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METEOTEST

Documentation and results of the SODAR and LIDAR Measurements at the Rudine site in Croatia

Measurement Campaign from February 12th to May 5th 2008 (SODAR) and April 9th to May 5th 2008 (LIDAR)

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Table of Contents

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 two Bora-dominated sites in Bosnia and Croatia, SODAR and LIDAR measurements were carried out by *METEOTEST*.

Adria Windpower is planning the installation of a wind farm at the Rudine site in Croatia and therefore installed a 50 m mast in November 2006.

This report outlines the SODAR and the LIDAR measurements at Rudine which have been carried out between the 12**th** of February and 5**th** of May 2008 and between the 9th of April and 5th of Mai 2008 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 on the mainland of Croatia, about 35 km northwest of Dubrovnik, approximately 380 m above sea level. The SODAR and the LIDAR were installed within a distance of 10 m. The mast was located 35 m away from the SODAR to the southeast. 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 50 m mast at Rudine.

Rudine	Coordinates (UTM WGS 84, zone 33)	Altitude
SODAR	727'287 / 4'746'365	385 masl
LIDAR	727'287 / 4'746'355	385 masl
50 m mast	727'315 / 4'746'335	385 masl

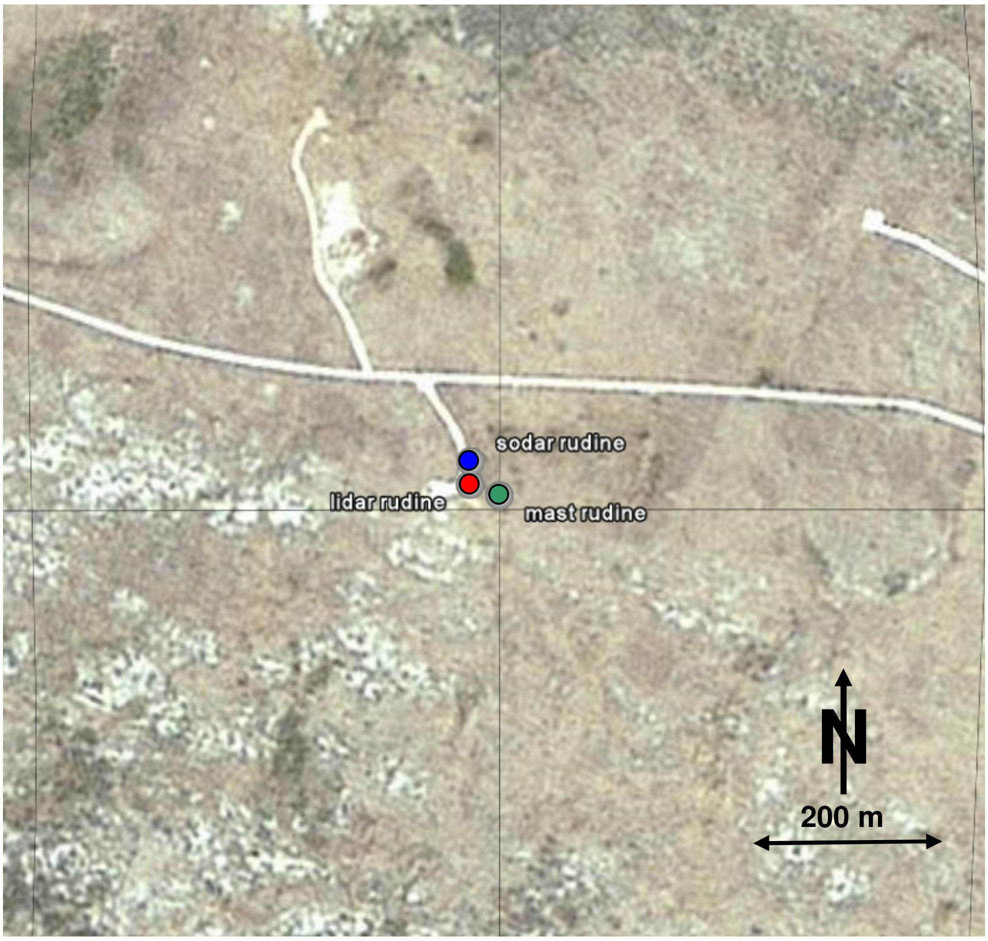

Fig. 1: Location of the SODAR (blue), the LIDAR (red) and 50 m mast (green) at Rudine (source Google Earth).

Fig. 2: Panoramic pictures taken at the measurement site facing north (left) and south (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 Rudine with the LIDAR and the 50 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	212°

3.2. SODAR measurement protocol

The measurement campaign started on the 12th of February 2008 and ended on the 5th of May 2008. Tab. 3 shows the measurement protocol of the campaign. A battery pack, once or twice a day loaded by a diesel generator was used as power supply. On February 27th a sudden incident occurred (most likely lightening) and 16 of the total 32 speakers failed at once. Nine speakers were replaced on March 11th, the rest on April 9th. Data quality and availability decreases rapidly with height if not all speakers are working properly.

Tab. 3: SODAR measurement protocol for Rudine.

Event	Date / Time (CET)
Start of SODAR measurements	February 12th 2008, 16:10
Stop of SODAR measurements (16 of 32 speakers broken, thunderstorm?)	February 27th 2008, 11:30
Restart of SODAR measurements (only 25 good speakers)	March 11th 2008, 15:00
Replacement of 7 broken speakers	April 9th 2008, 09:10 – 10:30
End of SODAR measurements	May 5th 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 Rudine.

Tab. 4: Configuration of the LIDAR.

Parameter	Value
Measurement heights above ground	30 m, 50 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 9th of April 2008 and ended on the 5th of May 2008. Tab. 5 shows the measurement protocol.

In the beginning of the measurement campaign the LIDAR did not record and collect any data due to a technical problem. Data collection started on the 14th of April. Apart from this problem no incidents happened during the LIDAR measurement period.

Tab. 5: Measurement protocol for Rudine.

Event	Date / Time (CET)
Start of LIDAR measurements	April 9th 2008, 11:10
Data is not recorded due to technical failure	April 9th, 11:10 to April 14th, 13:20
End of LIDAR measurements	May 5th 2008, 13:30

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

Fig. 3: Picture with the SODAR (left), the LIDAR (right) and the 50 m mast in the background facing southeast.

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 Rudine, Fig. 5 shows the amount of available data at each level after cleaning the data.

