Removal of range uncertainty of CW Wind Lidar by frequency modulation.

Gerhard Peters, Piet Markmann, METEK GmbH

Continuous wave (CW) wind Lidar is particularly useful for short ranges, where its range resolution is superior to pulsed Lidar.

The range resolution of CW Lidar is achieved by focusing the beam without trade-off between Doppler- and range-resolution as needed for pulsed Lidar.

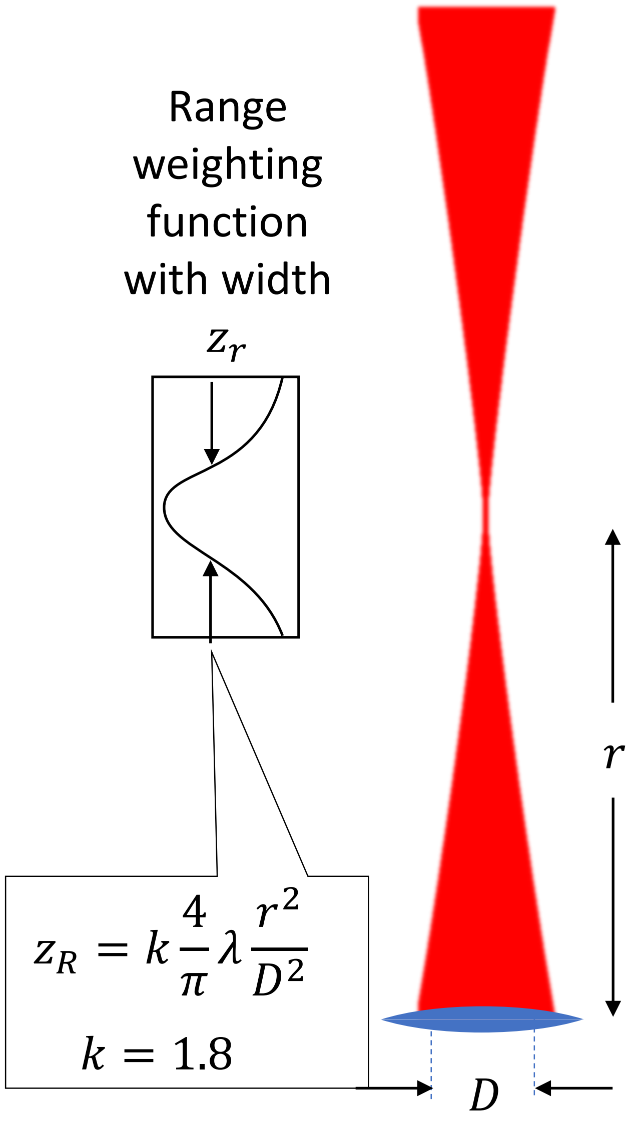
While focusing allows extremely fine resolution for short ranges, it becomes poorer proportional to the square of the range.

