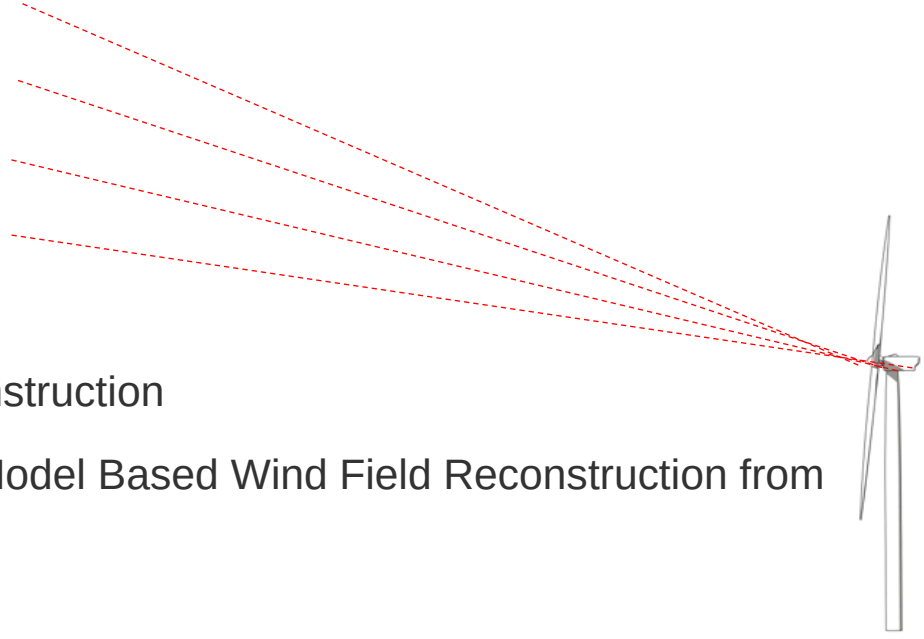
How does the wind field evolve over great distance and which influence does that have on the prediction?

Questions to answer:

- Can Taylor be applied?
- How big is the effect of the terrain?

Solution: Second measurement campaign

- Lidar mounted on a turbine
- Use rotor effective wind speed as reference
- Apply dynamic model based wind field reconstruction
- Raach et all. :Three Dimensional Dynamic Model Based Wind Field Reconstruction from Lidar Data, Torque 2014 Torque



University of Stuttgart

Thank you!

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Gefördert auf Grund eines Beschlusses des Deutschen Bundestages

Bundesministerium für Wirtschaft und Energie