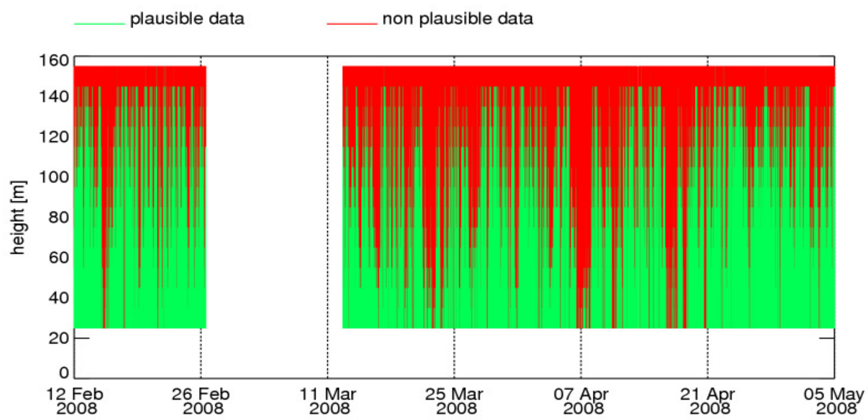

Fig. 4: Time series of the data availability of the SODAR measurements at Rudine for each measurement level. Plausible data are displayed in green, rejected values in red.

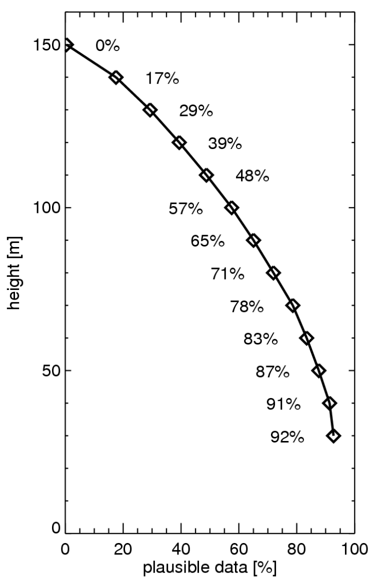

Fig. 5: Amount of available data of the SODAR measurements at each level at Rudine.

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. Less than 1.3% of the data has been rejected at each level (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.

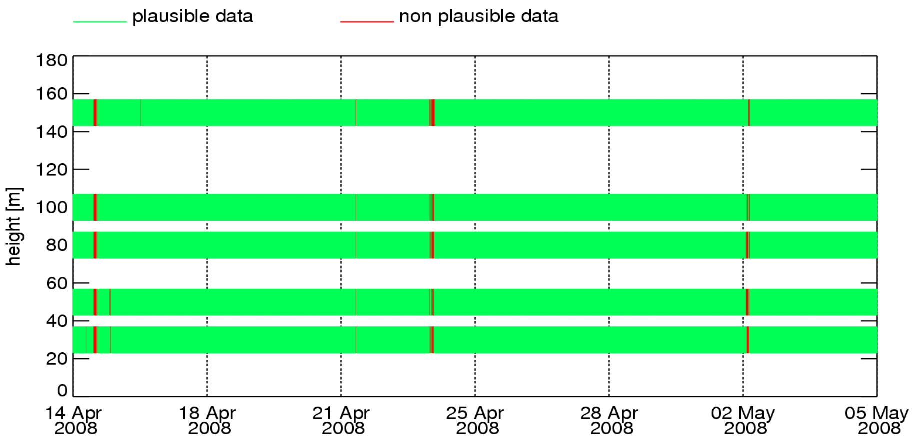

Fig. 6: Time series of the data availability of the LIDAR measurements at Rudine for each measurement level. Plausible data are displayed in green, rejected values in red.

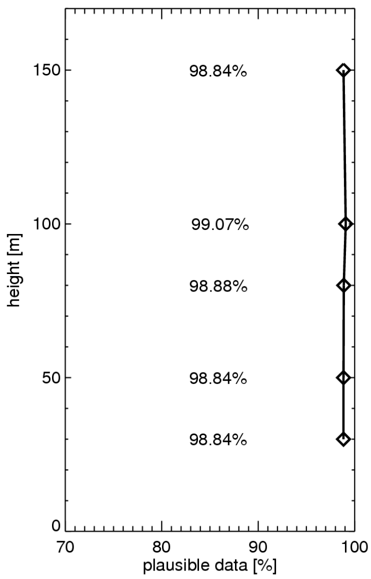

Fig. 7: Amount of available data of the LIDAR measurements at each level at Rudine.

5. Results SODAR

5.1. Wind speed / wind direction SODAR

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

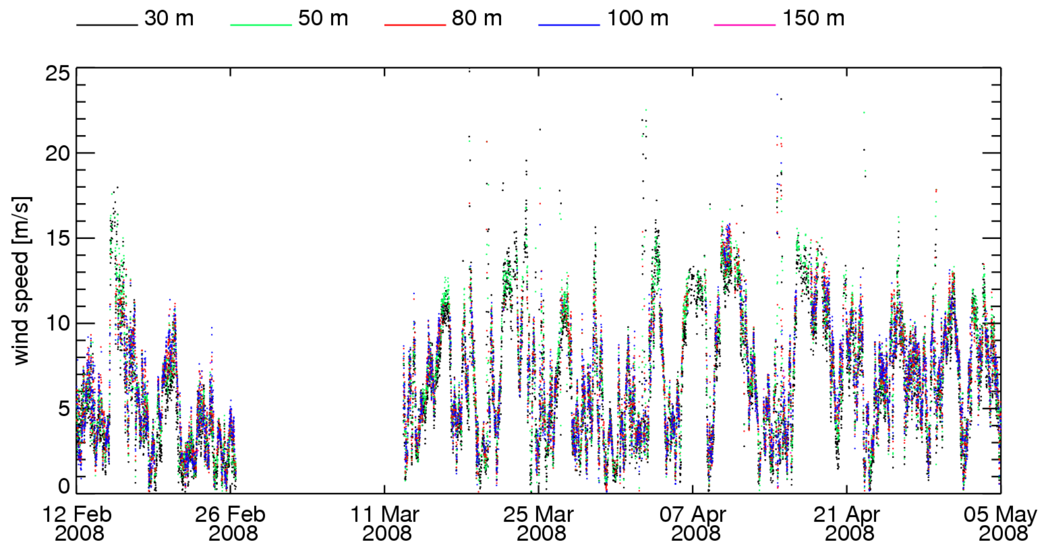

Fig. 8: The 10 minute wind speed averages of the SODAR measurements at Rudine at 30, 50, 80, 100 and 150 m above ground.

