Calibration and Classification of Lidars Using Fiber Optics and Monte Carlo Uncertainty Propagation

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Recap: Met-mast based calibration of ground based lidars

Mast-based lidar calibration

- Compare lidar measurements with cup anemometer mounted on met-mast
- Procedure: IEC 61400-50-2
- **Resulting uncertainty (k=1) : ~1.5 … 2%**
- **Duration: 6 to 8 weeks**
- Calibrated for flow conditions present at calibration site

Classification

- Linear regression of calibration data against atmospheric parameters
- Procedure: IEC 61400-50-2
- Extrapolation to flow conditions at campaign site
- Added uncertainty: 0-1%

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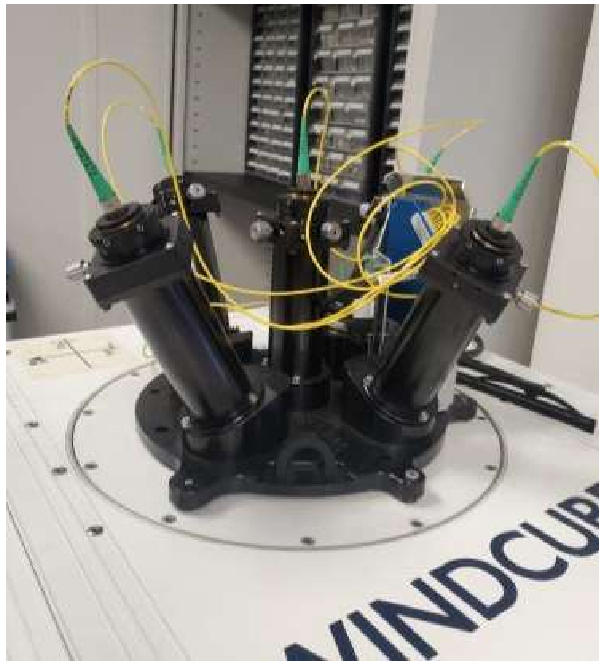
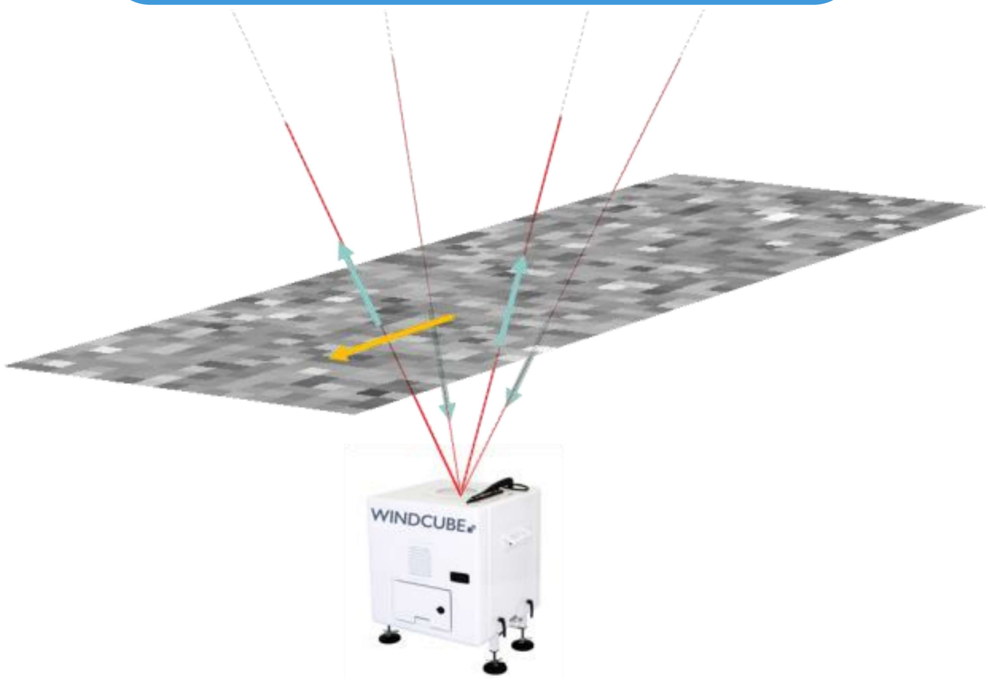
New 3-Step Calibration Concept

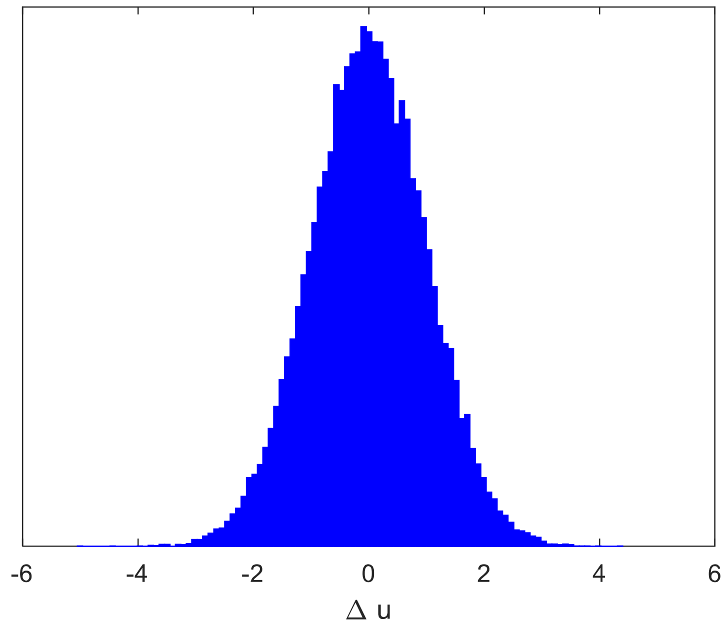
1. Calibration of the Line of Sight Speeds

