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METEOTEST

Documentation and results of the SODAR and LIDAR Measurements at the Maligrad site in Bosnia and Herzegovina

Measurement Campaign from October 30th 2007 to February 4th 2008 (SODAR) and November 20th 2007 to December 10th 2007 (LIDAR)

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1. Introduction

The South East Europe Wind Energy Exploitation (SEEWIND) project[1], embedded in the 6th framework program of the European Commission, aims to gain experience in wind measurements, site development and operation of wind turbines in complex terrain. In order to get information about the vertical wind profile at a Bora-dominated site in Bosnia and Herzegovina, SODAR and LIDAR measurements were carried out by *METEOTEST*.

Vjetroenergetika is planning the installation of a wind farm at the Maligrad site in Bosnia and Herzegovina and therefore a 30 m mast has been installed by the Austrian company Energiewerkstatt in November 2006.

This report outlines the SODAR and the LIDAR measurements at the Maligrad site which have been carried out between the 30th of October 2007 and 4th of February 2008 and between the 20th of November 2007 and 10th of December 2007 respectively. A detailed comparison of the vertical wind profiles measured with SODAR and LIDAR will be presented in an additional report.

[1] http://www.seewind.org/

2. The measurement site

The measurement site was located on a high plateau east of the village of Mostar at an altitude of 752 m above sea level. The SODAR and the LIDAR were installed within a distance of 10 m. The mast was located 47 m away from the SODAR to the east. All coordinates are listed in Tab. 1. Fig. 1 shows an overview of the area. The photos on Fig. 2 show panoramic pictures taken from the measurement position towards south and north.

Tab. 1: Coordinates of SODAR, LIDAR and 30 m mast at Maligrad.

Maligrad	Coordinates (UTM WGS 84, zone 33)	Altitude
SODAR	731'260 / 4'803'514	752 masl
LIDAR	731'270 / 4'803'526	752 masl
30 m mast	731'317 / 4'803'530	752 masl

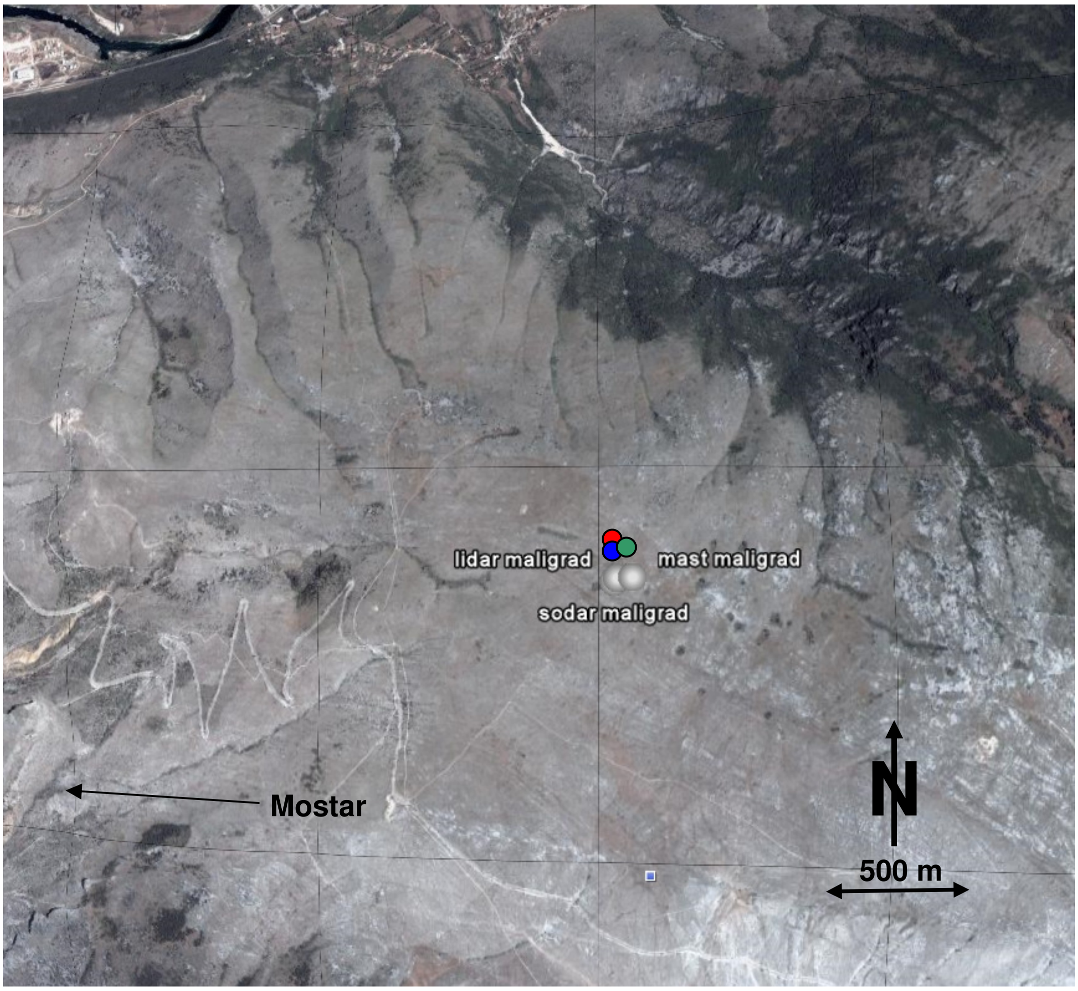

Fig. 1: Location of the SODAR (blue), the LIDAR (red) and the 30 m mast (green) at Maligrad (source: Google Earth).

Fig. 2: Panoramic pictures taken after sunset at the measurement site facing south (left) and north (right).

3. The measurement campaign

3.1. SODAR configuration

The installed SODAR was of type Aerovironment miniSODAR 4000F. Tab. 2 shows the configuration of the SODAR and Fig. 3 the installed SODAR at Maligrad with the LIDAR and the 30 m mast in the background.

Tab. 2: Configuration of the Aerovironment miniSODAR 4000F.

Parameter	**Value**
Minimum measuring height	20 m
Maximum measuring height	150 m
Measuring interval	10 m
Averaging interval	10 min
Alignment of the antenna	172°

3.2. SODAR measurement protocol

The measurement campaign started on the 30th of October 2007 and ended on the 4th of May 2008. A battery pack, once or twice a day loaded by a diesel generator was used as power supply. Tab. 3 shows the measurement protocol of the campaign. Several short incidents occurred due to technical problems with the generator. According to information received from locals no snowfall was expected at this time of year. But on November 15th a heavy snowfall filled the SODAR casing. Because the heating was not activated the snow did not melt and drain through the bottom holes. When temperatures raised again the melting snow-water penetrated into the electronics of the SODAR and produced a short circuit. On November 20th major revisions were carried out to repair the SODAR.

Tab. 3: SODAR measurement protocol for Maligrad.