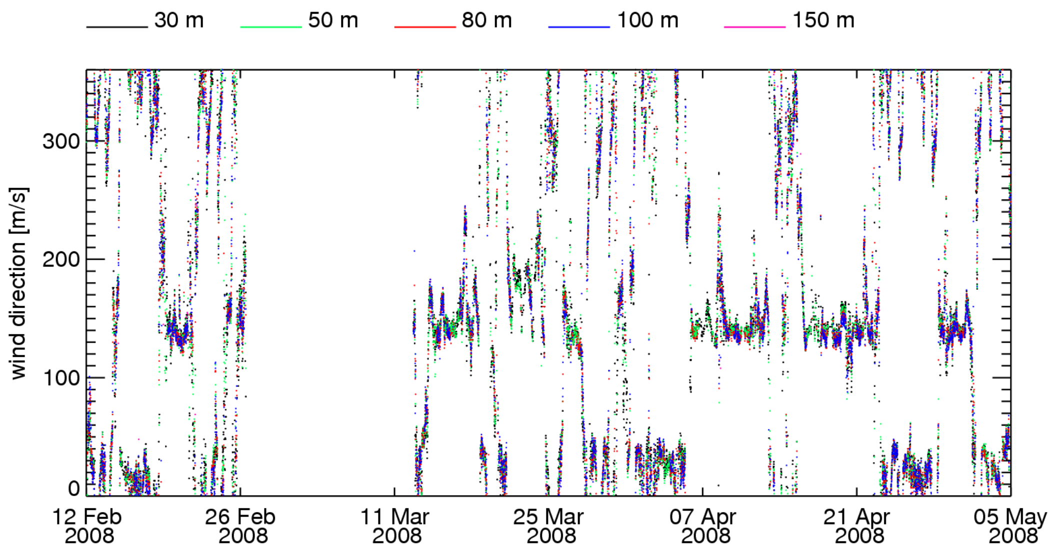

Fig. 9: The 10 minute wind direction averages of the SODAR measurements at Rudine at 30, 50, 80, 100 and 150 m above ground.

5.2. Wind roses / turbulence roses SODAR

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

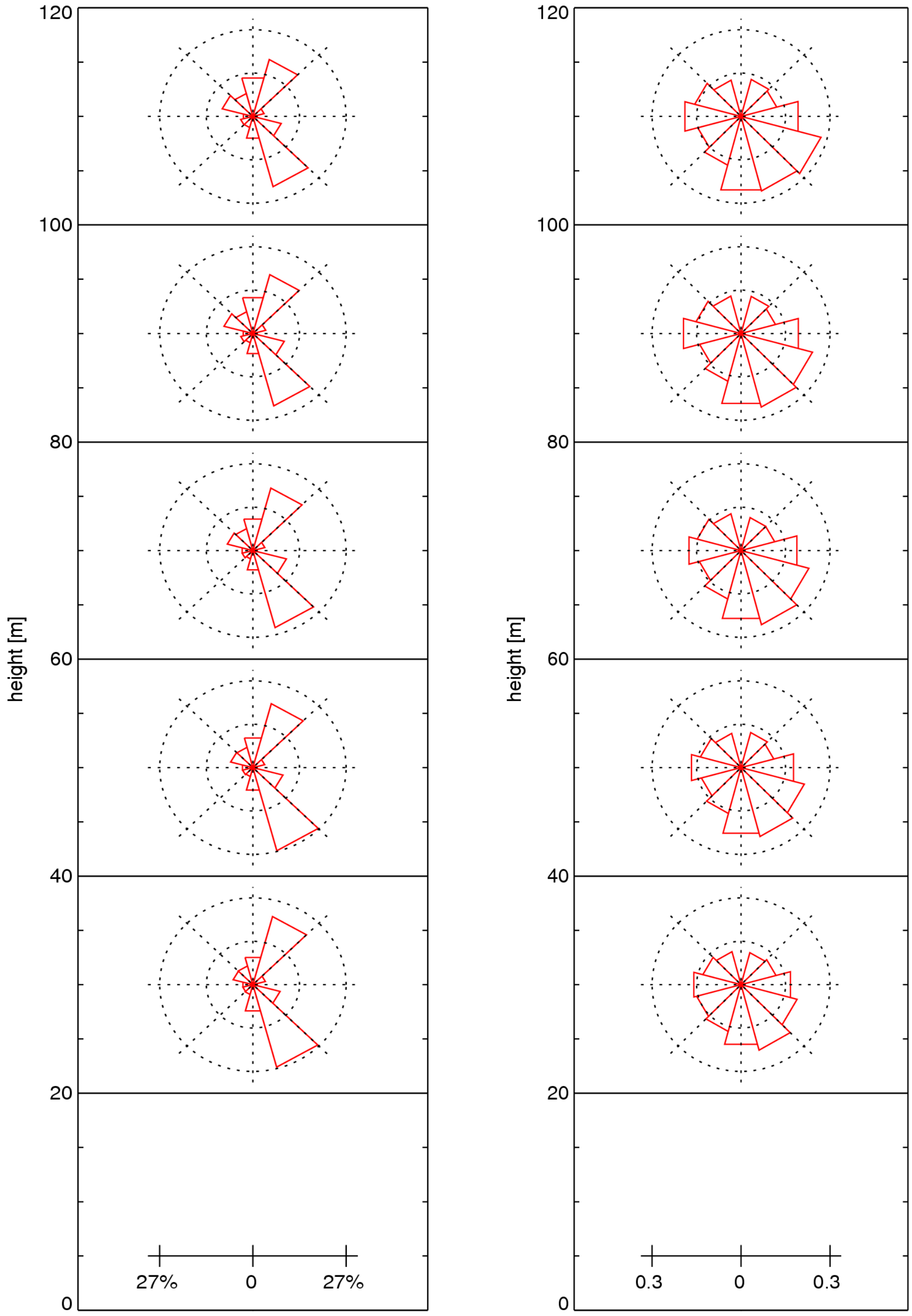

Fig. 10: Left: Wind roses of the SODAR measurement at Rudine at 30, 50, 70, 90 und 110 m above ground. Right: Turbulence roses at 30, 50, 70, 90 und 110 m above ground. The calculation of the turbulence intensity has only been carried out for wind speeds greater than 4 m/s.

5.3. Vertical profiles of wind speed SODAR

Fig. 11 shows the vertical profiles of wind speed scaled to 50 m height in 30° wind direction sectors.

