Wind profiles beyond mast height during rainy and dry conditions

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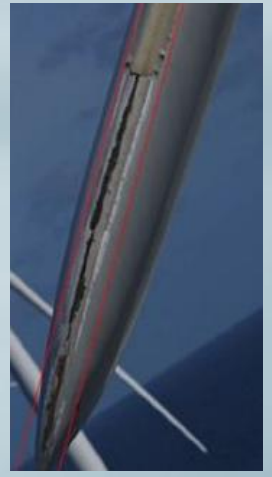
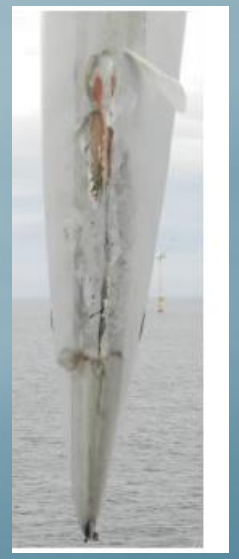
A different kind of wear and tear





EROSION!

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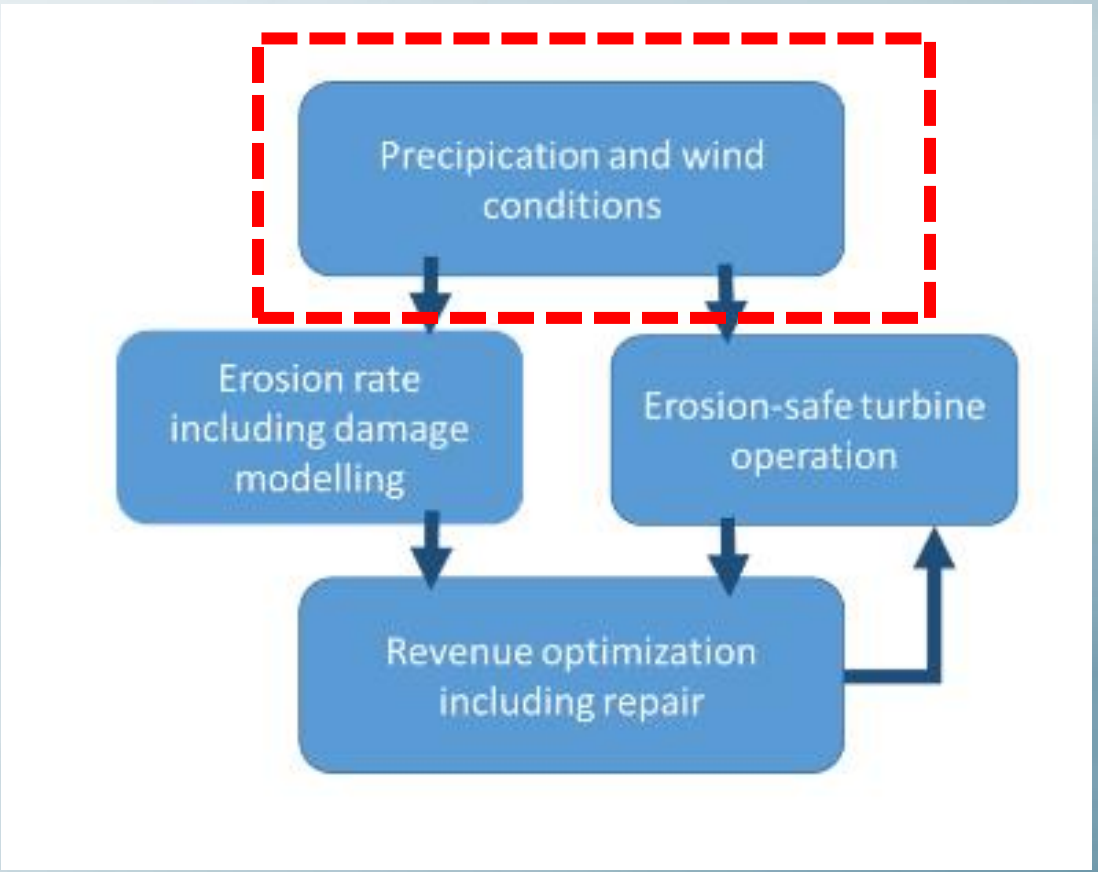
AIRE

How do we work with erosion?

Meteorology
Wind energy

Material science
Aerodynamics
Control

Economy



Flowchart from Hasager et al. 2020, Renewable energies

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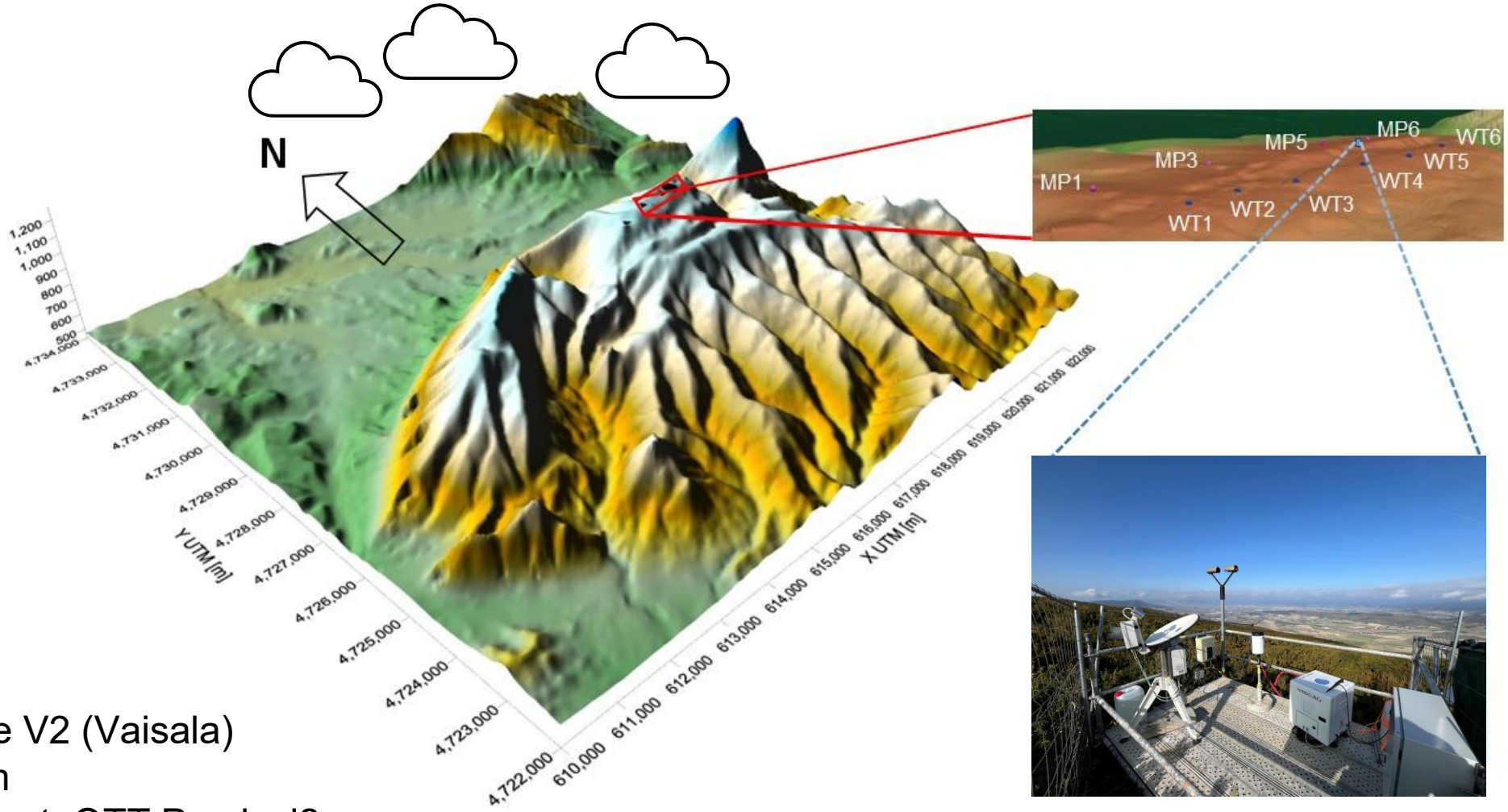
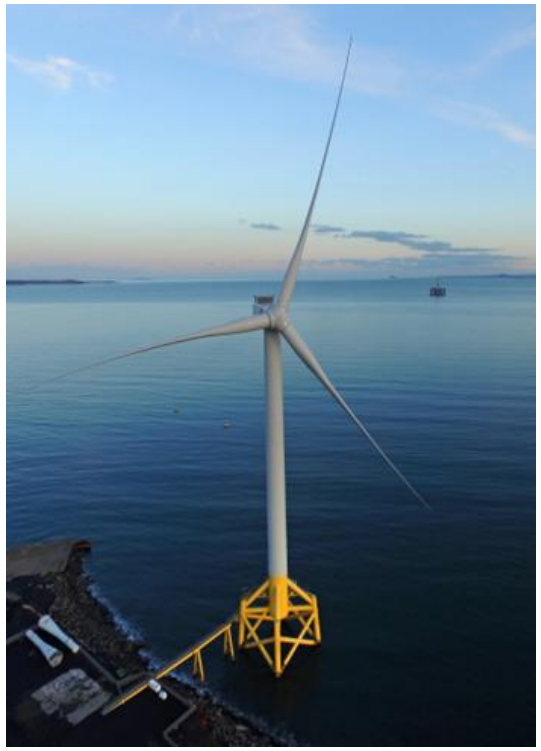
Alaiz



