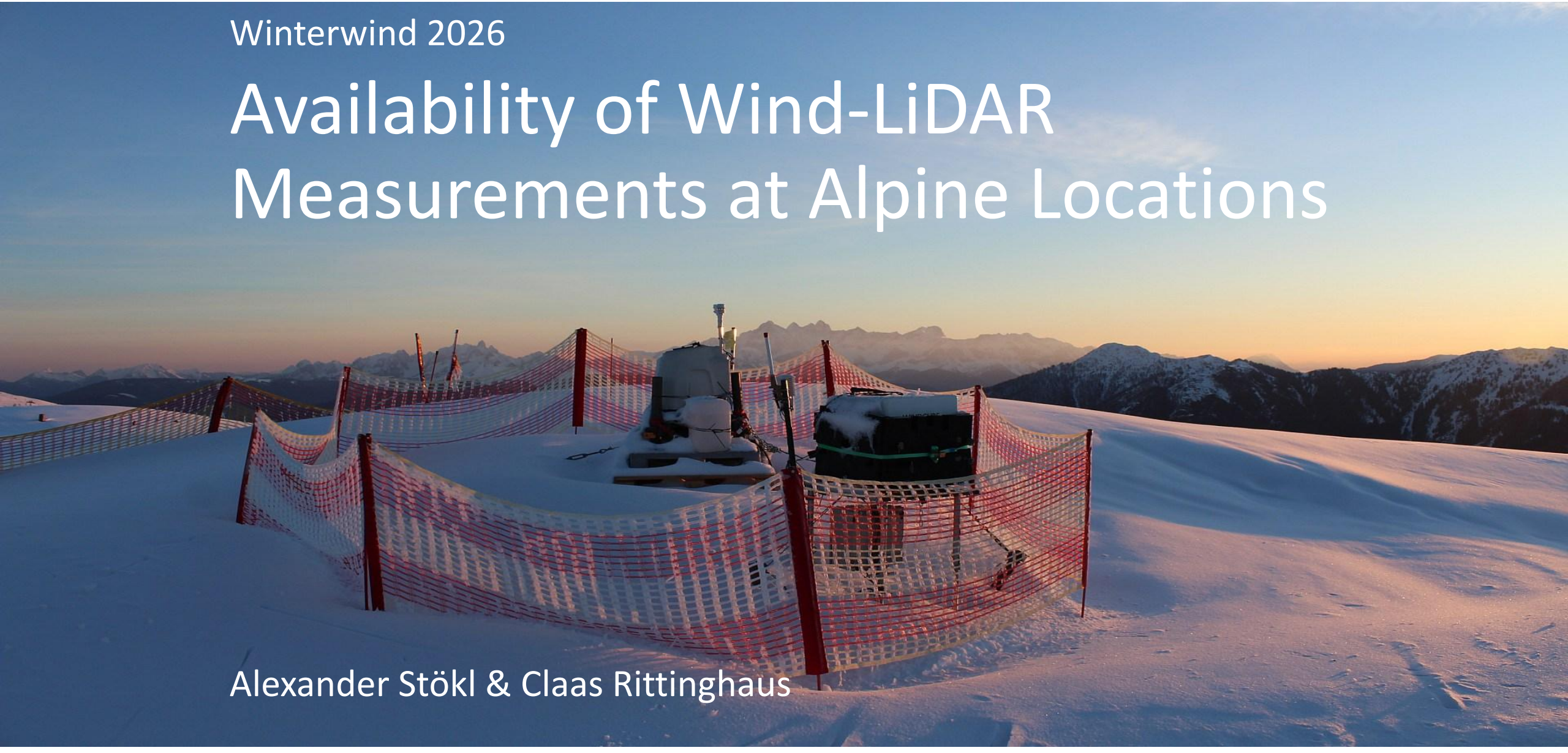
energie werkstatt

CONSULTING ENGINEERS FOR RENEWABLE ENERGY

Winterwind 2026

Availability of Wind-LiDAR Measurements at Alpine Locations



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Outline & Motivation

Energiewerkstatt's experience has shown that LiDAR measurements at Alpine sites can be severely affected by low availability, in particular during Winter.

Two activities in the framework of IEA Wind Task 52 (formerly Task 32):

- Survey of the yearly variation of LiDAR availabilities at alpine locations in comparison to non-mountainous sites.
- Comparison of availabilities of continuous wave and of pulsed LiDAR devices at an alpine location in Winter.