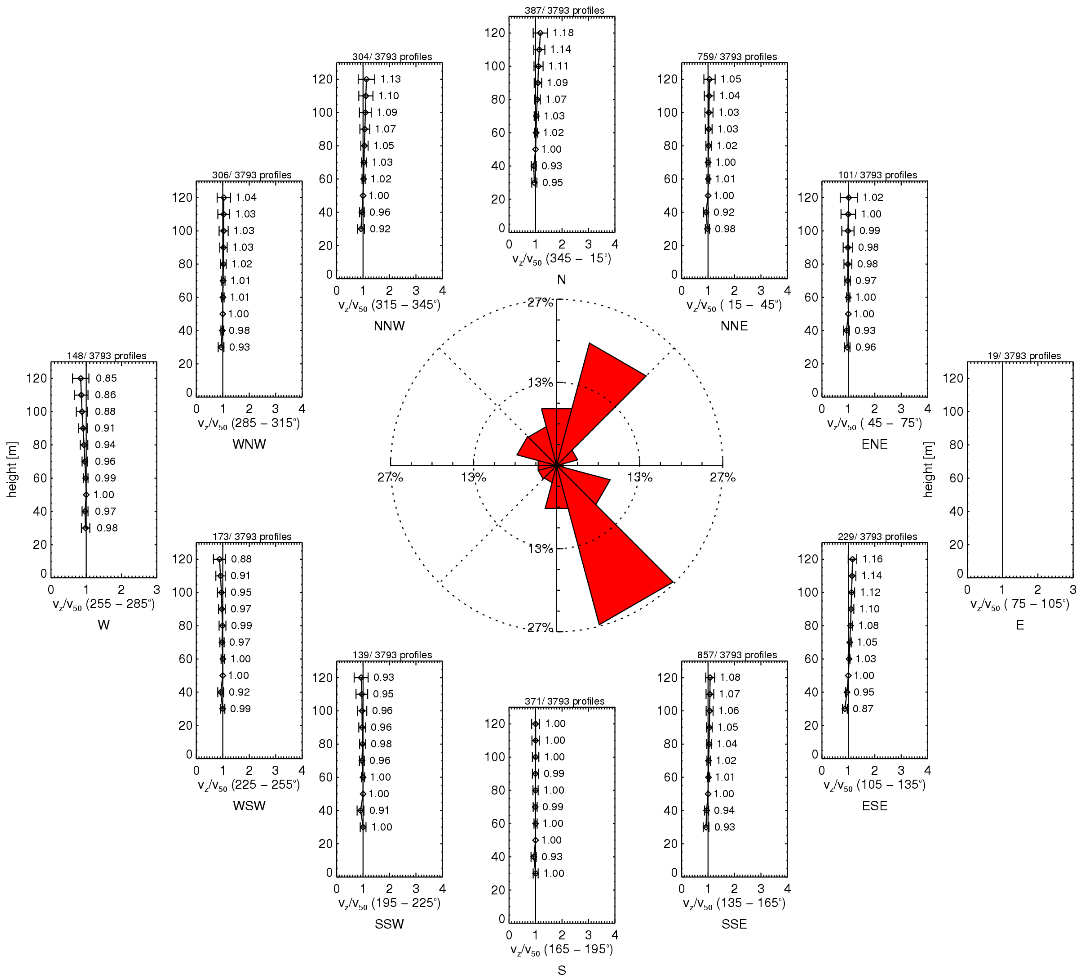

Fig. 11: Vertical profiles of wind speed for 30° wind direction sectors, scaled to 50 m height at the SODAR measurement site Rudine. The bars indicate the standard deviation. No profiles are shown for sectors with less than fifty 10 minute averages. In the center the wind rose at 50 m is displayed.

Fig. 12 shows the vertical profiles of wind speed scaled to 50 m height for the main wind directions northeast and southeast for different wind speeds as well as the statistical mean errors of the profiles.

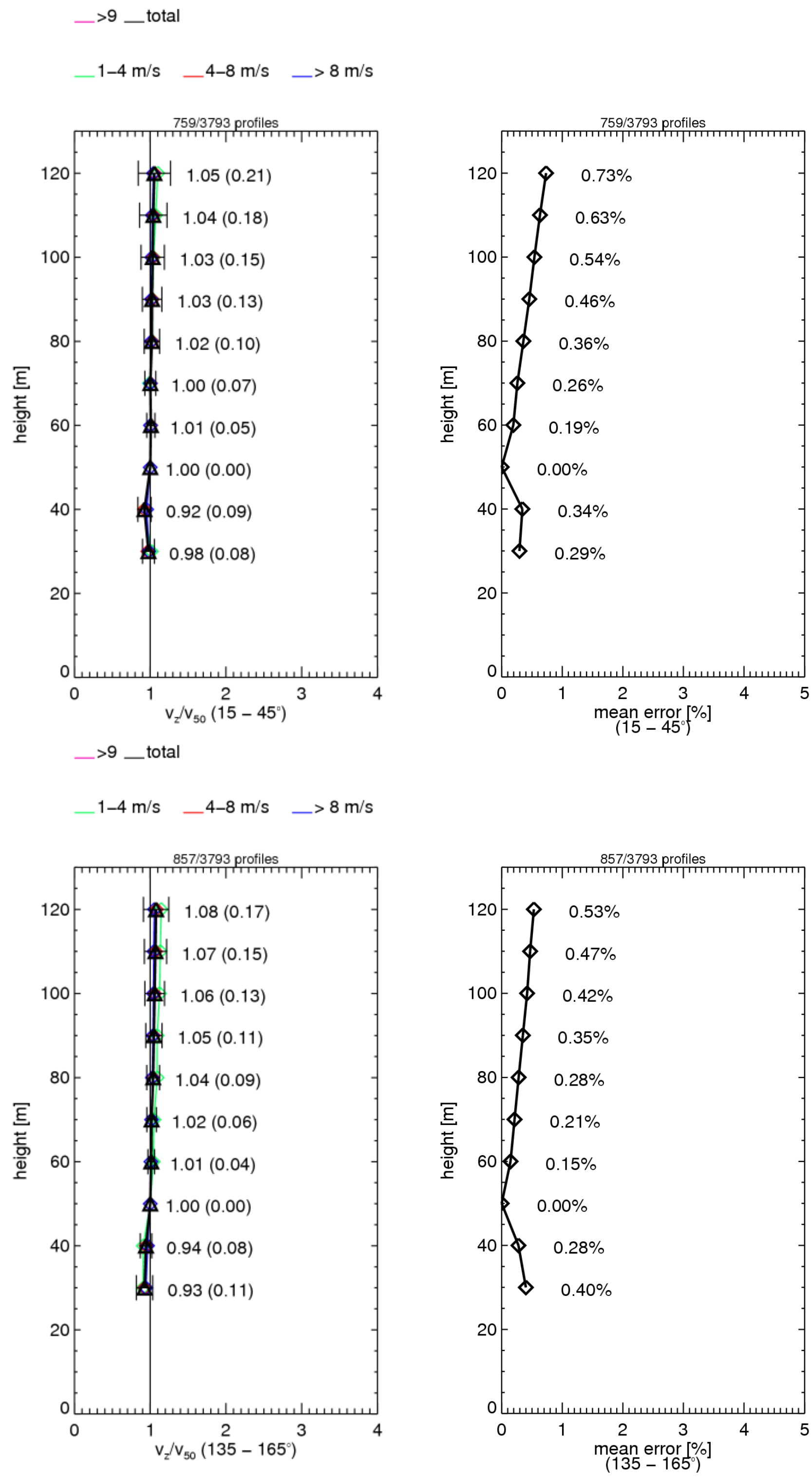

Fig. 12: Vertical profile of the wind speed for the main wind directions northeast (top) and southeast (bottom) for different wind speeds (left) and the mean error of the profile (right).

