Comprehensive Wind Profiling of the Atmospheric Boundary Layer by Integrating Pulsed and Continuous Wave Doppler Lidars

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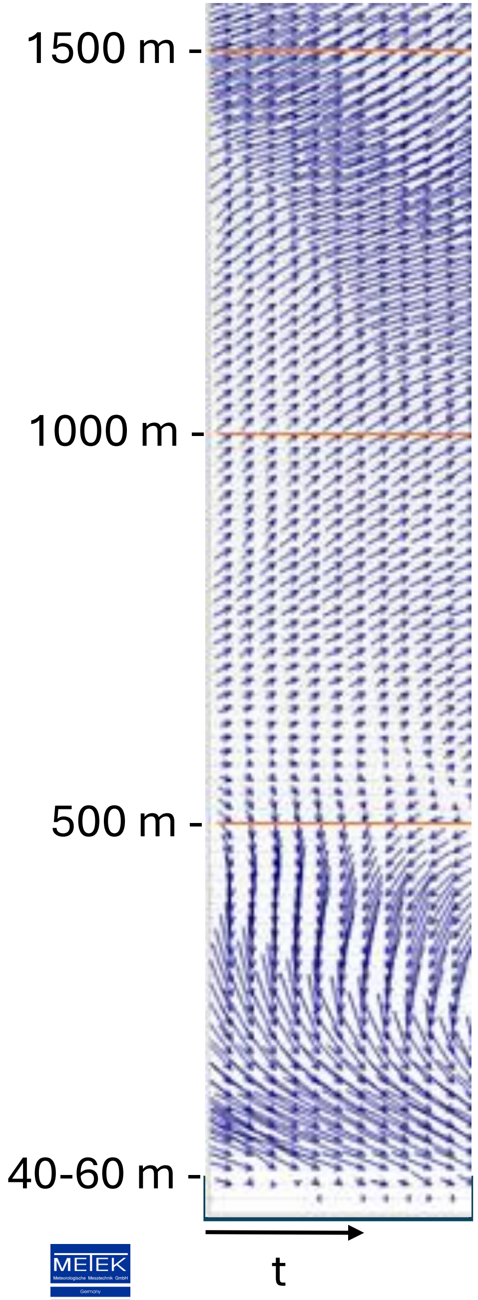
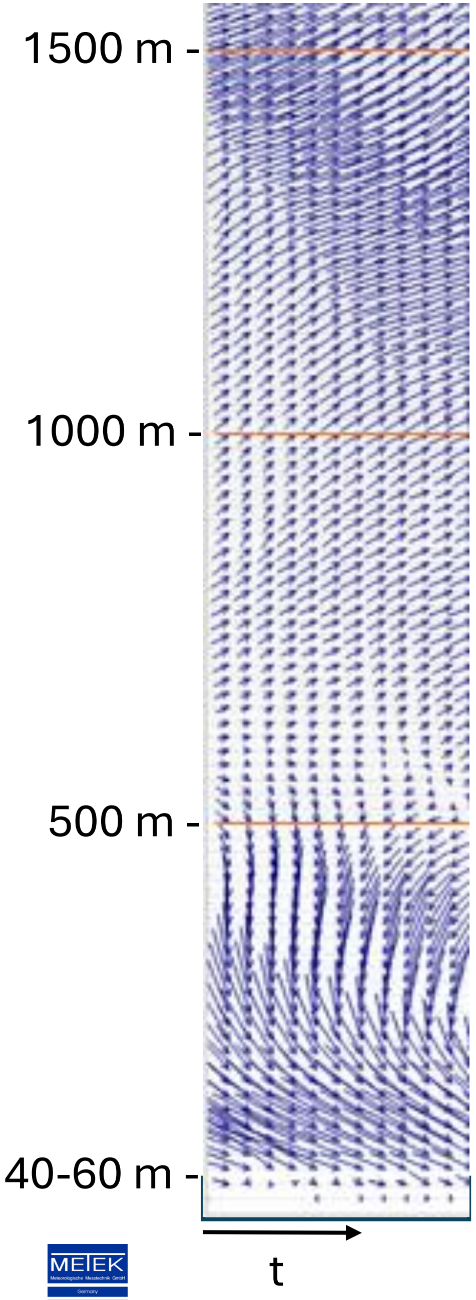


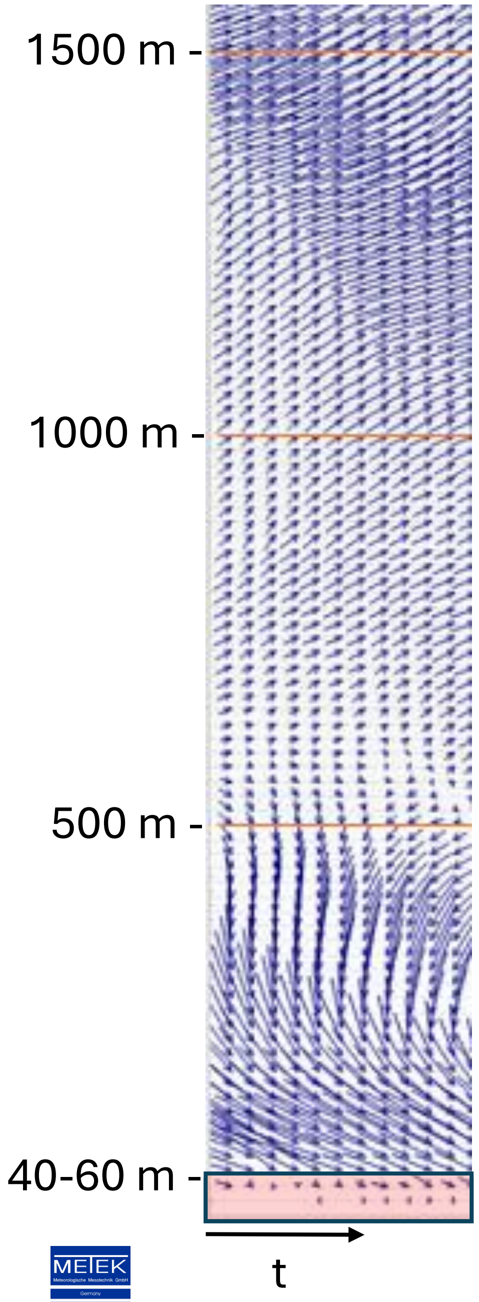
How much information yields a wind profile?

