Accuracy Test of a Sodar of Type Triton Wind Profiler

Serial No.: 225

Contracted by

Second Wind Inc.
366 Summer Street
Somerville, MA 02144
USA

Deutsche WindGuard Consulting GmbH

Oldenburger Straße 65
D-26316 Varel
Germany

Project No.: VC10160

Report No.: PP10111

Accuracy Test of a Sodar of Type Triton Wind Profiler

Serial No.: 225

Deutsche WindGuard Consulting GmbH
Oldenburger Straße 65
D-26316 Varel
Germany
Tel: 04451-9515-10
Fax: 04451-9515-29
E-Mail: info@windguard.de

Contracted by:	Second Wind Inc. 366 Summer Street Somerville; MA 02144 USA
Contact:	Margaret Eifert
Project no.:	VC10160
Report no.:	PP10111
Date:	2011-01-19

Deutsche WindGuard
Consulting GmbH
Oldenburger Straße 65
D-26316 Varel
Tel.: 04451 / 95 15 - 0 · Fax: 95 15 - 29

Author: Dipl.-Ing. A.-W. Janssen

Approved by: Dipl.-Phys. A. Albers

Contents

1 Introduction

The Triton Wind Profiler (in short: Triton) is a sodar (SOund Detection And Ranging) for wind measurements in the lower atmosphere. The device has been developed by Second-Wind Inc. with special intension to the needs of the wind energy industry.

This report describes a test of the accuracy of a Triton against conventional wind measurements with mast mounted cup and ultrasonic anemometers and conventional wind vanes. The accuracy test follows the latest requirements as developed in the so-called Lidar Acceptance Project [1], [2] and discussed in the frame of the ongoing revision of the standard IEC 61400-12-1 [3]. The test took place at a special test station for remote wind sensing devices close to the German North Sea Coast, where a 135 m high met mast is available [4].

This report covers 99 pages including front cover.

2 Measurement Site and Met Mast

The measurements have been performed about 3 km south of the village Rysum and about 700 m from the shore of the mouth of the river Ems, close to the German North Sea Coast. Rysum is located about 10 km west of the city Emden in the Northwest of Germany. At the measurement site, a 135 m high met mast serves for the measurement of the power curve of a wind turbine (135 m hub height). The measurement site is characterised by flat farmland with open appearance. A map of the measurement site is given Figure 1. Photos of the met mast and a panoramic view of the site are shown in Figure 2 and Figure 3.