Event	**Date / Time (CET)**	
Start of SODAR measurements	October 30th 2007, 11:20	
SODAR failures	**Begin**	**End**
Interruption of SODAR measurements: generator problems	November 8th 2007, 11:30	November 9th 2007, 08:40
Interruption of SODAR measurements: generator problems	November 12th 2007, 13:50	November 13th 2007, 11:20
Heavy snowfall: SODAR failure	November 15th 2007, 10:00	November 20th 2007, 15:10
Interruption of SODAR measurements: generator problems	November 21st 2007, 01:50	November 21st 2007, 09:00
Interruption of SODAR measurements: generator problems	December 10th 2007, 05:30	December 10th 2007, 08:50
Interruption of SODAR measure-	December 10th 2007, 19:20	December 11th 2007, 07:30

ments: generator problems		
Interruption of SODAR measurements: generator problems	December 18th 2007, 06:00	December 18th 2007, 11:00
Interruption of SODAR measurements: generator problems	December 24th 2007, 08:40	December 26th 2007, 09:30
Interruption of SODAR measurements: generator problems	December 31st 2007, 07:50	December 31st 2007, 09:30
Interruption of SODAR measurements: generator problems	January 5th 2008, 18:30	January 6th 2008, 09:10
End of SODAR measurements		February 4th 2008, 13:10

3.3. LIDAR configuration

The installed LIDAR was of type ZephIR[2]. Tab. 4 shows the configuration of the LIDAR and Fig. 3 the installed LIDAR at Maligrad.

Tab. 4: Configuration of the LIDAR.

Parameter	Value
Measurement heights above ground	30 m, 60 m, 80 m, 100 m, 150 m
Sampling interval	3 seconds
Averaging interval	10 minutes
Alignment of instrument, offset from geographic north	357°

3.4. LIDAR measurement protocol

The measurement campaign started on the 20th of November 2007 and ended on the 10th of December 2007. Tab. 5 shows the measurement protocol. No incidents occurred during the measurement campaign.

Tab. 5: Measurement protocol for Maligrad.

Event	Date / Time (CET)
Start of LIDAR measurements	November 20th 2007, 15:20
End of LIDAR measurements	December 10th 2007, 09:00

[2] http://www.naturalpower.com/zephir-laser-anemometer (January 2009)

Fig. 3: Picture with the 30 m mast (right), the LIDAR (middle) and the SODAR (left).

4. Data availability

4.1. SODAR

SODAR measurements do not produce complete time series, because factors like surrounding noises, clouds, atmospheric stabilities or precipitation lead to gaps in the data sets. These effects are filtered from the data sets considering the surrounding noise or the signal-to-noise ratio. Fig. 4 shows the time series of the data availability at each measurement level for the entire measurement campaign at Maligrad, Fig. 5 shows the amount of available data at each level after cleaning the data.

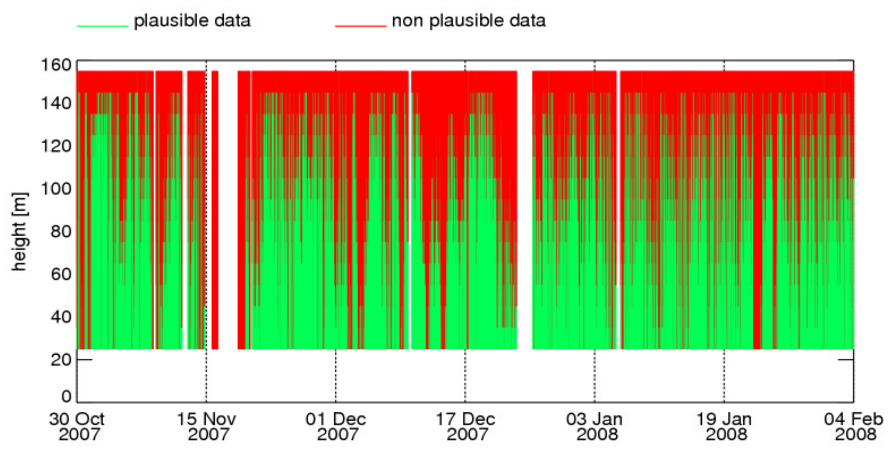

Fig. 4: Time series of the data availability of the SODAR measurements at Maligrad for each measurement level. Plausible data are displayed in green, rejected values in red.

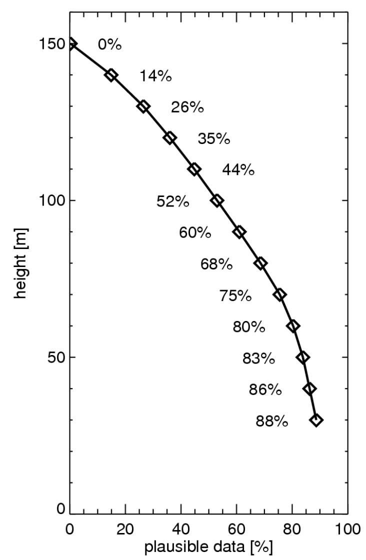

Fig. 5: Amount of available data of the SODAR measurements at each level at Maligrad.

4.2. LIDAR

Fig. 6 shows the time series of the data availability at each measurement level for the entire measurement campaign of the LIDAR. Between 9% (at 30 m) and 19% (at 150 m) of the data has been rejected (see Fig. 7). Data is rejected if an insufficient number of data points is collected at a certain level and time respectively. This happens in particular when the air is very dry. Additionally the LIDAR is not able to accurately measure wind speeds below 2 m/s. Therefore values below 2 m/s are rejected for further data analysis.

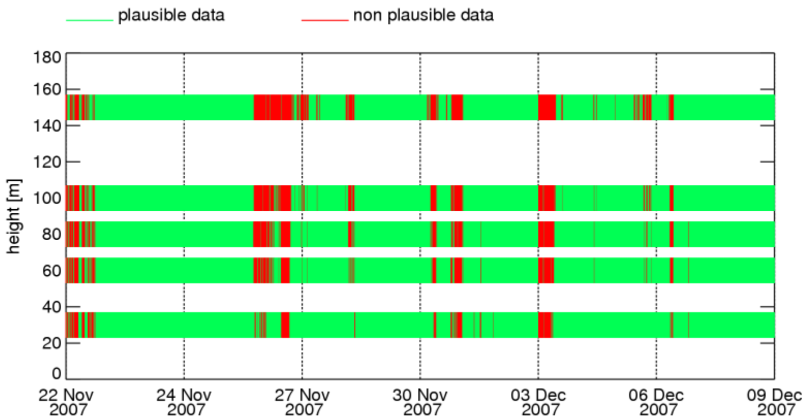

Fig. 6: Time series of the data availability of the LIDAR measurements at Maligrad for each measurement level. Plausible data are displayed in green, rejected values in red.

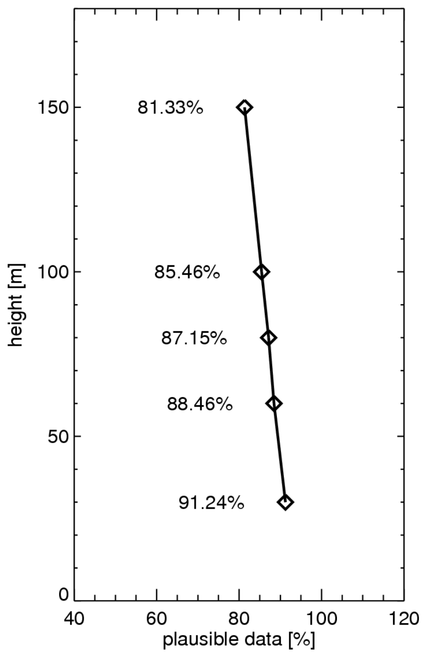

Fig. 7: Amount of available data of the LIDAR measurements at each level at Maligrad.