- Structures and processes in the atmospheric boundary layer (ABL) span a wide range of scales
- Scales of ABL flow structures increase with increasing distance from the surface
- The strongest gradients are typically observed near the surface.

Motivation from application



Environmental applications:	Air quality Dispersion of released materials Cold outflows Heated metropols
Engineering tasks:	Wind and gust loads Wind energy (high wind turbines, > 250 m)
Weather forecast:	Modelling
Aviation:	Flight safety Airport management Reduction of environmental impact
tbc	



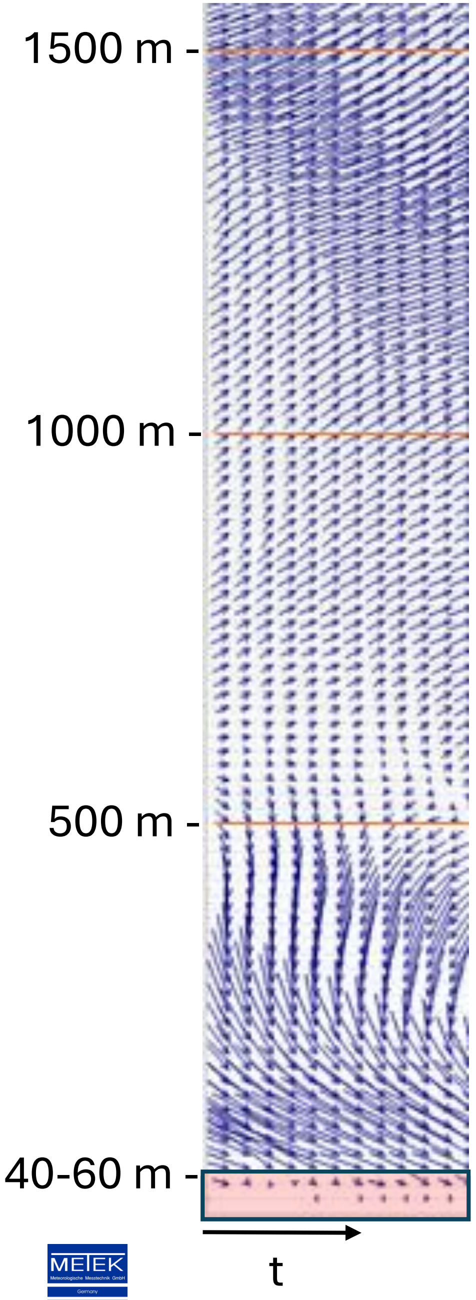
Seamless wind profiling of the atmospheric boundary layer

- Doppler lidars are a preferred remote sensing tool for the observation of wind profiles in the entire ABL.
- Scales of ABL flow structures cannot be fully captured by a single measuring technique.
- Red area indicate blind zone ~60 m depending on pulse length of lidar system (320 ns)

Urban and forest canopy flow

Doppler lidar

Pulsed lidars	Ranging by simple time counting Unambiguos range determination High SNR for a given <u>mean</u> power	High peak pulse power Limited range resolution Limited minimum measuring height
CW lidars	Ranging by optical focal setting Relatively small emission peak power Fine range resolution in low ranges Low minimum measuring height	Data affected by low hanging clouds Unknown sign of radial wind Blind zone around zero Limited to approx. 200 m Consecutive measurements in different heights
FMCW lidars	Ranging by optical focal setting Relatively small emission peak power Fine range resolution in low ranges Very low minimum measuring height Independent determination of effective measuring height	~~Data affected by low hanging clouds~~ ~~Unknown sign of radial wind~~ ~~Blind zone around zero~~ Limited to approx. 200 m Consecutive measurements in different heights



Comprehensive wind profiling of the atmospheric boundary layer

To retrieve the full vertical 3D wind profile from the surface to the top of the ABL, we propose using pulsed and FMCW Doppler lidars in combination.

FMCW Doppler lidar
Wind Ranger 200
7 m ... 200 m

+

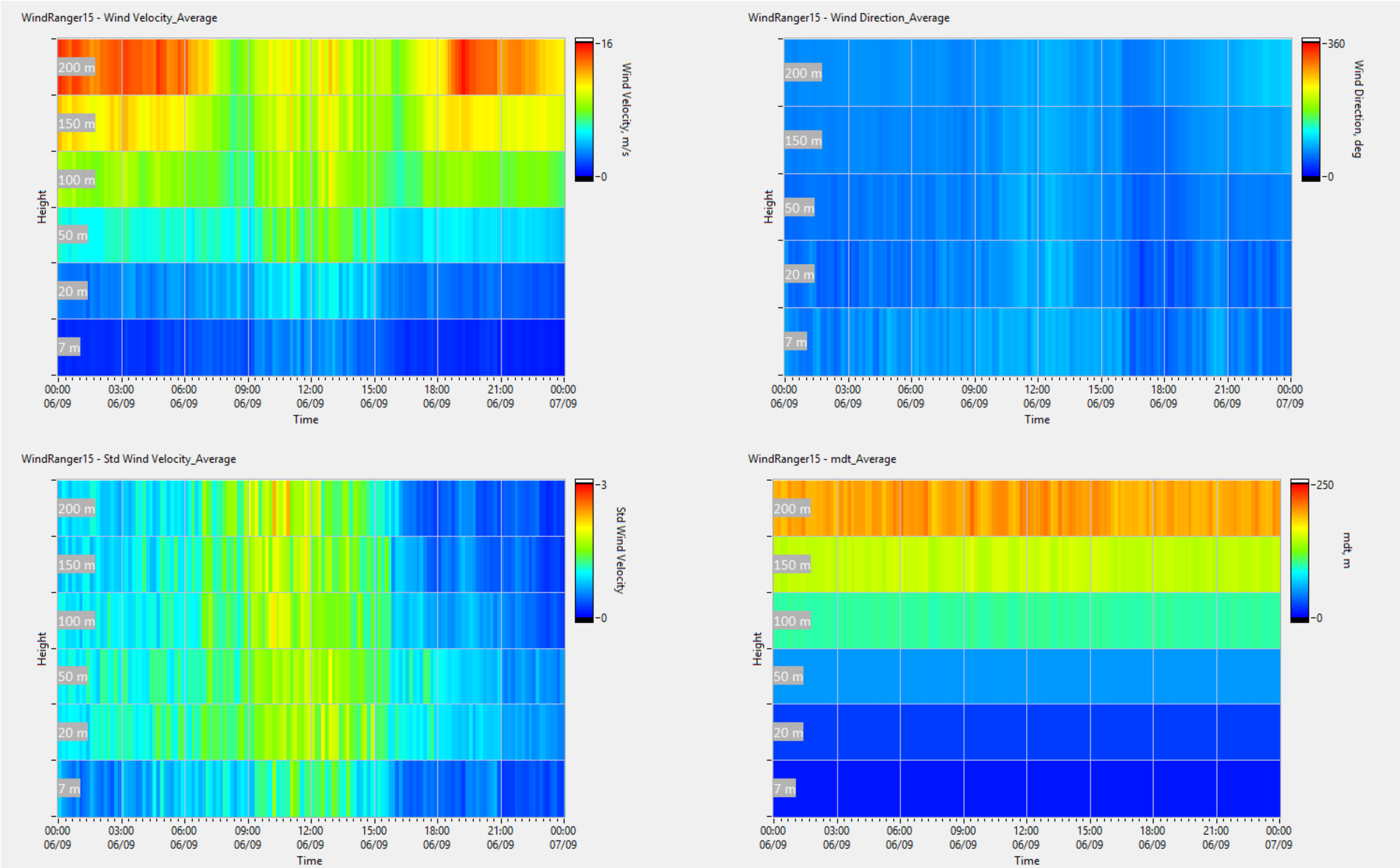
Pulsed Doppler lidar
Wind Ranger BL
35 m ... top of ABL