Survey of LiDAR availabilities: Study design

- Based on a selection of 10 LiDAR WindCube 2.0 measurements in Austria from the past years.
- Comparison from sites at Alpine locations with sites from low-lying, flat areas.
- Selection of measurements aimed at full coverage of the yearly cycle, as far as possible.
- Separation according to Austrian climate in
  - “Winter“ = December to February
  - “Summer” = March to November
- Evaluation at different height ranges (not exactly the same do to different LiDAR setups)
  - “Height 1” between 40 m and 60 m.
  - “Height 2” between 75 m and 85 m
  - “Height 3” between 135 m and 145 m
  - “Height 4” between 180 m and 200 m
- Completed by meteorological measurements on site (temperature, pressure, humidity) and close-by meteorological stations (global irradiation, precipitation, depth of snow cover)

Selected sites, elevations and characteristics

Lowland sites

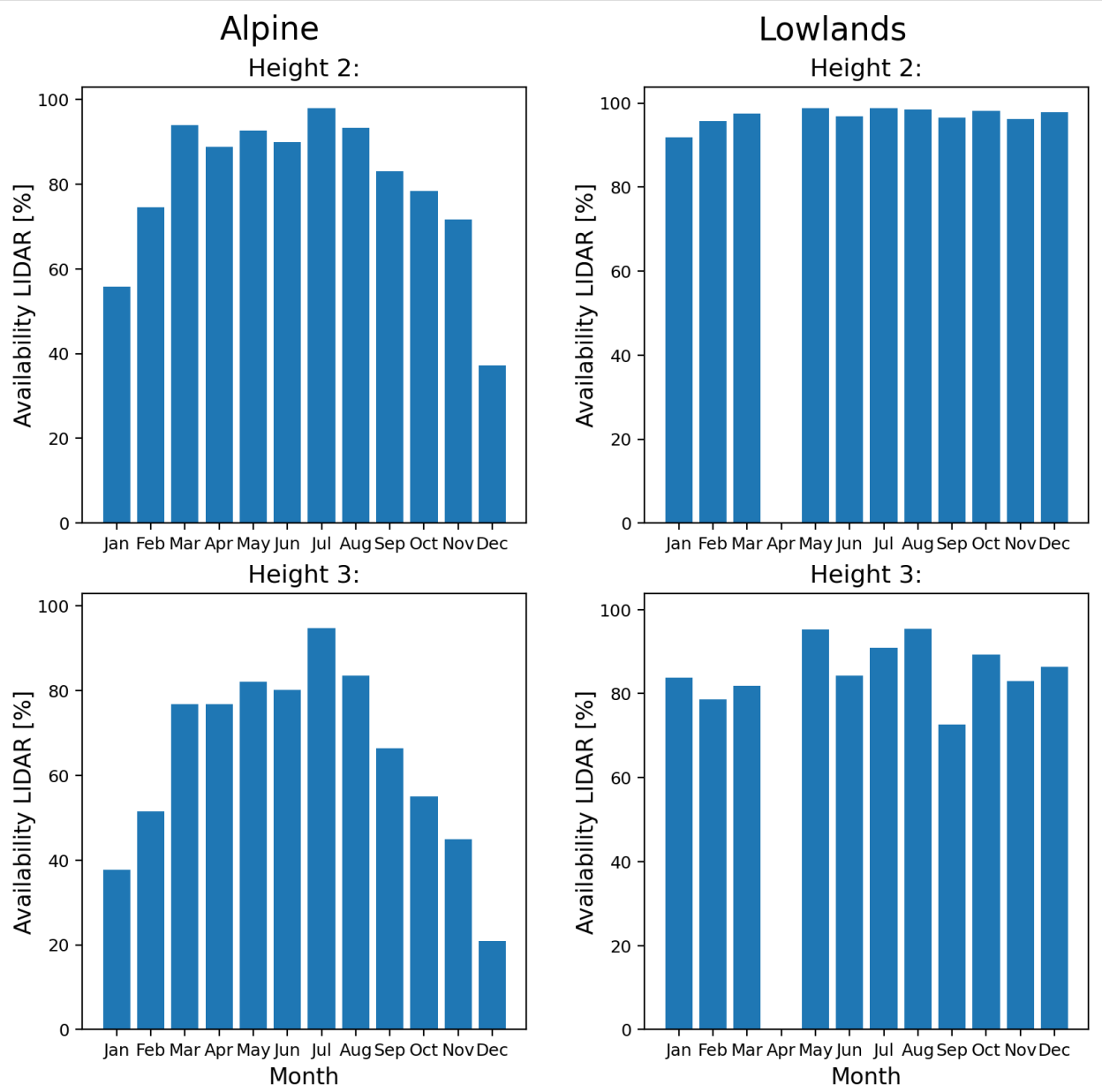
	Measurement period	Elevation	Vegetation / Orography
Site 1	Summer, Winter	200 m	Agricultural landscape (unforested), lowlands
Site 2	Fall – Spring	300 m	Agricultural landscape (unforested), lowlands
Site 3	Spring – Summer	200 m	Agricultural landscape (unforested), lowlands
Site 4	Fall – Winter	200 m	Agricultural landscape (sparse forest cover), lowlands
Site 5	Fall – Winter	300 m	Agricultural landscape (sparse forest cover), lowlands