5. Results SODAR

5.1. Wind speed / wind direction SODAR

Fig. 8 shows the 10 minute wind speed values of the SODAR measurements at Maligrad for five levels, Fig. 9 the 10 minute wind direction values for five levels.

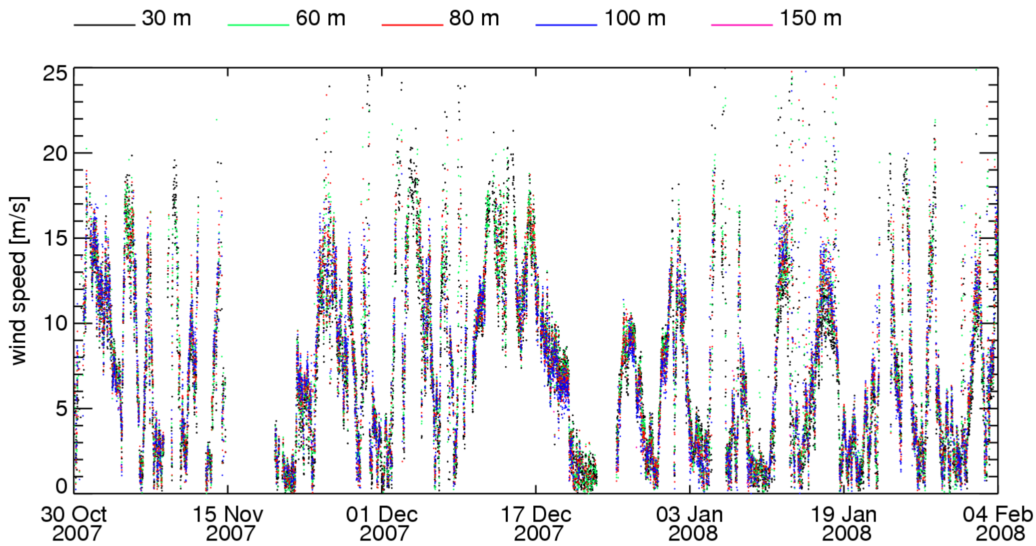

Fig. 8: The 10 minute wind speed averages of the SODAR measurements at Maligrad at 30, 60, 80, 100 and 150 m above ground.

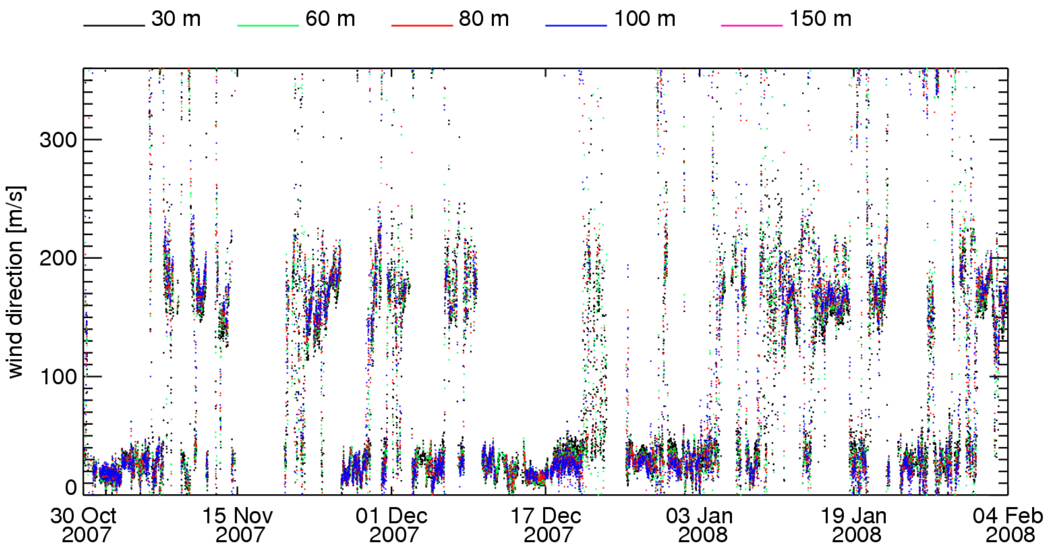

Fig. 9: The 10 minute wind direction averages of the SODAR measurements at Maligrad at 30, 60, 80, 100 and 150 m above ground.

5.2. Wind roses / turbulence roses SODAR

Fig. 10 shows wind roses and turbulence roses for five levels. During the measurement campaign winds from northeast and south-southeast were prevailing.