Urban and forest canopy flow

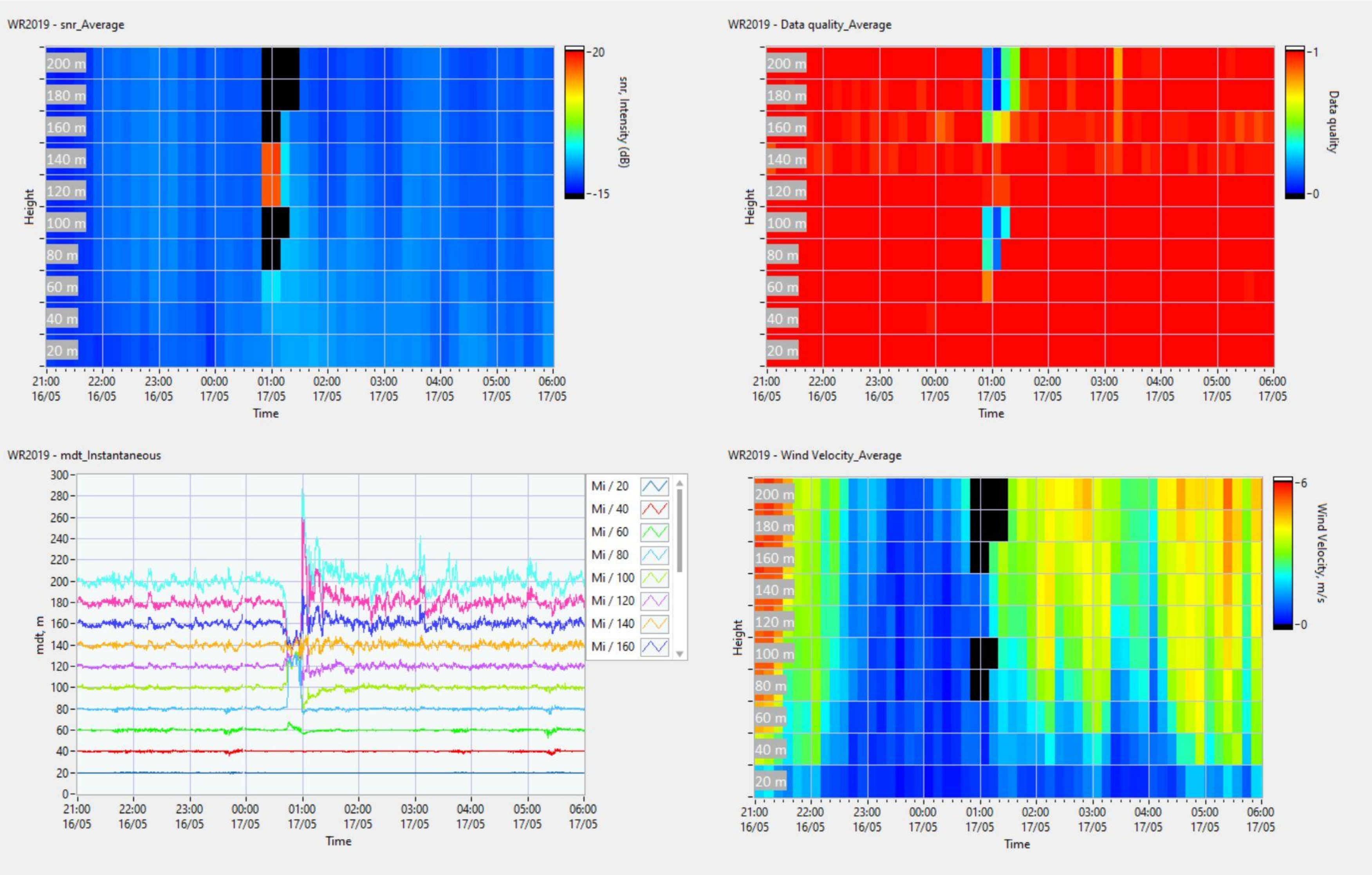
FMCW Doppler lidar **Wind Ranger 200**

- 3D wind vectors from continuous VAD scans 80° elevation at a rate of 0.5 … 2 rps
- Sample rate 100 Hz
- Narrow scan angle 10 °, in favor of vertical wind measurements
- Measuring heights 7 … 200 m
- Range resolution 0.05 … 32 m
- Up to 20 measuring heights available (typ. 6 … 10)
- Consecutive measurements -> composite profiles take 5 - 20 s
- No 180° ambiguity, no blind zero zone
- Determination of the effective measuring range
- Compact and light weight, 620 m x 415 mm x 550 mm w/o feet, 50 kg