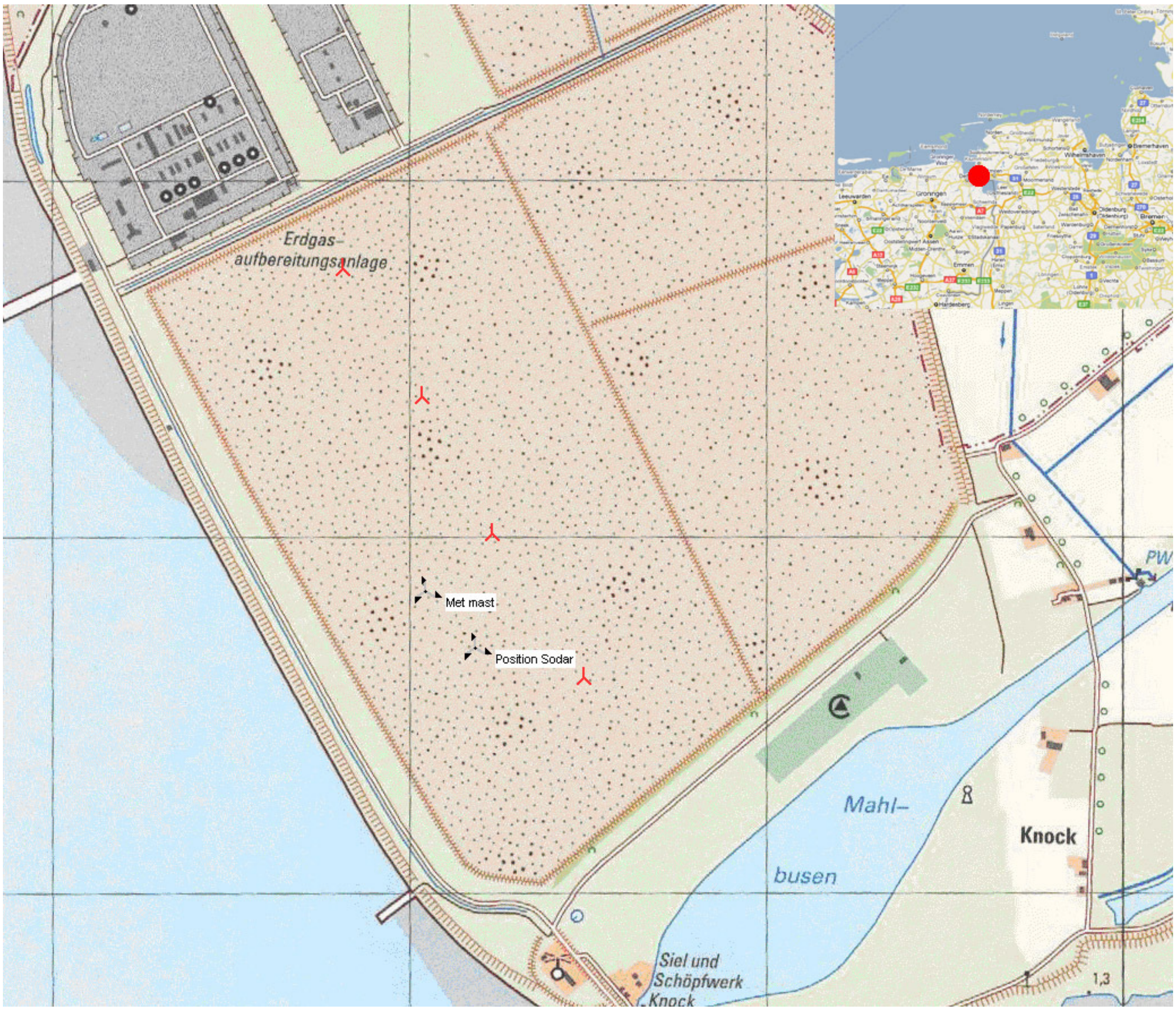


Figure 1: Map of the measurement site. The red stars mark the position of wind turbines. The met mast and the sodar are marked by a black star. The test site of the Triton was located 200 m in southeast of the met mast. The maximum measurement sector for the test is 154° to 316°.

Figure 2: Photo of the 135 m high met mast near Rysum, looking in direction west.

Figure 3: Panoramic view of the measurement site, taken from the mast platform at a height of 75 m above ground.

To avoid influences by fixed echoes or other noise sources, the Triton has been placed on an open field southeast of the met mast in a distance of 200 m, see Figure 4. The Triton emits three sonic beams, which are inclined by 11.4° to the vertical and spaced 120 °from one another (Figure 5).

The met mast is positioned about 500 m northwest of a test wind turbine. The test wind turbine and other neighbouring turbines influence the airflow at the mast at easterly wind directions. The coordinates and the resulting wake effects calculated according IEC 61400-12-1 for power performance measurements [1] can be seen in detail in Table 1. From all these wakes, an undisturbed and applicable sector of 154° to 316° remains for testing the Triton. The measurement sector must be reduced further for some reference sensors due to mast effects (see

Table 2**Fehler! Verweisquelle konnte nicht gefunden werden.**).

Figure 4: The Triton under test installed close to the met tower near Rysum.

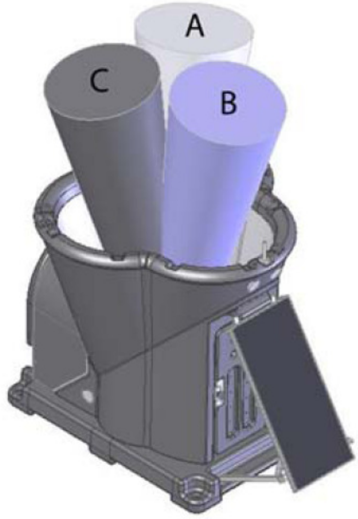


Figure 5 Illustration of sonic beams of the Triton Wind Profiler

The met mast is equipped with several cup and ultrasonic anemometers as well as wind vanes in different heights above ground. Mounting details of the sensors are shown in appendix 9.1. The calibration certificates of the sensors are given in annex 9.2.1 to 9.2.9. The airflow at the positions of the anemometers and vanes is significantly influenced by flow disturbance caused by the mast and neighbouring sensors (blockage effects, flow acceleration effects). The least influence occurs at the two cup anemometers of type Thies First Class which are mounted at 135 m height above ground at the top of the met mast on a U-shaped boom. An individual wind direction depending correction has been applied to the wind speed measurements of the cup and ultrasonic anemometers which were mounted on side booms to the mast (all mounting heights except 135 m). Those correction functions have been determined empirically (see appendix 9.3). The cup anemometers are of class 1.7A according to reference [3], [5]. The cup and also the ultrasonic anemometers have been calibrated in a wind tunnel according to DKD and MEASNET [6]. One of the calibration wind tunnels of DWG is applied by the German authority for controlling units, Physikalisch-Technische Bundesanstalt (PTB), for defining the unit m/s in airflow measurements. A more accurate tracing back of the anemometer measurements is currently not possible. The ultrasonic anemometers were calibrated for different horizontal and vertical orientations. The wind measurements with the mast follow the requirements of IEC 61400-12-1 [3].