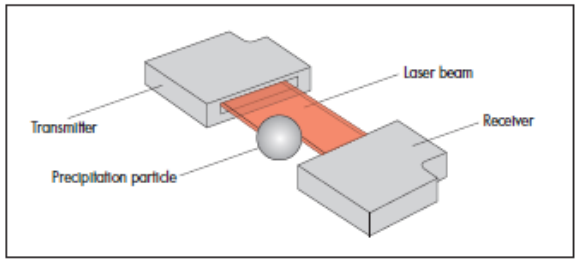
- 118m mast
- Lidar: WindCube V2 (Vaisala)
- Range 0 – 280m
- Rain measurement: OTT Parsivel2 disdrometer and rain gauge

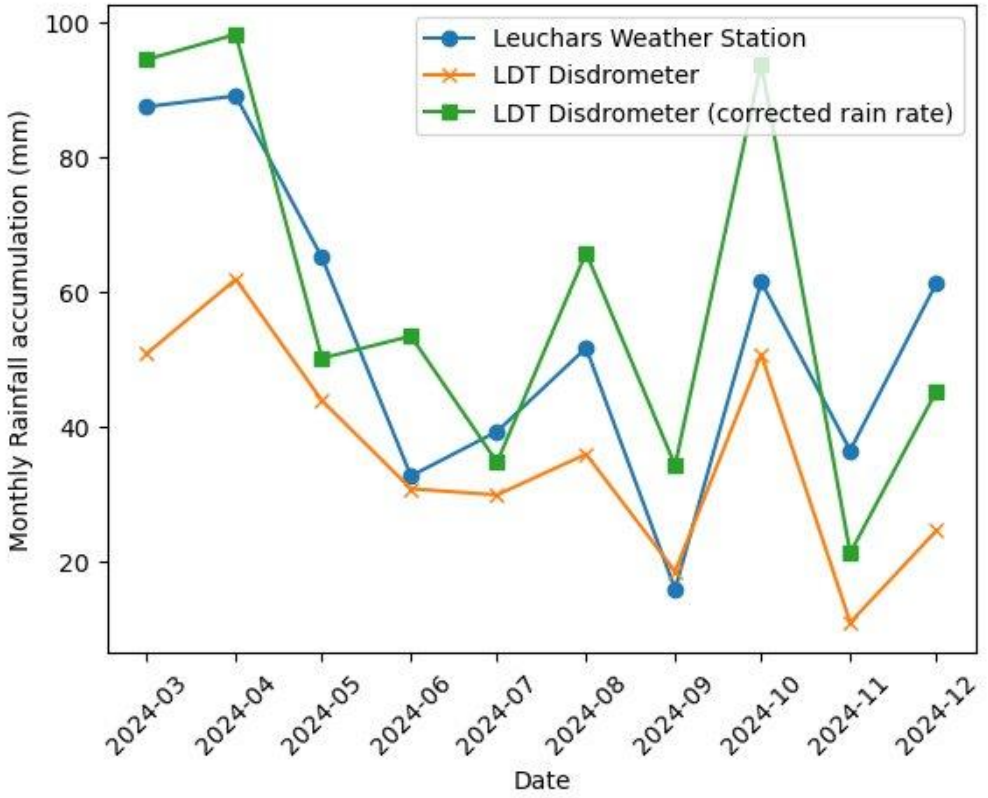
Levenmouth

- No mast
- Lidar: Galion 4000
- Range 0 – 1000m (0-2000m)
- Rain measurement: OTT Parsivel2 disdrometer



It is very difficult to measure rain accurately





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Western Denmark: Østerild test site for large wind turbines

- 250m mast
- Lidar: Lumibird Beam6x
- Range: 0 – 500m (7 months),
  0 – 1000m (1 month only)
- Rain measurement: rain gauge at
  3 km distance from lidar

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Eastern Denmark, Risø:

- 122m mast
- Lidar: WindCube V2 @ 122m (Vaisala), same as in Alaiz
- Range 0 – 250m
- Rain measurement: OTT Parsivel2 disdrometer and rain gauge

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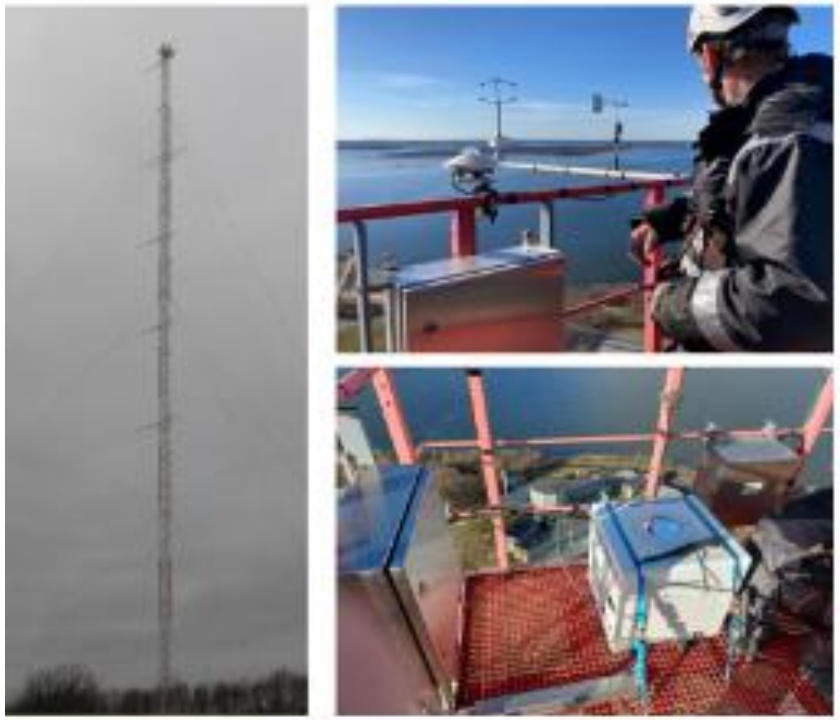
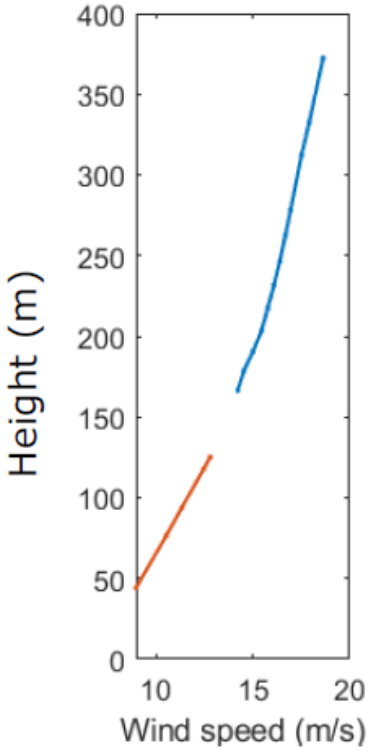
Eastern Denmark, Risø:





- 122m mast
- Lidar: WindCube V2 @ 122m (Vaisala), same as in Alaiz
- Range 0 – 250m
- Rain measurement: OTT Parsivel2 disdrometer and rain gauge

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How well do the lidars work during rainy and dry conditions?