5.4. Vertical profiles of turbulence SODAR

Fig. 13 shows vertical profiles of the turbulence intensity at Rudine. 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.

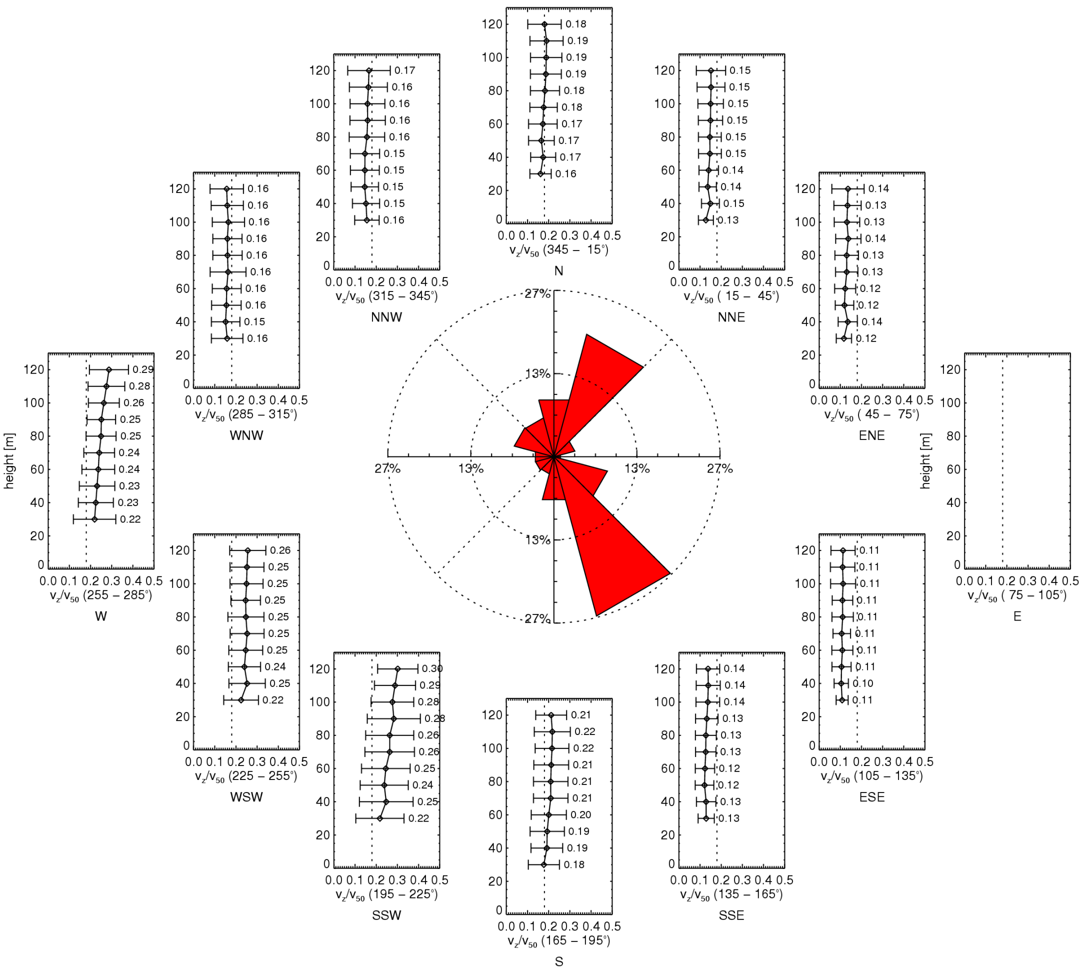

Fig. 13: Vertical profiles of turbulence intensity for 30° wind direction sectors at the SODAR measurement site Rudine. The bars indicate the standard deviation. In the center the wind rose at 50 m is displayed. Turbulence intensity was calculated only for wind speed greater than 4 m/s. No turbulence 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 Rudine for the wind directions northeast (blue) and southeast (red).

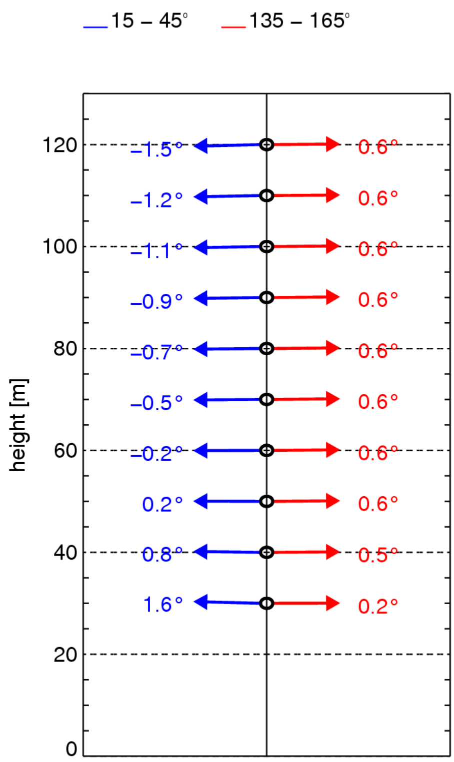

Fig. 14: Vertical component of the wind at Rudine for the wind directions northeast (blue) and southeast (red).

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 Rudine site for each measurement level, Fig. 16 the 10 minute wind direction for each level.