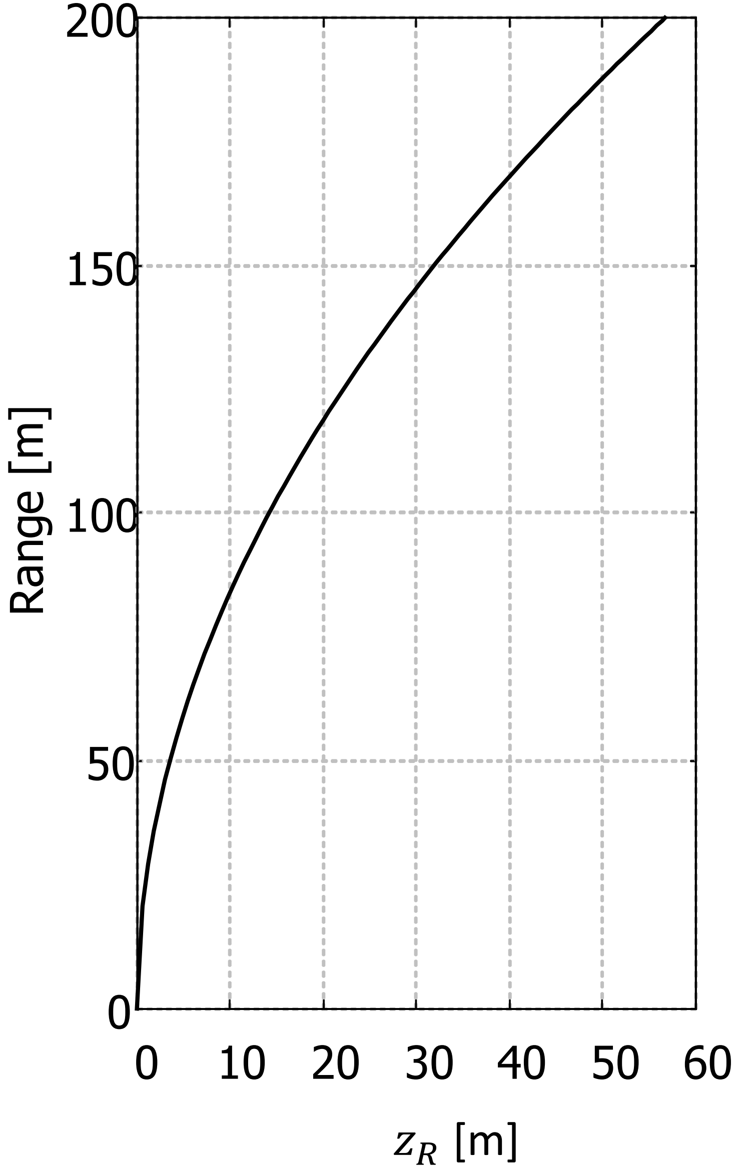
The useful sensing range scales with the beam diameter D at the Lidar telescope aperture. Nevertheless, there is an upper useful limit for D due to turbulent degradations of the beam. Therefore, the principal superiority to pulsed Lidar is lost at about 100 m and the useful range is limited to about 200 m. The next slide shows the relation beween range and range resolution for $D = 5\ \mathrm{cm}$.

Since the focus induced range weighting is a Lorentz function with fat tails, inhomogeneous reflectivity distribution can cause significant shifts of the center of gravity of the scattering volume, and thus deviations of the effective from the nominal measuring height (focus height). These deviations are of primary concern at the upper part of the measuring range, where the range resolution is coarse.

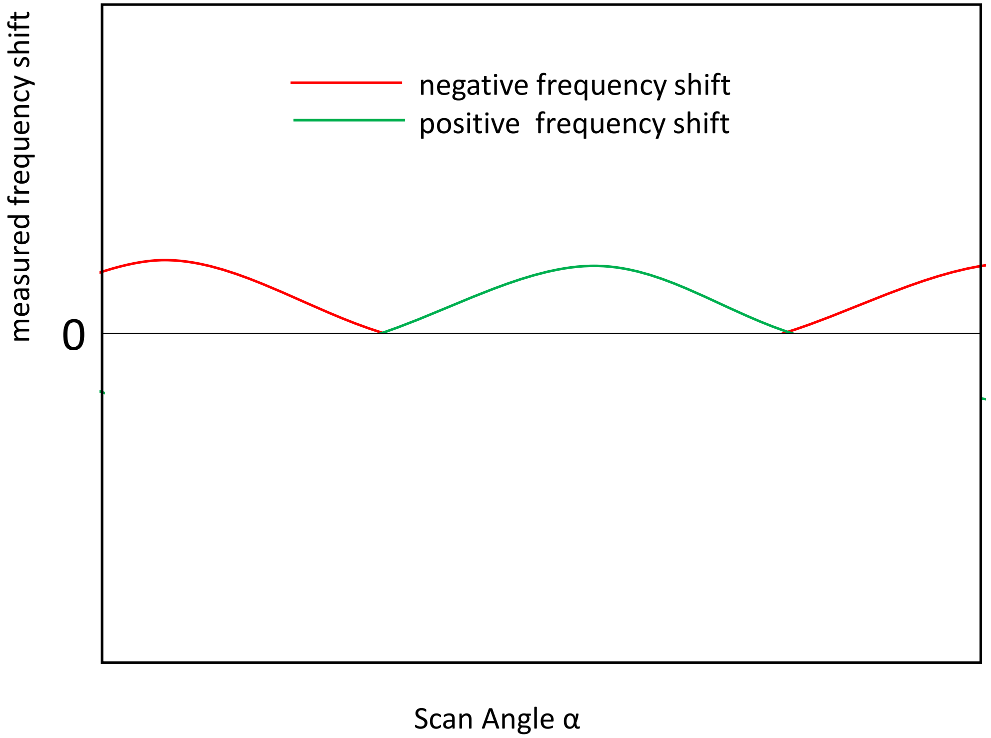
By frequency modulation of the transmit signal and suitable signal analysis the actual center of gravity of the measuring height can be detected. In addition, echoes from clouds above the focus range, which would dominate the signal in case of CW Lidar, cause a separate spectral peak, which is recognized as off-focus signal and can be discarded.

