
Performance of LiDAR in icing conditions

Comparison to a 200m mast in complex terrain



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Outline

- LiDAR in icing conditions
- Measurement site and measurement campaign
- Performance of LiDAR in icing conditions
 - Comparison to a 200m met mast
 - Analyses of LiDAR measurements
- Conclusion and outlook

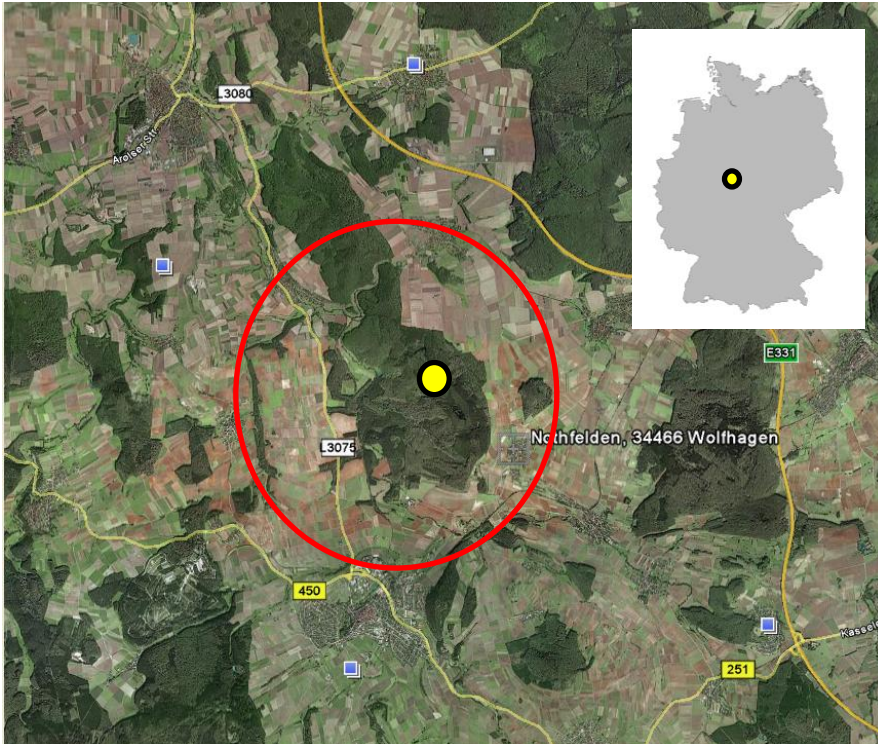
LiDAR in icing conditions

?



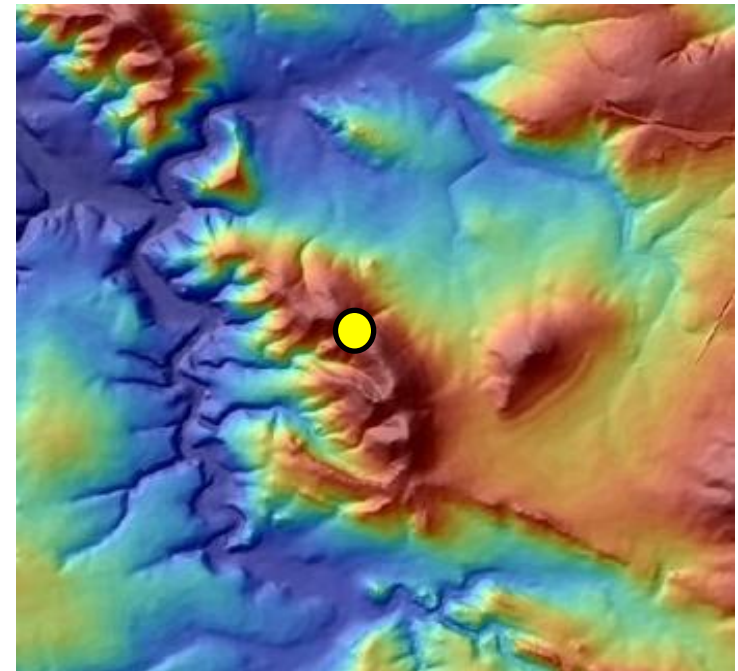
Icing conditions

Measurement location in central Germany



- ~ 160 m above surrounding area (400m altitude)

















- Average temperature : - 0.7 °C (winter 2012-2013)
- IEA ice classification: 2 ~ 3