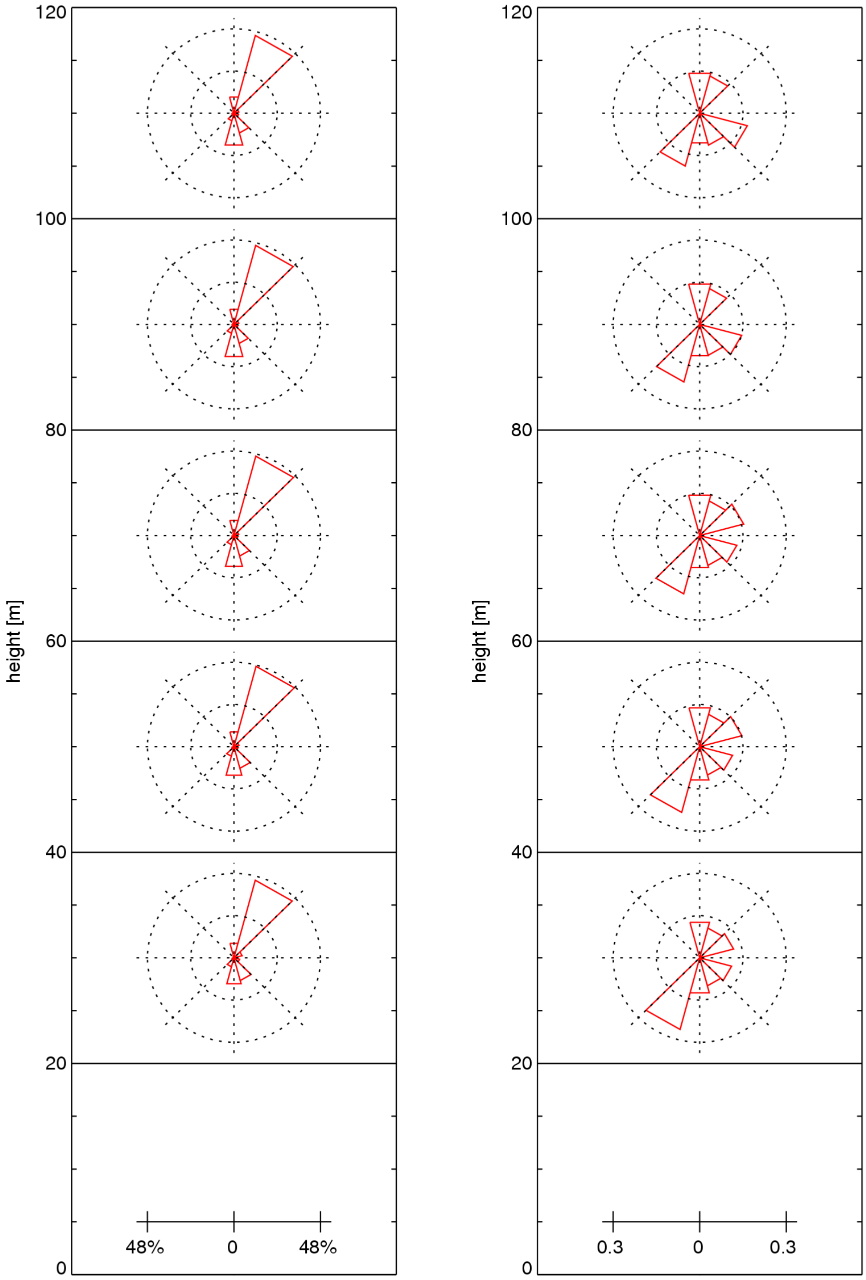

Fig. 10: Left: Wind roses of the SODAR measurement at Maligrad at 30, 50, 70, 90 und 110 m above ground. Right: Turbulence roses at 30, 50, 70, 90 und 110 m above ground. The calculation of the turbulence intensity has only been carried out for wind speeds greater than 4 m/s.

5.3. Vertical profiles of wind speed SODAR

Fig. 11 shows the vertical profiles of wind speed scaled to 30 m height in 30° wind direction sectors.

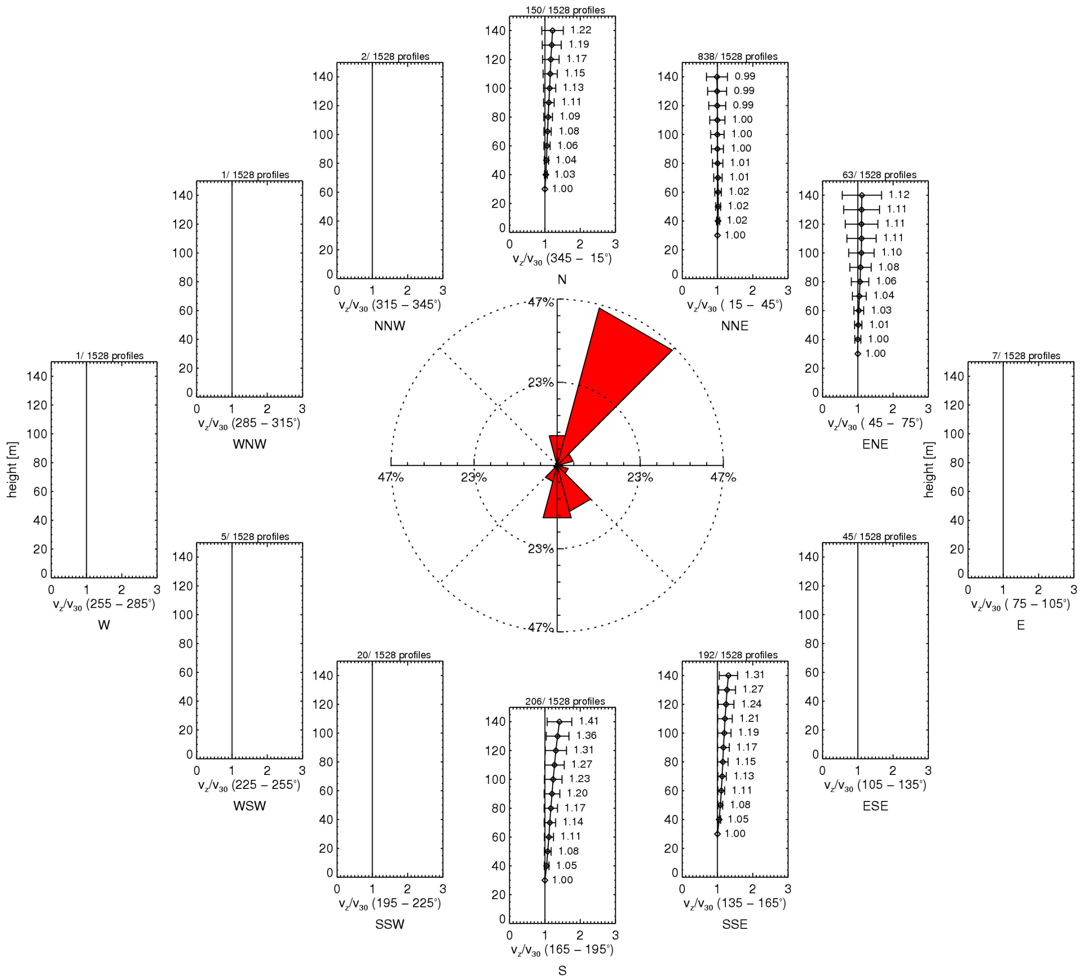

Fig. 11: Vertical profiles of wind speed for 30° wind direction sectors, scaled to 30 m height at the SODAR measurement site Maligrad. The bars indicate the standard deviation. No profiles are shown for sectors with less than fifty valid 10 minute averages. In the center the wind rose at 30 m is displayed.

Fig. 12 shows the vertical profiles of wind speed scaled to 30 m height for the main wind directions northeast and south-southeast for different wind speeds as well as the statistical mean errors of the profiles.