2. Simulation of Measurement Process

3. Repeated Simulations of Measurement







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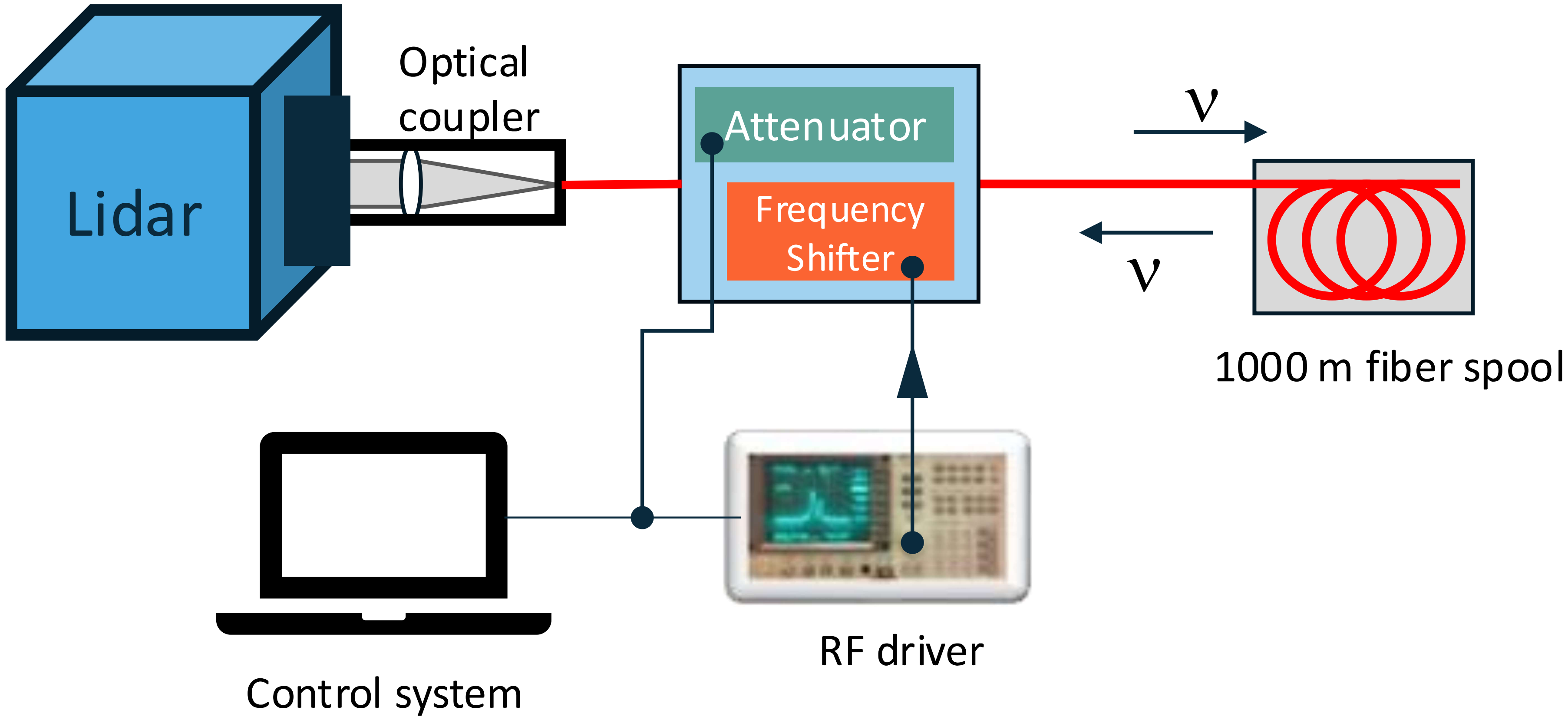
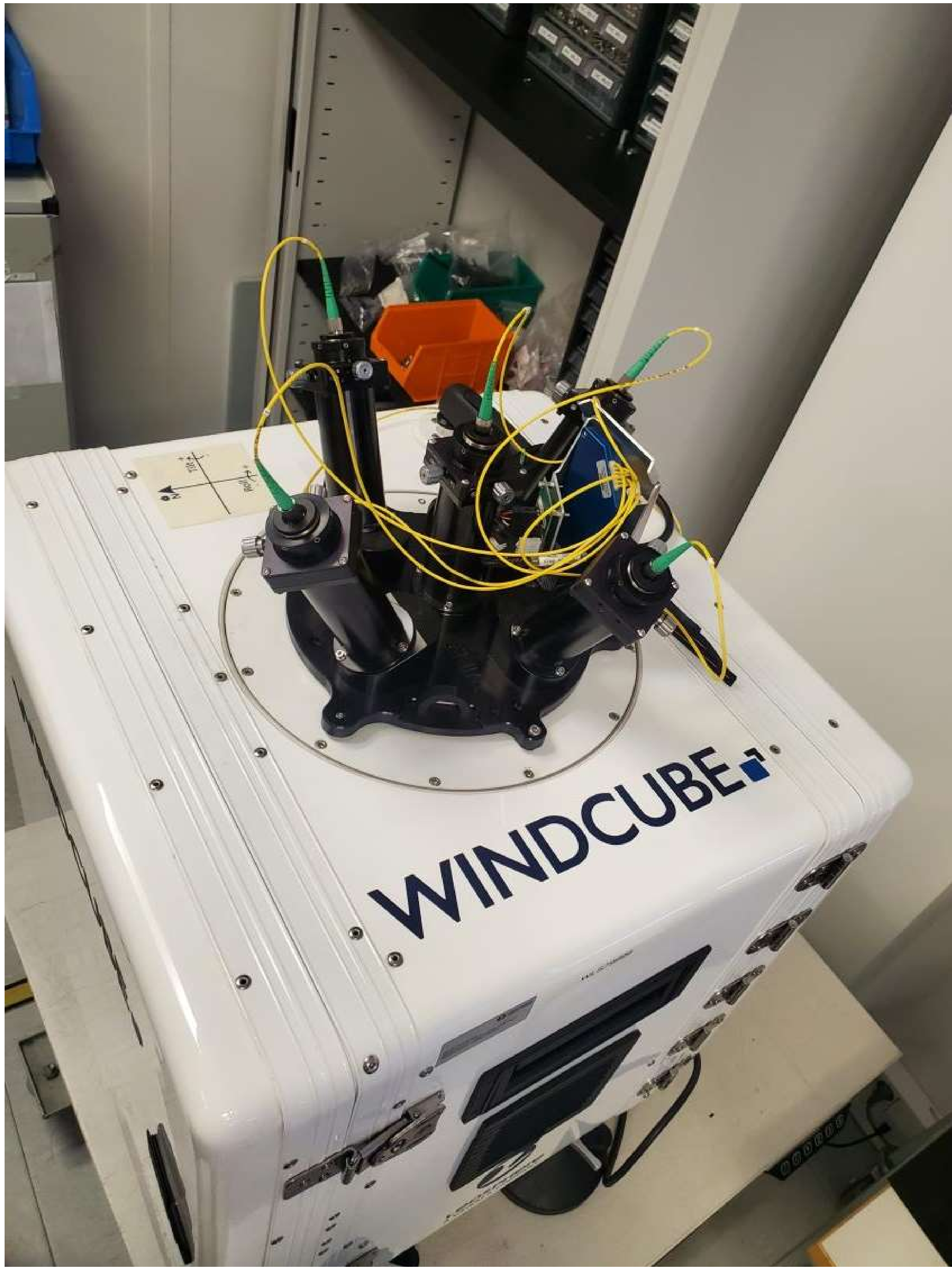
1. Optical Bench Calibration: SAFO-MV