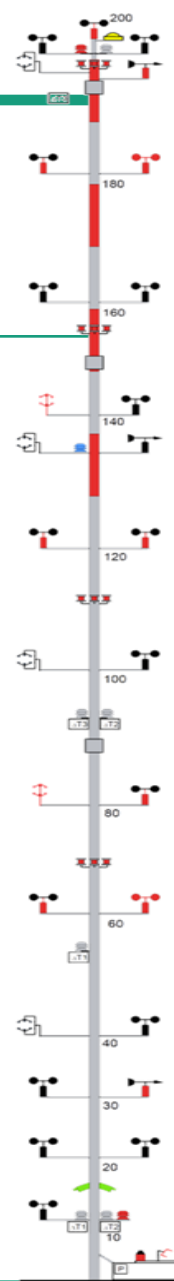


Fraunhofer IWES 200 m Wind Measurement Mast

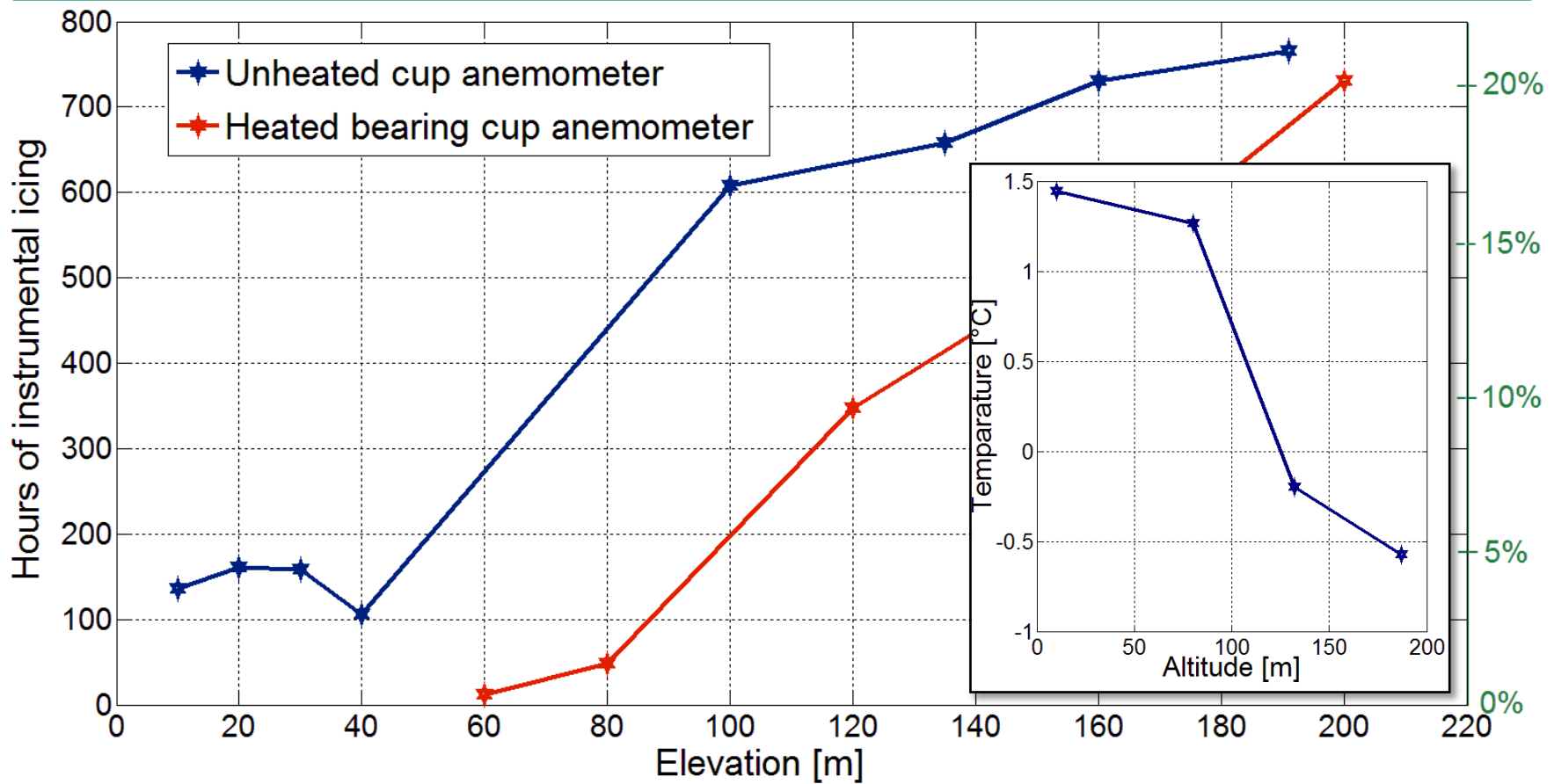
- High quality IEC conform measurement system with more than 40 sensors at 15 heights
- 7 Wind lidars for mobile measurement campaigns. (6 pulsed “Windcube” and 1 CW “Zephyr”)



	Cup (unheated)
	Cup (fully heated)
	Cup (heated bearing)
	USA (unheated)
	USA (heated)
	Vane (unheated)
	Vane (heated bearing)
	Temperature Sensor
	Pressure Sensor
	Thermo/Hygro Sensor
	Pyranometer
	Precipitation Monitor
	Rain Gauge
	Temperature Difference
	Webcam
	Light



Fraunhofer IWES 200 m Wind Measurement Mast - Instrumental Icing



Winter 2012/2013 (01.11.2012 - 30.04.2013)

Average rel. humidity = 94%

Measurement campaign at Roedese Berg

Mast – LiDAR comparison

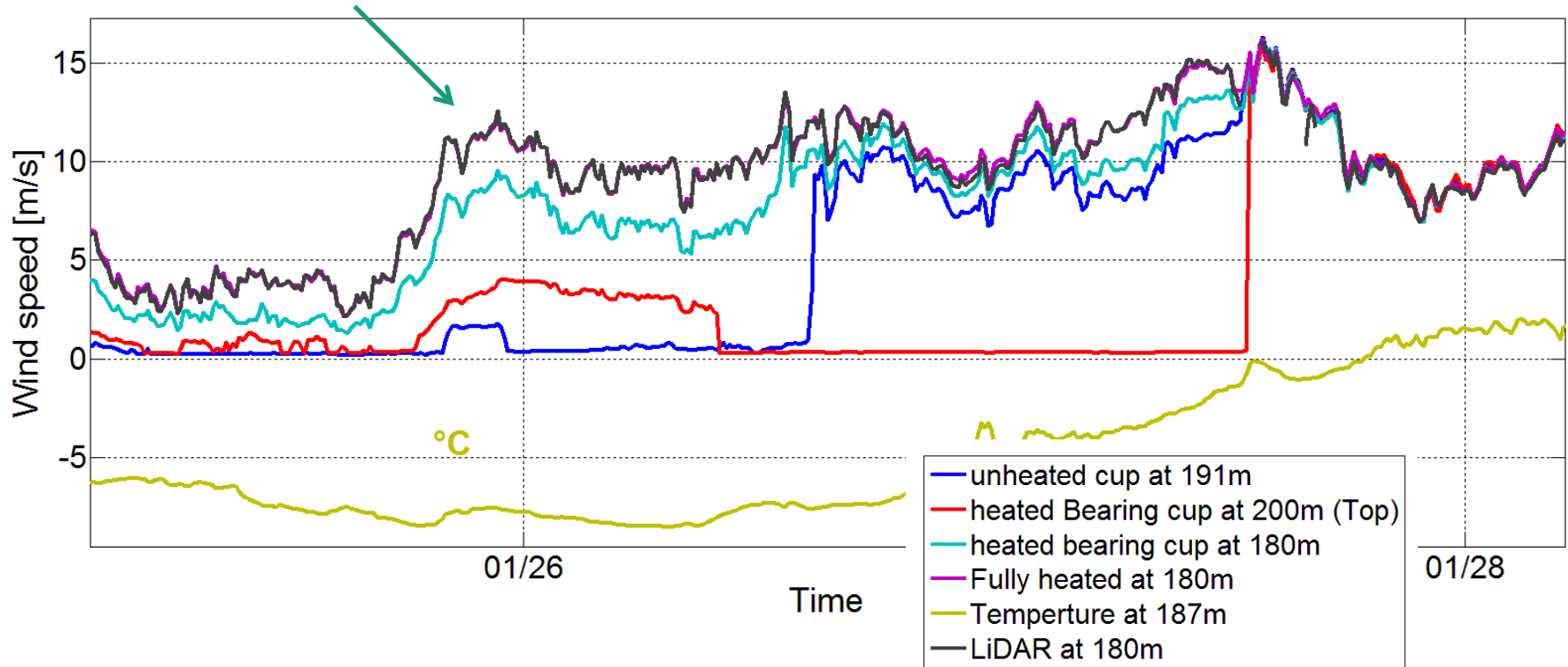
- Measurement period: 28.11.2012 and 07.02.2013
- Measurements of Windcube V2 were compared to several sensors at different heights:
 - Fully heated, bearing heated and unheated