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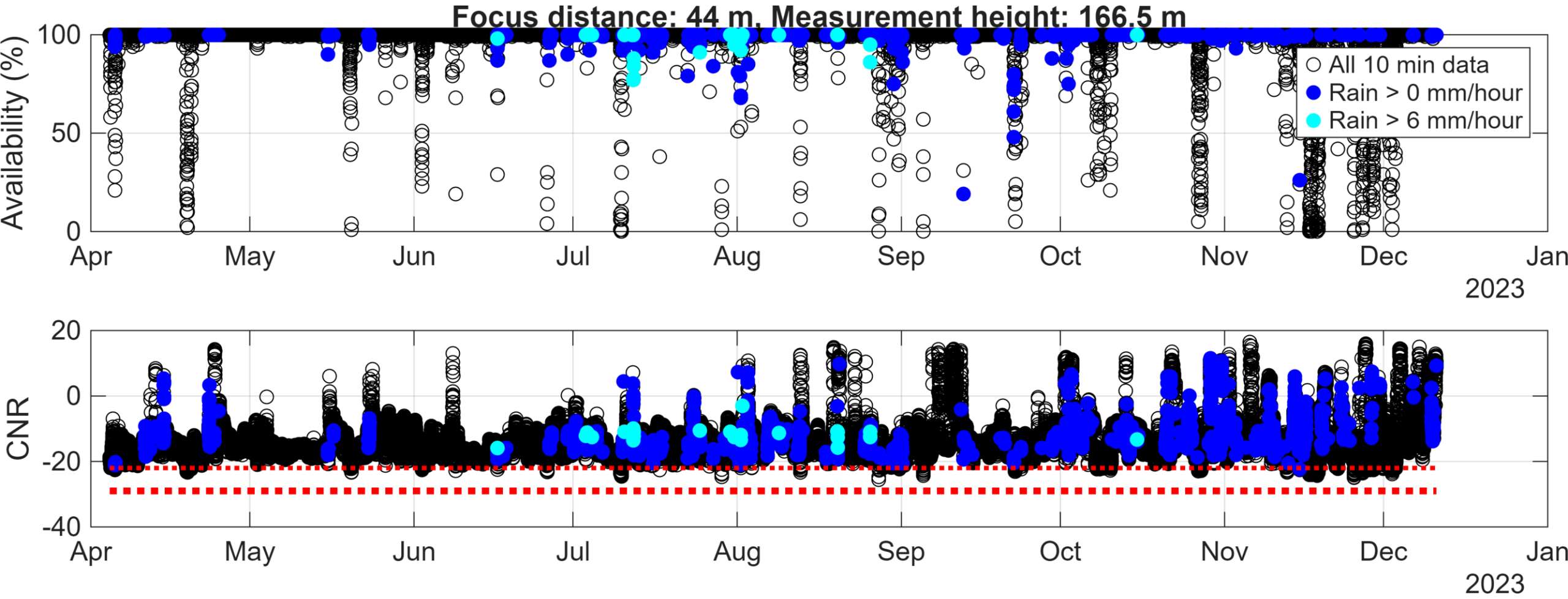
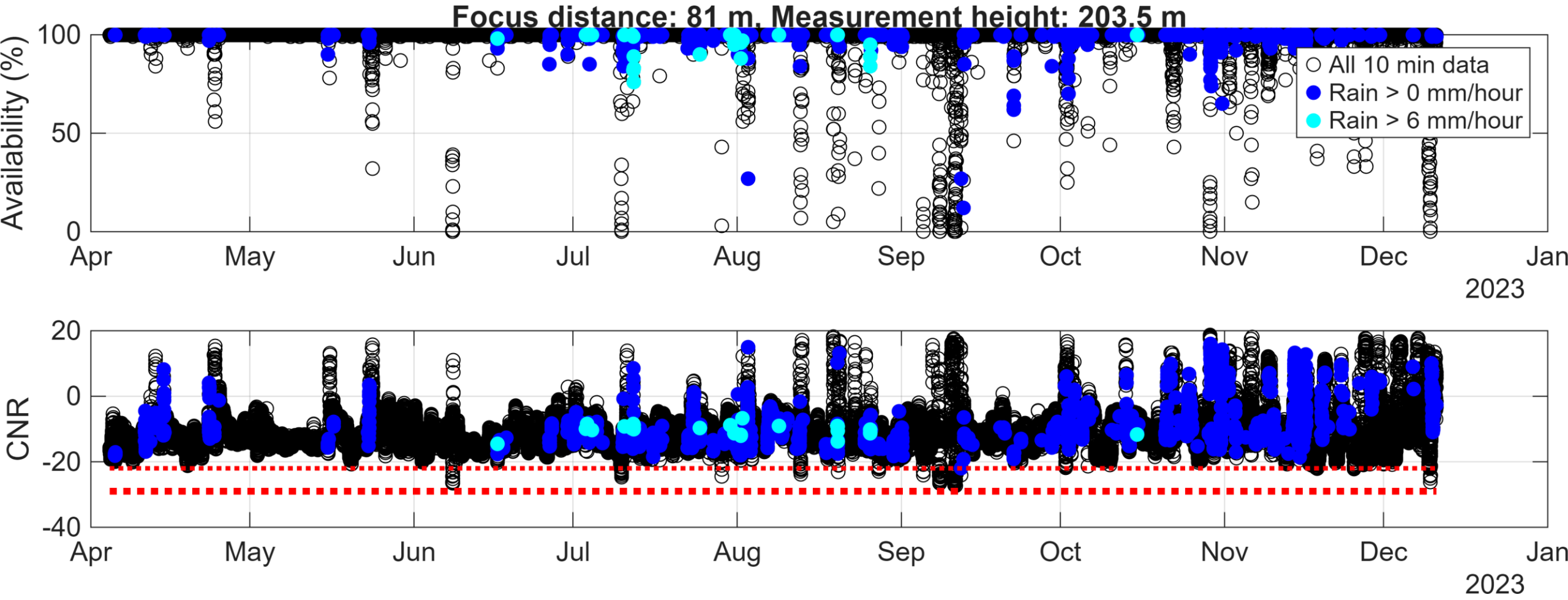
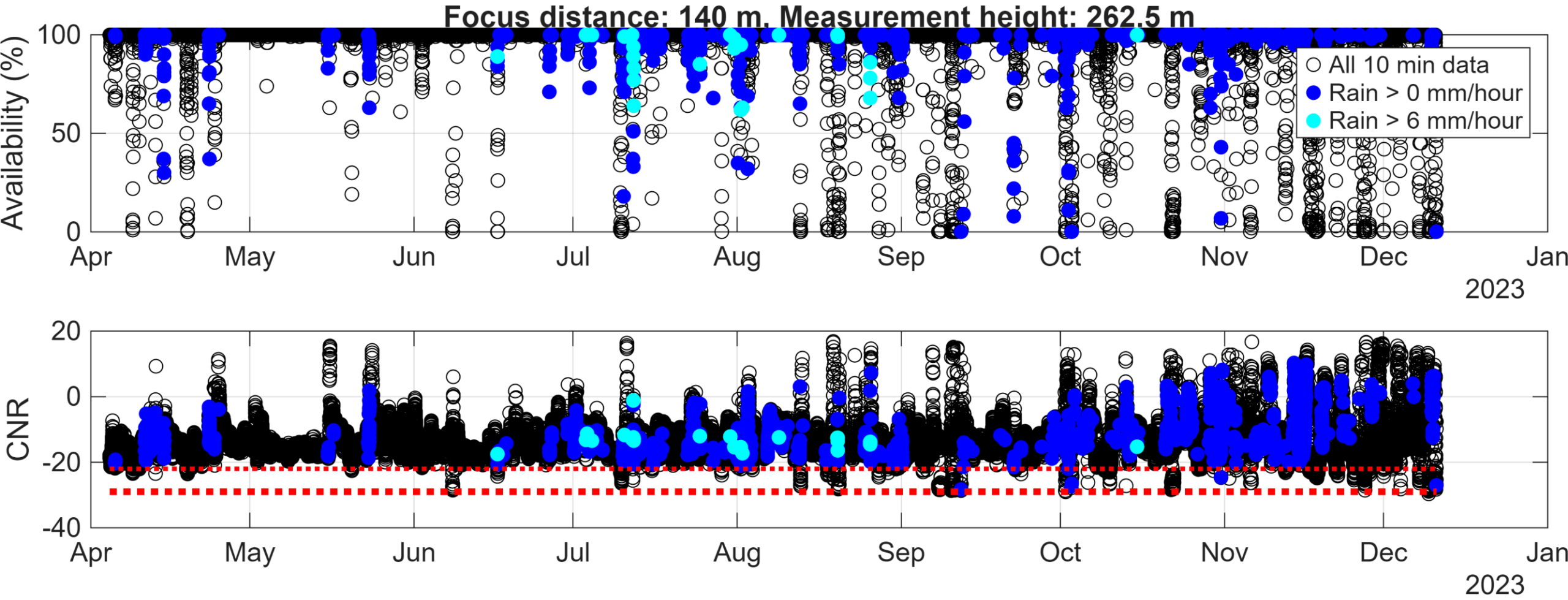
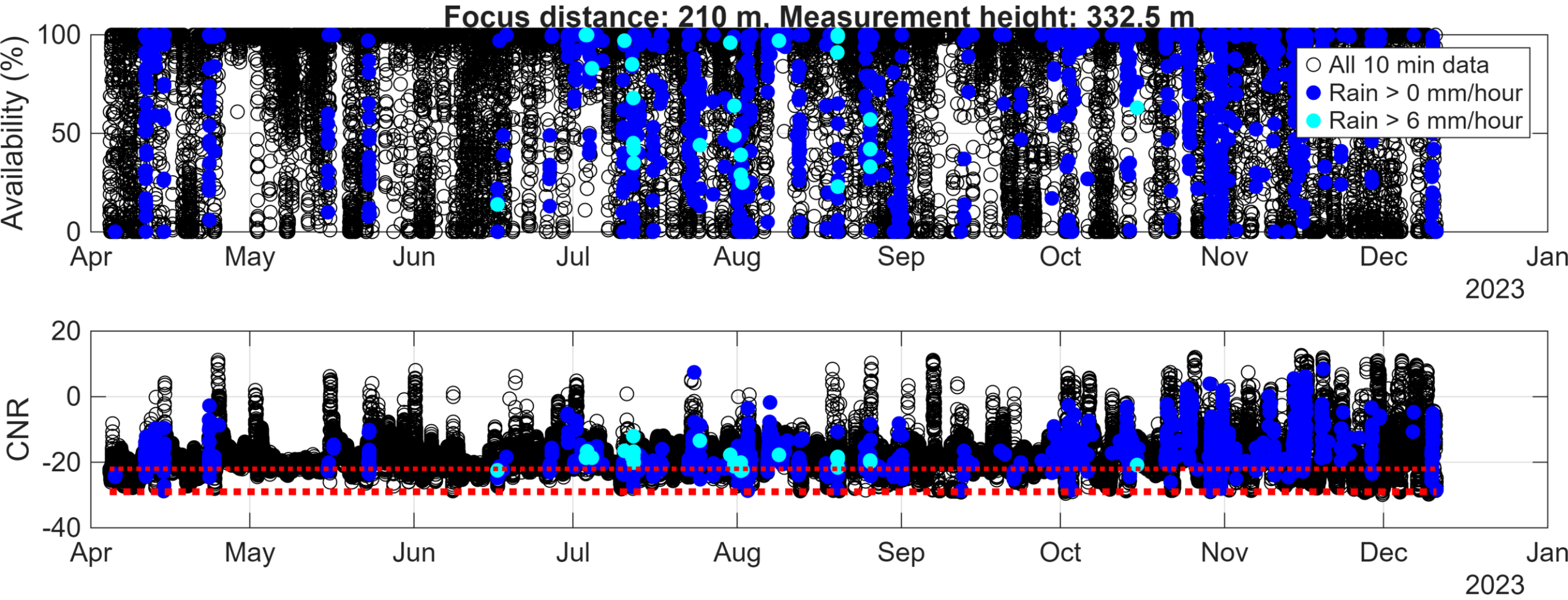
Eastern Denmark, Risø: WindCube at 122m platform