FMCW Doppler lidar **Wind Ranger 200**



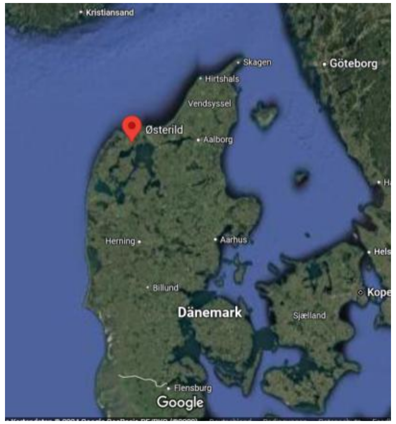
Detection of low hanging clouds



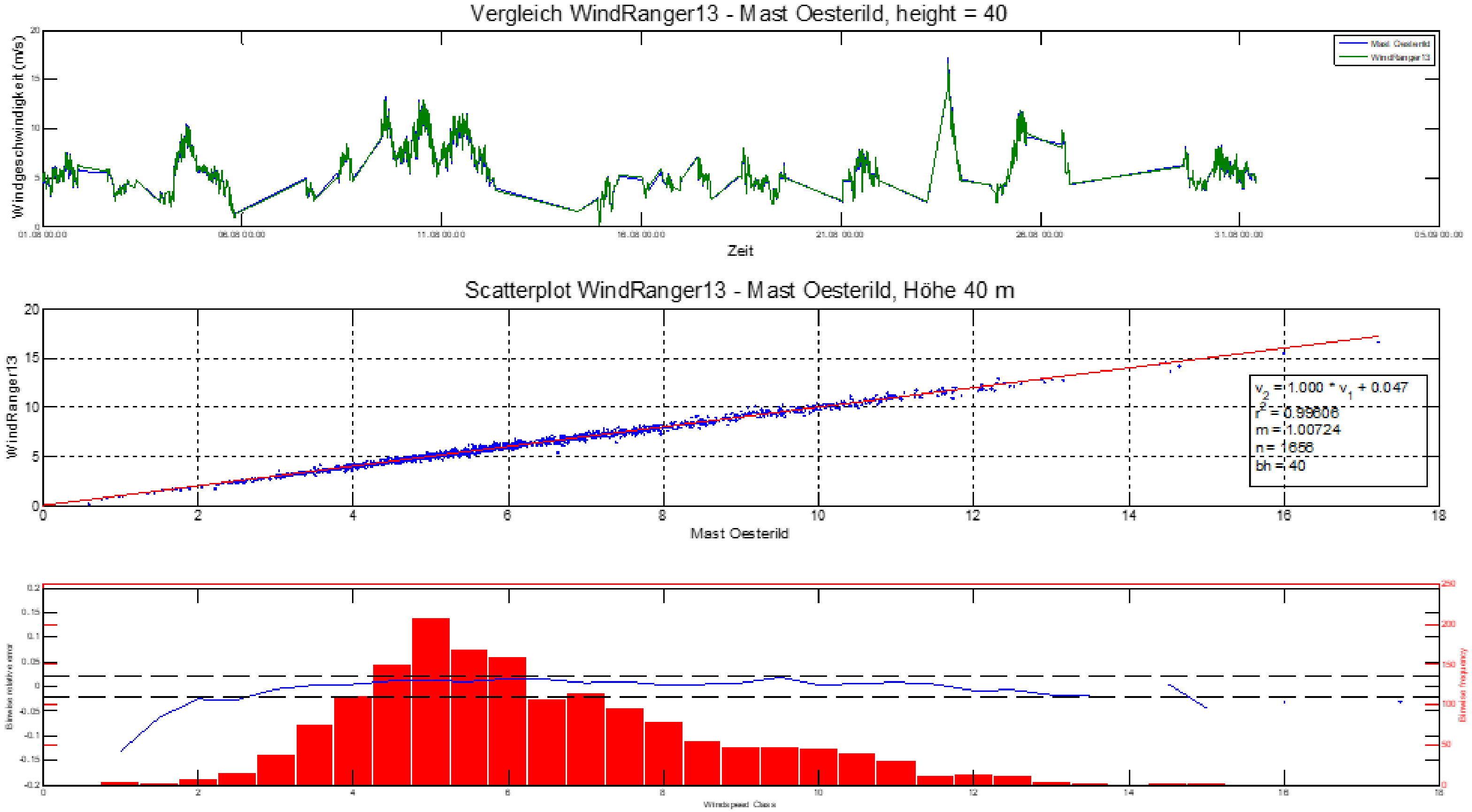
Ceilometer confirms cloud layer at ~140 m