Data processing

- Invalid or physically unreasonable values were removed
- Mast measurements influenced by mast shadow were also removed
- More than 80% of measured values in 10 minute averaging interval must be available for comparison

Comparison LiDAR and Mast

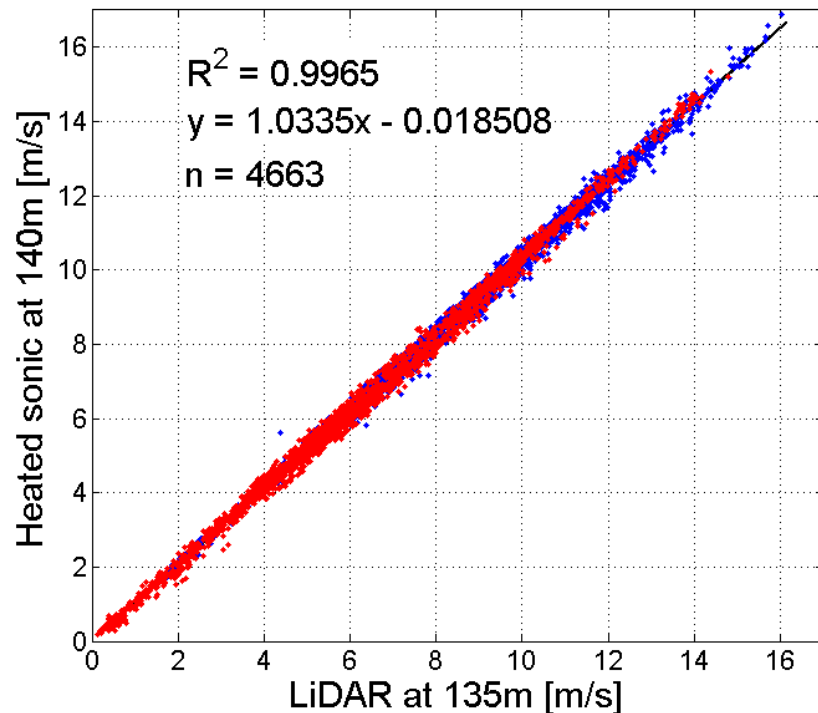
A good correlation between LiDAR and heated anemometer