A list of the undertaken comparisons of sensors of the met mast and measurements of the Triton are given in

Table 2**Fehler! Verweisquelle konnte nicht gefunden werden.**. From the table, the disturbed sectors caused by the mast and the neighbouring turbines and the chosen evaluation sectors can be seen. The positions of the sonic beams in dependence of the measuring height have been taken into account for the calculation of the disturbed sectors. Table 3 shows the specifications of the sensors mounted at the met mast.

The Triton provides measurements at fixed heights above ground, i.e. not exactly at the heights of the reference sensors at the mast. Consequently the measurements of the Triton have been interpolated to the exact heights of the reference anemometers for the comparison of wind speed measurements. For the comparison of the wind direction measurements of the Triton and vanes at the mast, the measurement height nearest to the referring vane has been applied, without any interpolation.

The ultrasonic anemometer mounted at 133 m height at the mast shows abnormal calibration values. The application of this calibration results in implausible deviations of the measurements of this anemometer to the cup anemometers mounted at similar heights. This is likely caused by an abnormity during the calibration of the ultrasonic anemometer. As a consequence, the calibration of the ultrasonic anemometer at 133 m height has not been applied for the data evaluation.

Table 1: Position of met mast, Triton and neighbouring turbines. All coordinates are given in Gauß-Krüger coordinates (Bessel-Ellipsoid).

Object	Position		Rotor	Distance	Direction	Met Mast	
	X	Y	diameter	from	from	in Wake	
			D	met mast	met mast	from	to
	[m]	[m]	[m]	[m]	[deg]	[deg]	[deg]
Met mast	2567813	5913423	---	---	---	---	---
Triton	2567960	5913271	---	208	308	---	---
E-126-001 (WRN12)	2568268	5913200	127	507	0	87	146
E-126-003 (WRN 11)	2567996	5913592	127	249	116	7	88
Bard WRN 10	2567781	5913970	122	548	47	329	25
Bard WRN 9	2567546	5914319	122	935	357	322	5

Table 2: List of the undertaken comparisons, sensors/channels of met mast and Triton measurements with measuring heights, orientation of sensor mounting booms and sector restrictions due to wake effects of the mast and neighbouring turbines, as well as effective evaluation sectors. For some measuring heights of the Triton, no corresponding sensor at the mast exists.

name	Triton selected/ interpolated height	met mast sensor					mast or beam in turbine wake		evaluation sector	
		signal	measur. height	boom orient.	in mast wake					
					from	to	from	to	from	to
[m]	[m]	[-]	[m]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
v135N	135.12	V0	135.12	336	136	176	316	154	176	316
v135S	135.12	V1	135.12	156	316	356	316	154	176	316
v133	132.62	V2	132.62	156	316	356	316	154	176	316
v133usa	132.62	USA1	132.62	339	139	179	316	154	179	316
v104	104.08	V3	104.08	286	86	126	319	154	154	266
v72usa	71.66	USA2	71.66	339	139	179	320	151	179	266
v72	71.66	V4	71.66	159	319	359	320	154	154	266
v35S	35	V5	35.00	157	317	357	321	154	154	316
v35N	35	V6	35.00	337	137	177	321	149	177	316
dir131	140	Dir0	130.92	336	136	176	318	154	176	316
dir104	100	Dir1	104.08	106	266	306	319	154	154	266
dir72	80	Dir2	71.66	159	319	359	320	154	154	316
dir35	40	Dir3	35.00	157	317	357	321	154	154	316

Table 3: Sensor specification list of mast mounted sensors.

Sensor	Acronym	Make	Serial
Cup Anemometer v0	v135N	Thies First Class	0309119
Cup Anemometer v1	v135S	Thies First Class	0209798
Cup Anemometer v2	v133	Thies First Class	0209552
Cup Anemometer v3	v104	Thies First Class	0309117
Cup Anemometer v4	v72	Thies First Class	0209542
Cup Anemometer v5	v35S	Thies First Class	205939
Cup Anemometer v6	v35N	Thies First Class	309115
Wind vane dir0	dir131	Thies Classic	1107079
Wind vane dir1	dir104	Thies Classic	0604056
Wind vane dir2	dir72	Thies Classic	604061
Wind vane dir3	dir35	Thies Classic	604060
Ultrasonic anemometer USA1 Ultrasonic anemometer USA2	v133usa v72usa	Gill Windmaster Gill Windmaster	93120 525

3 Set-Up of the Triton, Data Collection and Data Processing

3.1 Set-Up of the Triton

The Triton Wind Profiler has been set-up at 2010-09-08 by staff members of Second Wind and DWG. The Triton was running without any standstills due to technical problems until it was stopped at 2010-11-08. Only the satellite communication was disturbed at the end of the measurement due to problems with the telecommunication provider.