Alpine sites

	Measurement period	Elevation	Vegetation / Orography
Site 6	Winter – Spring	1700 m	At the tree line, lowest point of a mountain ridge
Site 7	Summer – Winter	1500 m	Forest cover (not continuous), rolling hills
Site 8	Fall – Winter	1500 m	Thick forest cover, slight ridge
Site 9	Spring – Fall	1800 m	Above the tree line, summit plateau
Site 10	Summer	1500 m	Forest cover (not continuous), moderate ridge

Results for availability

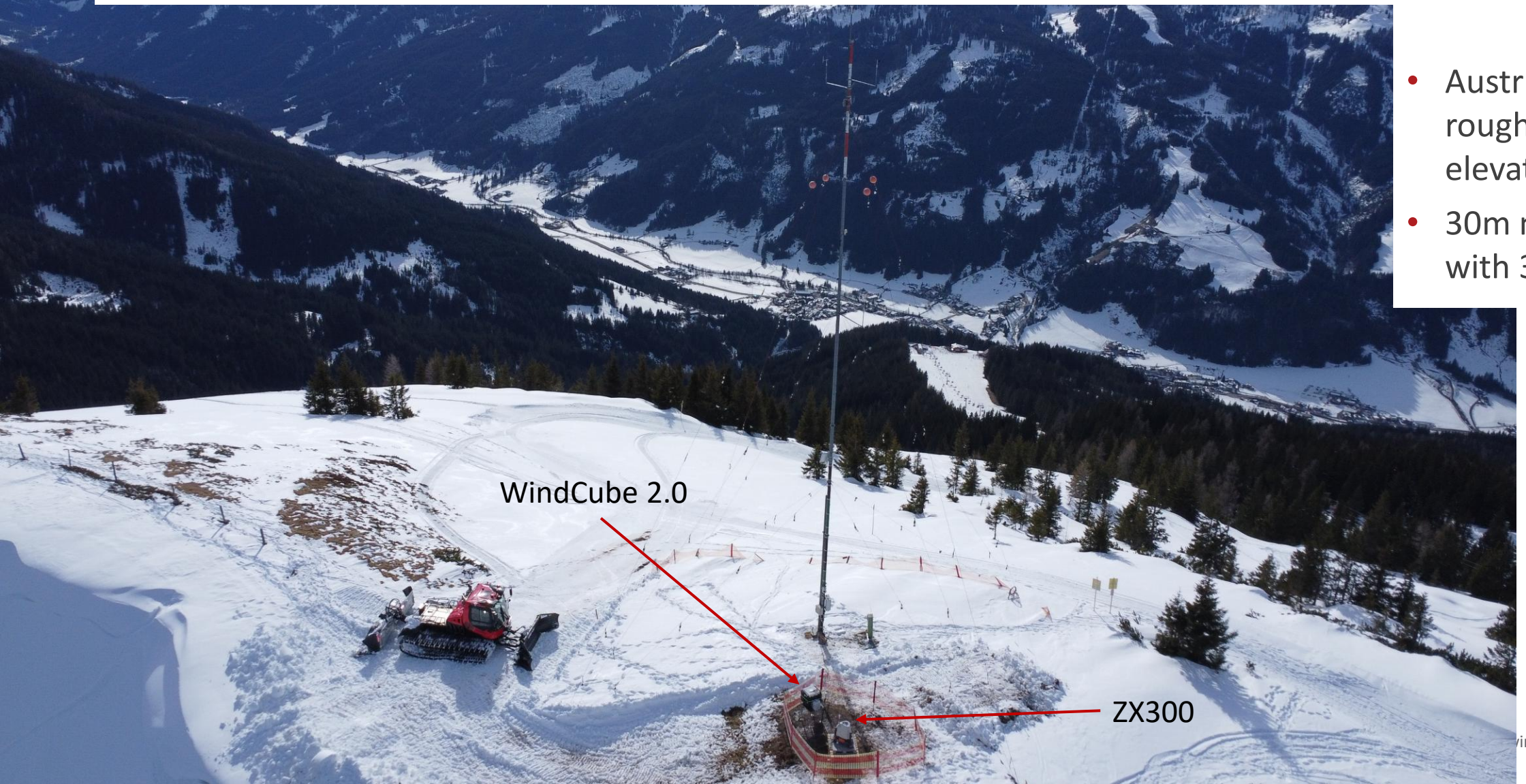
	Height 1	Height 2	Height 3	Height 4
Lowland – whole year	94%	96%	85%	54%
Alpine – whole year	65%	73%	55%	39%
Lowlands – Summer	96%	**97%**	86%	52%
Lowlands – Winter	92%	**94%**	82%	56%
Alpine – Summer	80%	**83%**	66%	49%
Alpine – Winter	32%	**48%**	30%	17%



Analysis & Conclusions

- On Alpine sites, LiDAR availability in winter at no height exceeded 50%.
- Correlations with meteorological conditions:
  - Temperature – some correlation, but probably just a proxy for the yearly cycle
  - Snow cover (ruling out soil as a source of aerosols)
  - Precipitation – some effect, but heavy precipitation is very rare
  - Humidity (Fog) – again some effect, but also comparatively rare
  - Solar irradiation (as a proxy for atmospheric stability) – no correlation found
- The likely cause for the observed low availabilities is the stable atmospheric temperature gradient in winter. With no mixing from convection, there are little aerosols at greater heights.
- Lowland sites, on the other hand, are within the shear-driven turbulent boundary layer with efficient mixing throughout the year, and thus see only very little variation of LiDAR availability.