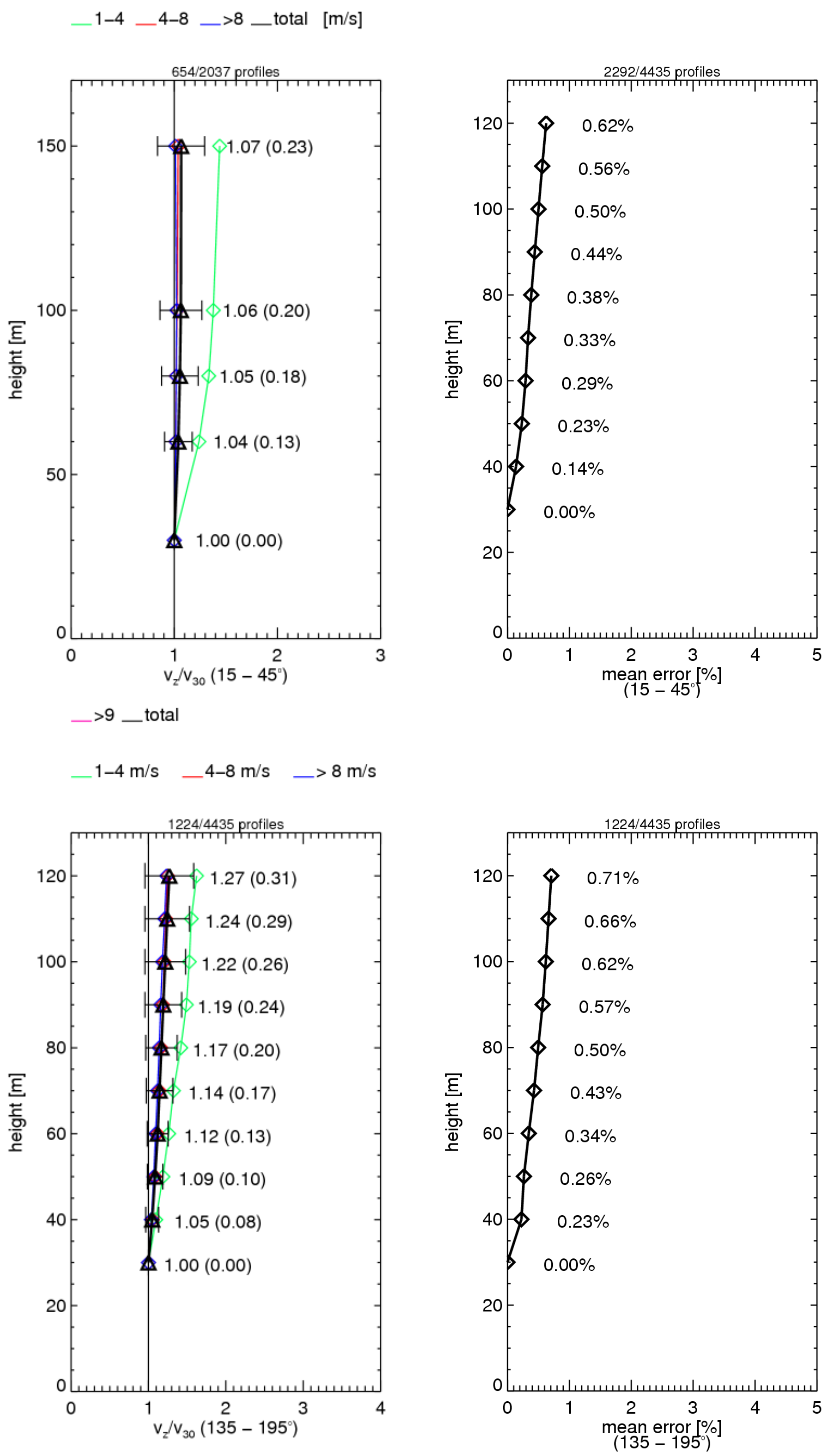

Fig. 12: Vertical profile of the wind speed for the main wind directions northeast (top) and south-southeast (bottom) for different wind speeds (left) and the mean error of the profile (right).

5.4. Vertical profiles of turbulence SODAR

Fig. 13 shows vertical profiles of the turbulence intensity at Maligrad. Turbulence intensity was calculated only for wind speeds above 4 m/s. No turbulence was calculated for sectors/levels with less than ten valid 10 minute averages.

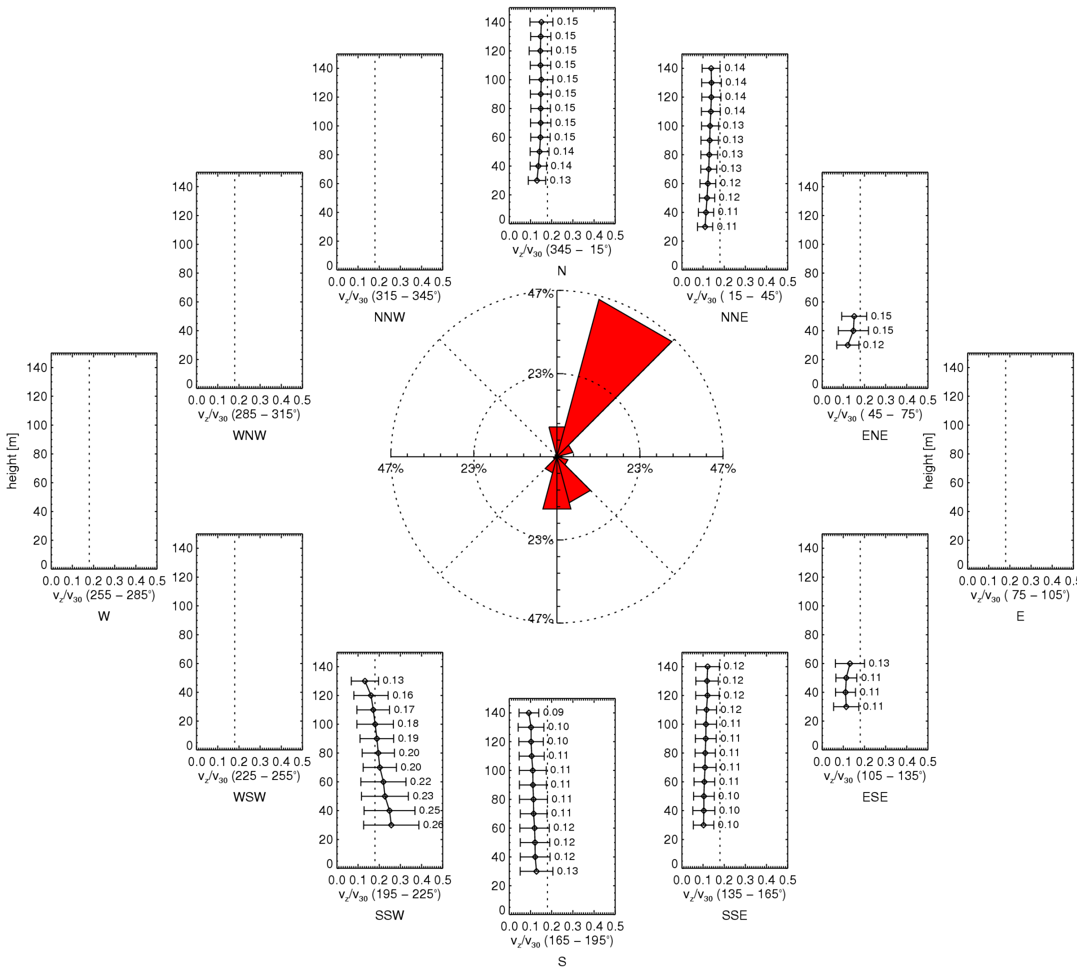

Fig. 13: Vertical profiles of turbulence intensity for 30° wind direction sectors at the SODAR measurement site Maligrad. The bars indicate the standard deviation. In the center the wind rose at 30 m is displayed. Turbulence intensity was calculated only for wind speed greater than 4 m/s. No turbulence was calculated for sectors/levels with less than ten valid 10 minute averages.

5.5. Vertical wind component SODAR

Fig. 14 shows the vertical component of the wind at Maligrad for the wind directions northeast (blue) and south-southeast (red).

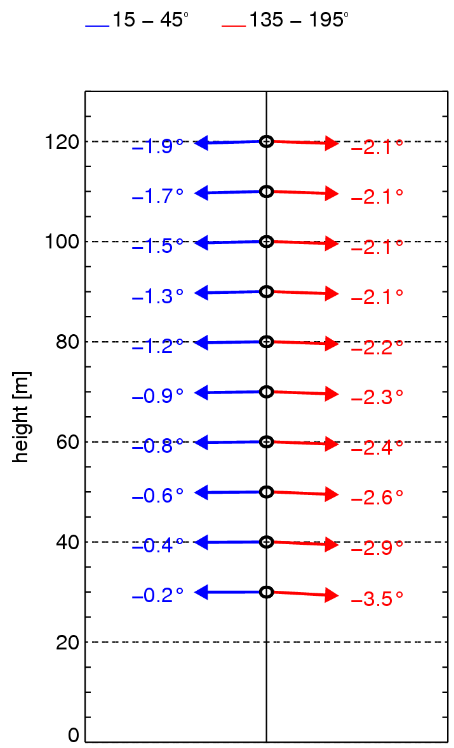

Fig. 14: Vertical component of the wind at Maligrad for the wind directions north-east (blue) and south-southeast (red).