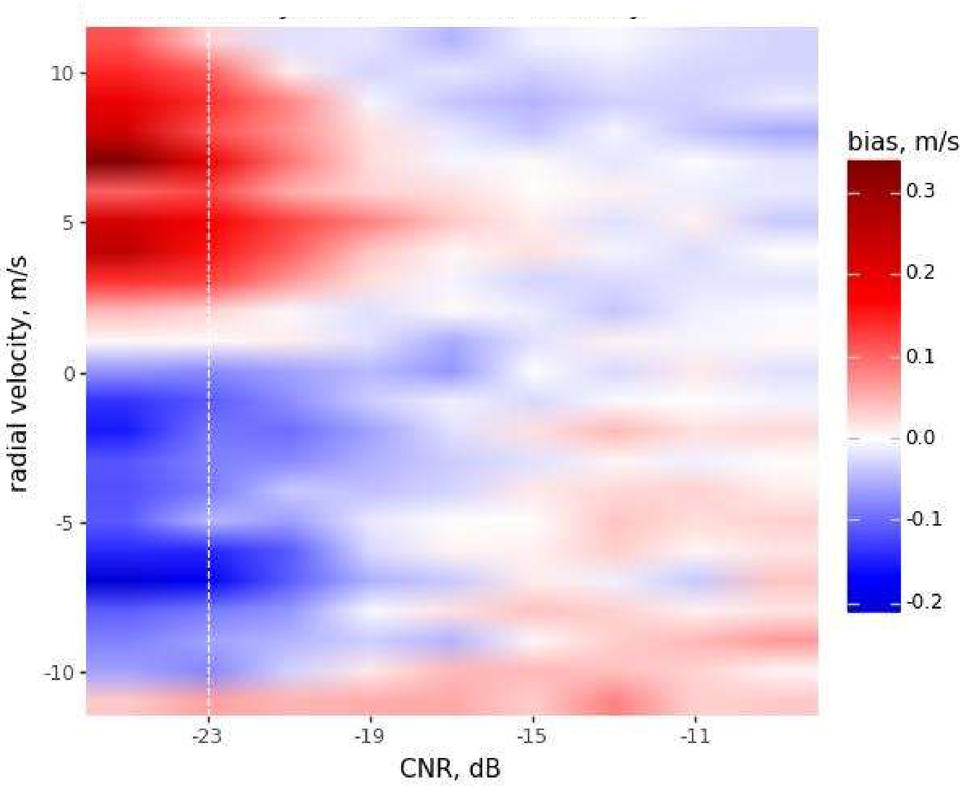


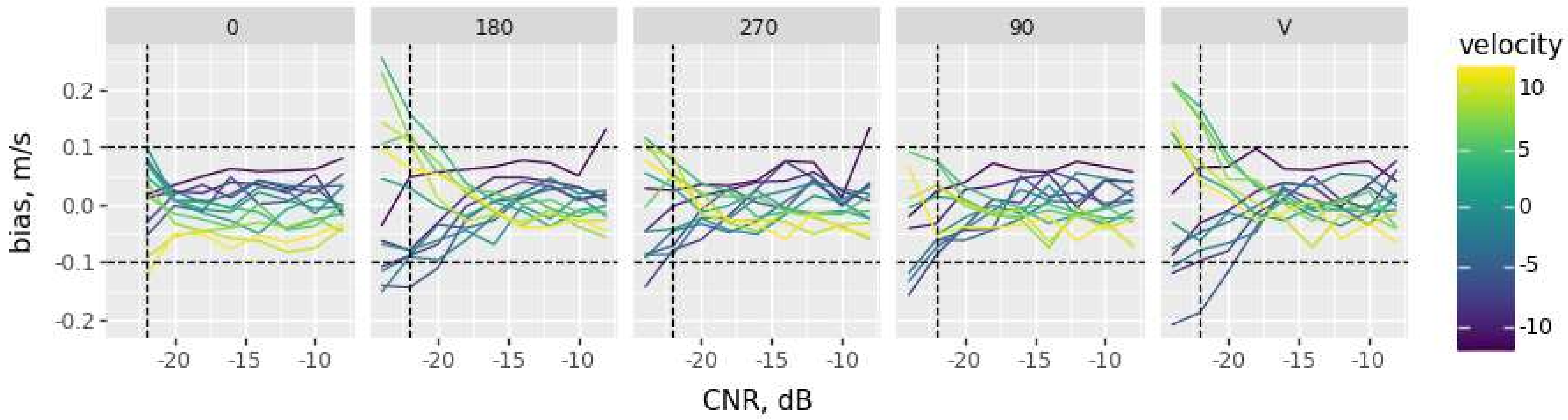


- Calibration takes a few days
- SAFO-MV test bench is calibrated traceably
    - Reference uncertainty of bench itself
    - Repeatability and reproducibility uncertainties

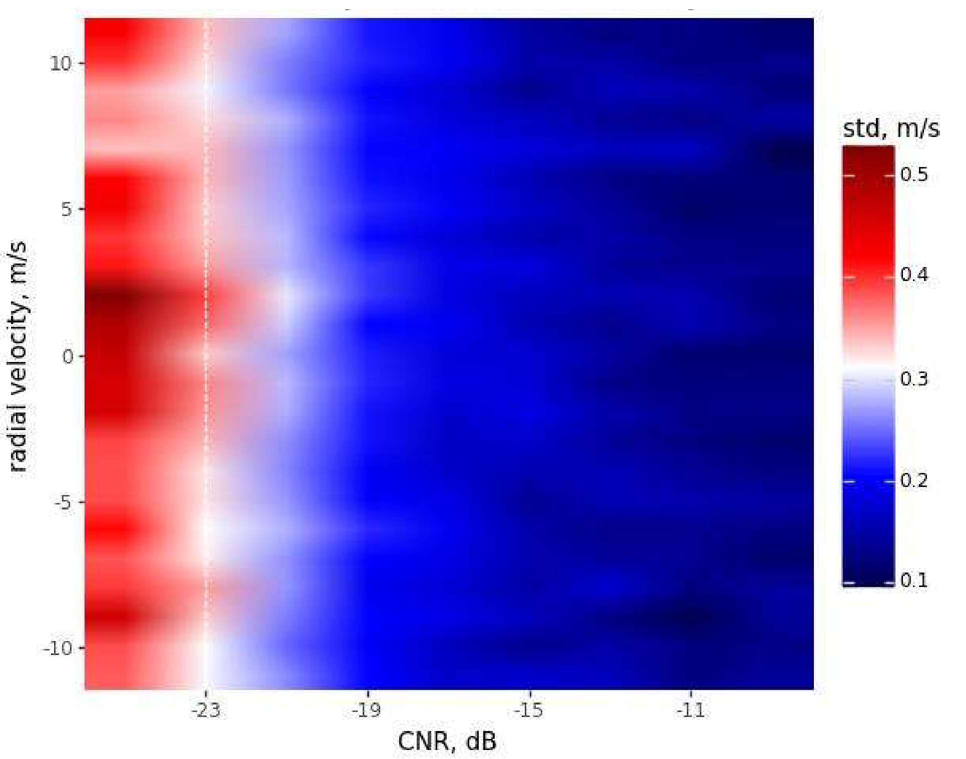
1. Results from SAFO-MV Bench Calibration