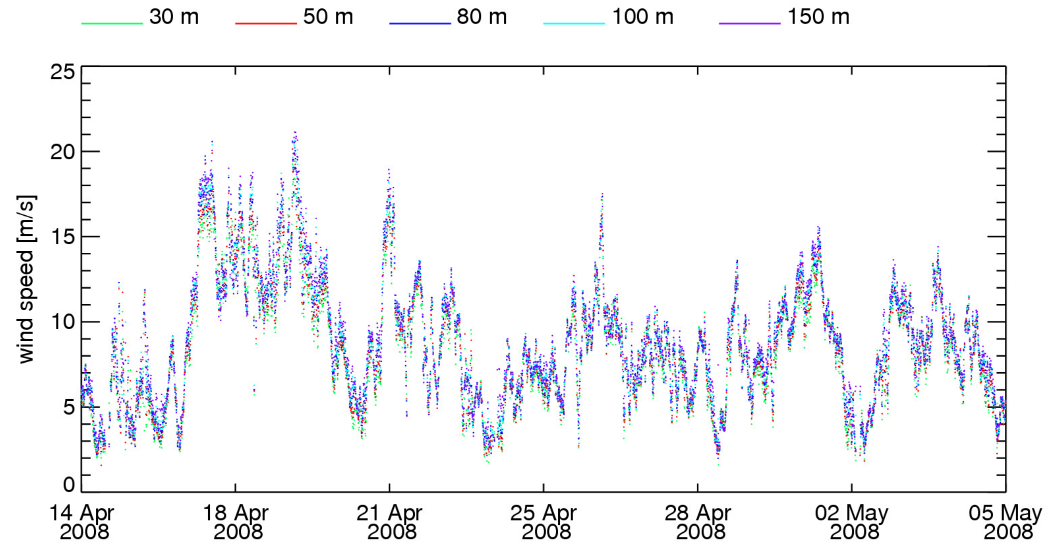

Fig. 15: The 10 minute wind speed of the LIDAR measurements at Rudine at 30, 50, 80, 100 and 150 m above ground.

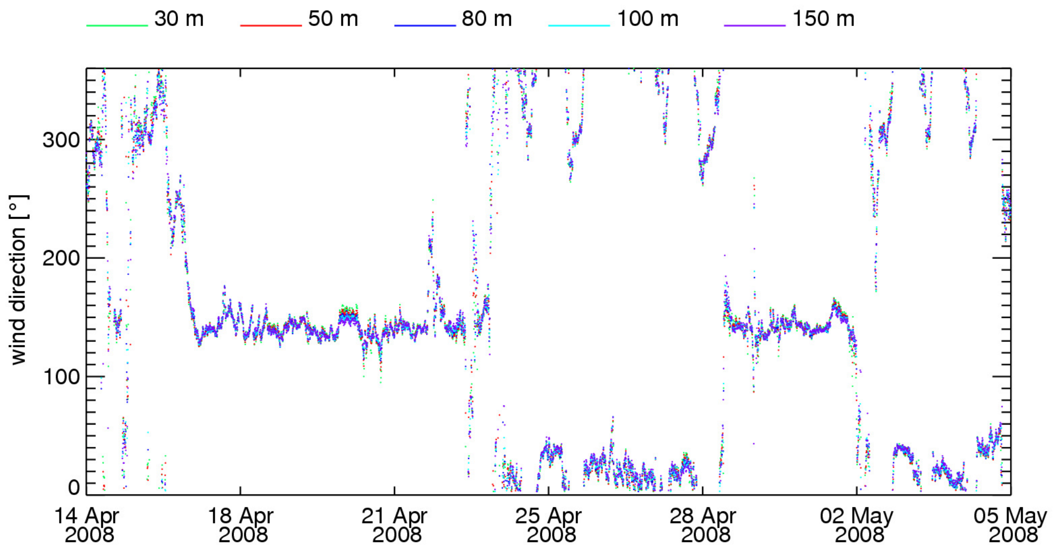

Fig. 16: The 10 minute wind direction of the LIDAR measurements at Rudine at 30, 50, 80, 100 and 150 m above ground.

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 southeast and northeast were prevailing.