6. Results LIDAR

6.1. Wind speed / wind direction LIDAR

Fig. 15 shows the 10 minute wind speed values of the LIDAR measurements at the Maligrad site for each measurement level, Fig. 16 the 10 minute wind direction for each level.

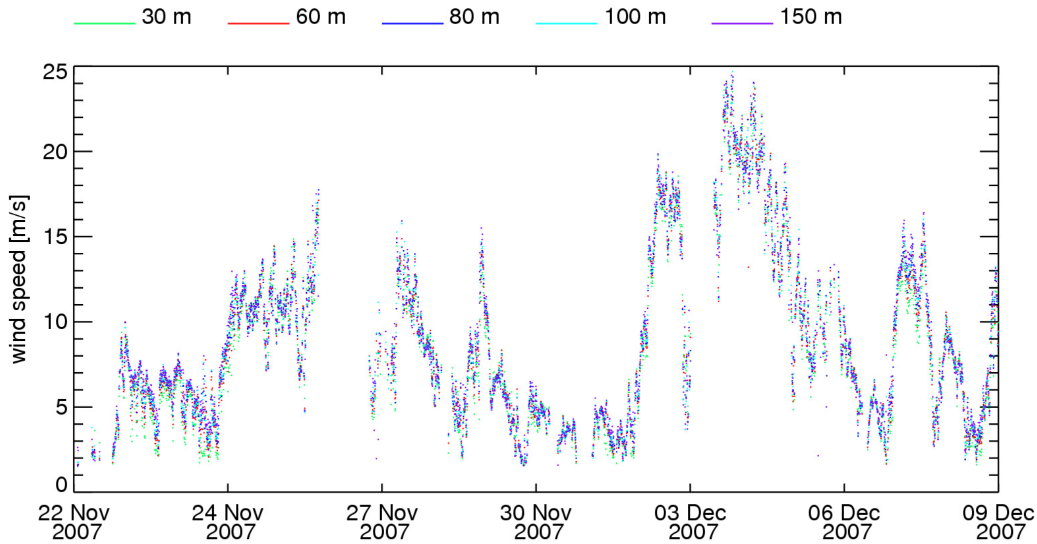

Fig. 15: The 10 minute wind speed of the LIDAR measurements at Maligrad at 30, 60, 80, 100 and 150 m above ground.

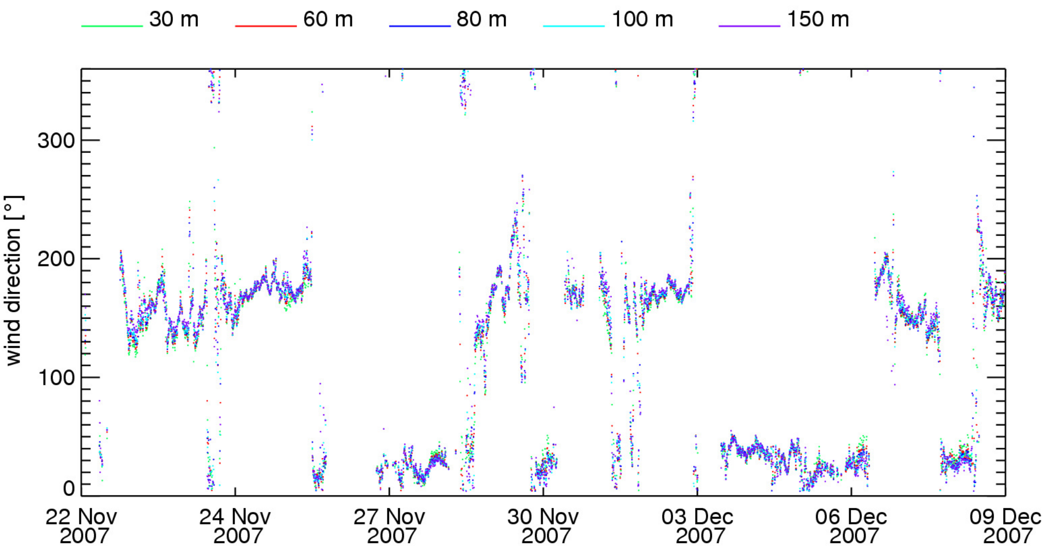

Fig. 16: The 10 minute wind direction of the LIDAR measurements at Maligrad at 30, 60, 80, 100 and 150 m above ground.

6.2. Wind roses / turbulence roses LIDAR

Fig. 17 shows wind roses and turbulence roses for each measurement level. During the measurement campaign winds from south-southeast and northeast were prevailing.