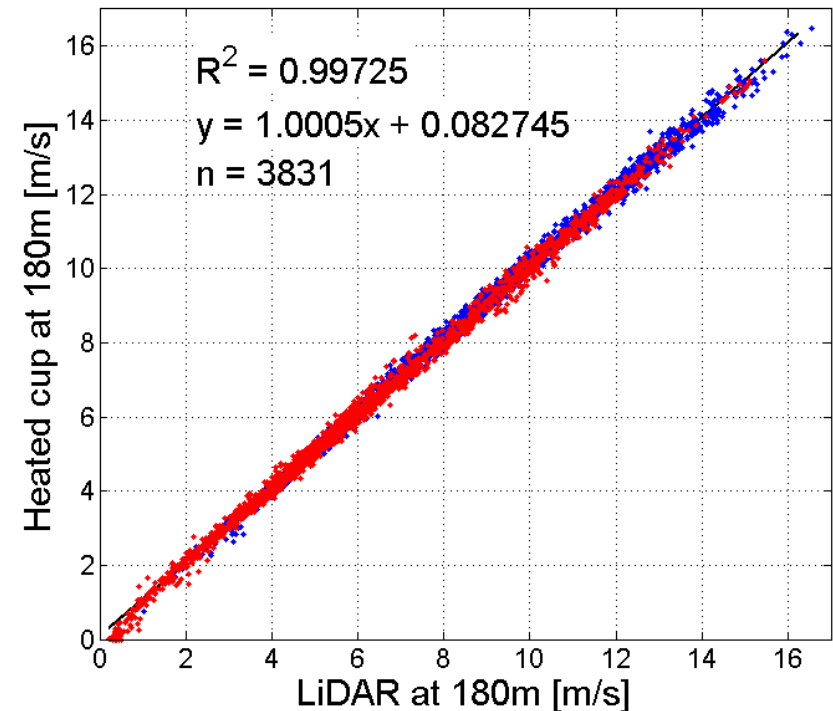
Comparison LiDAR and Mast

LiDAR vs. heated anemometer

Heated sonic 135m vs. LiDAR 140m



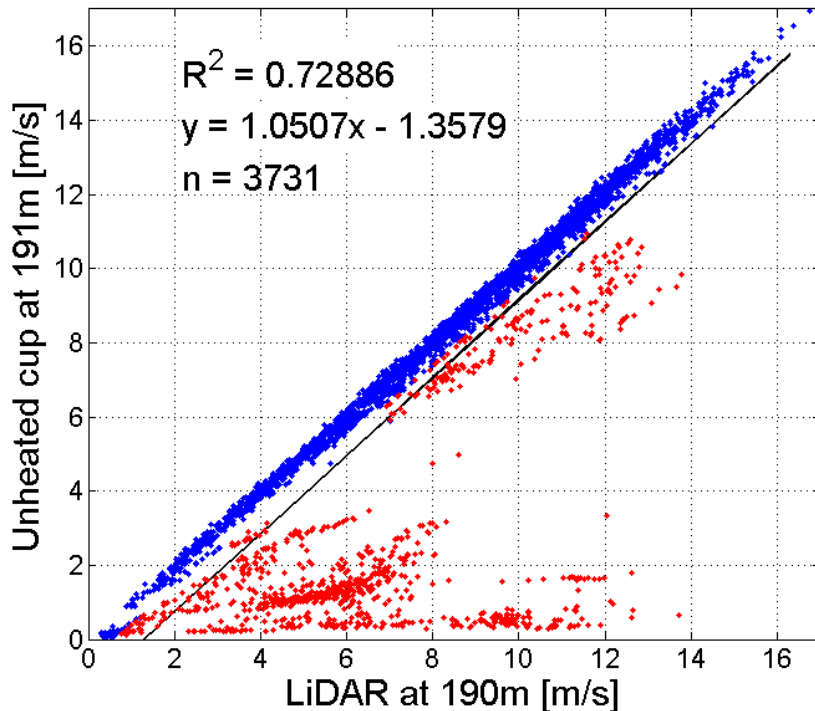
Heated cup 180m vs. LiDAR 180m



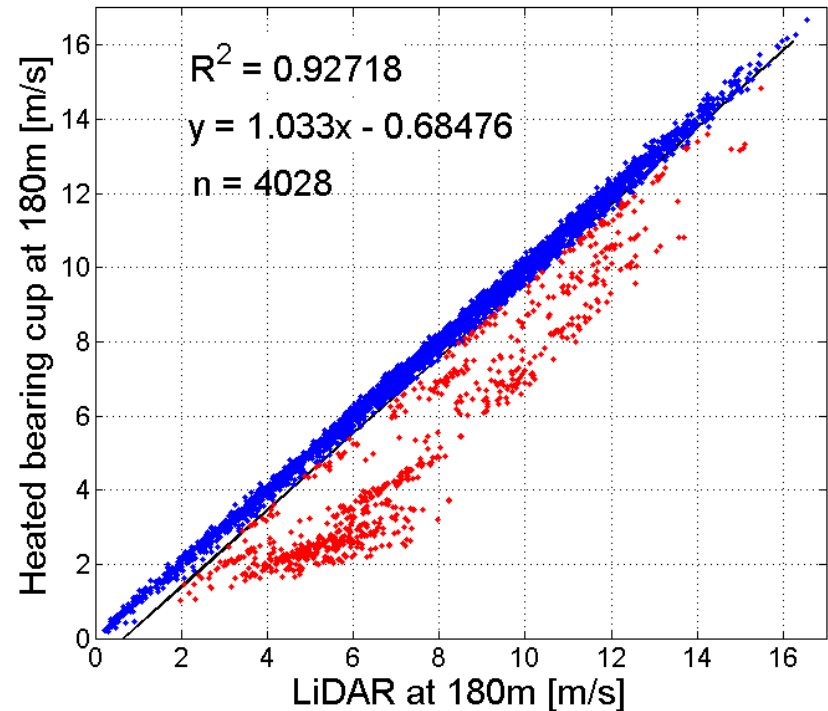
- * Blue: data points - ice free
- * Red: data points in icing conditions