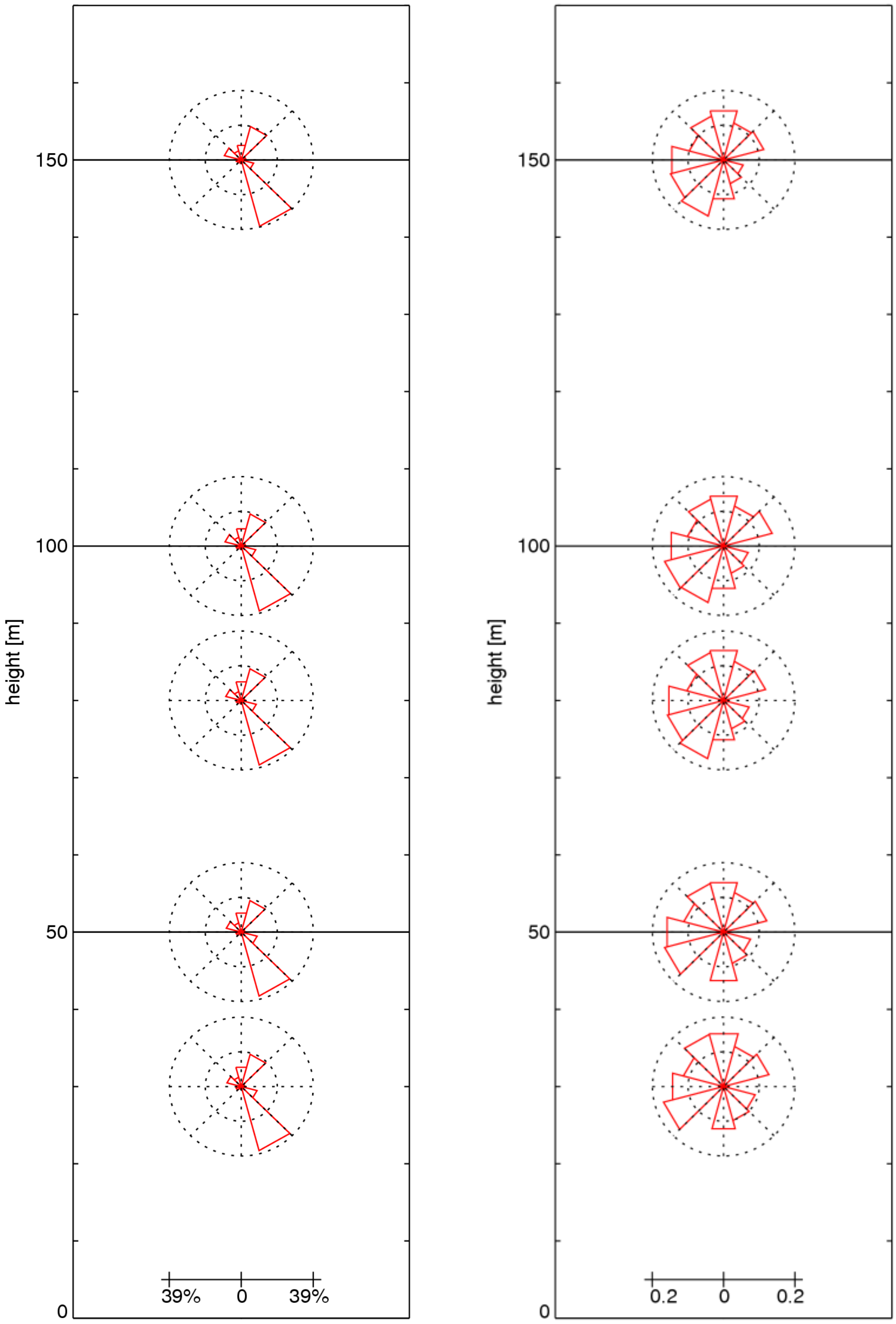

Fig. 17: Left: Wind roses of the LIDAR measurement at Rudine at 30, 50, 80, 100 und 150 m above ground. Right: Turbulence roses at 30, 50, 80, 100 und 150 m above ground. The calculation of the turbulence intensity has only been carried out for wind speeds greater than 4 m/s.

6.3. Vertical profiles of wind speed LIDAR

Fig. 18 shows the vertical profiles of wind speed scaled to 50 m height in 30° wind direction sectors.

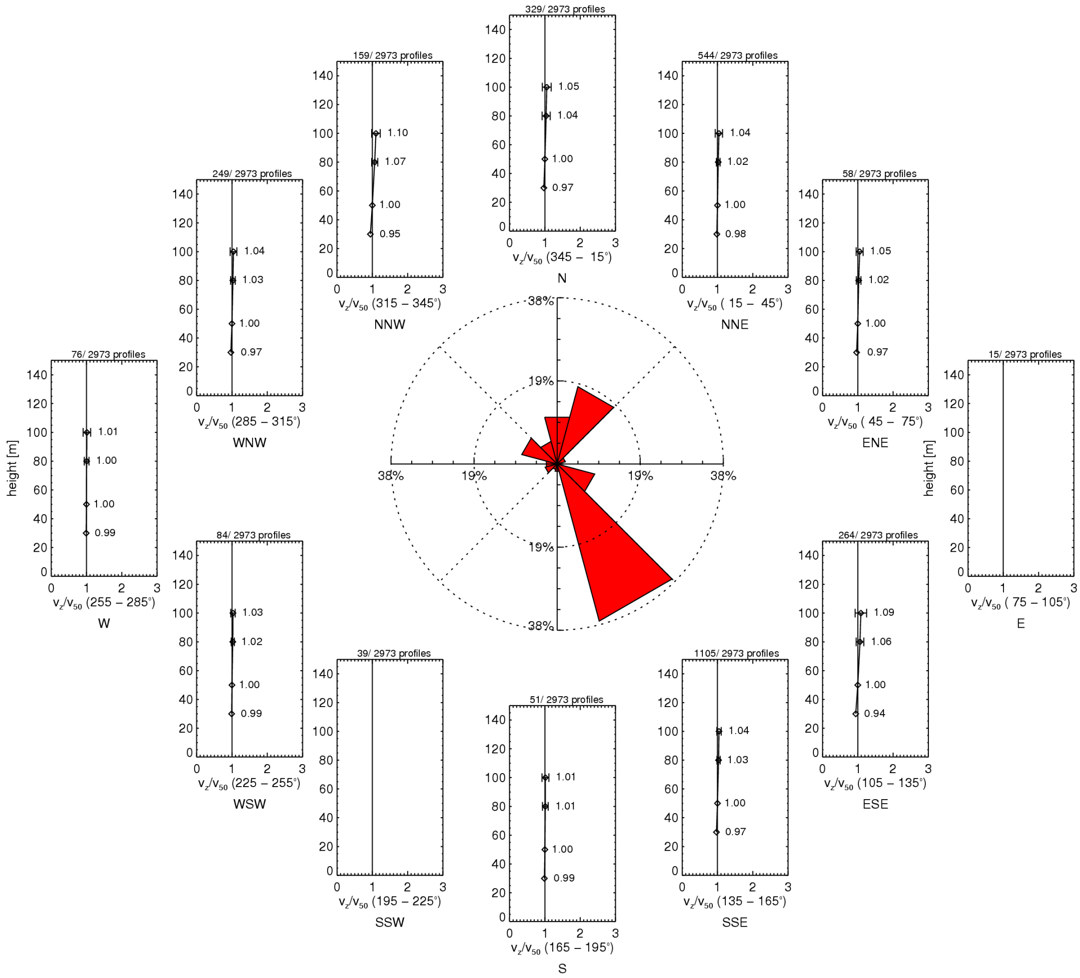

Fig. 18: Vertical profiles of wind speed for 30° wind direction sectors, scaled to 50 m height at the LIDAR measurement site Rudine. The bars indicate the standard deviation. No profiles are shown for sectors with less than fifty 10 minute averages. In the center the wind rose at 50 m is displayed.

Fig. 19 shows the vertical profiles of wind speed scaled to 50 m height for the main wind directions northeast and southeast for different wind speeds as well as the statistical mean errors of the profiles.