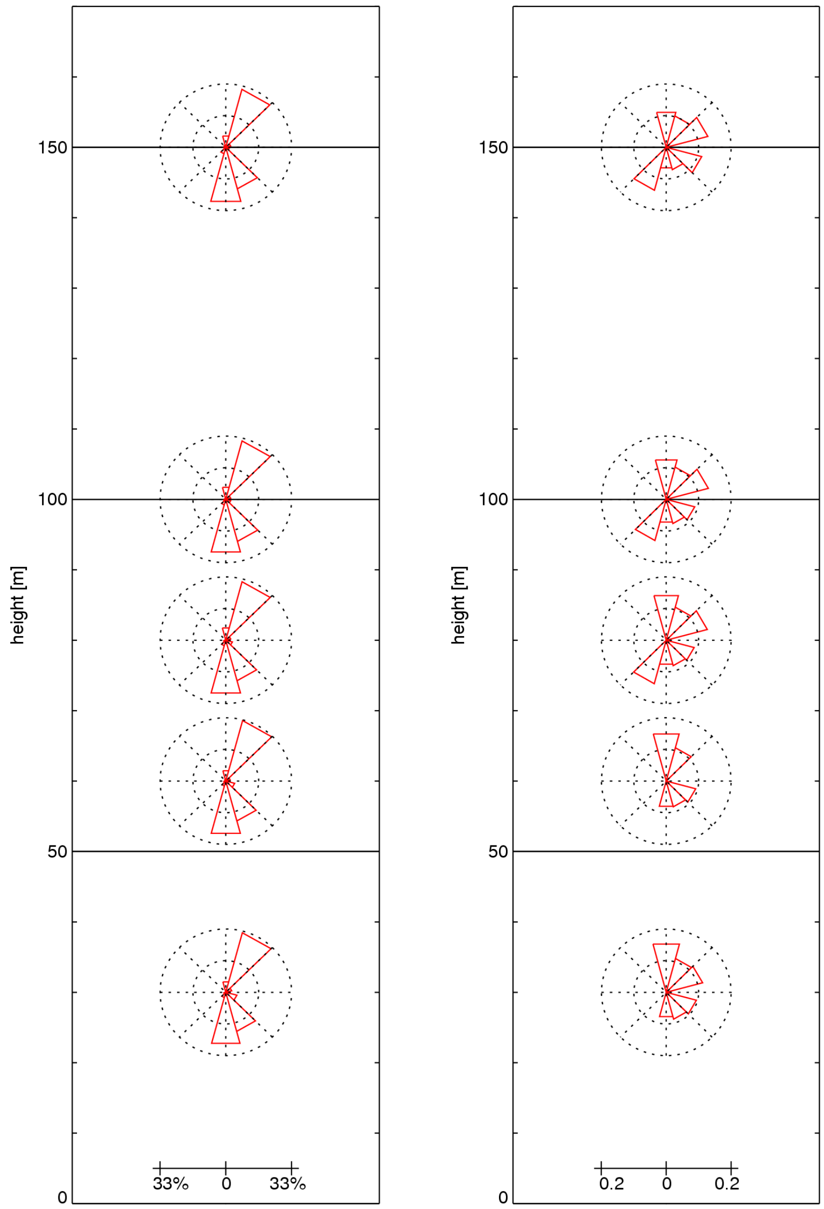

Fig. 17: Left: Wind roses of the LIDAR measurements at Maligrad at 30, 60, 80, 100 und 150 m above ground. Right: Turbulence roses at 30, 60, 80, 100 und 150 m above ground. The calculation of the turbulence intensity has only been carried out for wind speeds greater than 4 m/s.

6.3. Vertical profiles of wind speed LIDAR

Fig. 18 shows the vertical profiles of wind speed scaled to 30 m height in 30° wind direction sectors.

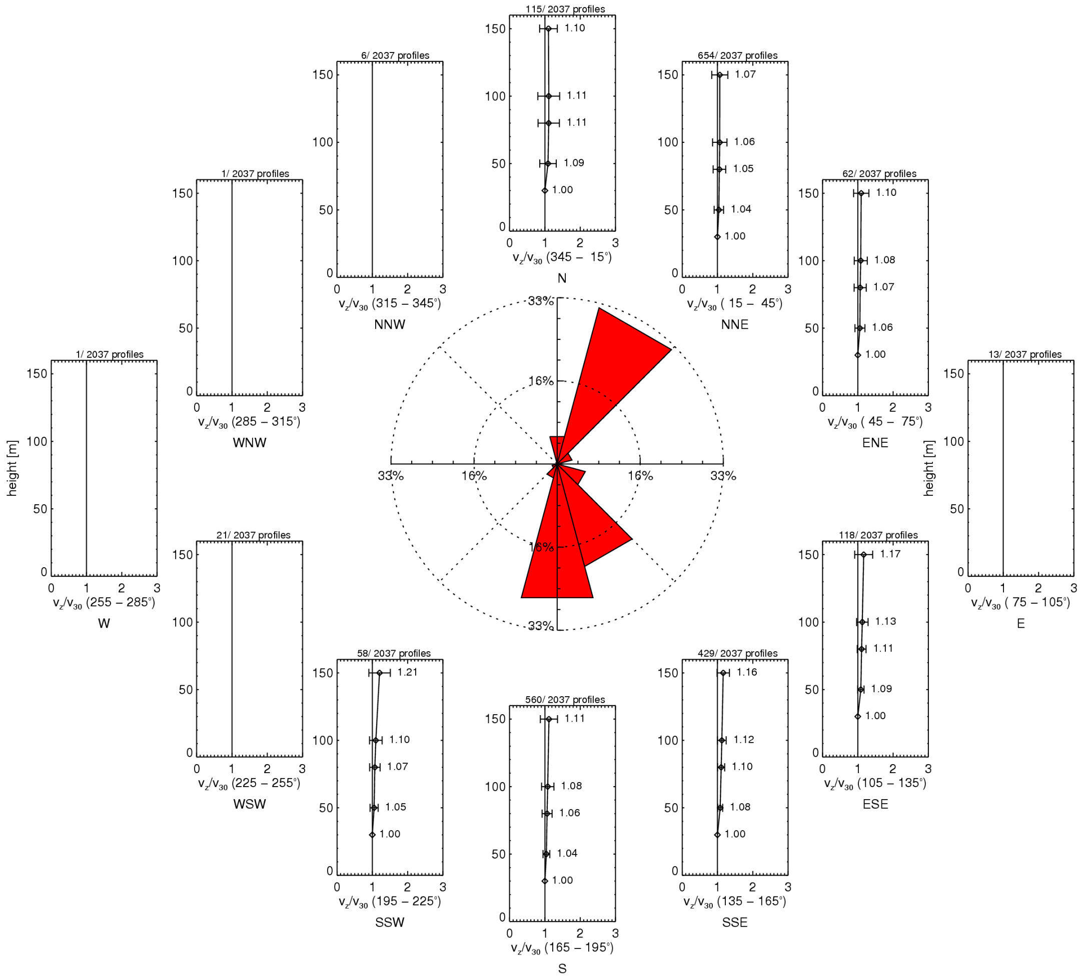

Fig. 18: Vertical profiles of wind speed for 30° wind direction sectors, scaled to 30 m height at the LIDAR measurement site Maligrad. The bars indicate the standard deviation. No profiles are shown for sectors with less than fifty valid 10 minute averages. In the center the wind rose at 30 m is displayed.

Fig. 19 shows the vertical profiles of wind speed scaled to 30 m height for the main wind directions northeast and south-southeast for different wind speeds as well as the statistical mean errors of the profiles.