Comparison of continuous wave and of pulsed LiDARs



- Austrian site at roughly 2000m elevation.
- 30m met-mast with 3D-Sonic

Comparison of wind speeds

Height	Ratio WC/ZX
41m	0.995
60m	0.999
80m	0.997
100m	0.997
110m	0.997
130m	0.999
150m	1.005
170m	1.012
200m	1.025

Availability threshold per 10‘ bin: WC min. 80%, ZX min. 8 PIA
Only periods with parallel availability & wind speeds > 4 m/s

No correlation of measurement deviation found with:

- Wind direction
- Wind speed

Comparison of availabilities

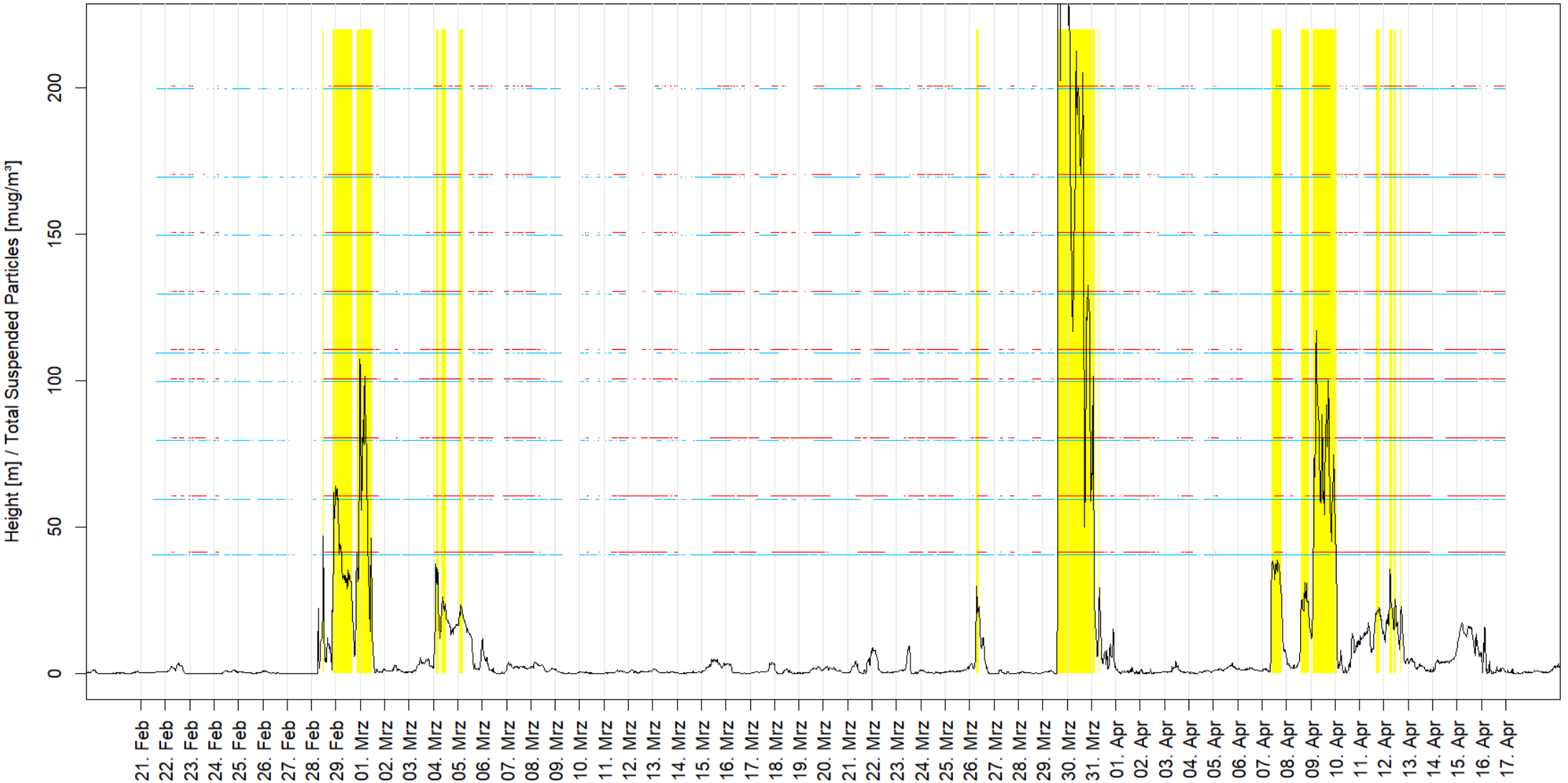
Height	WC	ZX
41m	48.3%	73.1%
60m	49.8%	66.4%
80m	49.9%	61.1%
100m	48.7%	59.2%
110m	46.2%	57.2%
130m	40.7%	55.6%
150m	35.5%	54.5%
170m	30.7%	53.7%
200m	23.4%	51.8%