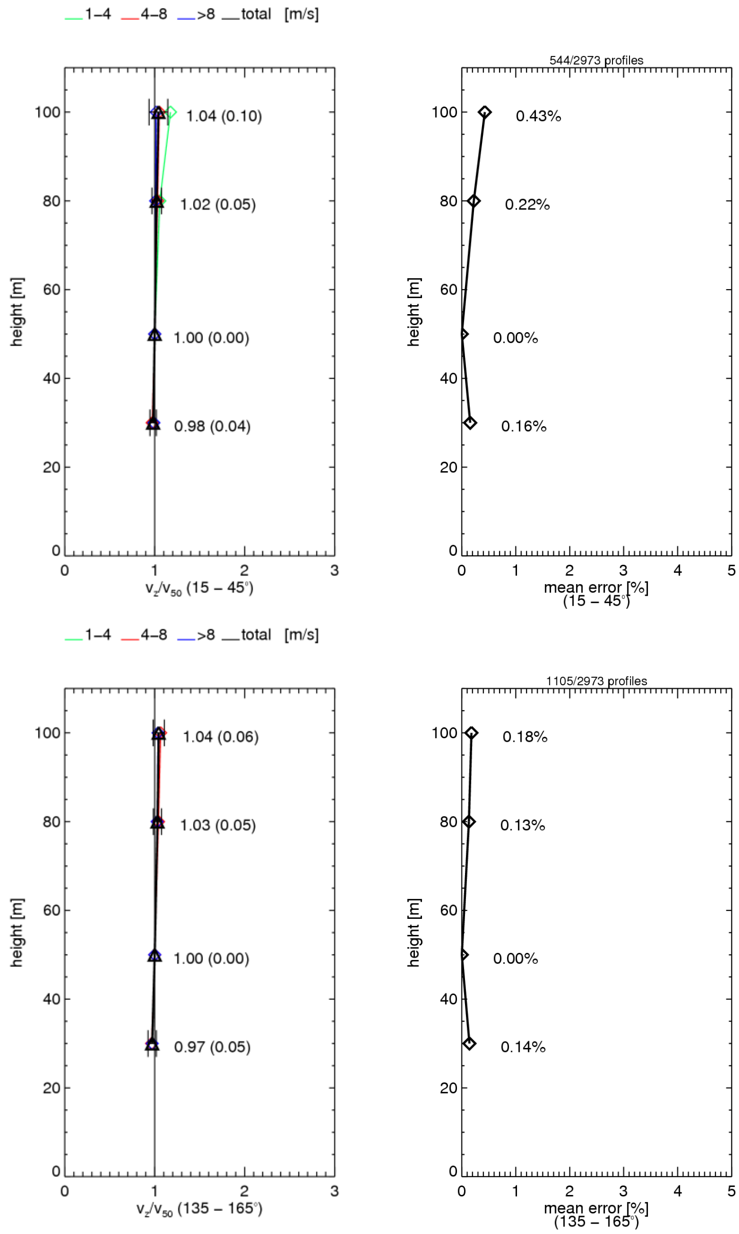

Fig. 19: Vertical profile of the wind speed for the main wind directions northeast (top) and southeast (bottom) for different wind speeds (left) and the mean error of the profile (right).

6.4. Vertical profiles of turbulence LIDAR

Fig. 20 shows vertical profiles of the turbulence intensity at Rudine. 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.

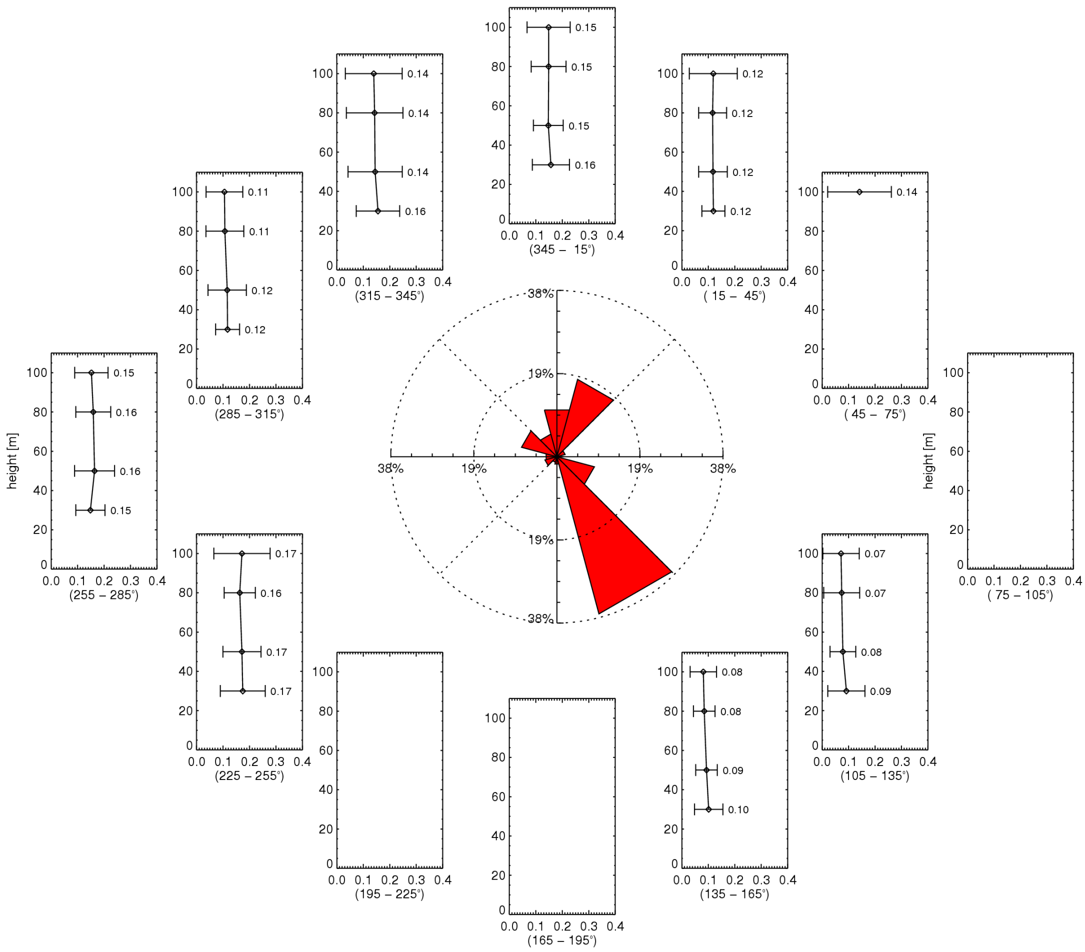

Fig. 20: Vertical profiles of turbulence intensity for 30° wind direction sectors at the LIDAR measurement site Rudine. The bars indicate the standard deviation. In the center the wind rose at 50 m is displayed. Turbulence intensity was calculated only for wind speeds above 4 m/s. No turbulence was calculated 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 Rudine for the wind directions northeast (blue) and southeast (red).

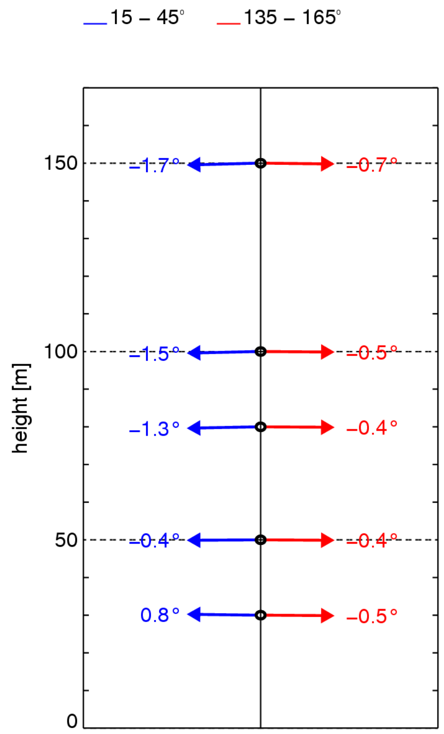

Fig. 21: Vertical component of the wind at Rudine for the wind directions northeast (blue) and southeast (red).