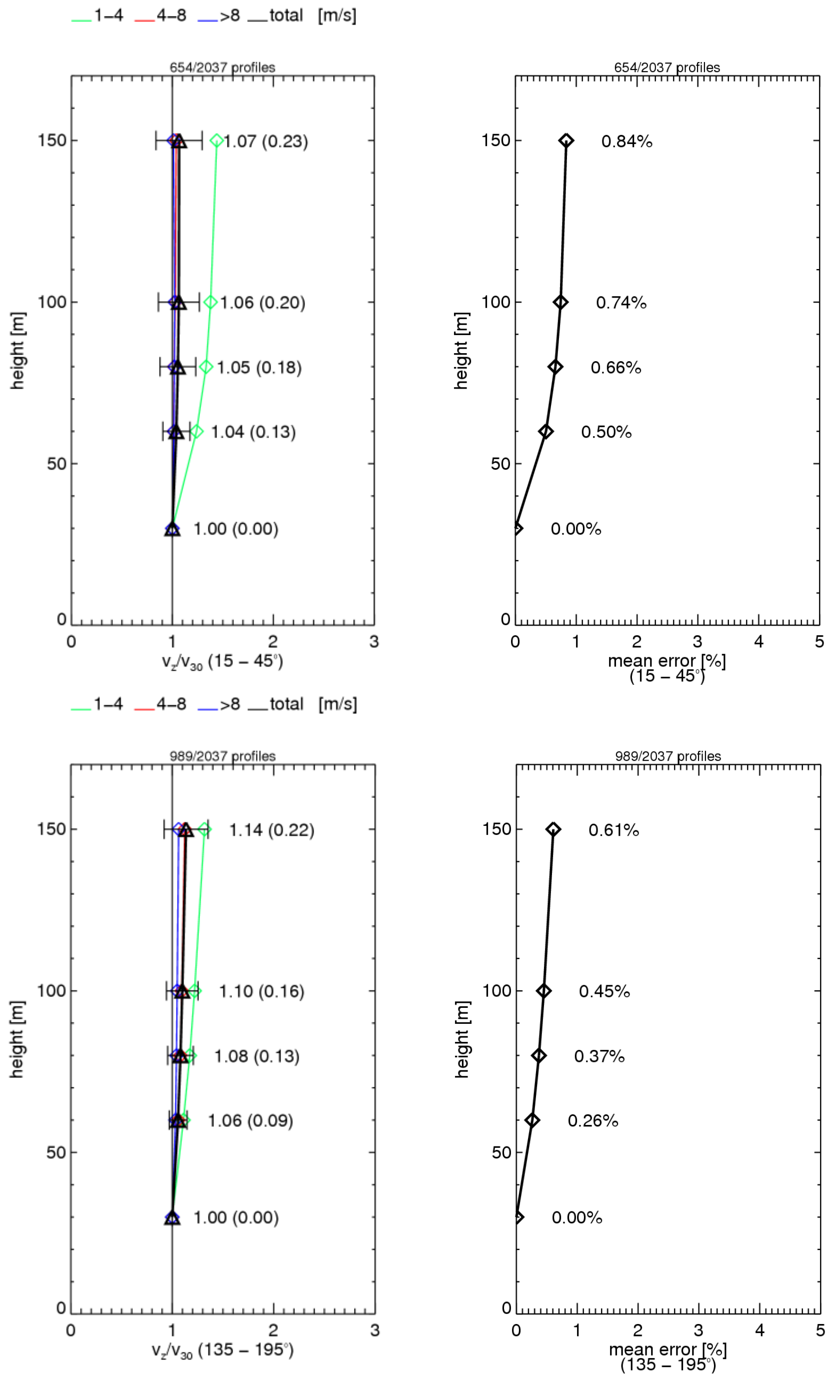

Fig. 19: Vertical profile of the wind speed for the main wind directions northeast (top) and south-southeast (bottom) for different wind speeds (left) and the mean error of the profile (right).

6.4. Vertical profiles of turbulence LIDAR

Fig. 20 shows vertical profiles of the turbulence intensity at Maligrad. Turbulence intensity was calculated only for wind speeds above 4 m/s. No turbulence was calculated for sectors/levels with less than ten valid 10 minute averages.

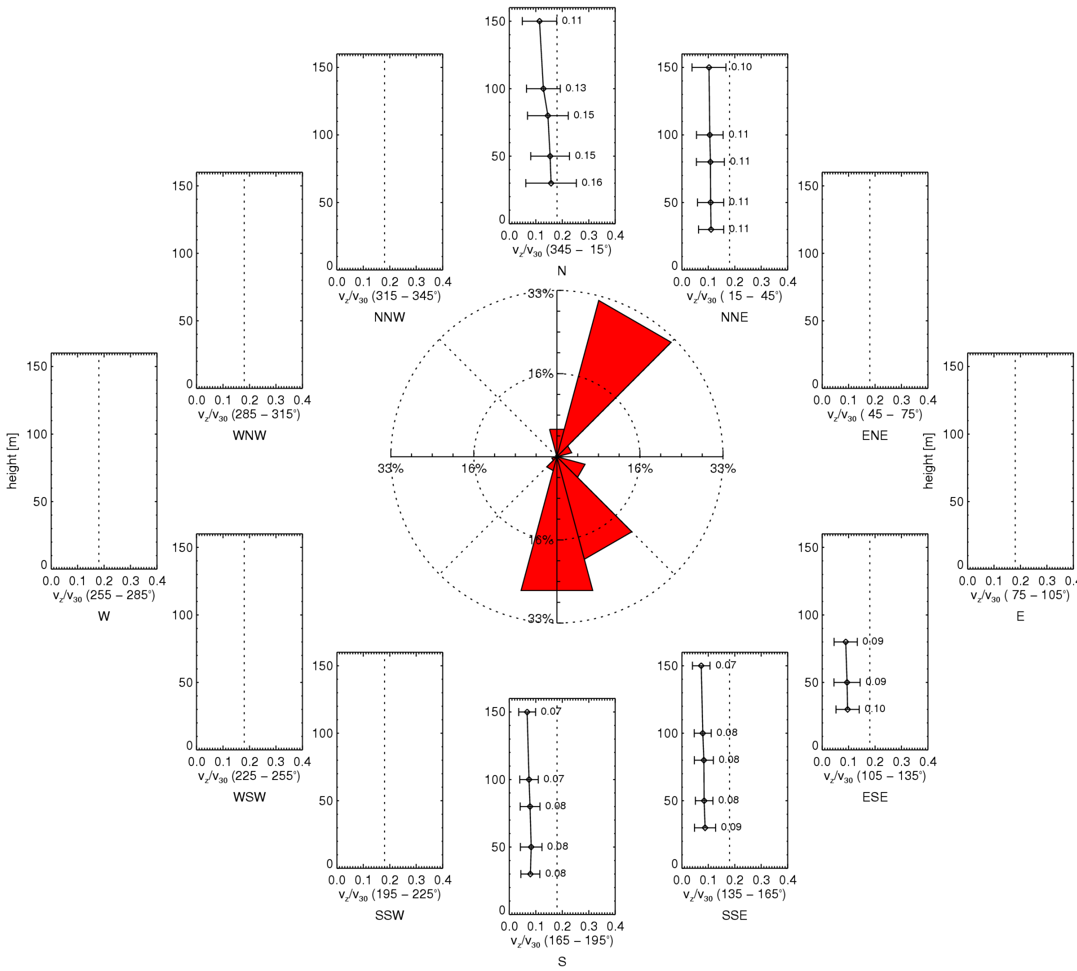

Fig. 20: Vertical profiles of turbulence intensity for 30° wind direction sectors at the LIDAR measurement site Maligrad. The bars indicate the standard deviation. In the center the wind rose at 30 m is displayed. Turbulence intensity was calculated only for wind speeds above 4 m/s. No turbulence was calculated for sectors/levels with less than ten valid 10 minute averages.

6.5. Vertical wind component LIDAR

Fig. 21 shows the vertical component of the wind at Maligrad for the wind directions northeast (blue) and south-southeast (red).

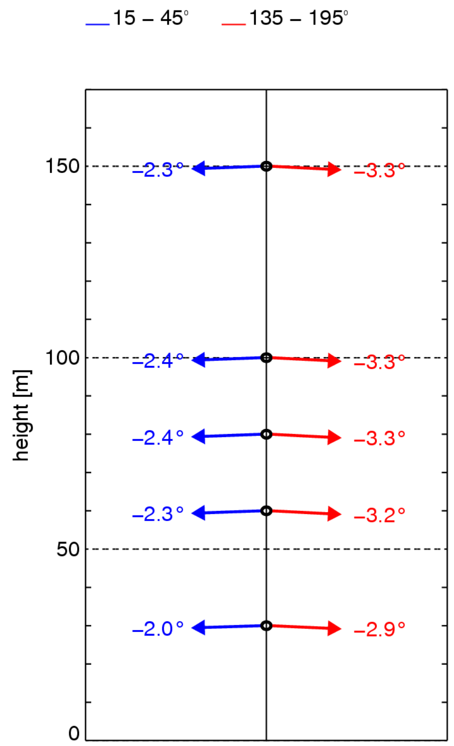

Fig. 21: Vertical component of the wind at Maligrad for the wind directions northeast (blue) and south-southeast (red).