The Triton was supplied by solar panels in the measurement period.

The basic information and key settings of the Triton are shown in the following table. The settings have not been changed in the measurement period.

Table 4: Basic information and key settings of the tested Triton.

Evaluated measurement period	2010-09-08 to 2010-11-08
Triton model	Triton Wind Profiler
Unit serial number	225
Selected measurement heights	40, 50, 60, 80, 100, 120, 140, 160, 180, 200 m
Beam angle from vertical	11.4 °
North beam orientation during test	0 °
Firmware version	1.12
Power supply	Solar panels

The vertical and horizontal alignment was adjusted by stuff member of Second Wind at the start of the measurements. The vertical alignment was measured with conventional spirit levels. The horizontal orientation was controlled by a compass. The horizontal orientation was 0°.

The alignment did not change during the course of the measurements.

The Triton and the data acquisition system of the met mast have been synchronised to CET time at the beginning of the campaign.

3.2 Data Collection

The Triton stores the data files containing statistics of 10-minute periods by an internal computer. This data has been read out via internet on a daily basis.

3.3 Data Processing

3.3.1 Horizontal Wind Speed Component

The Triton has fixed heights for measuring the wind. To avoid deviations that occur when horizontal wind speeds are compared from different measurement heights, the wind speed measurements of the Triton averaged over 10-miunte periods have been interpolated to the exact measurement heights of the reference sensors of the met mast. For this, a power law has been adjusted to the measurements of the horizontal wind speed component of the Triton at two successive measurement heights around the height of the reference sensor within each 10-minute period:

$$\alpha_v = \frac{\ln\left(\frac{v_{Triton,h_1}}{v_{Triton,h_2}}\right)}{\ln\left(\frac{h_1}{h_2}\right)}$$

$$v_{Triton,interpolated} = v_{Triton,h_1}\left(\frac{h_{interpolation}}{h_1}\right)^{\alpha_v}$$

where

α_v:	power law exponent in terms of the horizontal wind speed component
h_1:	measurement height of Triton below height of reference sensor
h_2:	measurement height of Triton above height of reference sensor
$h_{interpolated}$	interpolation height
v_{Triton,h_1}:	measurement of horizontal wind speed component of Triton at height h_1
v_{Triton,h_2}:	measurement of horizontal wind speed component of Triton at height h_2
$v_{Triton,h_{interpolated}}$:	interpolated wind speed

The so interpolated wind speeds determined on the basis of the measurements of the Triton have been compared to the reference measurements with the mast mounted sensors. Mast effects on the anemometers below the mast top have been corrected by empirically determined corrections according to appendix 9.3.

3.3.2 Wind Shear

A power law has been adjusted to the measurements of the horizontal wind speed component of the Triton at two measurement heights as close to a pair of successive measurement heights at the met mast within each 10- minute period. The wind shear exponents determined from the measurements of the Triton have been compared to the wind shear exponents determined from the mast measurements.

3.3.3 Wind Direction

The wind directions measured by the Triton as average of 10-minute periods have been compared directly to the measurements with the vanes at the nearest measurement heights of the mast.

3.3.4 (Horizontal) Turbulence Intensity

A similar interpolation then in case of the horizontal wind speed component has also been performed for the turbulence intensity as measured by the Triton within each 10-minute period:

$$\alpha_I = \frac{\ln\left(\frac{I_{Triton,h_1}}{I_{Triton,h_2}}\right)}{\ln\left(\frac{h_1}{h_2}\right)}$$

$$I_{Triton,interpolated} = I_{Triton,h_1}\left(\frac{h_{interpolation}}{h_1}\right)^{\alpha_I}$$

where

h_1:	measurement height of Triton below height of reference sensor
h_2:	measurement height of Triton above height of reference sensor
$h_{interpolated}$	interpolation height
α_I:	power law exponent in terms of turbulence intensity
I_{Triton,h_1} :	turbulence intensity measured by Triton at height h_1
I_{Triton,h_2} :	turbulence intensity measured by Triton at height h_2
$I_{Triton,h_{interpolated}}$:	interpolated turbulence intensity

The so interpolated turbulence intensities determined on the basis of the measurements of the Triton have been compared to the reference measurements with the mast mounted sensors.