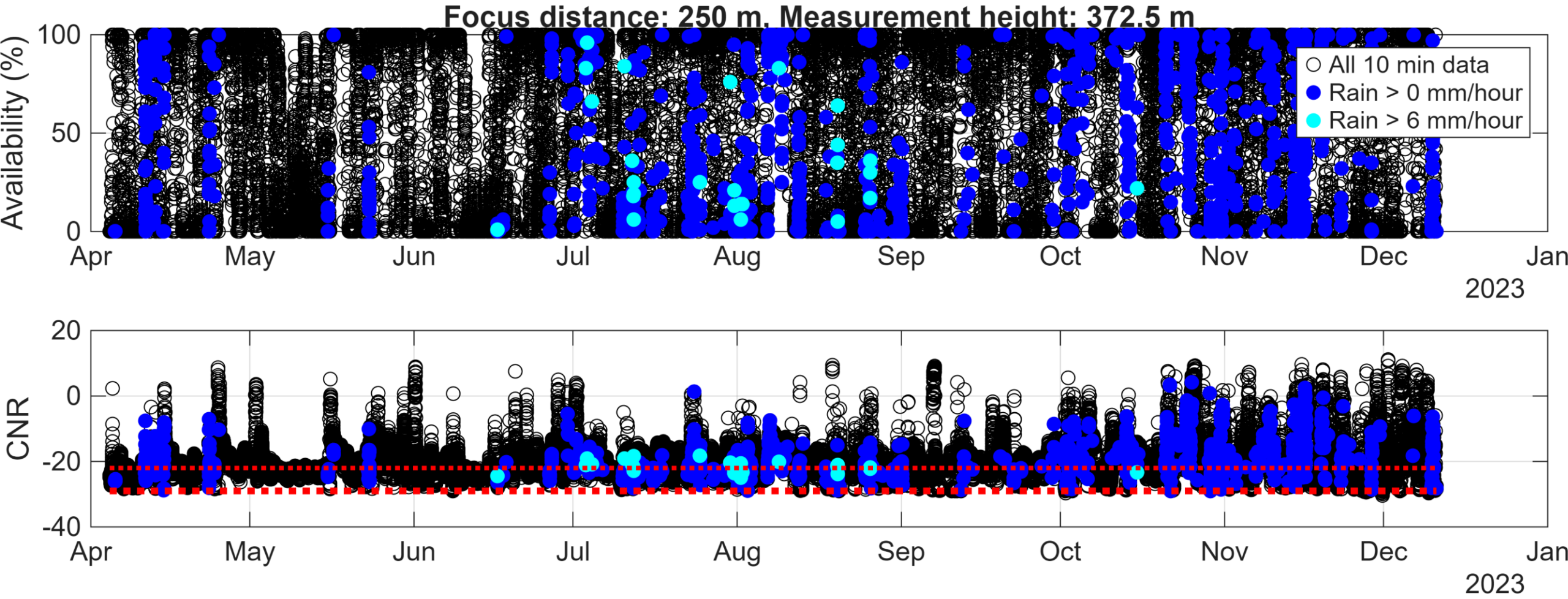



Focus distance: 81 m, Measurement height: 203.5 m
Availability (%)
100
50
0
All 10 min data
Rain > 0 mm/hour
Rain > 6 mm/hour
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
2023
CNR
20
0
-20
-40
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
2023


Focus distance: 140 m, Measurement height: 262.5 m
Availability (%)
100
50
0
All 10 min data
Rain > 0 mm/hour
Rain > 6 mm/hour
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
2023
CNR
20
0
-20
-40
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
2023

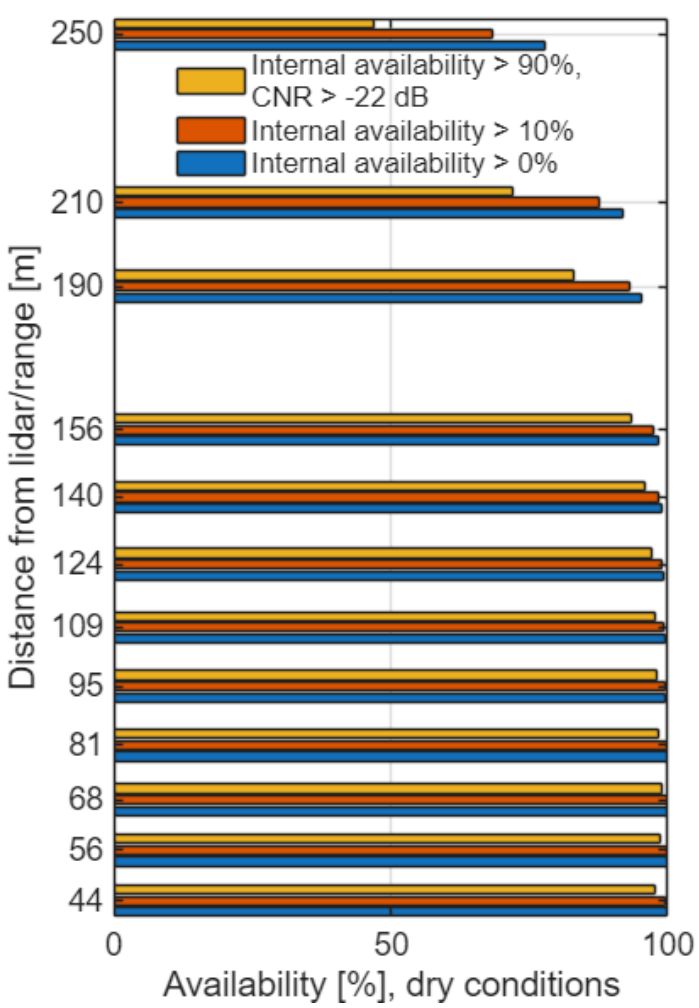
Show availability per height before summary