Comparison LiDAR and Mast LiDAR vs. heated and heated bearing anemometer

Unheated cup 190m vs. LiDAR 190m



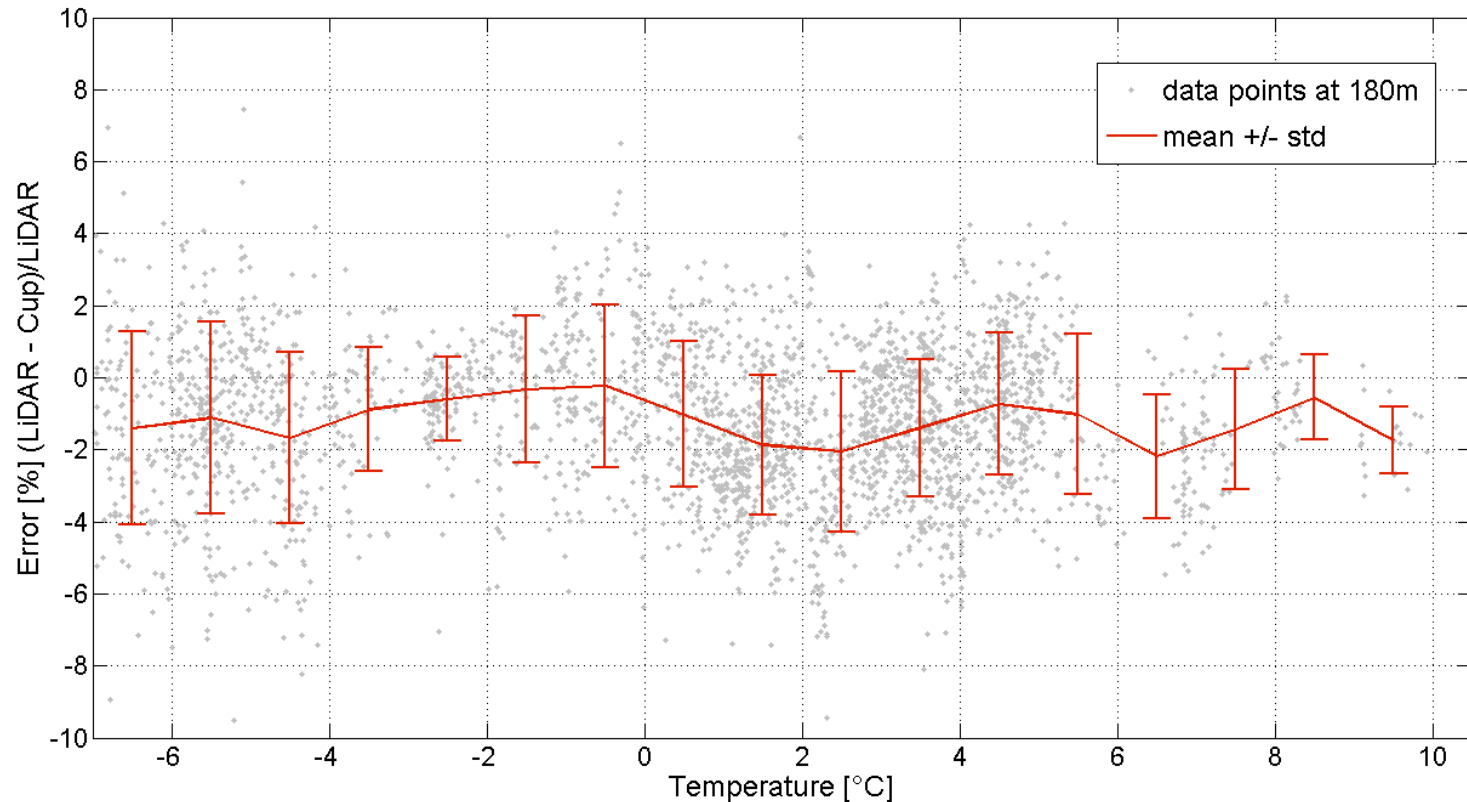
Heated bearing cup 180m vs. LiDAR 180m



- * Blue: data points - ice free
- * Red: data points in icing conditions

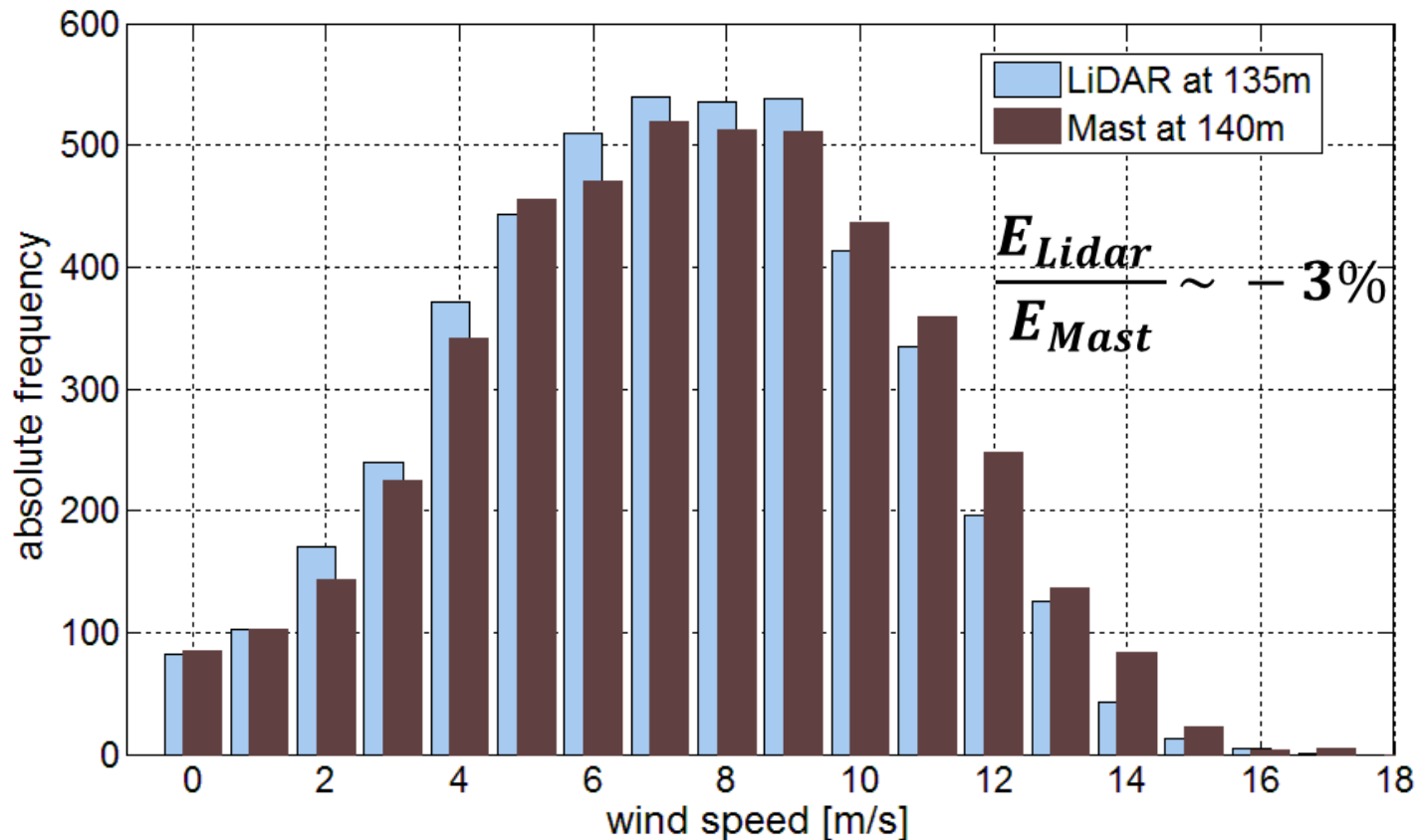
Comparison LiDAR and Mast

Temperature dependence at 180m



- Small underestimation of LiDAR measurement (between -0.1 and -2%)
- No significant dependency between LiDAR error and temperature

Comparison LiDAR and Mast Wind distribution



Period: 28.11.2012 - 07.02.2013

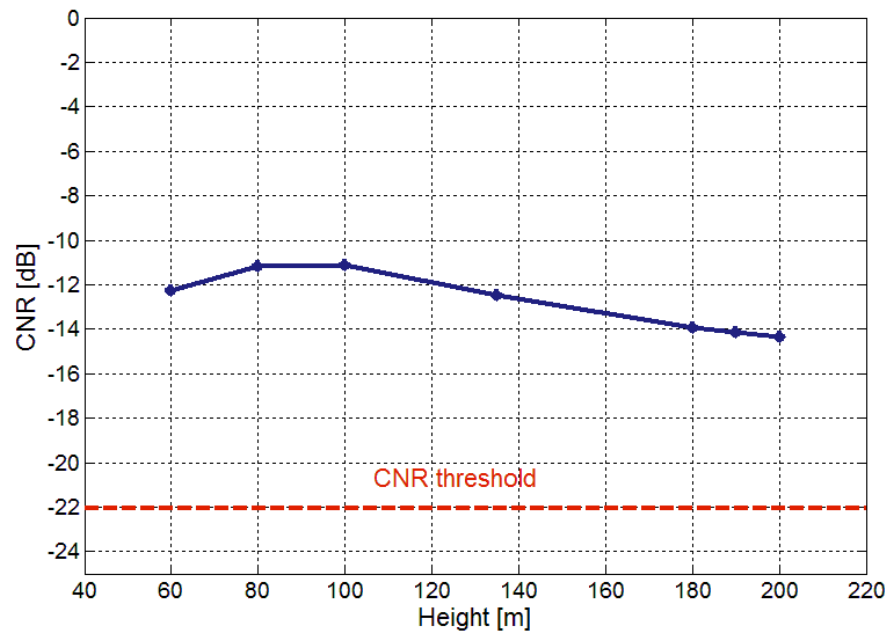
LiDAR data availability

CNR (carrier-to-noise ration)