3.3.5 Vertical Wind Speed Component and its Standard Deviation

The vertical wind speed component measured by the Triton as average of 10-minute periods has been compared directly to the measurement with the ultrasonic anemometer at the nearest measurement height of the met mast.

3.4 Data Filtering

The following data filtering has been applied for the comparison of the measurements of the Triton and the mast based sensors:

Only wind directions, where the Triton and the reference sensor are exposed to free wind conditions (no wake effects), have been considered, i.e. the measurement sector according to

- Table 2**Fehler! Verweisquelle konnte nicht gefunden werden.** has been applied.
- Only wind speeds in the range 4-16 m/s as measured by the reference anemometer have been considered for the following reasons:
  - The wind tunnel calibration of the cup anemometer has been performed in the wind speed range 4-16 m/s according to MEASNET [6].
  - At low wind speeds, the cup anemometer measurements are linked to higher uncertainties.
  - Lower wind speeds are less relevant as hardly any energy is produced by wind turbines below 4 m/s.

- At higher wind speeds, the accuracy of the wind speed measurement is less relevant, because here the power production of wind turbines is hardly dependent on the wind speed.

- Only 10-minute periods, where the quality signal of the Triton is at least 85, have been considered.
- Only 10-minute periods, where the vertical wind speed component of the Triton is between +/- 1.5 m/s, have been considered. Measurements outside this range have been found to be mostly associated to rain conditions. Rain has found to have a significant influence on the accuracy of the measurements of the Triton.
- Regarding the evaluation of turbulence intensity (chapter 4.5), only 10-minute periods, where the turbulence quality factor of the Triton is at least 85 have been considered.
- 10-minute periods, where a rain sensor of the mast measurement indicated rain, have been filtered out.
- The ultrasonic anemometer at 133 m showed some implausible measurement data. This data has been filtered out by demanding a range of -0.2 m/s to 0.5 m/s for the vertical wind speed component as measured by this anemometer. This filter has been applied only for comparison of sodar data with this anemometer.

It is noted that the derived results are valid only for these filters. Thus, the evaluated accuracy of the Triton can be expected in a later application only if the above filters on the quality signals of the Triton and the filter on the vertical wind speed are applied.

3.5 Logbook

The following table lists the main events during the test.

Table 5: Logbook of Triton test

Date	**Staff**	**Event**
08.09.2010	awj	Installation of the Triton sodar at the test site; Start at 11:30
22.09.2010		System not available via internet
23.09.2010	awj	System checked at the site; modem error
12.10.2010	kc	Modem repaired by staff member of SecondWind
05.10.2010	awj	Data collected manually

4 Results

4.1 Availability of the Triton

A total amount of 7534 10-minute periods was covered by the evaluated measurement period.

The Triton has been defined as available when the quality signal was at least at a value of 85.. No other filter has been applied for the evaluation of the availability of the system. The so evaluated data availability at the different measurement heights is shown Figure 6.

As can be seen in Figure 6, the availability of wind speed decreases with increasing measurement height. An availability of 95 % or higher, as required by the MEASNET Site Assessment Procedure [7], is reached for measurement heights up to 80 m.

During the test period, the Triton had no breakdown despite the fact that it was supplied by solar panels as delivered by Second Wind together with the sodar.