Thank you to Geosphere for providing this data

Comparison against MEASNET-mast Oesterild



08/2024, 40 m,
Data gaps due to disturbed wind directions

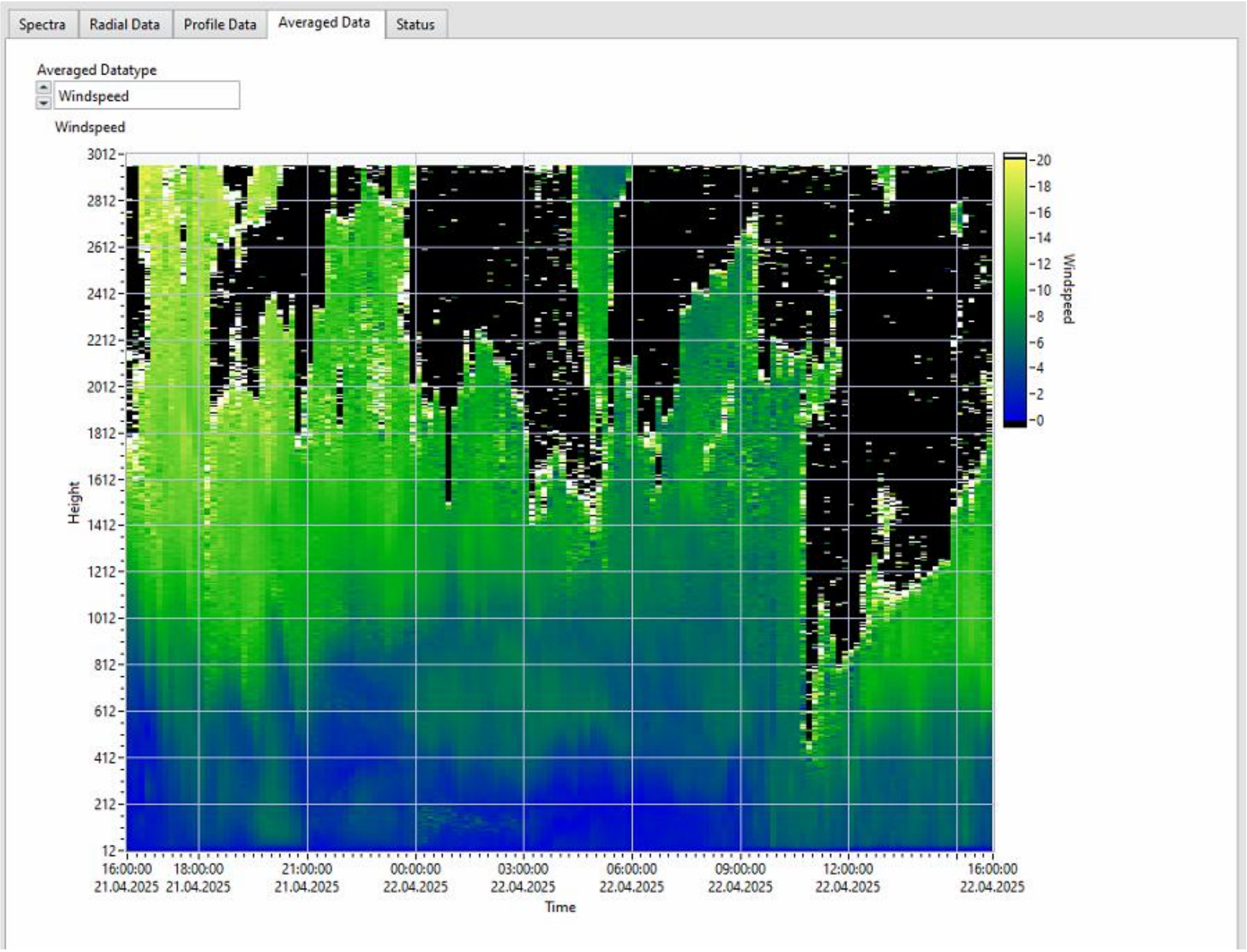


Y = 1,00 + 0,05
R^2 = 0,996
m = 1,01

Pulsed Doppler lidar **Wind Ranger BL**

- 3D wind vectors from continuous VAD scans 80° elevation at a rate of 1 rps
- Narrow scan angle 10 °, in favor of vertical wind measurements
- Pulse rate 10 kHz
- Adjustable pulse length 165 ... 660 ns
- Measuring heights 40 m ... Top of ABL
- Up to 2000 measuring heights available
- Compact and light weight, 620 m x 415 mm x 550 mm w/o feet, 50 kg

Pulsed Doppler lidar **Wind Ranger BL**



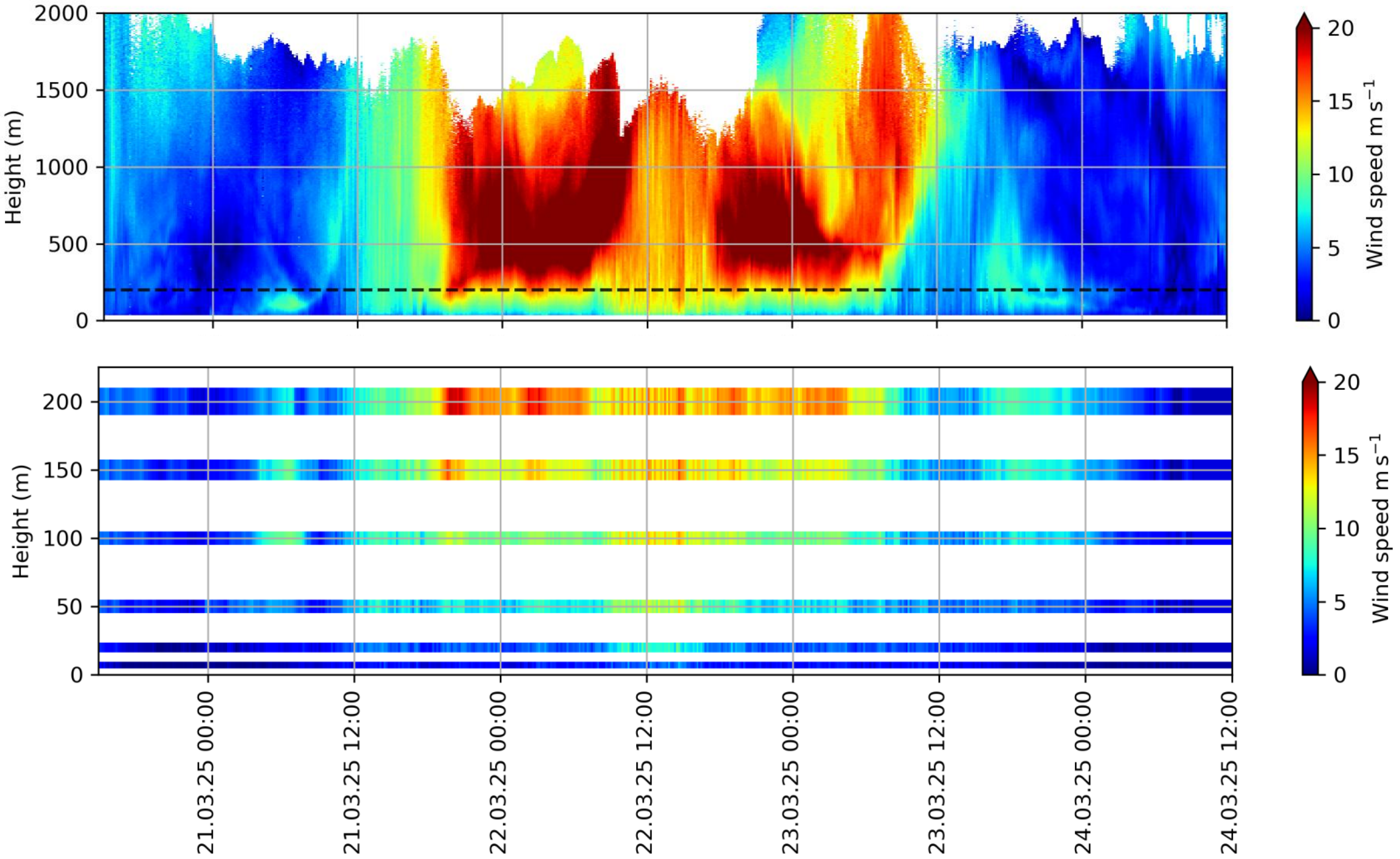
Comprehensive wind profiling of the atmospheric boundary layer