Another benefit of frequency modulation is the detection of the sign of the Doppler shift. This renders auxiliary wind direction measurements or expensive frequency shift devices unnecessary.

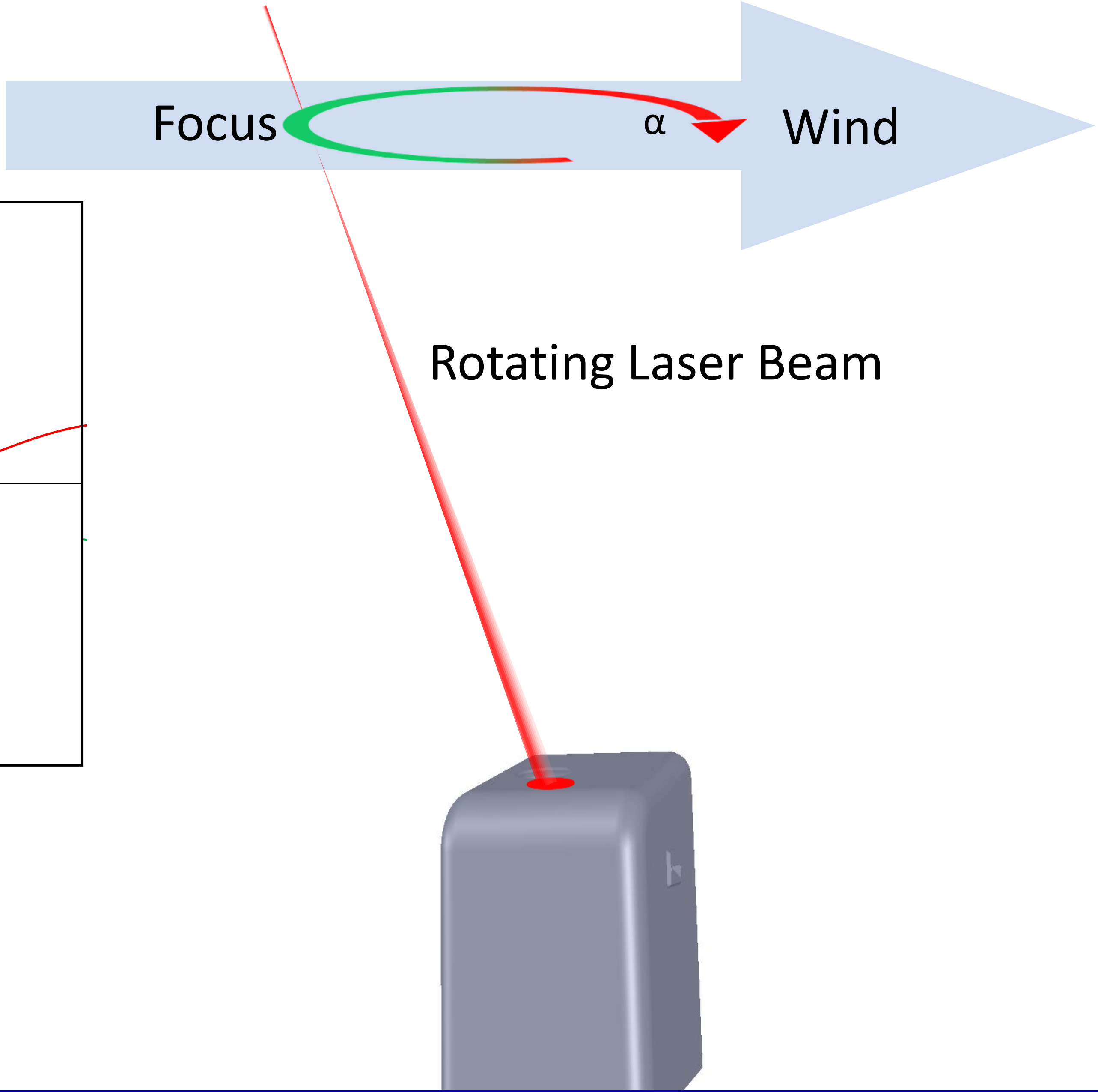

Range
weighting
function
with width
z_r
$z_R = k\frac{4}{\pi}\lambda\frac{r^2}{D^2}$
$k = 1.8$
r
D


Range [m]
200
150
100
50
0
0
10
20
30
40
50
60
z_R [m]