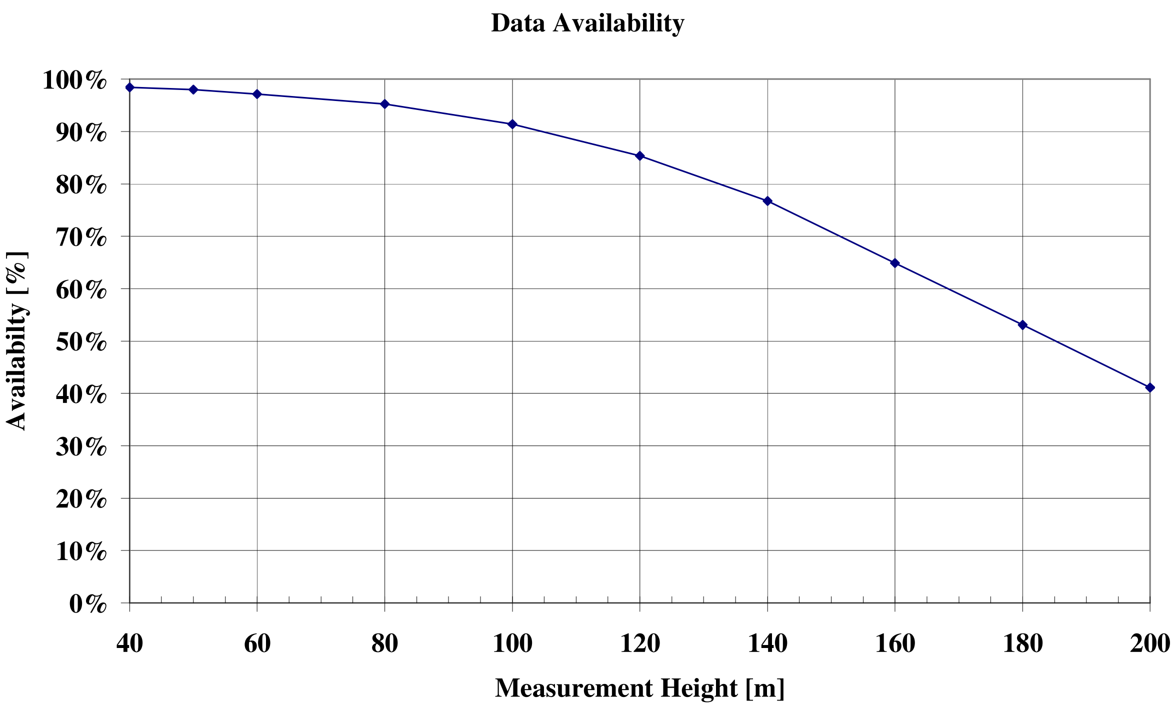


Figure 6: Availability of measurements of the horizontal wind speed component at different heights as measured by Triton. Only 10- minute averages with a quality value of at least 85 were considered. No other filters were applied.

4.2 Accuracy in Terms of the Horizontal Wind Speed Component

During the test period of the Triton some periods of heavy rain occurred. Precipitation has negative influence regarding the measurement accuracy of the Triton. To filter out periods of precipitation the vertical wind component of the Triton was limited to +/- 1.5 m/s. Additionally, the 10-minute data sets were filtered out when the rain sensor of the met mast showed precipitation signals. Figure 8 to Figure 10 gives an impression how the accuracy of the Triton is influenced by rain.

Detailed results of the comparison of cup anemometer measurements and measurements of the Triton in terms of the horizontal wind speed component are presented in the following sub chapters. The results can be summarised as follows:

- The 10-minute mean values of the horizontal wind speed component as measured by the Triton and by cup anemometers show a reasonable correlation (square of correlation coefficient about 0.96). There is no dependency of the correlation on the measurement height.
- There is hardly obvious outlier data present in the scatter plots of wind speed measured by the Triton and wind speed measured by the cup anemometers.
- The mean deviation between the wind speed measurements of the Triton and the cup anemometers is rather low: about 0.005 m/s or +0.1 % at the height level of 135 m, between 0.06 m/s and 0.11 m/s or 0.7 % and 1.4 % at the lower height levels.
- The standard deviation of the deviation of the wind speed measurements of the Triton and the cup anemometers is with 5 % to 7 % in the different measurement heights relatively high.
- As the statistics gained from the 10-minute raw data can in principle be influenced by the distribution of data within the measurement period, the measurements of the Triton have been bin averaged against the cup anemometer measurements, and the bin wise deviation between the measurements has been analysed. There is a systematic behaviour: In the wind speed range of about 7-11 m/s, the Triton tends to overestimate the wind speed. At high wind speeds above about 13 m/s, the Triton tends to underestimate the wind speed (Figure 7).
- The bin wise deviation of the measurements of the Triton and the cup anemometer measurements remains almost always inside of the uncertainty of the cup anemometer measurements cumulated with the statistical uncertainty of the comparison.

As the measurements with the cup anemometers are traced back to national standards, the comparison between the cup anemometers and the Triton can be used in order to define an uncertainty of the wind speed measurement of the Triton. The following uncertainty components have been considered in order to evaluate the uncertainty of the measurements of the Triton:

- Wind tunnel calibration of cup anemometers
- Classification of the cup anemometers according to IEC 61400-12-1
- Cup anemometer mounting effects
- Uncertainty of correction of mast effects on anemometers
- Bin wise deviation of Triton and cup anemometer measurements
- Statistical uncertainty of bin average of deviation of Triton and cup anemometer measurements

The different uncertainty components have been treated as independent uncertainties for the evaluation of the total uncertainty of the measurements of the Triton as gained from the comparison. The resulting wind speed dependent uncertainties of the measurements of the horizontal wind speed component by the Triton are in the order of 2-3 % in most wind speed bins for all measurement heights. The variation of the uncertainty reaches from 1.5 % to 7.7 % for the different measurement heights and wind speed bins (Table 6 to Table 9).