The carrier-to-noise ratio is defined as the ratio of the received modulated carrier signal power C to the received noise power N

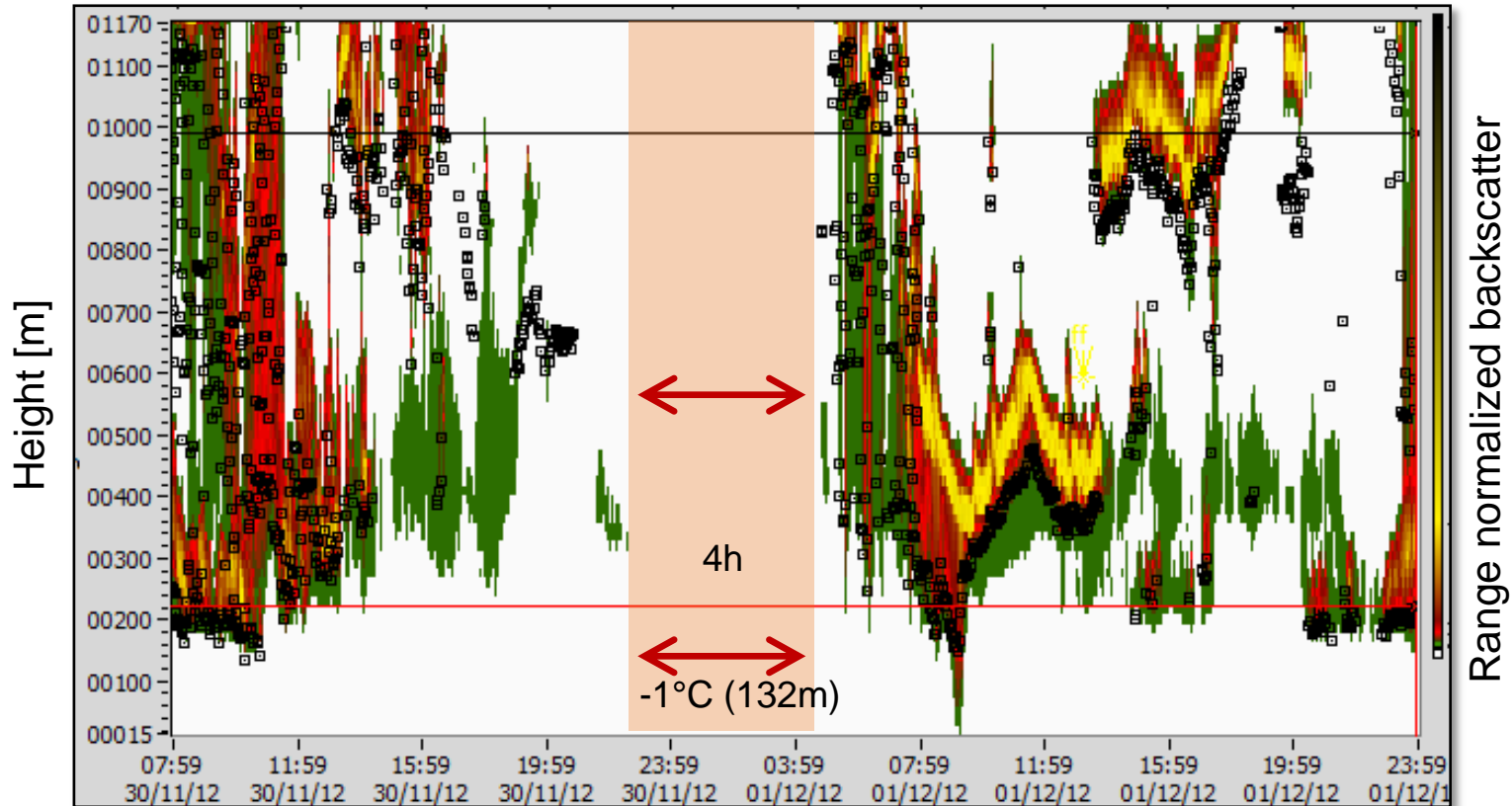
$$CNR = \frac{C}{N} \text{ the value of CNR is often specified in decibels } CNR_{dB} = 10 \log_{10} \left(\frac{C}{N} \right)$$

- CNR threshold of Windcube is -22dB
- All data with $CNR < -22dB$ will be automatically removed
→ No Availability