CW Lidar

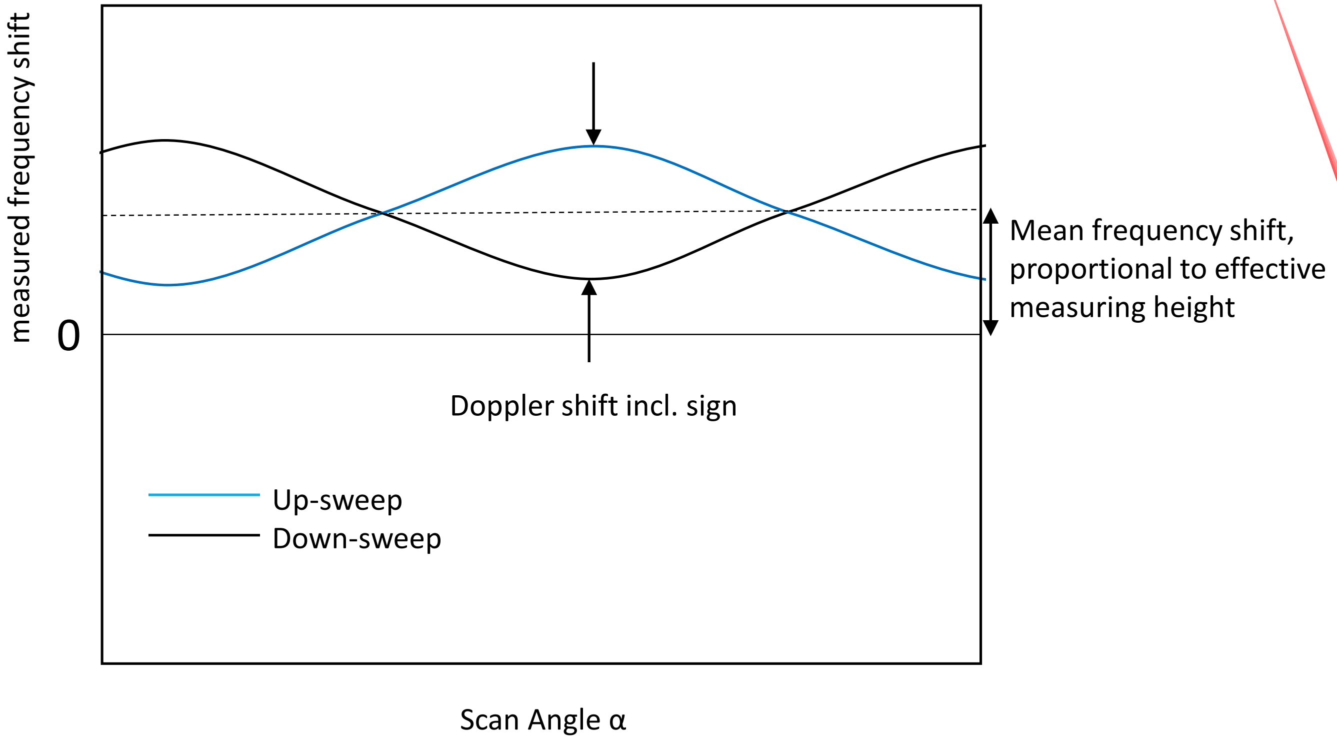


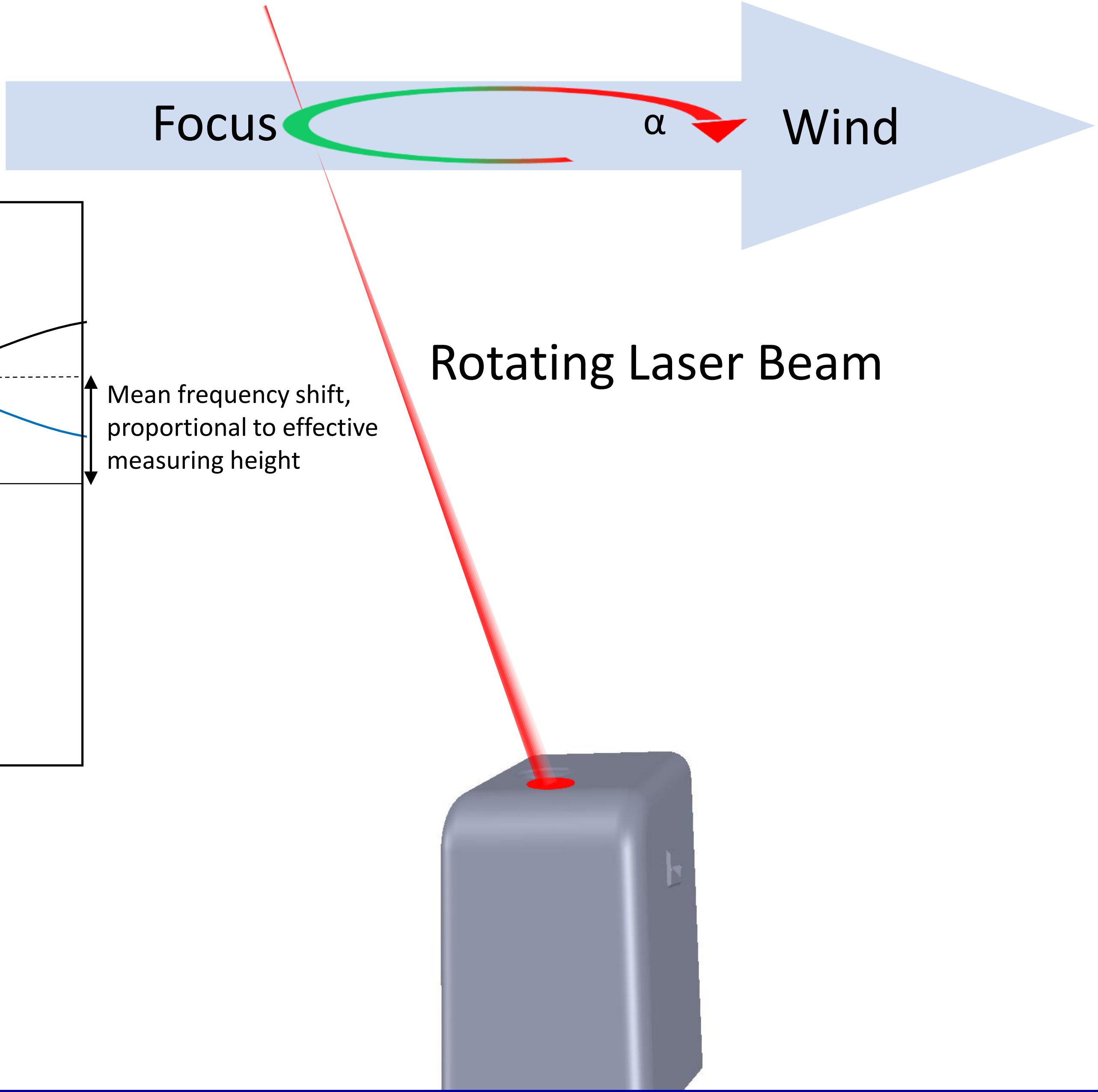
negative frequency shift
positive frequency shift
measured frequency shift
0
Scan Angle α