A linear regression of the bin averages of the wind speed measurements of the Triton against the wind speed measurements of the cup anemometers systematically shows a regression offset clearly above zero and a regression slope clearly below 1 in all measurement heights (Figure 10, Figure 12, Figure 14 and Figure 16). An attempt has been made to apply such regressions (regressions of cup anemometer measurements against Triton measurements) for correcting/calibrating the measurements of the Triton, especially because the bin averaged deviations between the measurement of the Triton and the cup anemometers party exceed the uncertainty of the cup anemometer measurements cumulated with the statistical uncertainty of the tests [1]. However, the correction of the measurements by simple linear regressions turned out not leading to a significant improvement of the accuracy of the Triton, nor to a proper removal of the systematic deviations observed between the measurements of the Triton and the cup anemometers. Consequently, such corrections cannot be recommended for the tested Triton.

It is noted that the uncertainty of the Triton as resulting from this comparison does not reflect all uncertainties of the system during an application at another site. The following additional uncertainties should be considered for an application of the system:

- Uncertainties of the Triton due to deviating meteorological conditions during this test and during an application. These uncertainties can be evaluated on the basis of a test of the sensitivity of the measurements of the Triton on meteorological variables [1]. Such a test is not subject of the contracted work.
- The algorithms applied in the Triton for evaluating the three wind speed components are valid only if the wind conditions do not vary between the three measurement volumes around the sodar beams. This assumption is to a good approximation valid at the applied test station. However, the assumption can be heavily violated in complex terrain, what can be linked to significant measurement errors [8].
- Mounting errors of the Triton during an application (vertical alignment)
- Measurement errors caused by ambient noise
- The evaluated uncertainty is not valid during operation in rain or snow (see chapter 3.4).

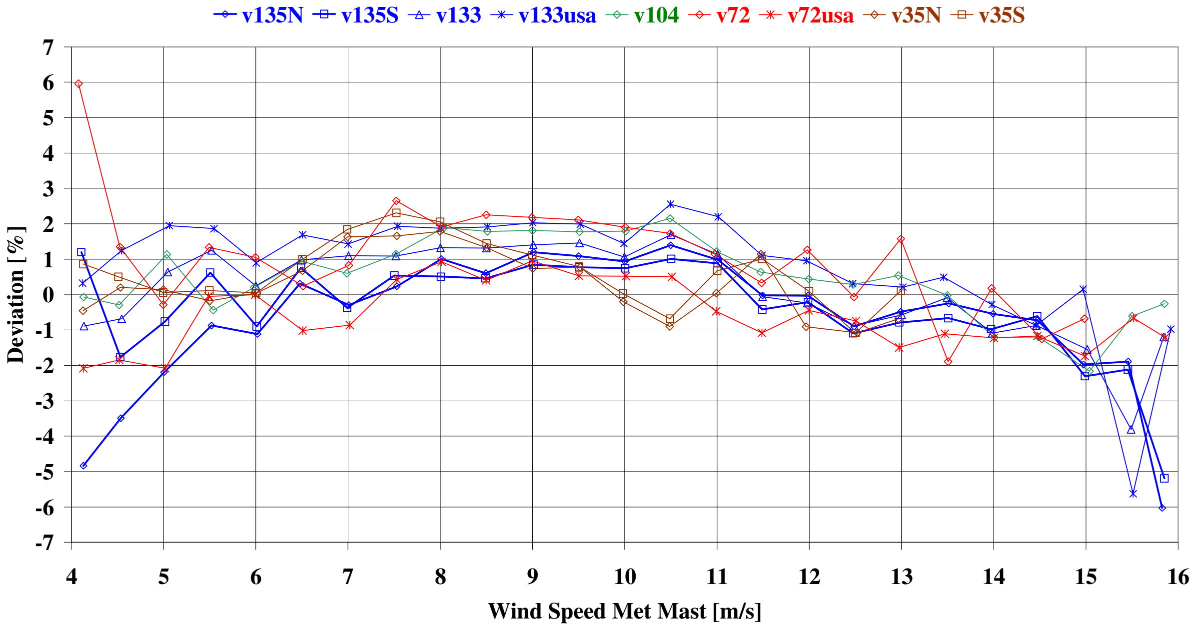


Figure 7 Bin averaged deviations of 10-minute averages of the horizontal wind speed component measured by Triton and cup and ultrasonic anemometer measurements at several heights above ground. The titles in the legend correspond to the names in

Table 2**Fehler! Verweisquelle konnte nicht gefunden werden.**.**Fehler! Verweisquelle konnte nicht gefunden werden.**.