Availability threshold per 10‘ bin: WC min. 80%, ZX min. 8 PIA
only periods with parallel operation

No correlation of availabilities found with:

- Time of day
- Wind speed
- Air temperature
- Humidity

Availability vs. Sahara dust

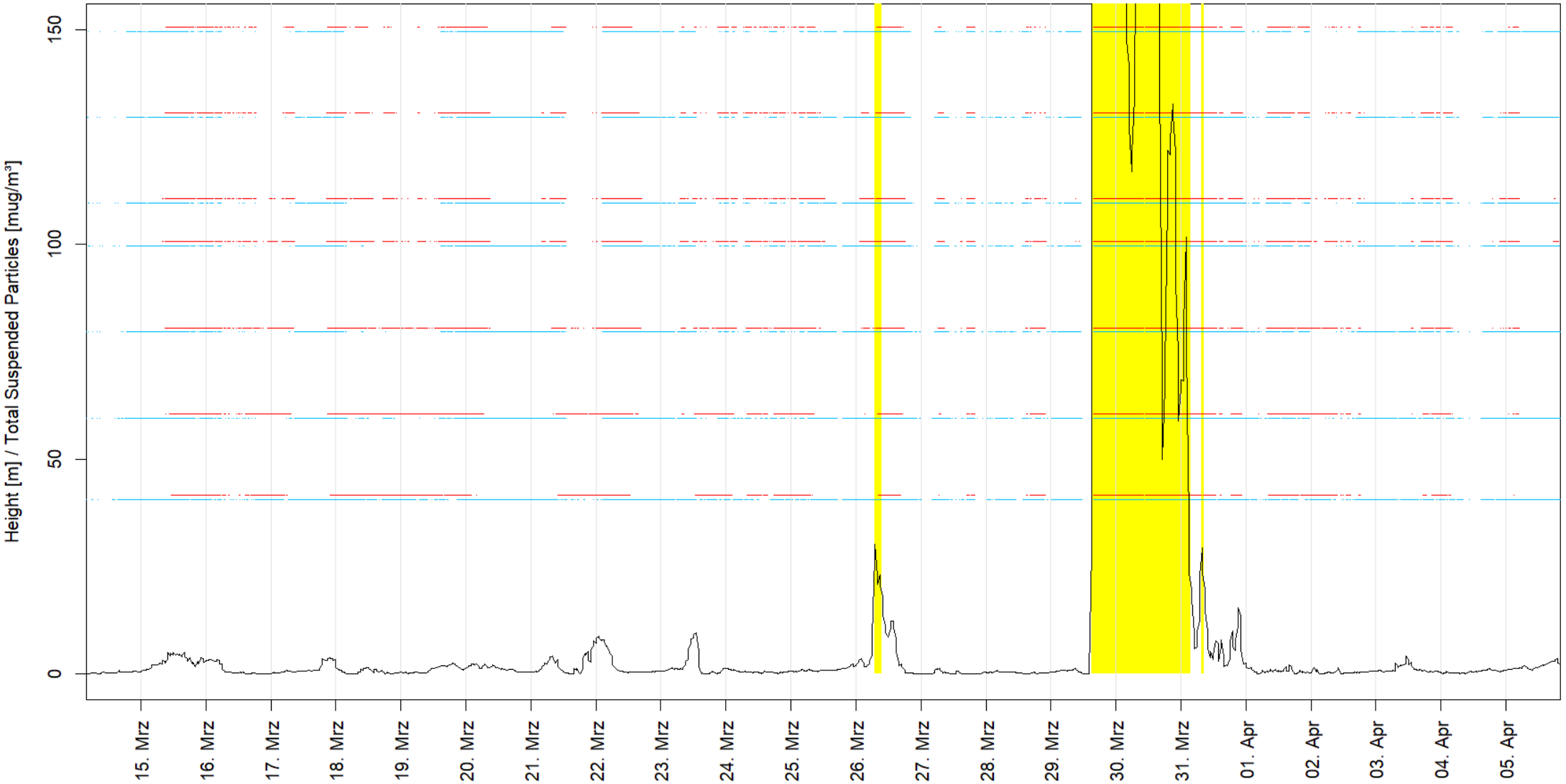


Very distinct yellow dust haze on March 29th & 30th and on April 8th & 9th.