Wind Ranger BL
3060 m … 35 m

$\Delta z = \sim 25$ m

Wind Ranger 200
200 m … 7 m

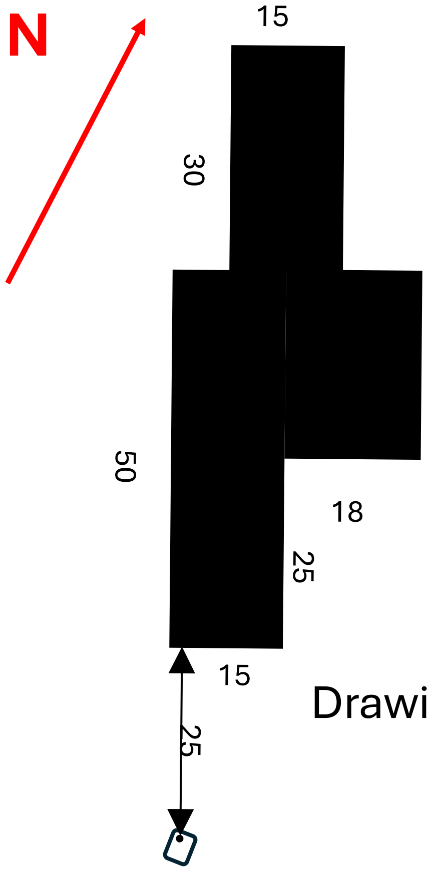
$\Delta z \propto z^2$



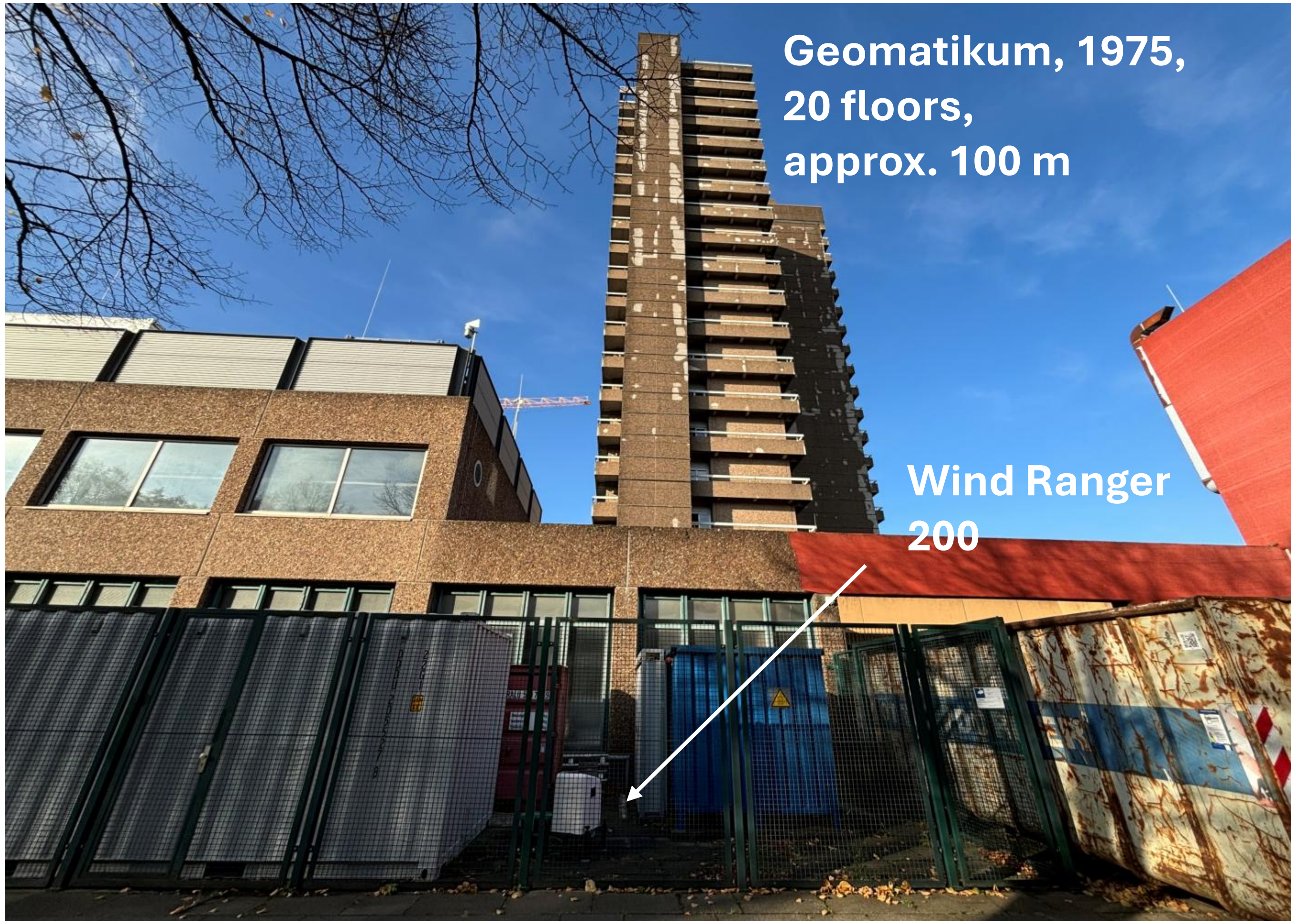
Conclusions and Outlook

- Deployment of compact and light weight pulsed and FMCW Doppler lidars facilitates monitoring of “entire” ABL in good weather conditions
- Fine resolution in low ranges, 8 cm in 7 m height
- Lowest heights down to 7 m
- Measurements to the upper limit of PBL are possible
- Pulsed and FMCW Doppler lidars are in very good agreement at common heights
- Narrow scan angles allow measurements inside street canyons, metropole areas and forests
- Measurement campaign performed in the immediate vicinity of a large building (100 m, Hamburg, Germany) => Data is available on request
- Further verification and measurement campaigns are planned in urban areas and forests.