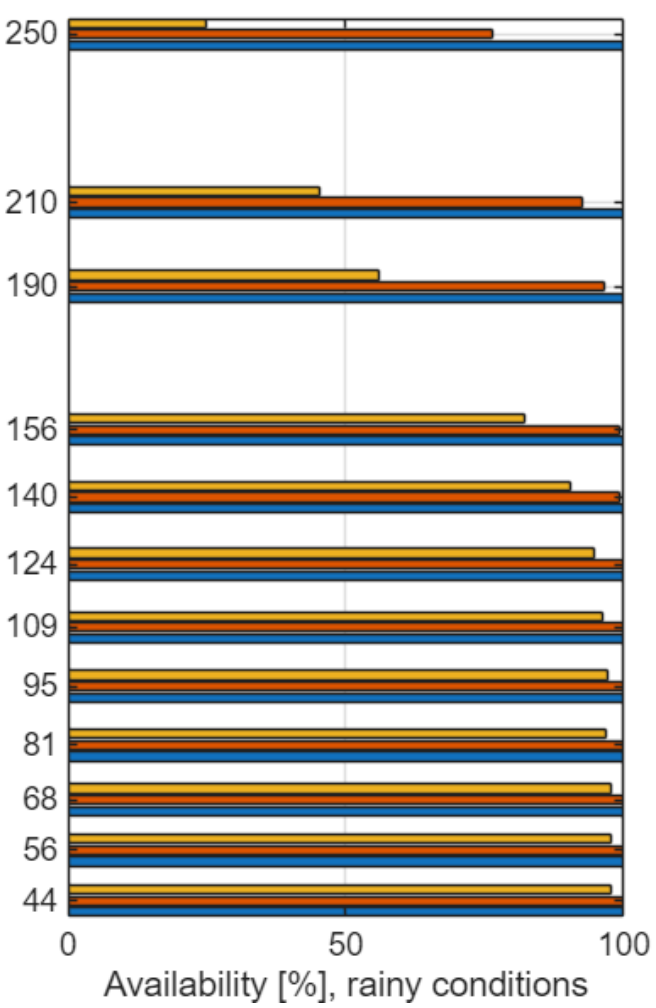


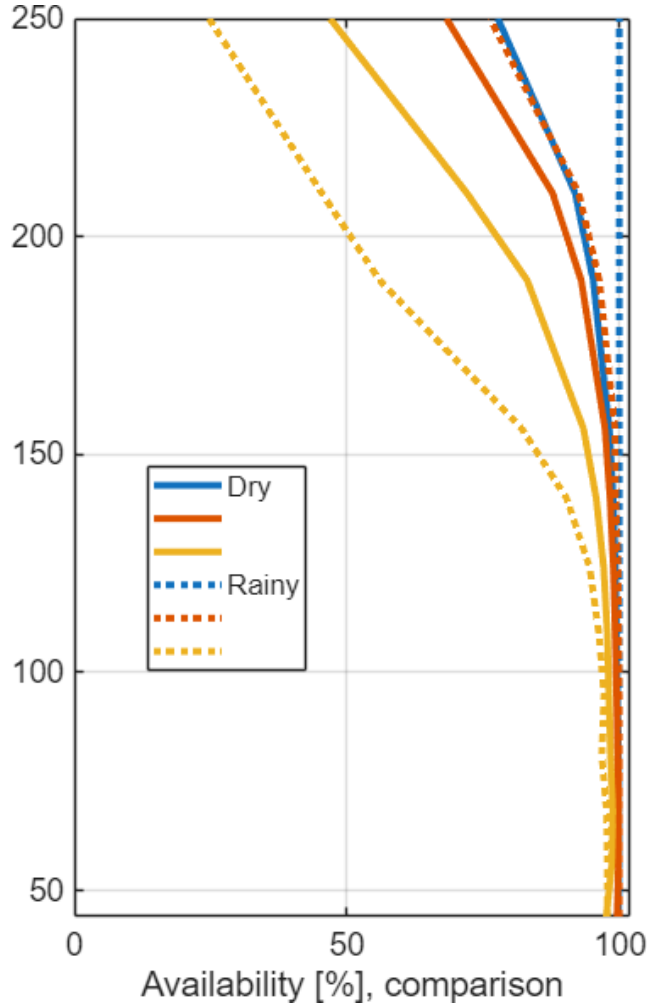

Focus distance: 250 m, Measurement height: 372.5 m
Availability (%)
100
50
0
All 10 min data
Rain > 0 mm/hour
Rain > 6 mm/hour
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
2023
CNR
20
0
-20
-40
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
2023