LiDAR availability

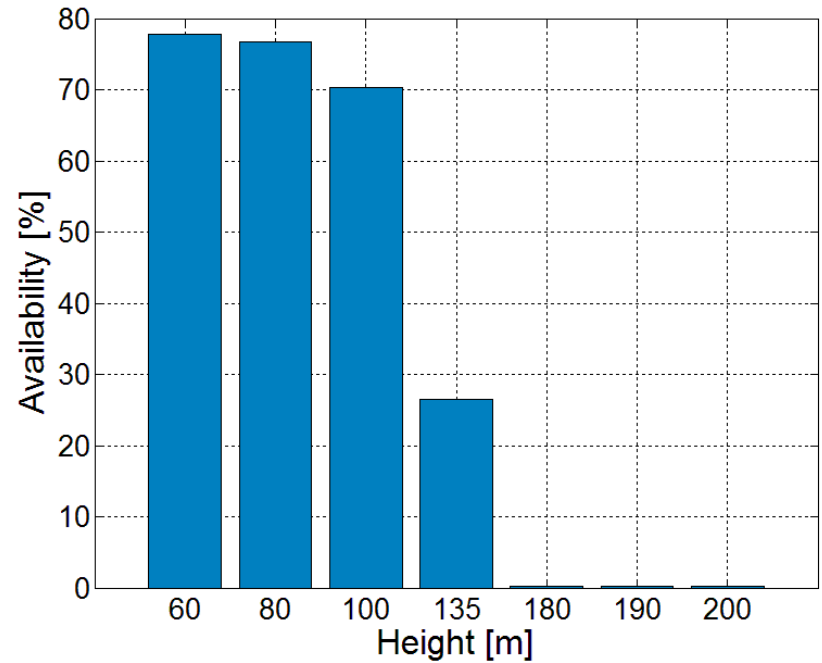
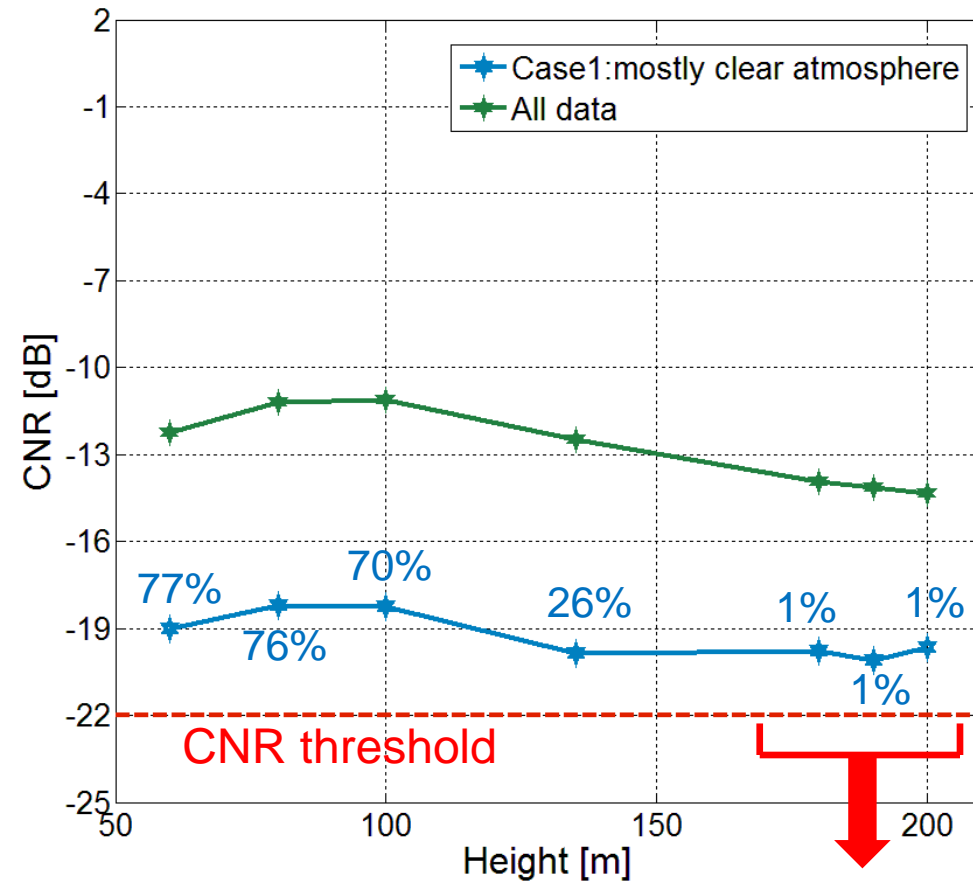
Case 1: mostly clear atmosphere