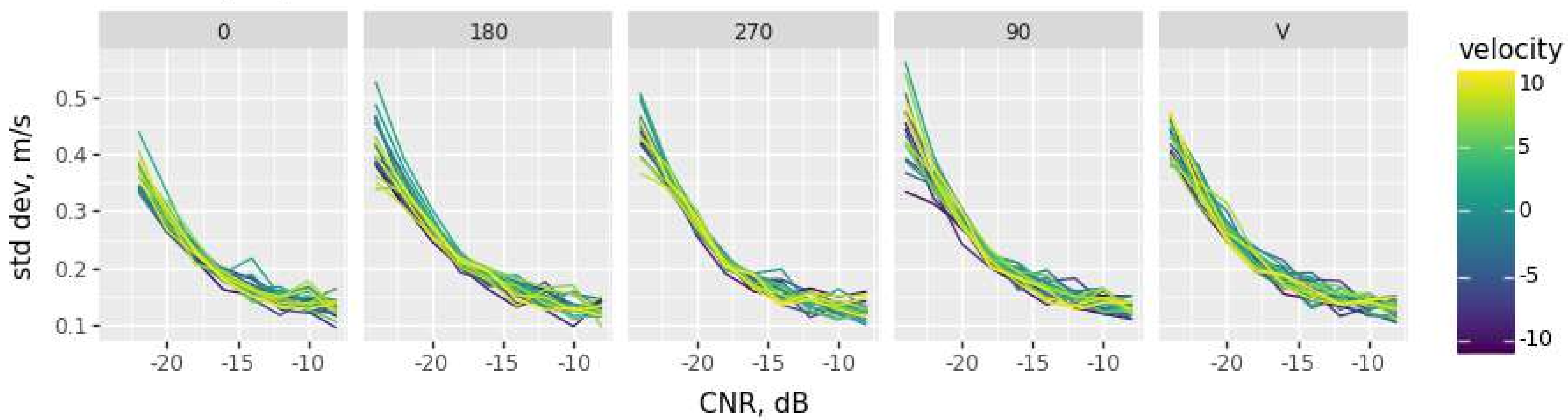
BIAS



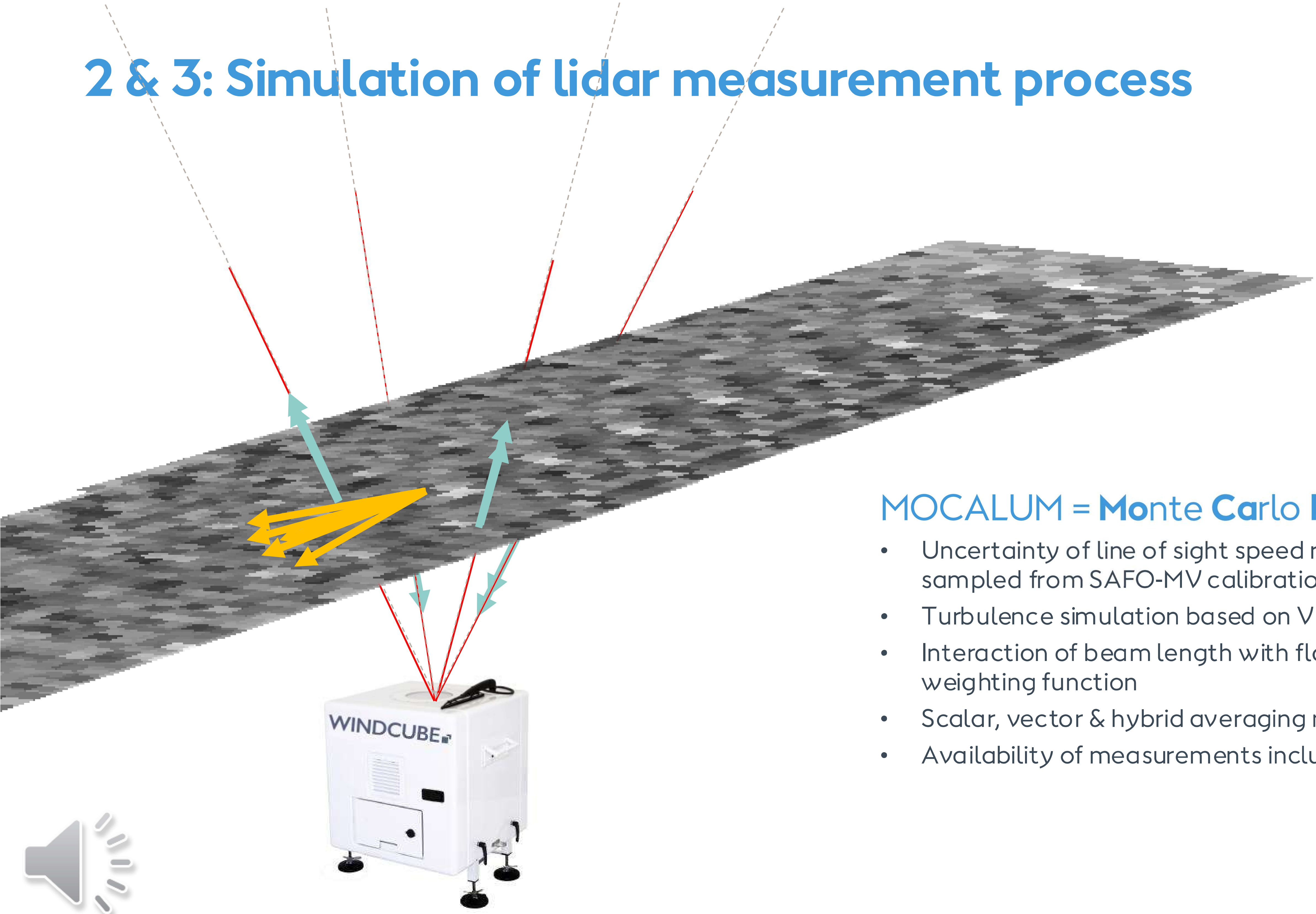


STANDARD DEVIATION





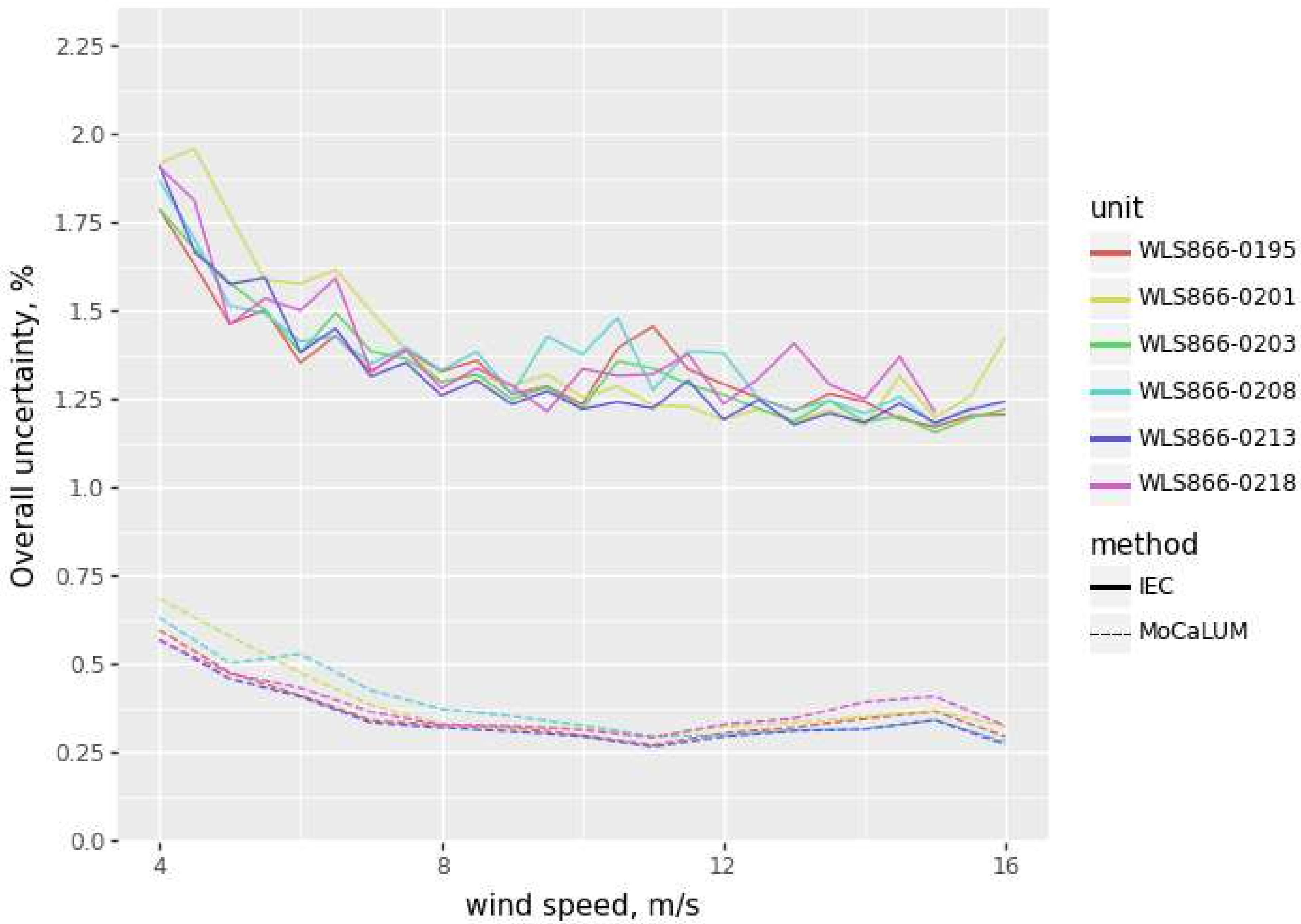
2 & 3: Simulation of lidar measurement process



MOCALUM = **Mo**nte **Ca**rlo **L**idar **U**ncertainty **M**odel

- Uncertainty of line of sight speed retrieval and other input variables sampled from SAFO-MV calibration
- Turbulence simulation based on Veers turbulence (PyConTurb)
- Interaction of beam length with flow field by device specific range weighting function
- Scalar, vector & hybrid averaging method
- Availability of measurements included as input parameter

3. Comparison between mast and lab/simulation based calibration



Flow conditions during calibration:

- TI = 15%
- Average CNR = -10dB
- Measurement height: 106m
- Availability > 90%

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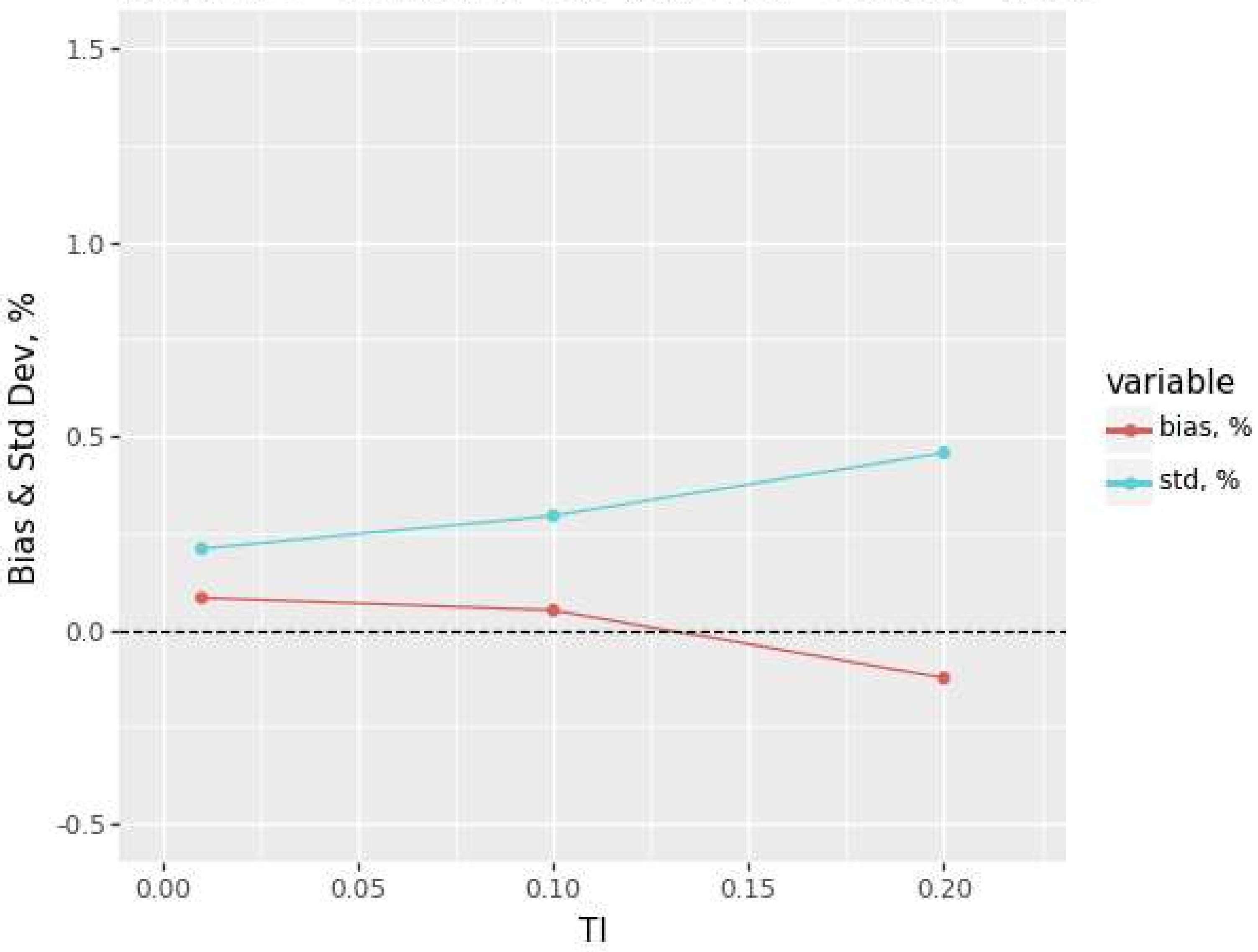
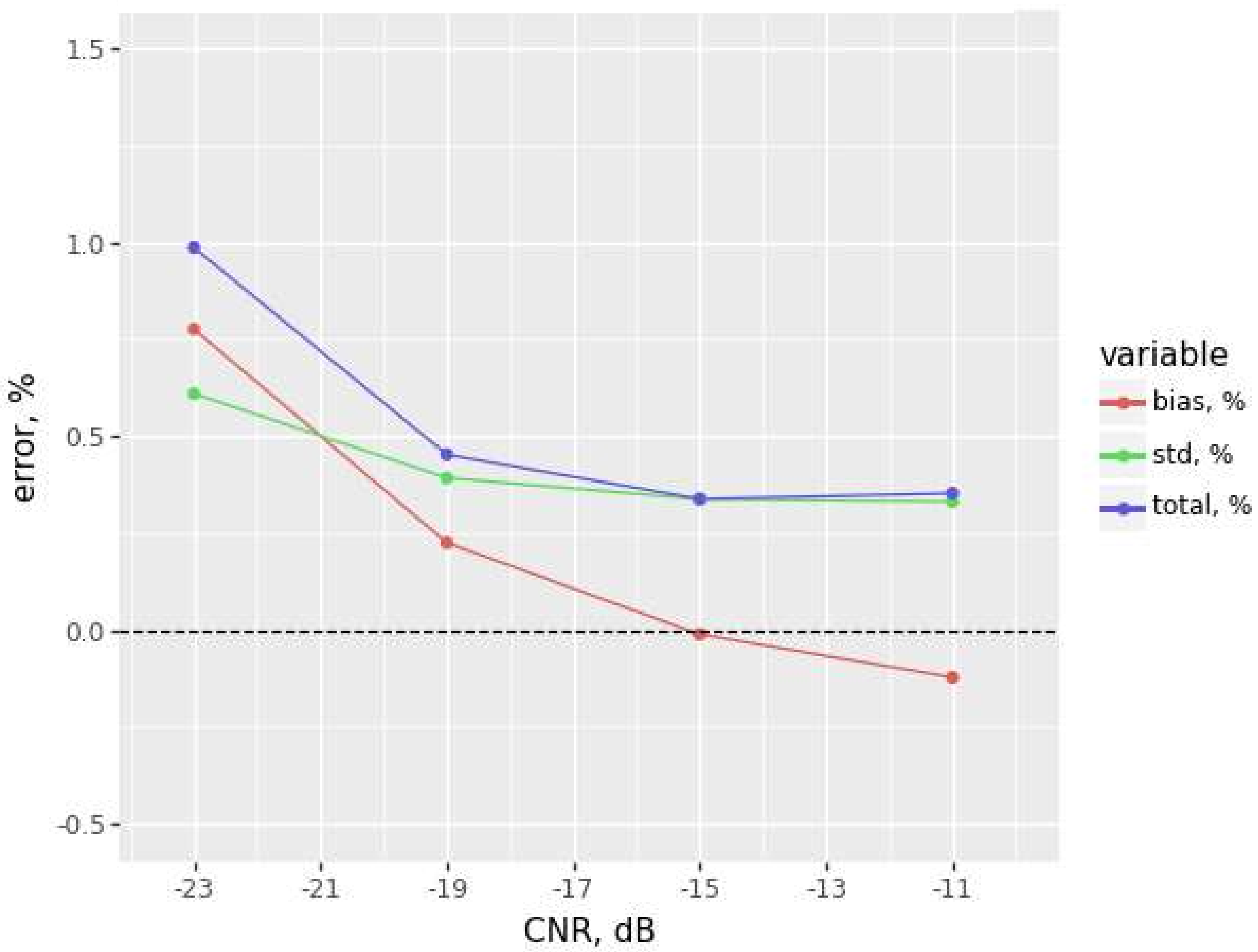
3. Sensitivity Examples