Summary lidar availability for Risø

10 minute lidar data: 3.5% rainy, 96.5% dry

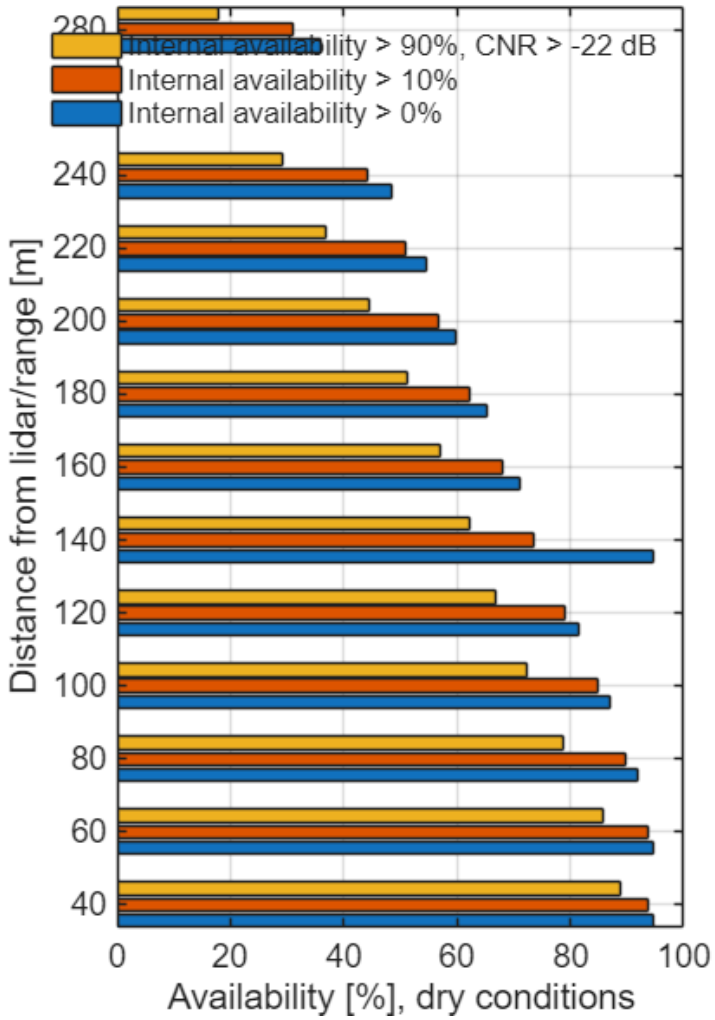


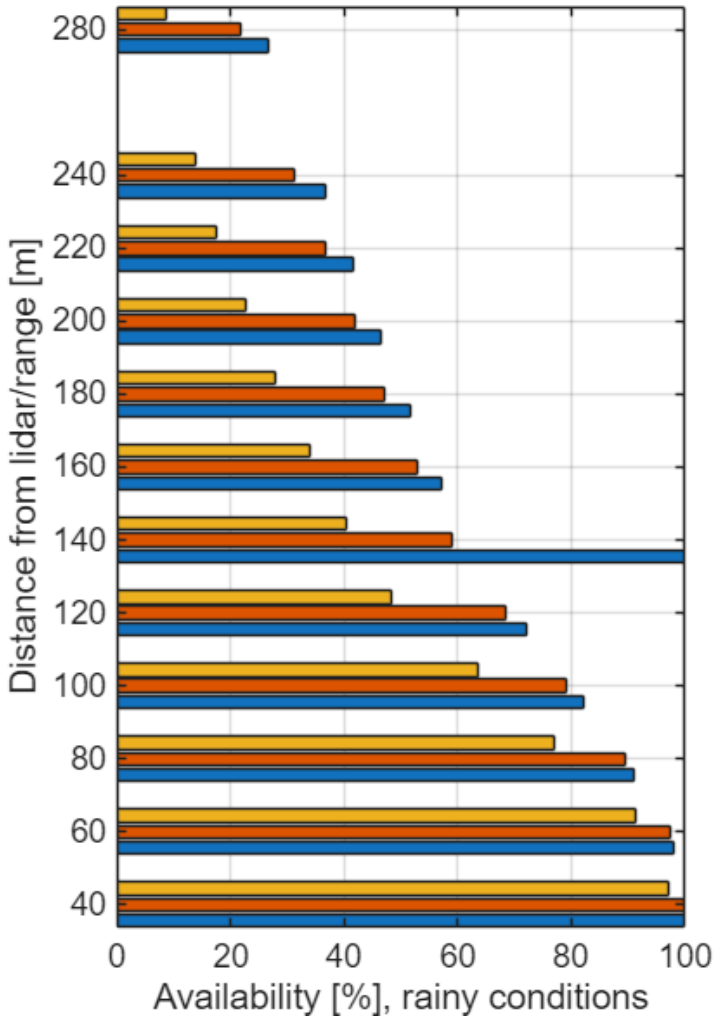


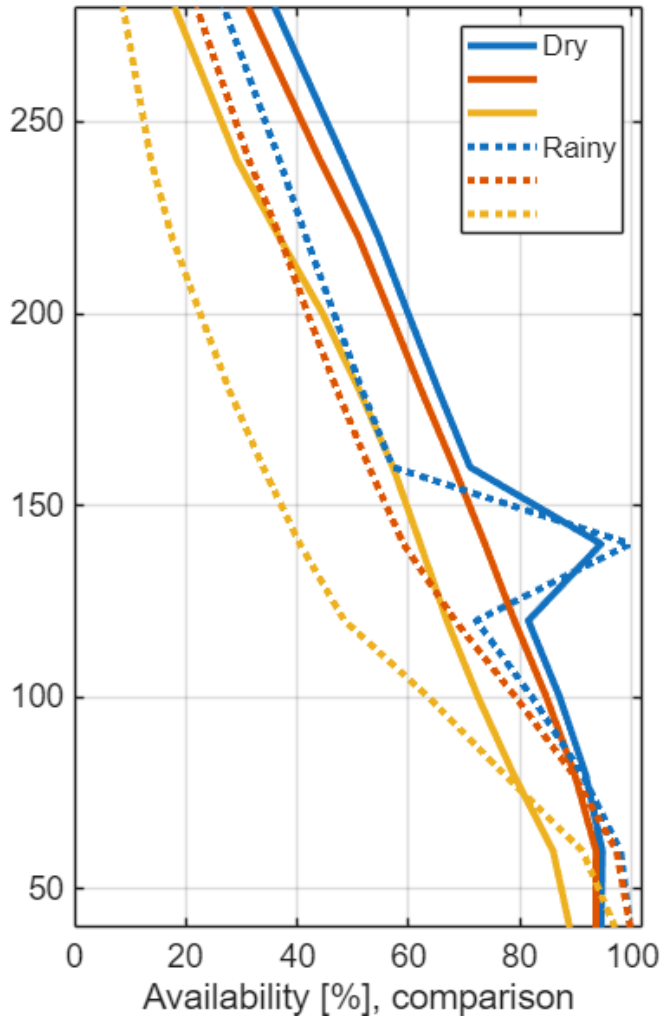


Summary lidar availability for Alaiz

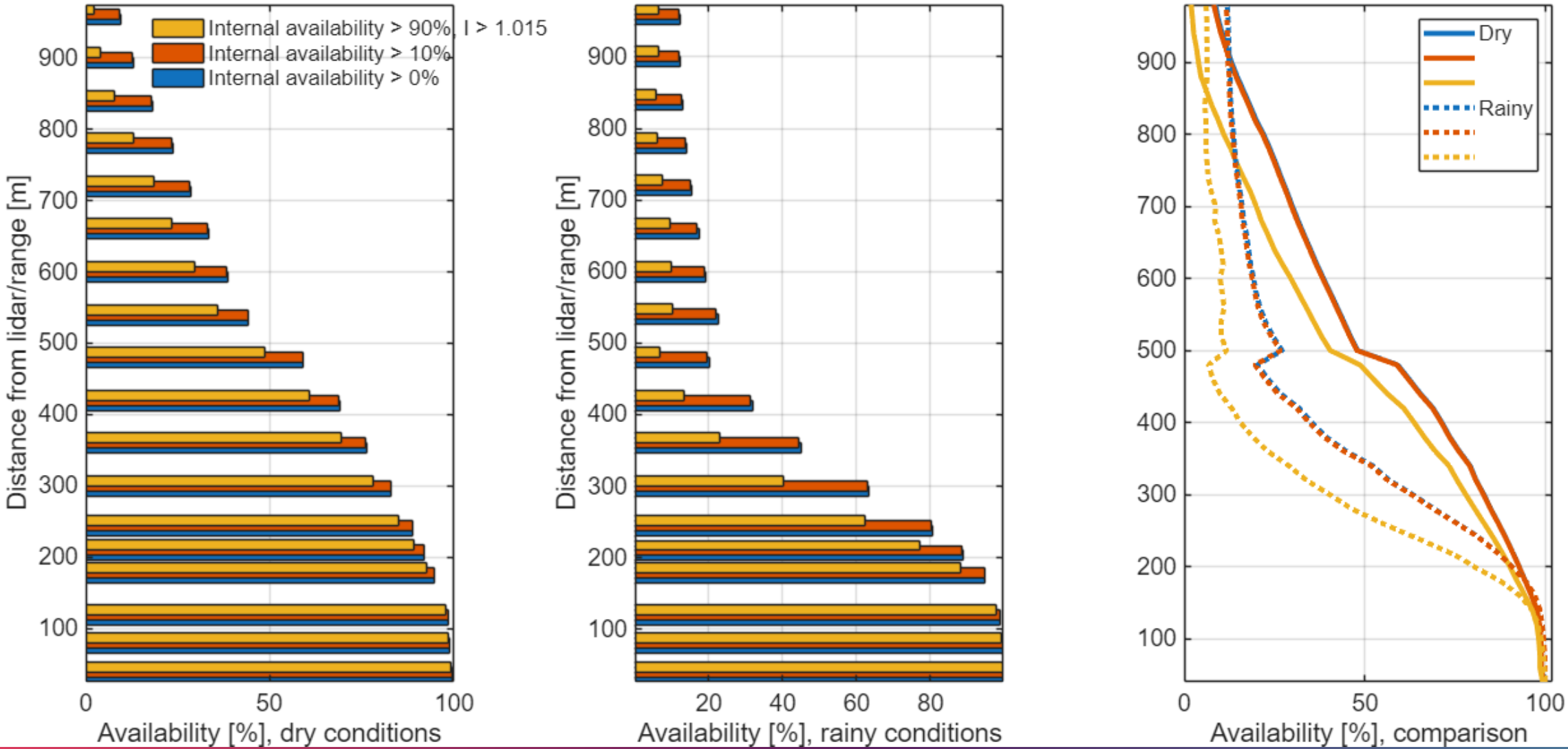
1 minute lidar data from 1st December 2024 to 31th May 2025: 1.3% rainy, 98.7% dry