Density and structure of the atmosphere measured by Ceilometer

LiDAR availability

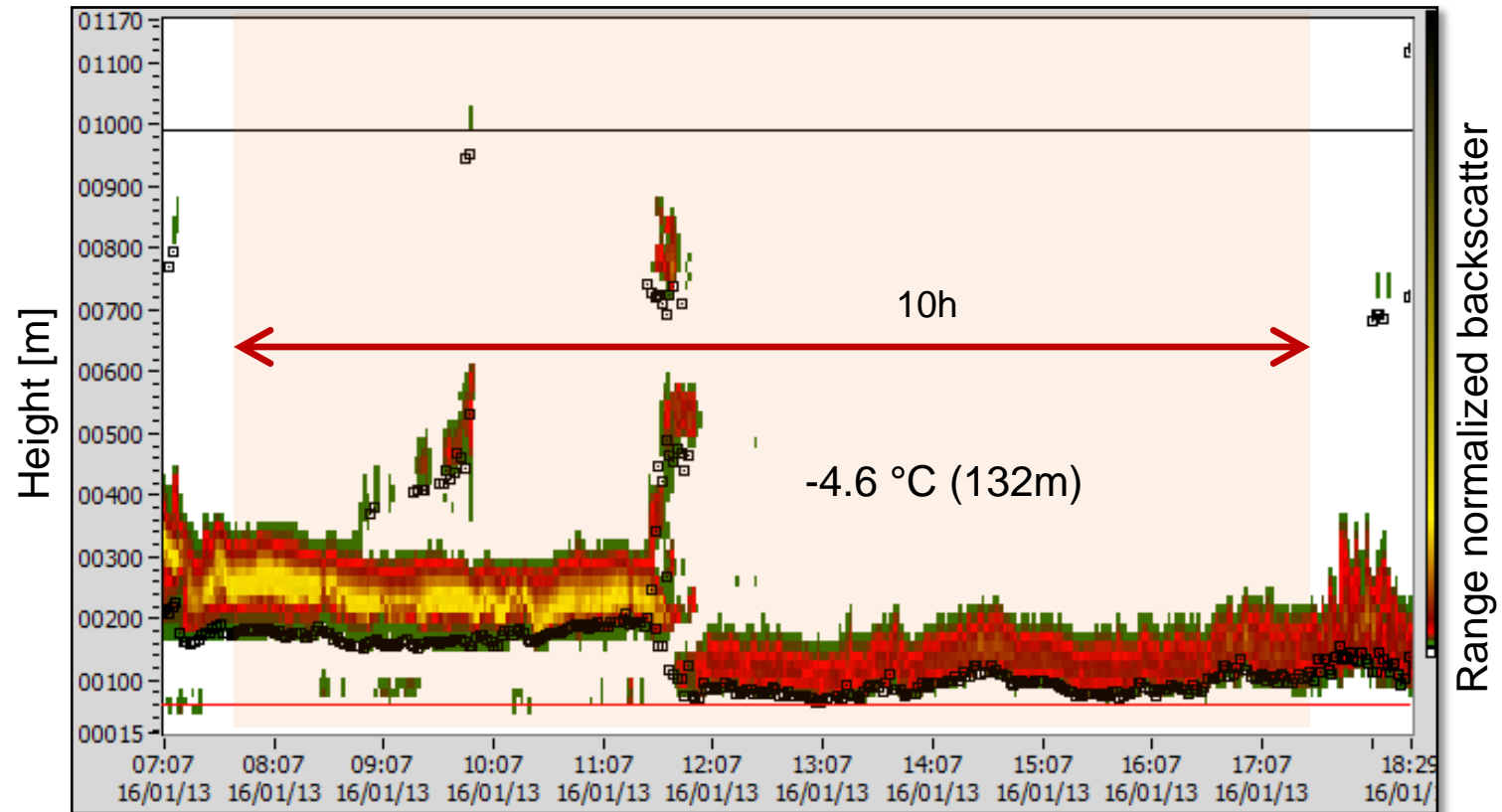
Case 1: mostly clear atmosphere



more than 99% of CNR < threshold

LiDAR Availability

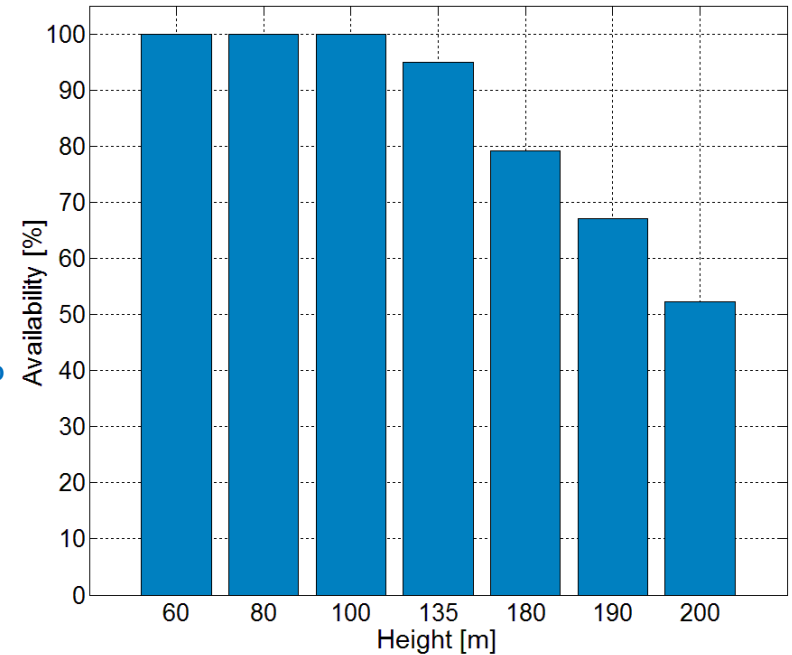
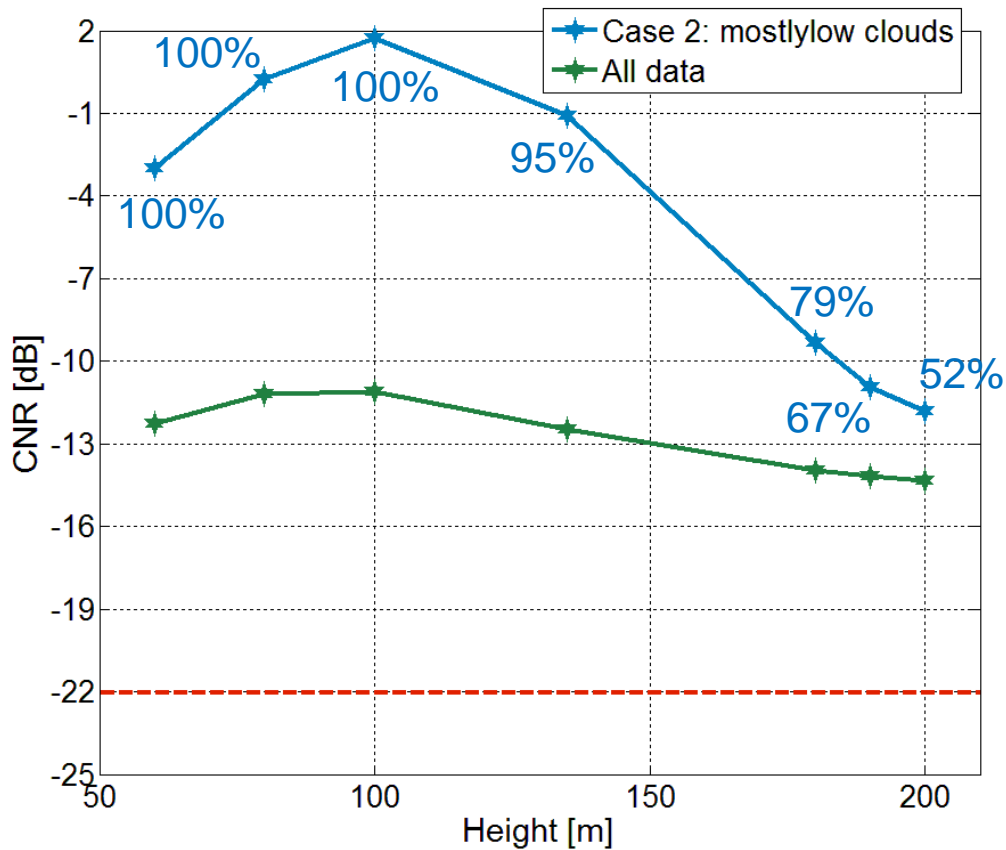
Case 2: mostly low clouds



Density and structure of the atmosphere measured by Ceilometer

LiDAR Availability

Case 2: mostly low clouds



High availability at low altitudes

Conclusion and Outlook

Conclusion

- LiDAR data show a good performance in icing conditions
- LiDAR shows a variation in data availability in very clear skies or under low clouds conditions atmosphere

Outlook

- Quantification of case 1 and case 2
- Same analysis with continuous LiDAR (Zephir)
- Relevance of icing to yield estimations
 - Comparison with production data

Thank you for your attention!



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