Sensitivity of uncertainty with turbulence intensity



Sensitivity of uncertainty with CNR



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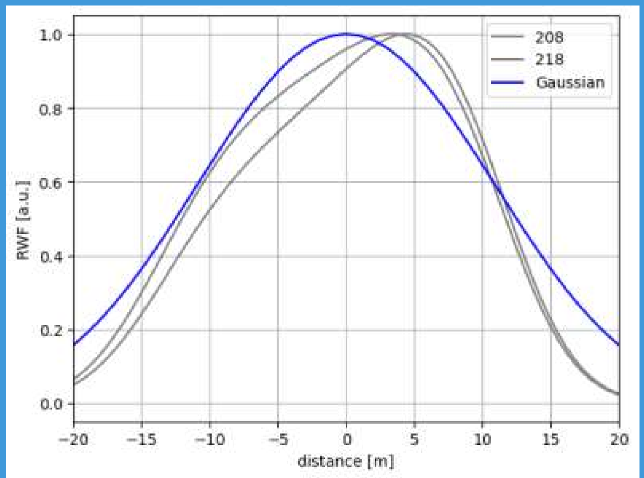
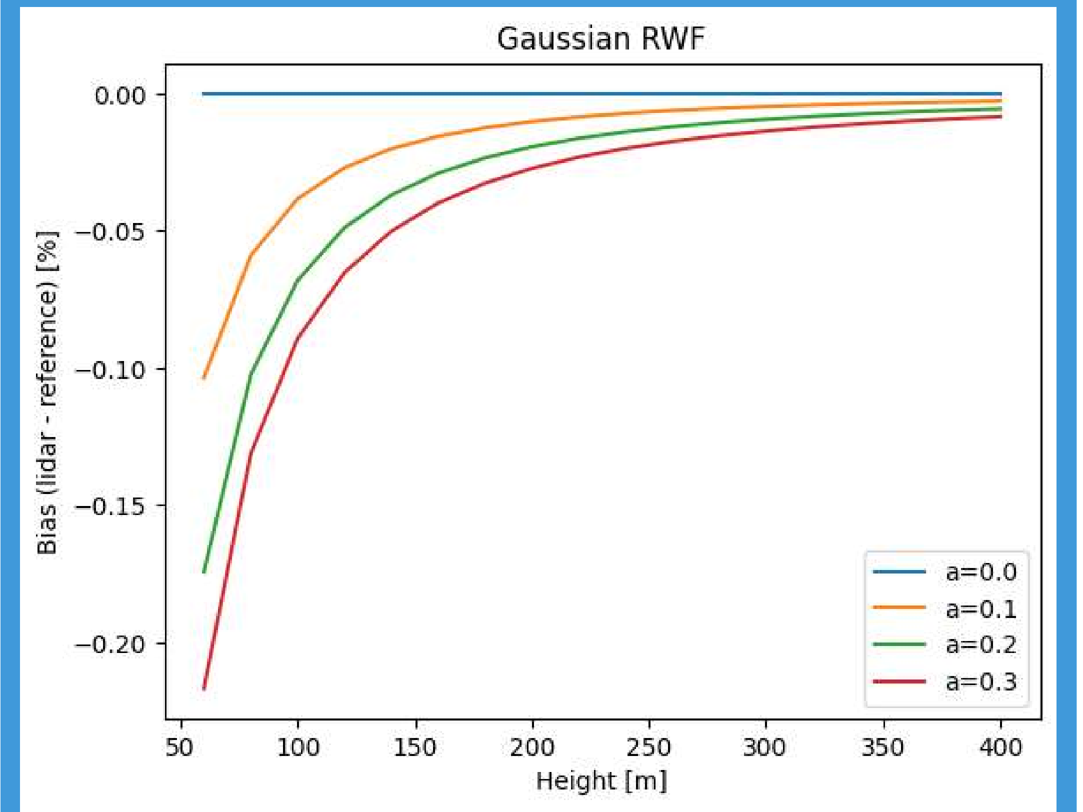
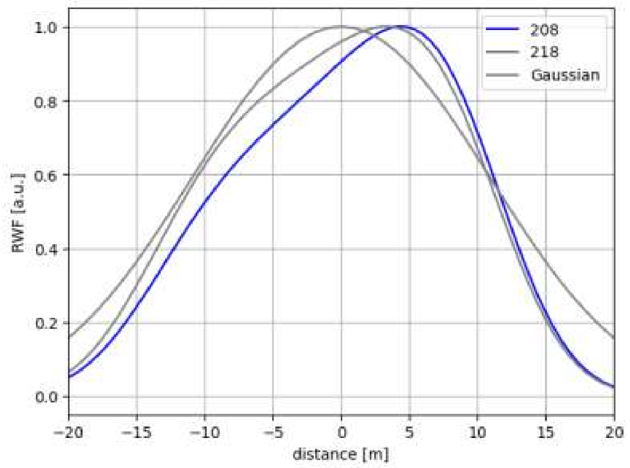
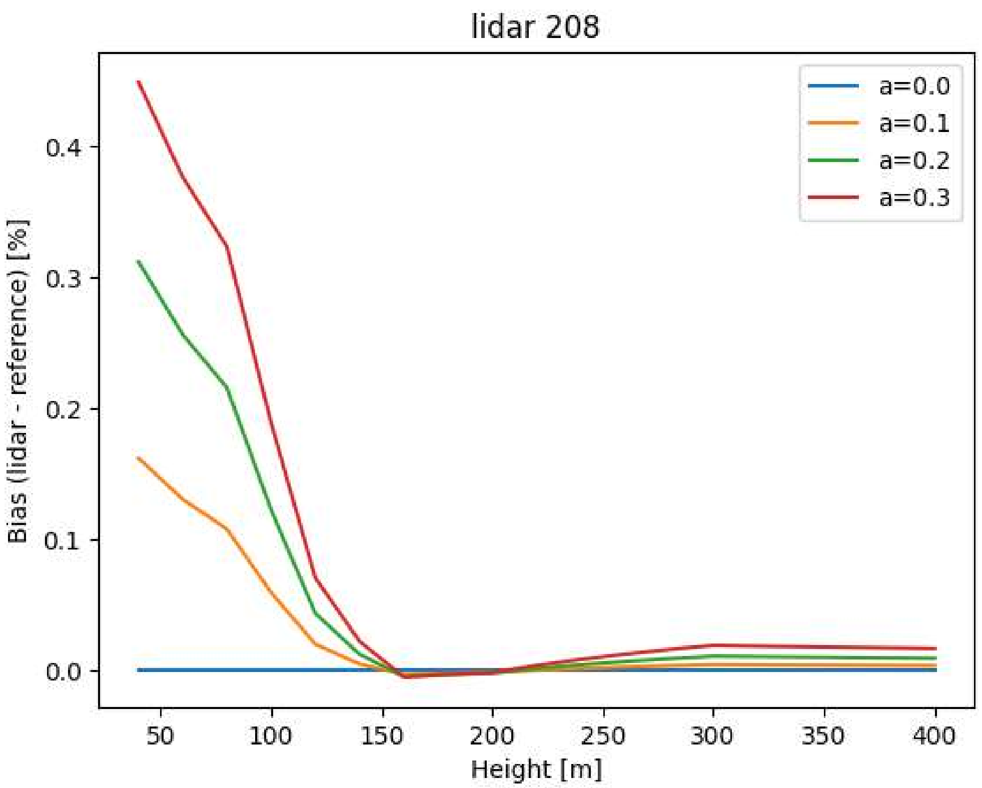
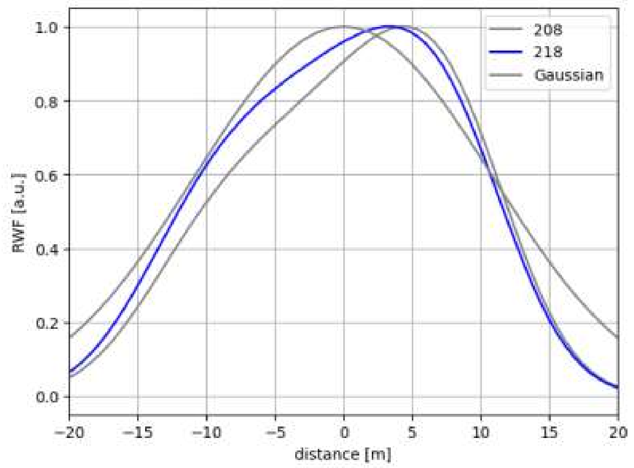
3. Shape of Range Weighting Function has Strong Impact on Bias in Sheared Flow