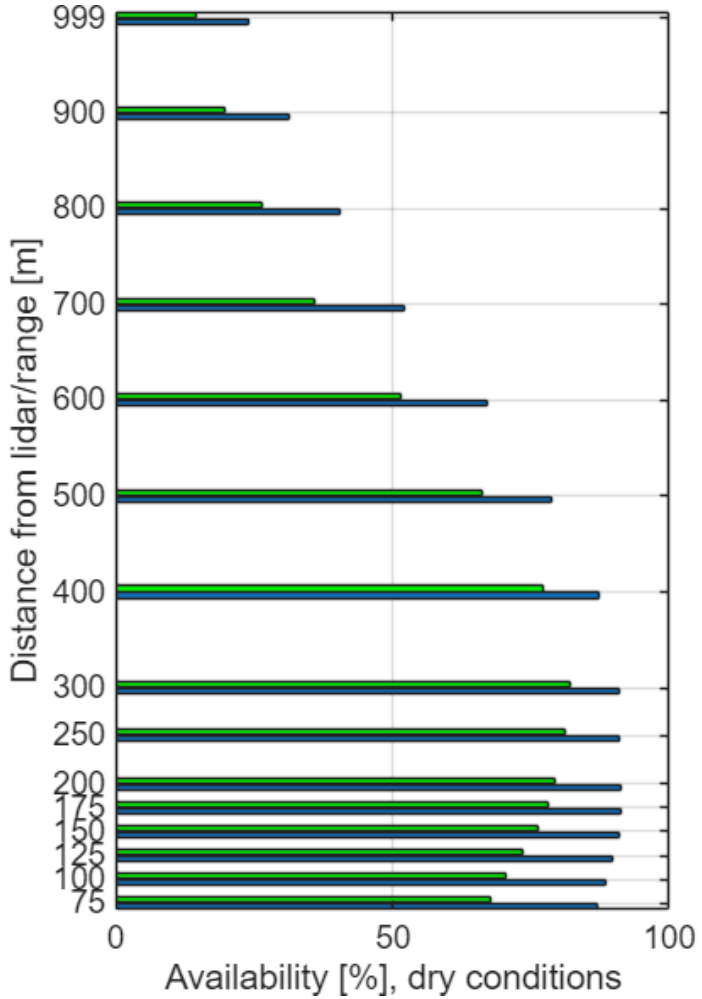


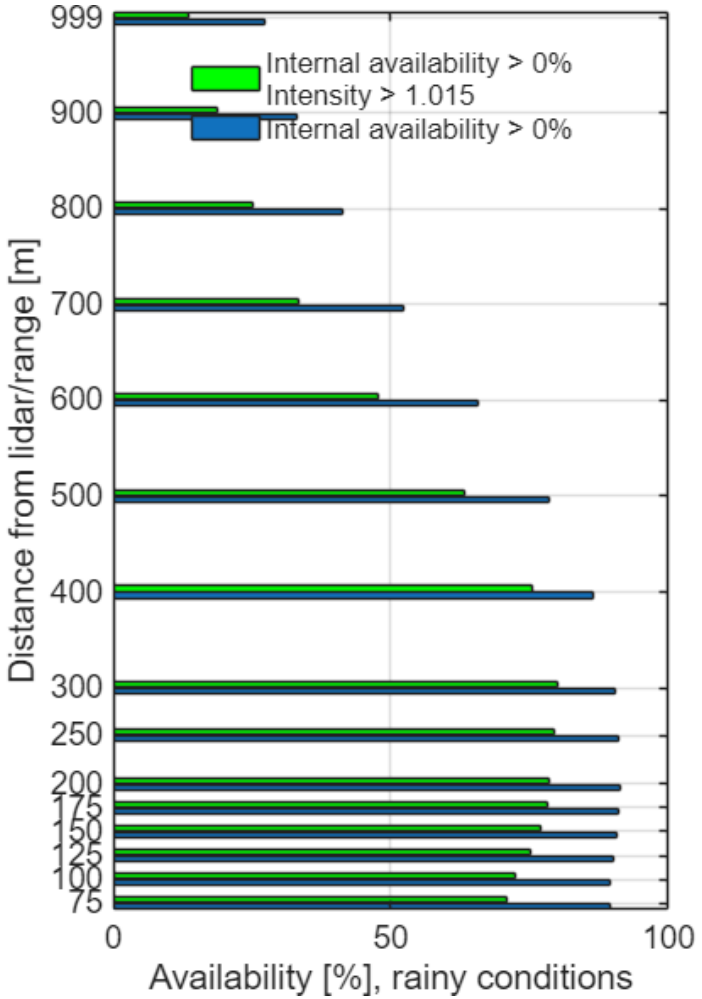


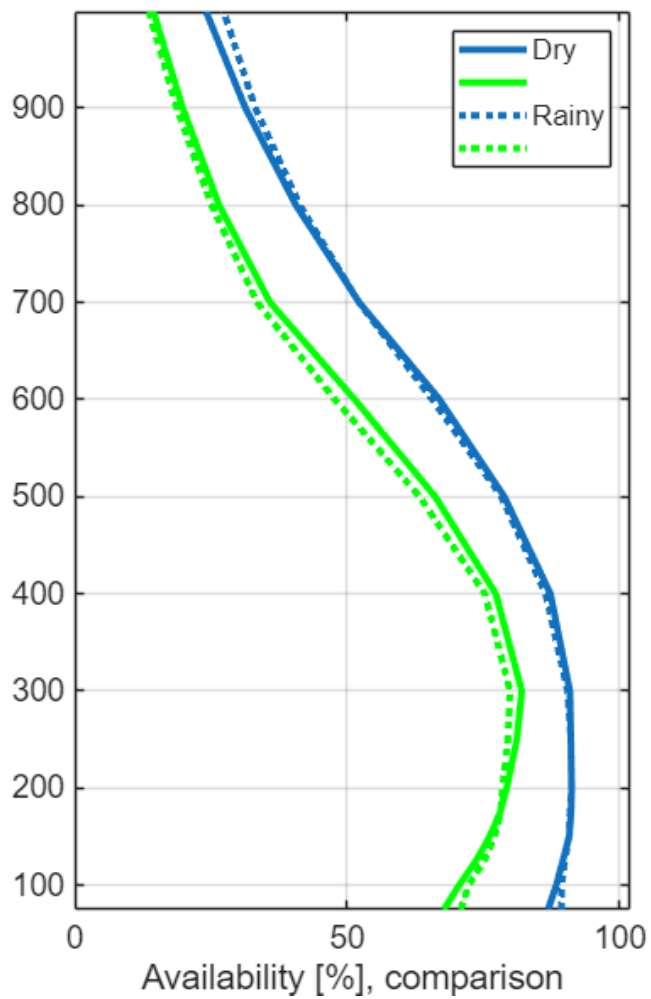
Summary lidar availability for Østerild

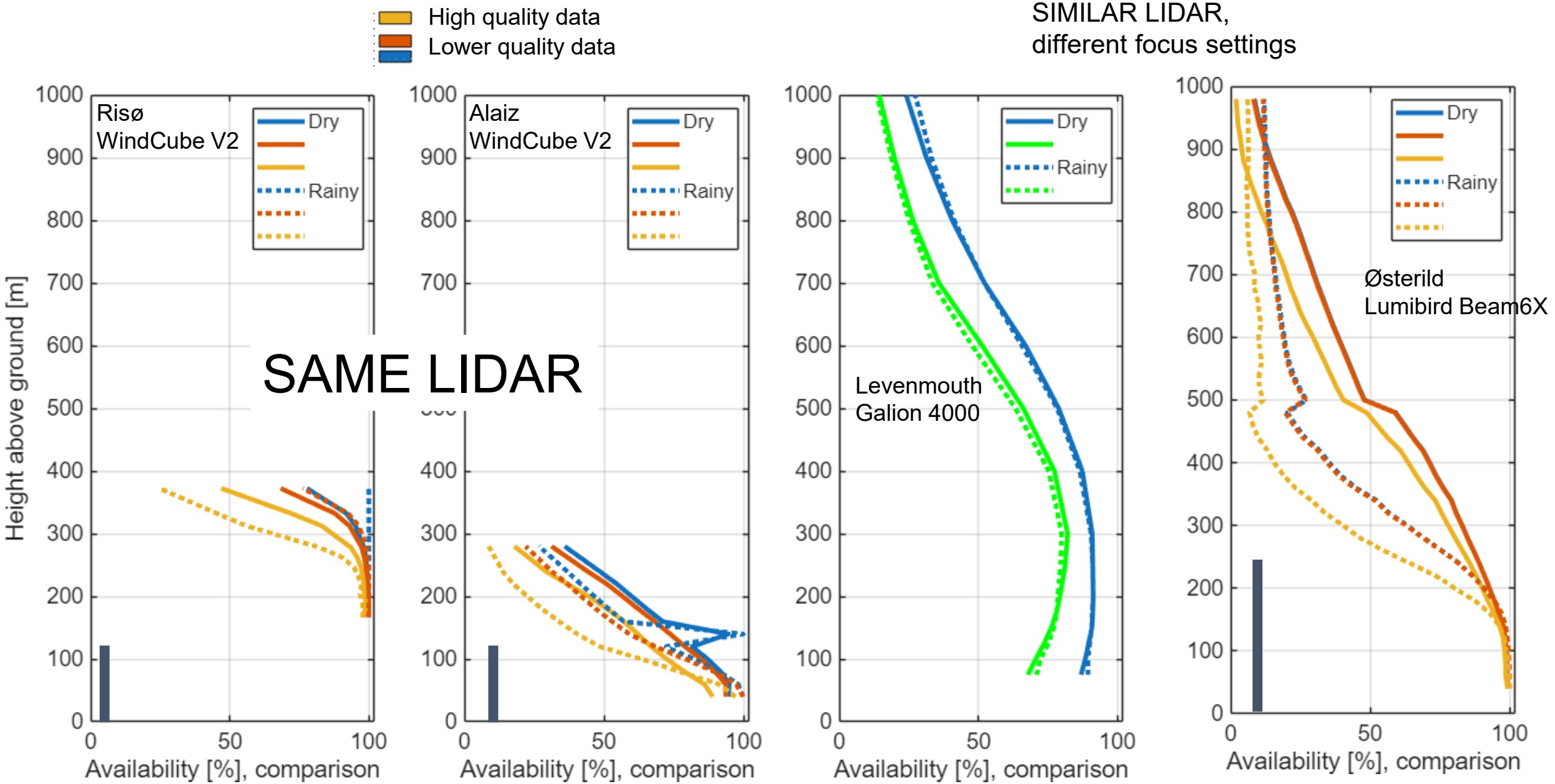


Summary lidar availability for Levenmouth








High quality data
Lower quality data
SIMILAR LIDAR,
different focus settings
SAME LIDAR
Risø
WindCube V2
Alaiz
WindCube V2
Levenmouth
Galion 4000
Østerild
Lumibird Beam6X
Dry
Rainy
Height above ground [m]
Availability [%], comparison
0
100
200
300
400
500
600
700
800
900
1000
0
50
100

How does the lack of 100% data coverage change the observed wind speed profiles?

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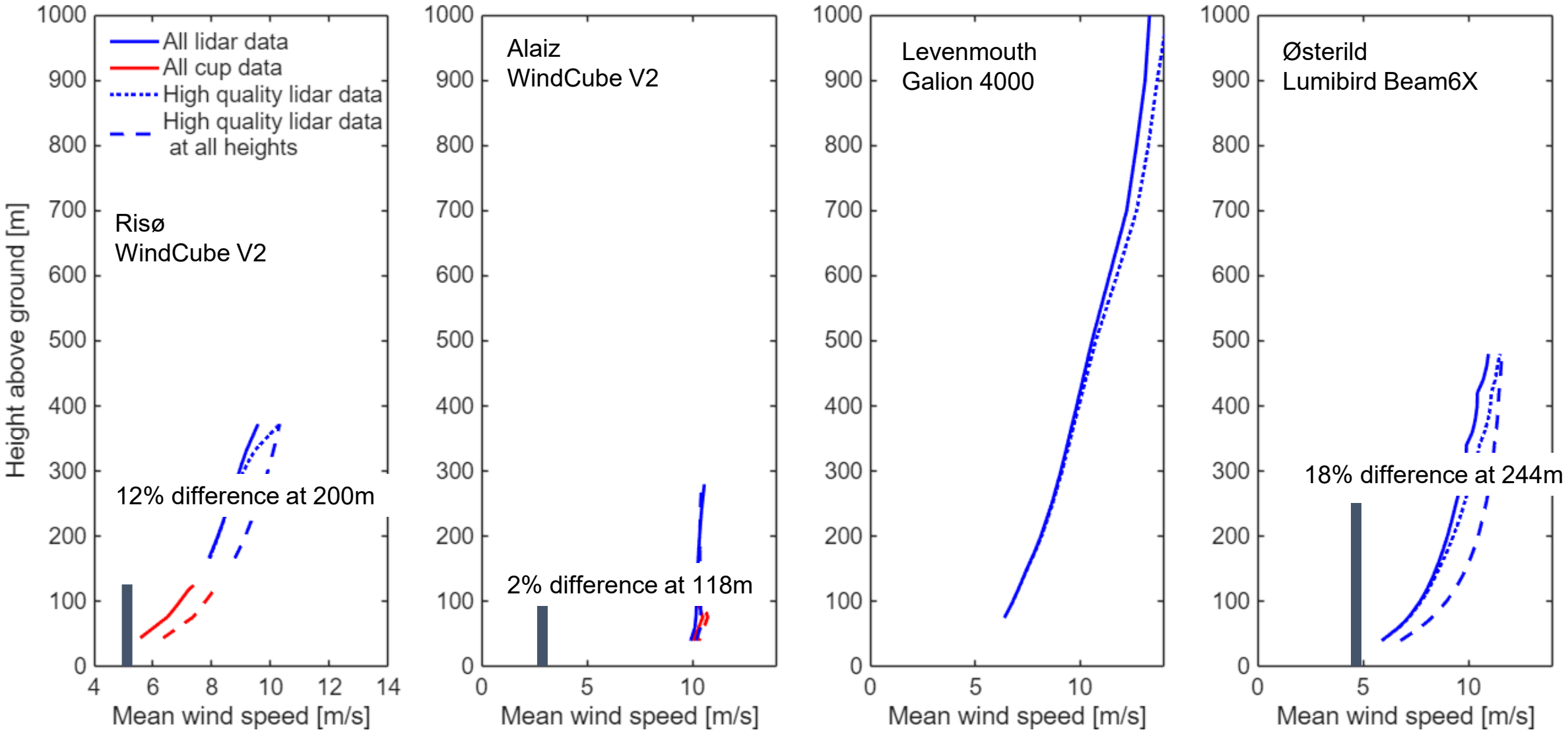
Availability bias: $\Delta = 100\frac{U_{QC,all} - U_{100\%}}{U_{100\%}}$



How does the wind profile change when it is raining?