Dust data from Sonnblick observatory, about 40 km to the south-west

Blue: ZX
Red: WC
Yellow: Sahara dust events (TSP > 20 mu g/m³)

Availability vs. Sahara dust



Blue: ZX
Red: WC
Yellow: Sahara dust events (TSP > 20 mu g/m³)

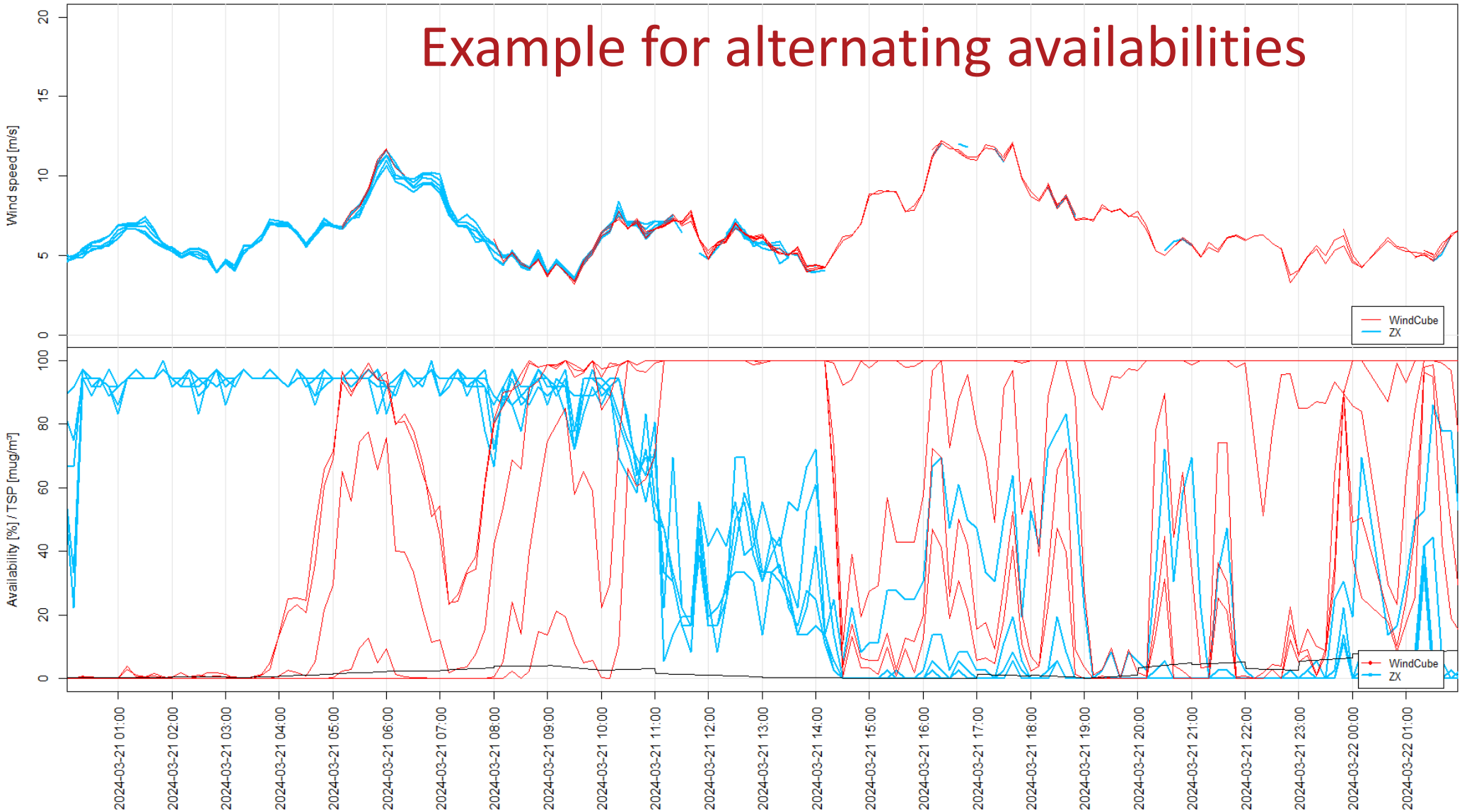
Availability vs. Sahara dust

- Very distinct yellow dust haze on March 29th and 30th and on April 8th and 9th.
- Dust data from Sonnblick observatory, about 40 km to the south-west
- Total availability differs, but at an individual time, it can be either way,
  i.e.: ZX measures but WC does not, or WC measures but ZX does not.