Focus
α
Wind
Rotating Laser Beam

FM-CW Lidar


measured frequency shift
0
Mean frequency shift, proportional to effective measuring height
Doppler shift incl. sign
Up-sweep
Down-sweep
Scan Angle α


Focus
α
Wind
Rotating Laser Beam

The following two slides show 24 h with FMCW-Lidar wind measurements at two nominal measuring heights: Next slide 10 m, second next slide ~170 m.

Each slide has four panels showing

- wind speed
- wind direction
- mean vertical wind
- standard deviation of vertical wind.

Common in all panels is the indication of the effective and nominal measuring height (MDT, mean distance to target) by dashed dotted lines.

The plot position of the nominal MDT (blue line) is scaled to appear at center of the y-range in each panel. The effective MDT is normalized to the nominal MDT.

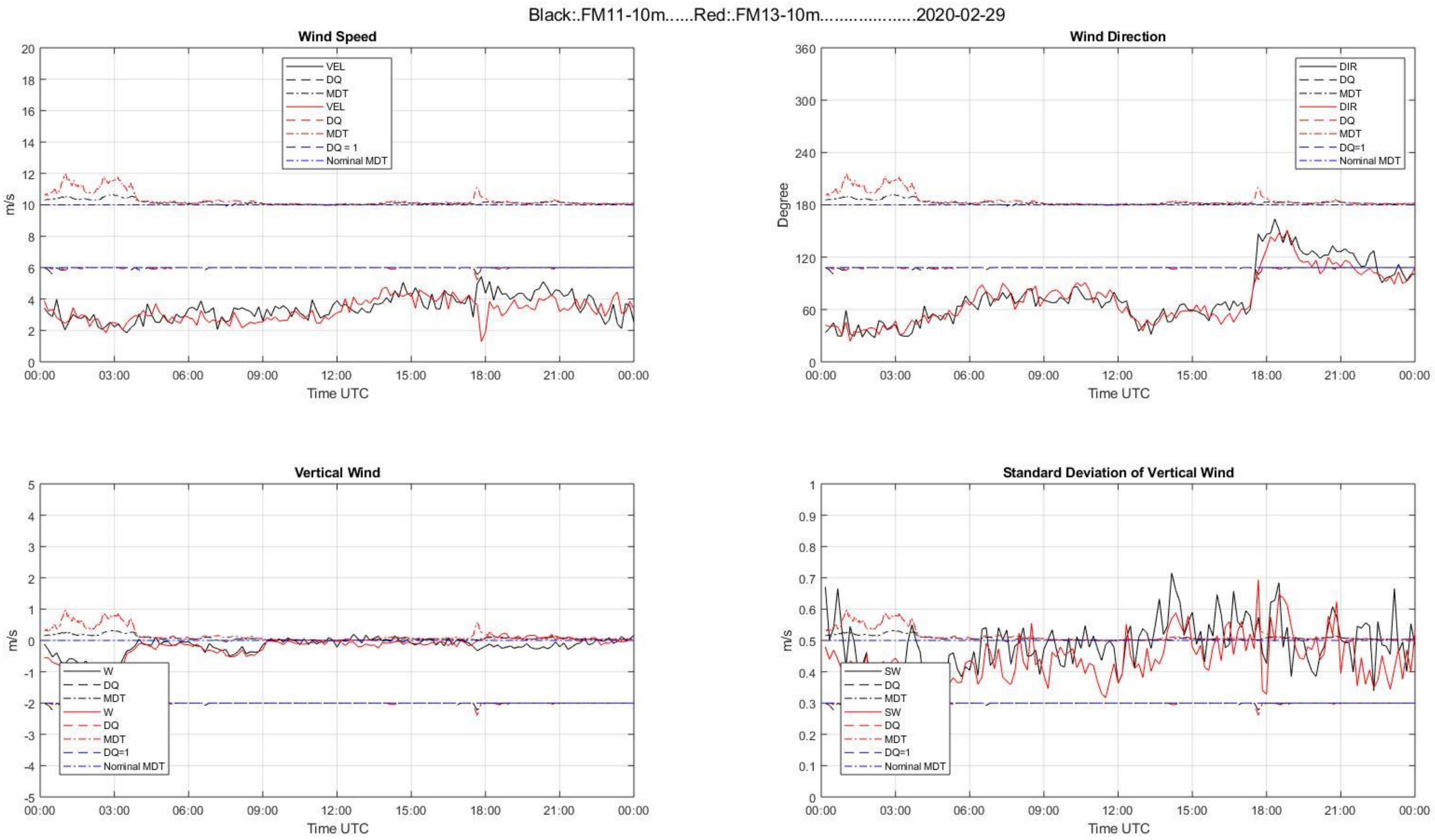
In addition, a data quality parameter (DQ, dahed lines) is shown, which is based on a suite of plausibilty checks on several signal processing levels. The best possible value is indicated by the blue line, scaled to appear at 0.3 of the y-range in each panel. The actual DQ is <= DQ-best and plotted normalized to DQ-best.

Two FM-CW-Lidars were operated side by side. (FM11: Black lines, FM13: Red lines.) Generally the deviations of MDT show the same trend for both systems, which corroborates our assumption that we see atmospheric effects rather than (individual) technical misfunctions.