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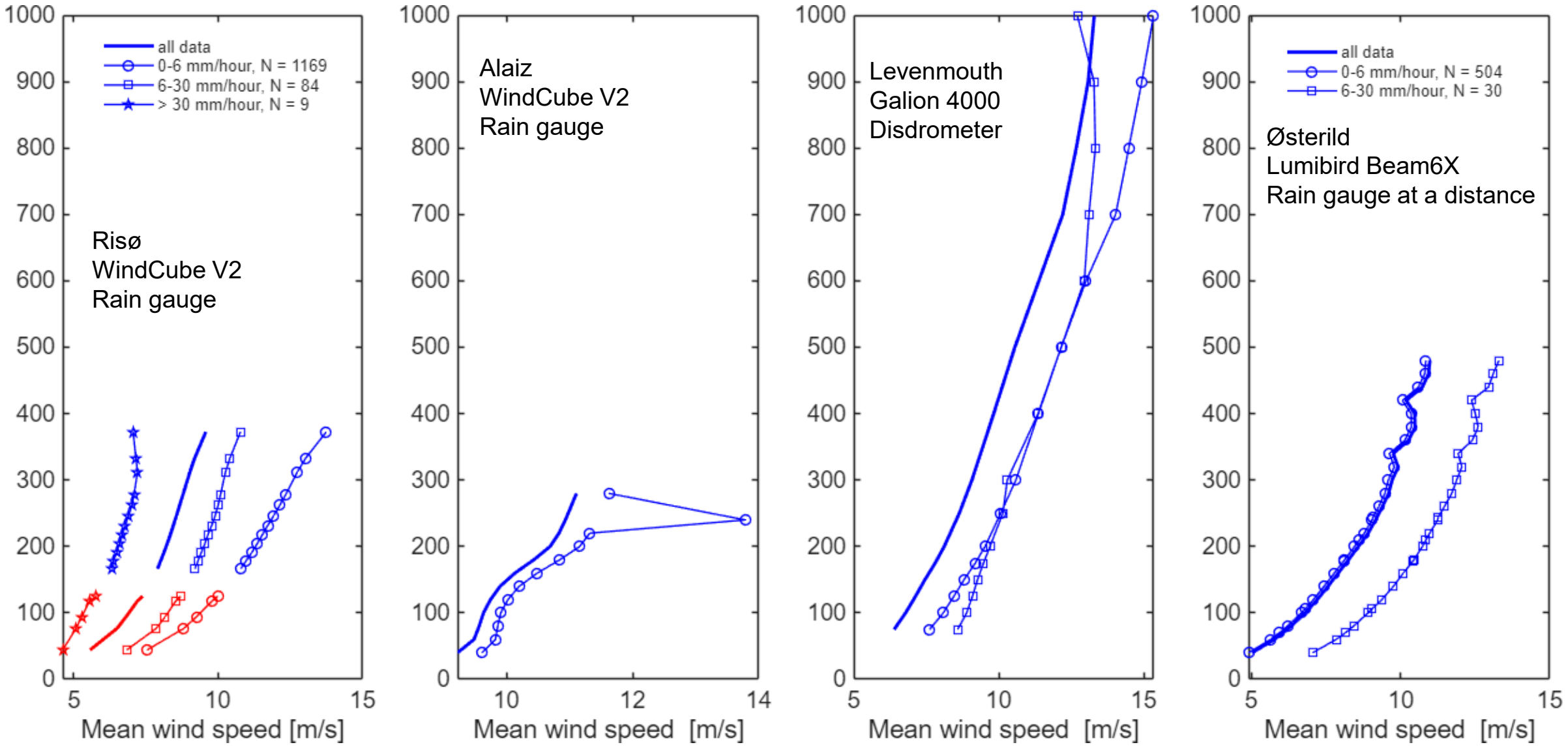
all data
0-6 mm/hour, N = 1169
6-30 mm/hour, N = 84
> 30 mm/hour, N = 9
Risø
WindCube V2
Rain gauge
Mean wind speed [m/s]
Alaiz
WindCube V2
Rain gauge
Mean wind speed [m/s]
Levenmouth
Galion 4000
Disdrometer
Mean wind speed [m/s]
all data
0-6 mm/hour, N = 504
6-30 mm/hour, N = 30
Østerild
Lumibird Beam6X
Rain gauge at a distance
Mean wind speed [m/s]

Conclusions

- All tested lidars measured well during rain, but availability decreased with height, and also decreased strongly with higher requirements for data quality.
- For heights above ~150m, the lidar availability was always lower during rain events than during dry weather.
- At the Danish sites, the lidars tend to lose low wind speed data, which led to an availabilty bias of 10-20%.
- At the Alaiz site, there was generally low lidar availability, but also a low availability bias.
- *For all four sites, mean wind speed tends to be higher when it rains than during dry conditions meaning that leaading edge erosion potentially becomes more serious.*

Thank you.

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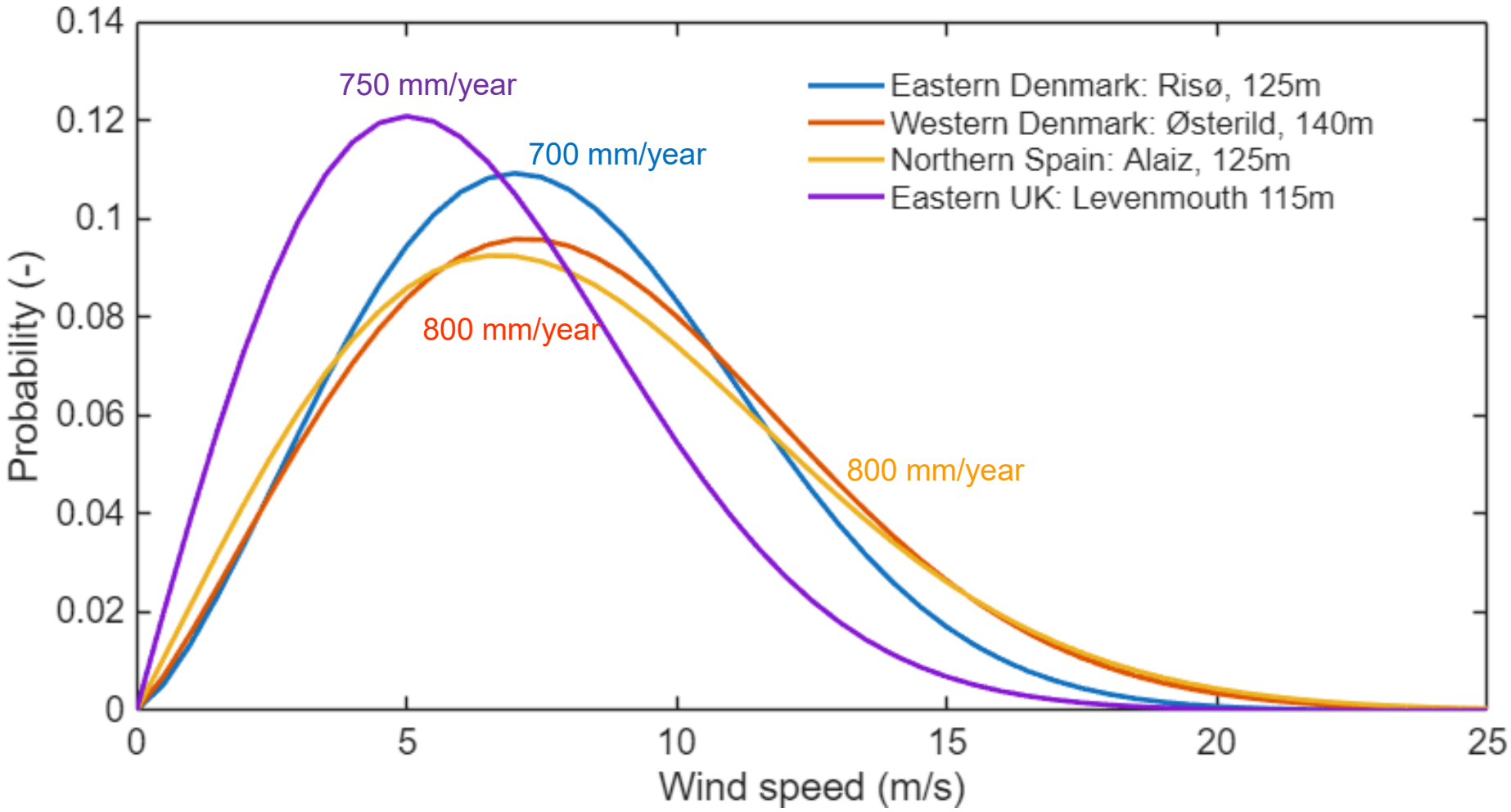
Overview comparison between sites:

What is the annual rain fall, what is the wind resource at 125m?



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