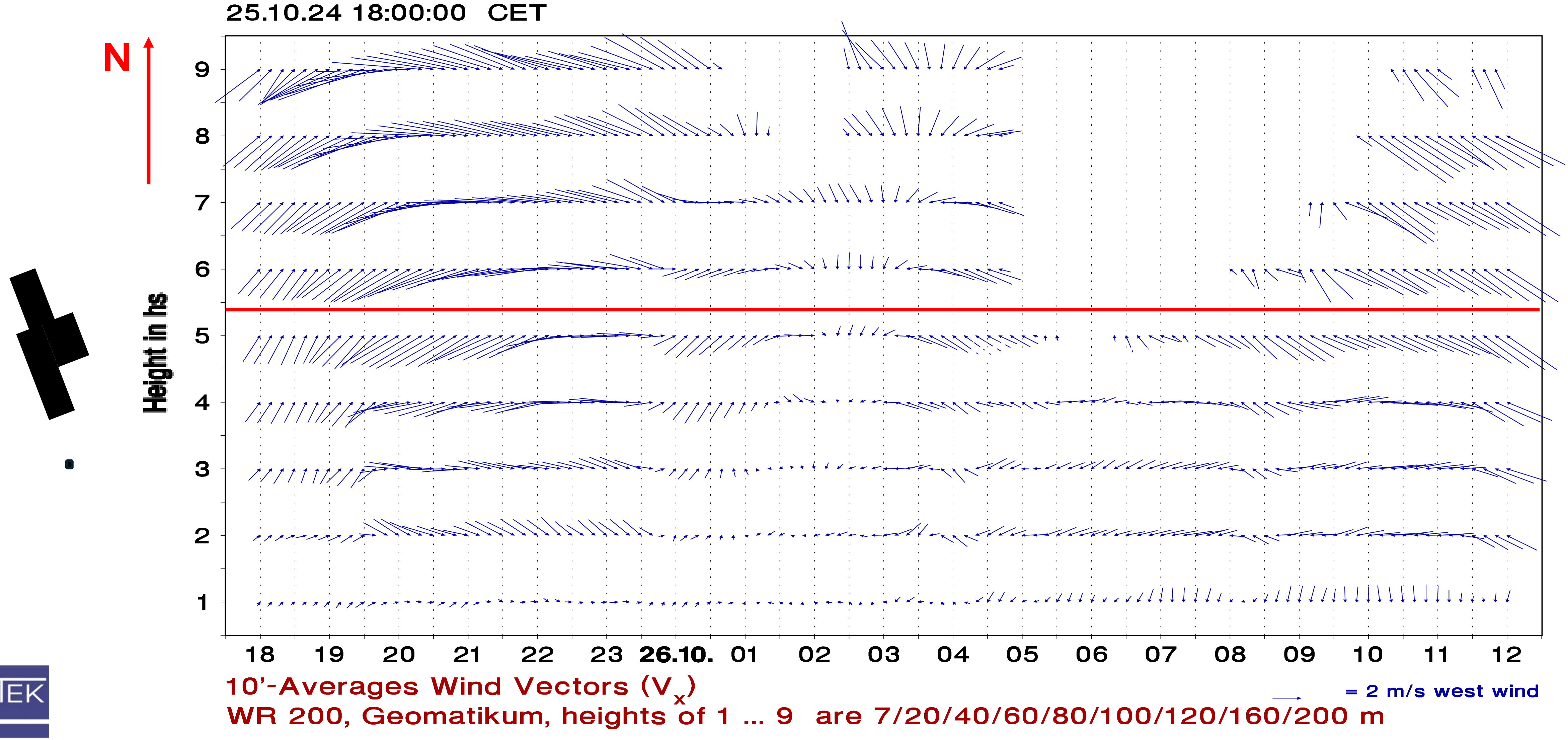
Appendix Lidar measurement campaign



Drawing Geomatikum



Appendix Lidar measurement campaign



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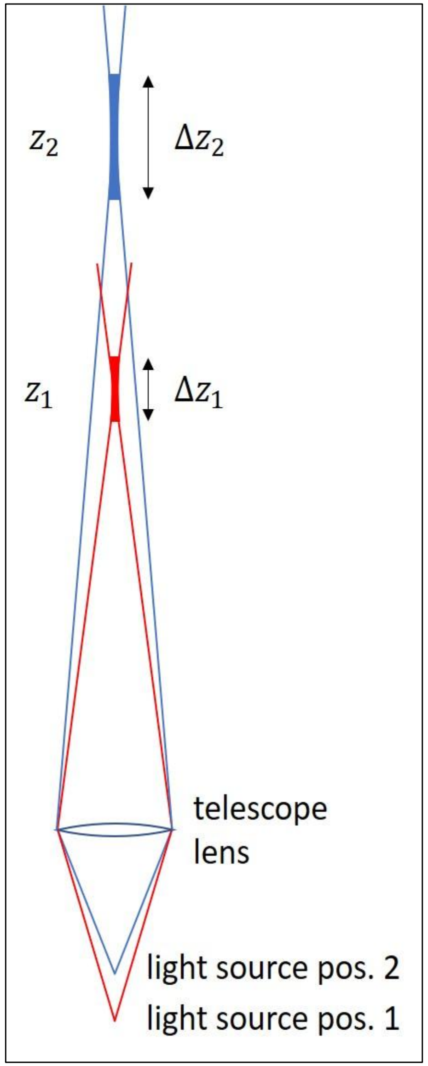
Appendix CW Doppler lidar systems



- 7 m -> ~0,05 m range resolution
- 20 m -> ~0,32 m range resolution
- 100 m -> ~8 m range resolution
- 200 m -> ~32 m range resolution