Typical Sahara dust event – both LiDARs operating

Typical no (negligible) dust – both LiDARs operating

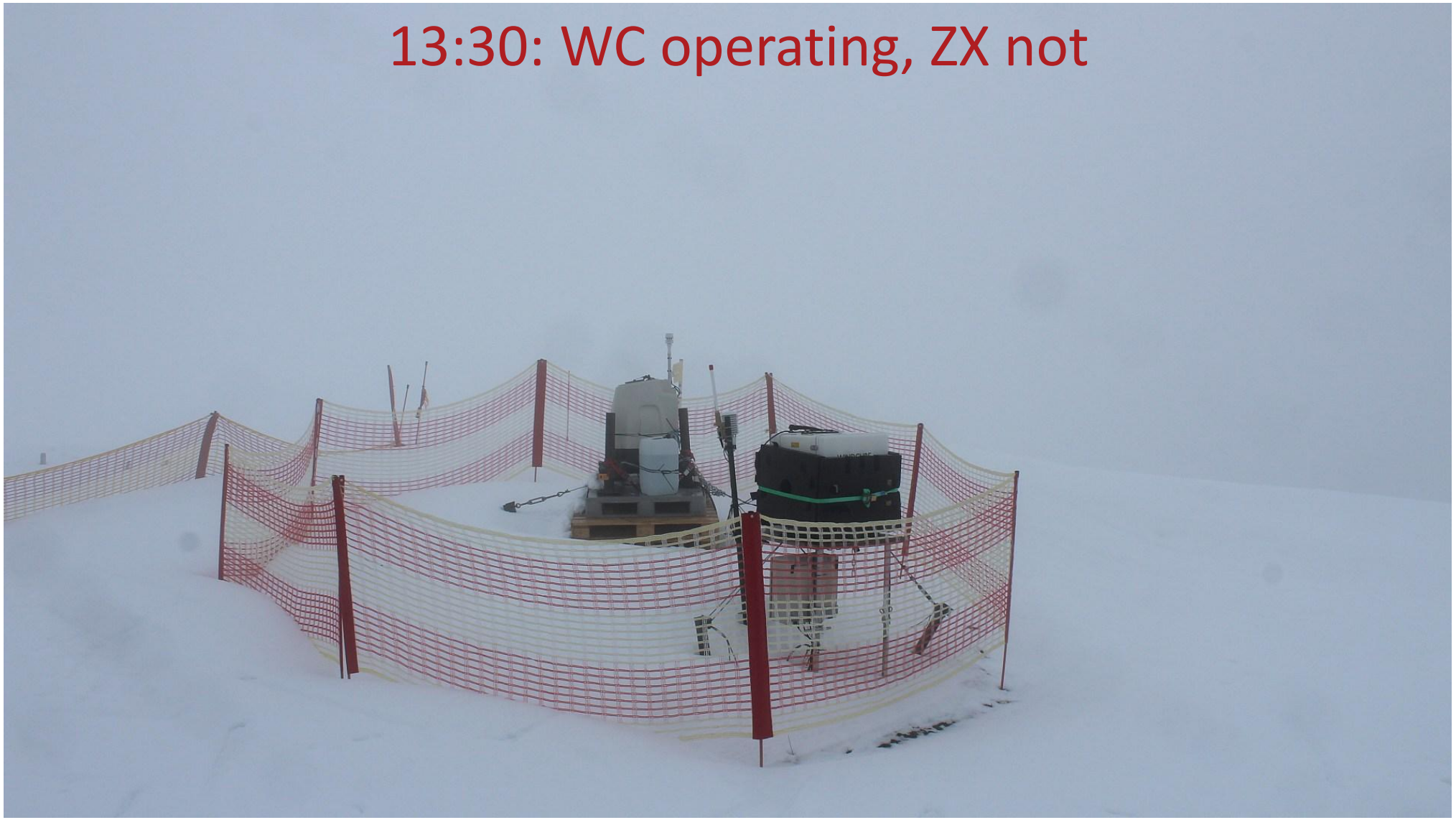
Example for alternating availabilities



For clarity only levels from 41 m to 110 m

07:00: ZX operating, WC not

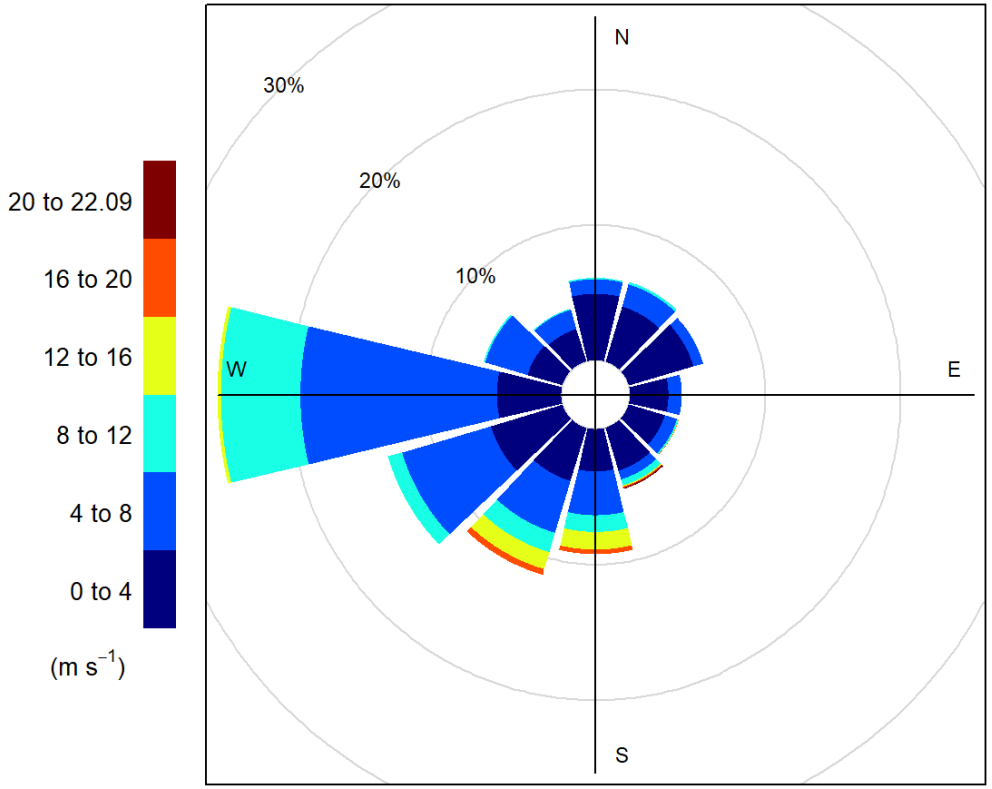
13:30: WC operating, ZX not

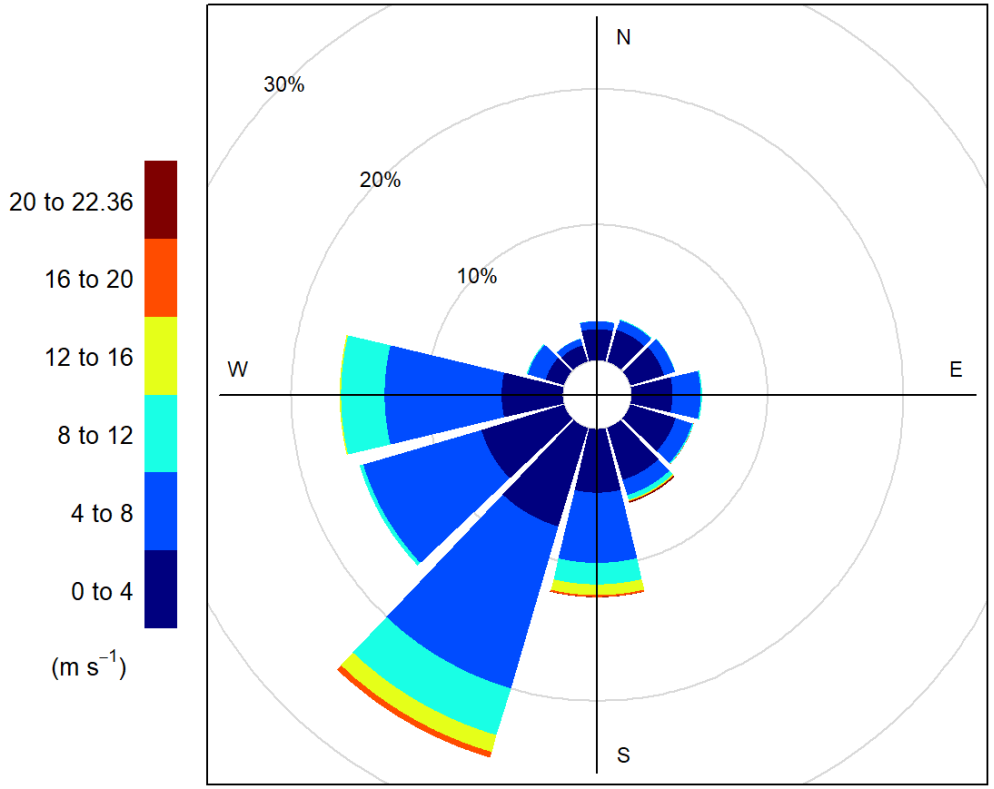


Analysis & Conclusions

- In this comparison better availabilities for ZX, about 10% at 100m, somewhat more at greater height. Should probably not generalized, availabilities are model-specific (Ørsted comparison).
- In both cases insufficient availability for a reliable standalone wind assessment (the reason for the met-mast on this site)
- No correlations found with meteorological conditions:
  - Temperature
  - Humidity
  - Wind speed
  - Time of day (as a proxy for what?)
- ZX better in clear air conditions ?
- WC better in fog & precipitation?

Low availabilities might skew results





WC (left), ZX (right)

WC (red), 30m MM (green)

Low availabilities might skew results

Summary

- The issue of very clean air due to stable atmospheric stratification in winter is likely a challenge specific to alpine sites, the push to higher measurement heights, however, makes availability a more general concern.
- There have been recent efforts by the LiDAR OEMs, both continuous-wave and pulsed, to optimize and improve availabilities (e.g. previous talk).
- SoDAR can be a solution to wind measurements in clean air conditions. For this reason Energiewerkstatt also operates SoDARs, which give good results, accuracy and availability-wise.
- Systematic, complex flow-induced LiDAR measurement errors and the requirement to obtain cup-equivalent TI data can make it worthwhile to revert to met-masts (as, e.g., at that particular site)

Thanks for your attention!

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