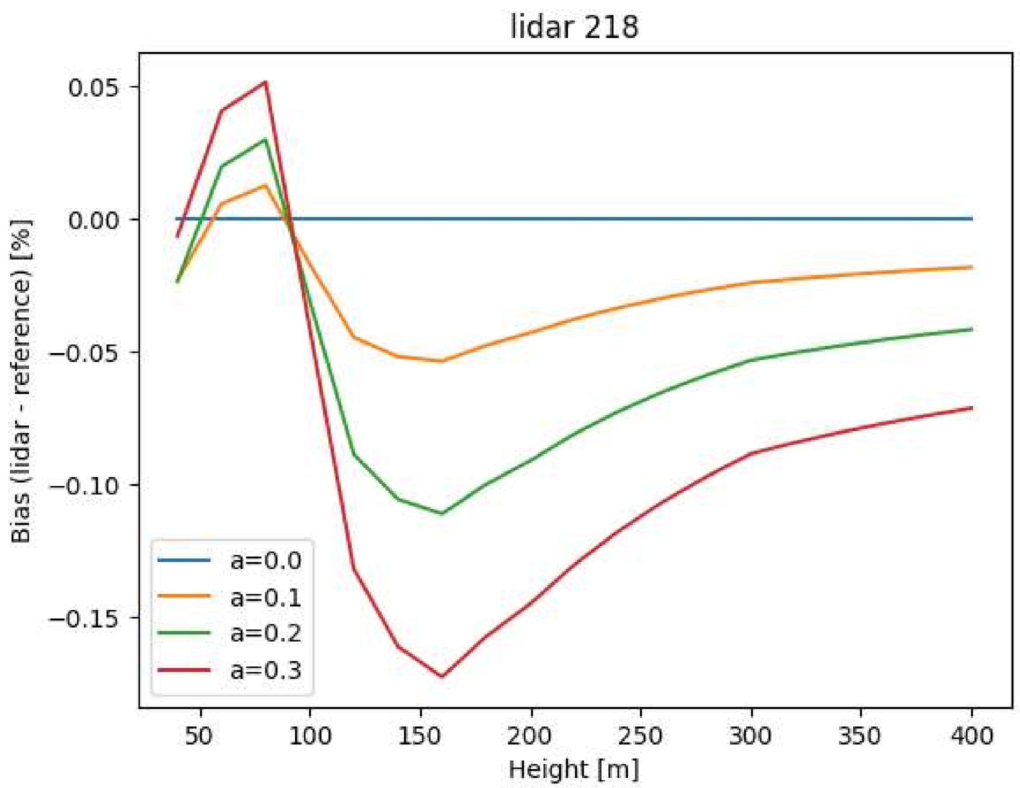












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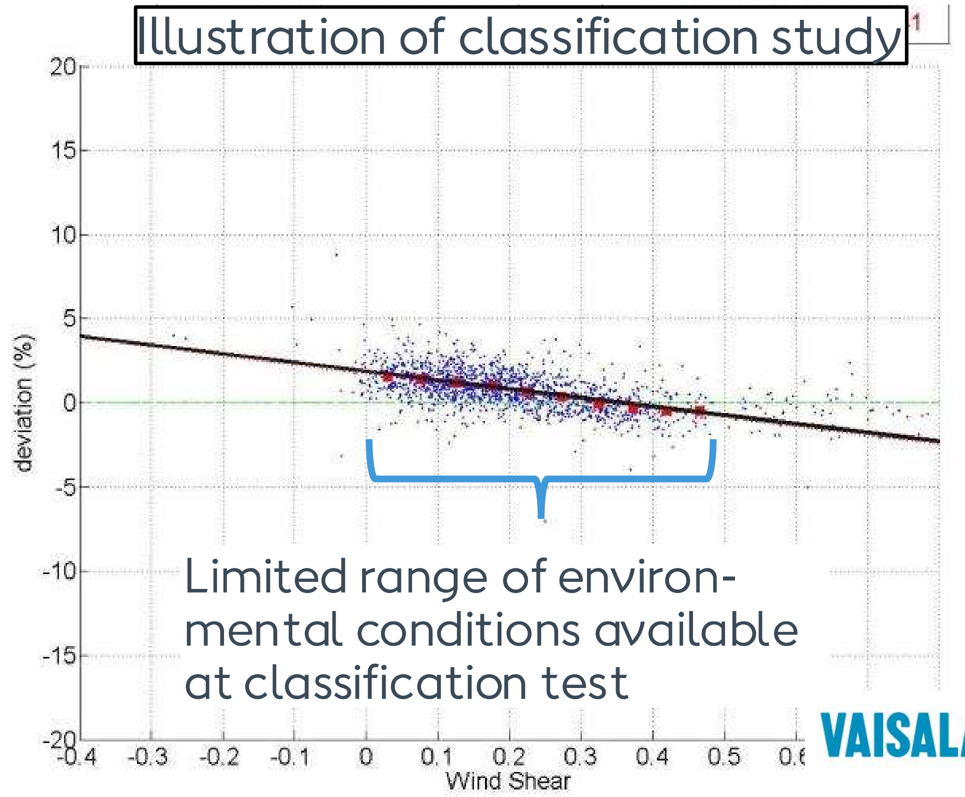
More accurate and faster calibration method

- Calibration uncertainty typically a third of conventional calibration method
- Duration: a few of days instead of several weeks

No classification needed

- Uncertainty for any (extreme) flow conditions
  - ➢ No need for extrapolation
- Calculation of sensitivities by individual environmental variable
  - ➢ No ambiguity about correlated variables



Next steps

- Upcoming detailed article in a wind energy journal
- Engage in discussion with industry
  - Is our measurement model complete?
  - If yes, can we mature this concept to a standard?
- Identification and analysis of measurement campaigns with interesting trends in bias or uncertainty
- Plenty ideas for other use cases of Monte Carlo simulations

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Thank you for your attention!

Monte Carlo Uncertainty Propagation

Input uncertainties

Measurement model

Output distribution

- Type A uncertainty from SAFO-MV runs
- Reference uncertainty of SAFO-MV bench
- Repeatability / "mounting" uncertainty
- Other input uncertainties: range & beam geometry angles

stochasticity of wind field (turbulence)

Calculate horizontal wind speed

Flow and measurement parameter, e.g. wind speed & direction, CNR, ...