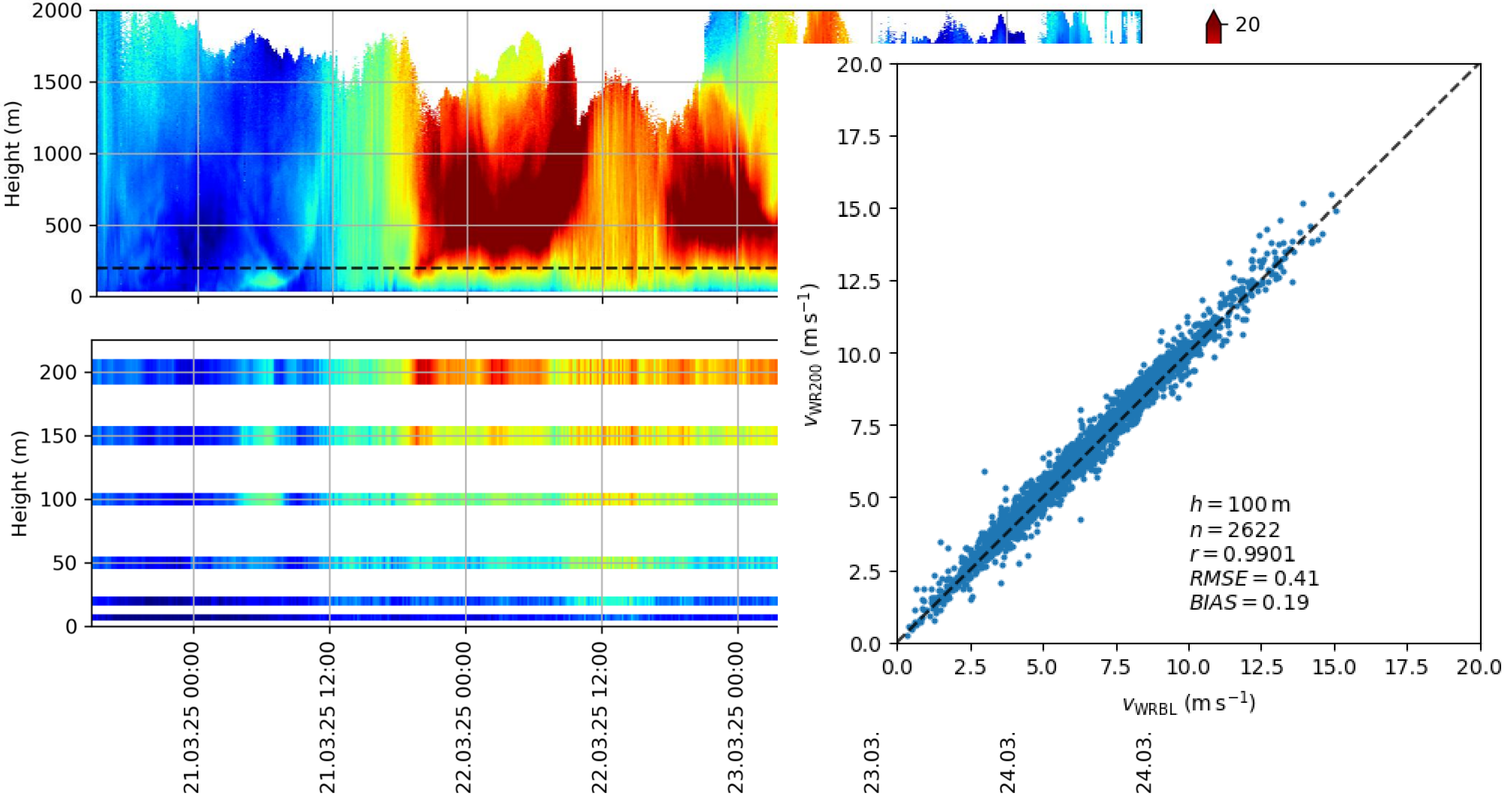
Appendix Agreement Wind Ranger BL and Wind Ranger 200

Wind Ranger BL
3060 m ... 35 m

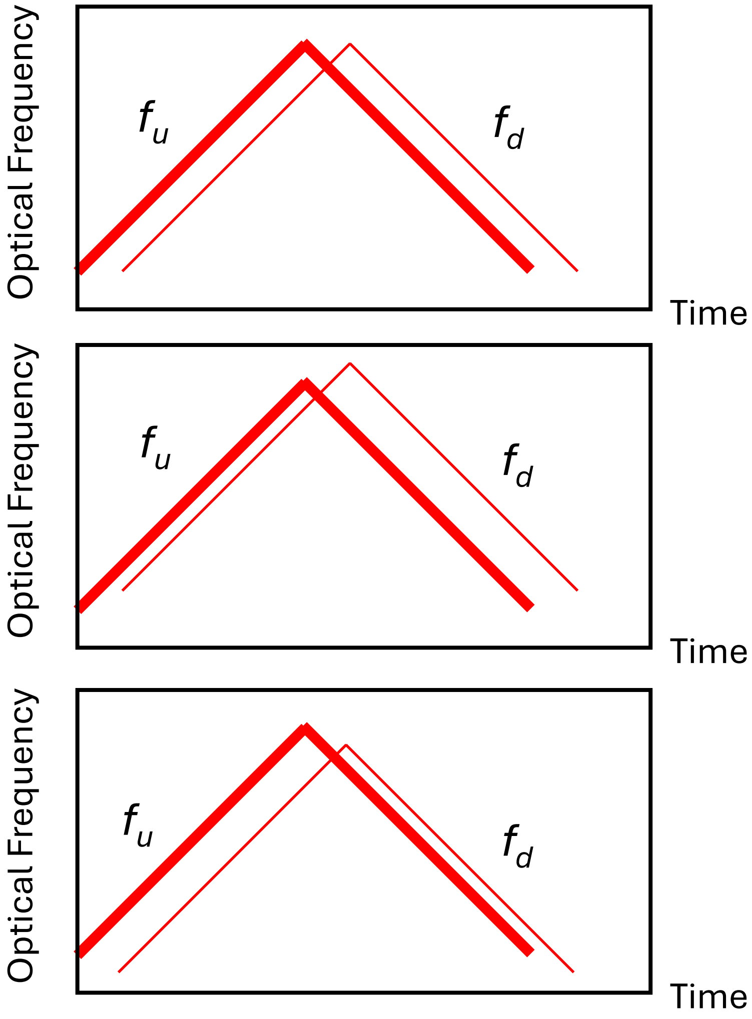
$\Delta z = \sim 25$ m

Wind Ranger 200
200 m ... 7 m

$\Delta z \propto z^2$



Appendix FMCW Doppler lidar Wind Ranger 200 principle



Case 1 velocity = 0:
Beat frequency at receiver depends only on distance to target

$$f_u = | f_{MOD}|$$
$$f_d = | - f_{MOD}|$$

Case 2 velocity > 0:
Beat frequency at receiver depends on distance to target and Doppler shift

$$f_u = | f_{MOD} + f_{Doppler} |$$
$$f_d = | - f_{MOD} + f_{Doppler}|$$

Case 3 velocity < 0:
Beat frequency at receiver depends on distance to target and Doppler shift

$$f_u = | f_{MOD} - f_{Doppler} |$$
$$f_d = | - f_{MOD} - f_{Doppler}|$$

f_u and f_d are the frequency shift between transmitted and received signal

Sum of f_u and f_d gives f_{MOD}, i.e. height

Sum of f_u *and* f_d gives f_{MOD}, i.e. height

Difference of f_u and f_d gives $f_{Doppler}$, i.e. wind component