For nominal MDT = 10 m there is perfect agreement with the effective MDT most of the time. This is expec-ted, because the focus is well defined at this short range.
Nevertheless, during the first three hours there occurs a significant deviation. During this interval the vertical component is strongly negative, which indicates rain fall. The reason for the MDT deviation is not fully understood here, but may be related to the violation of the beam filling target model in case of rain drop scattering.

For nominal MDT = 170 m deviations up to more than 50% of the nominal height occur during the first 4 hours. The effective MDT reaches up to 250 m. This example shows that the measurement of MDT can present a significant added value.

(The short but very high deviation of MDT/FM11 at 09:30 is accompanied by a deep dip of DQ, so that these measurements would be discarded as invalid.)


Black:.FM11-10m......Red:.FM13-10m..................2020-02-29
Wind Speed
m/s
Time UTC
VEL
DQ
MDT
VEL
DQ
MDT
DQ = 1
Nominal MDT
Wind Direction
Degree
Time UTC
DIR
DQ
MDT
DIR
DQ
MDT
DQ=1
Nominal MDT
Vertical Wind
m/s
Time UTC
W
DQ
MDT
W
DQ
MDT
DQ=1
Nominal MDT
Standard Deviation of Vertical Wind
m/s
Time UTC
SW
DQ
MDT
SW
DQ
MDT
DQ=1
Nominal MDT

Black:.FM11-170m......Red:.FM13-176m.................2020-02-29