4.2.1 Accuracy of Triton in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 135.12 m Measurement Height (v135S)

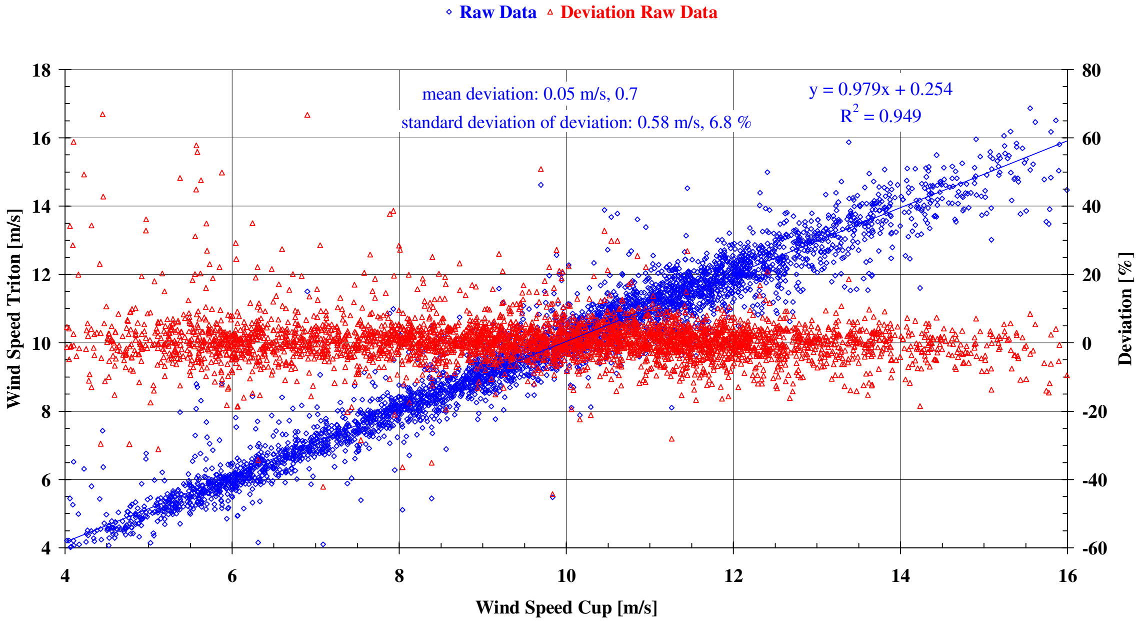


Figure 8: Scatter plot of horizontal wind speed component as measured by Triton against cup anemometer readings at 135.12 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average. Rain filter inactive.

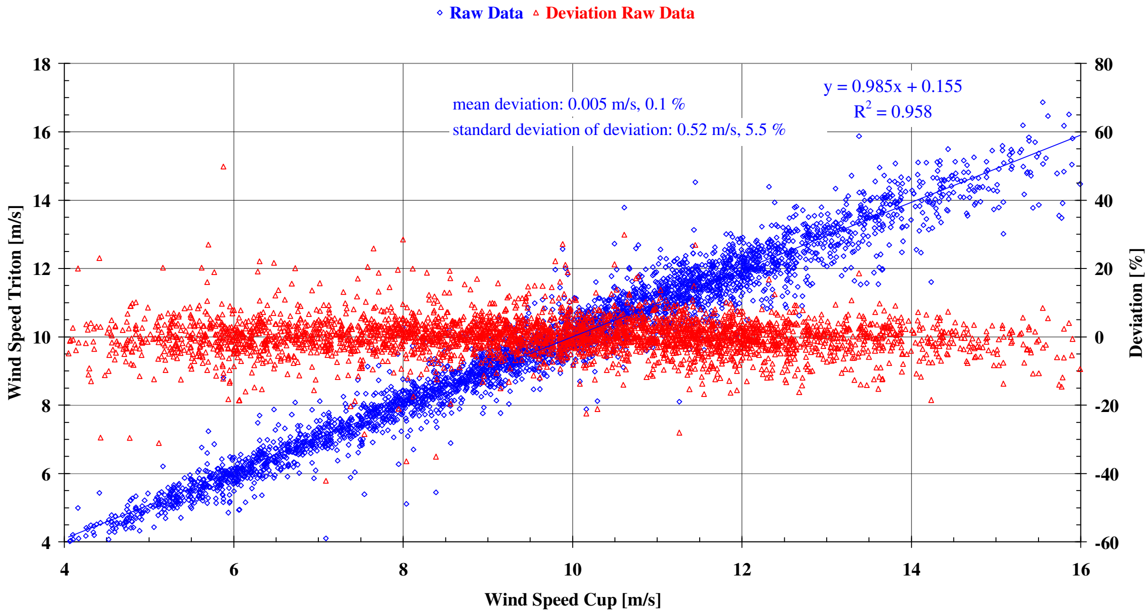


Figure 9: Scatter plot of horizontal wind speed component as measured by Triton against cup anemometer readings at 135.12 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average. Rain filter active.

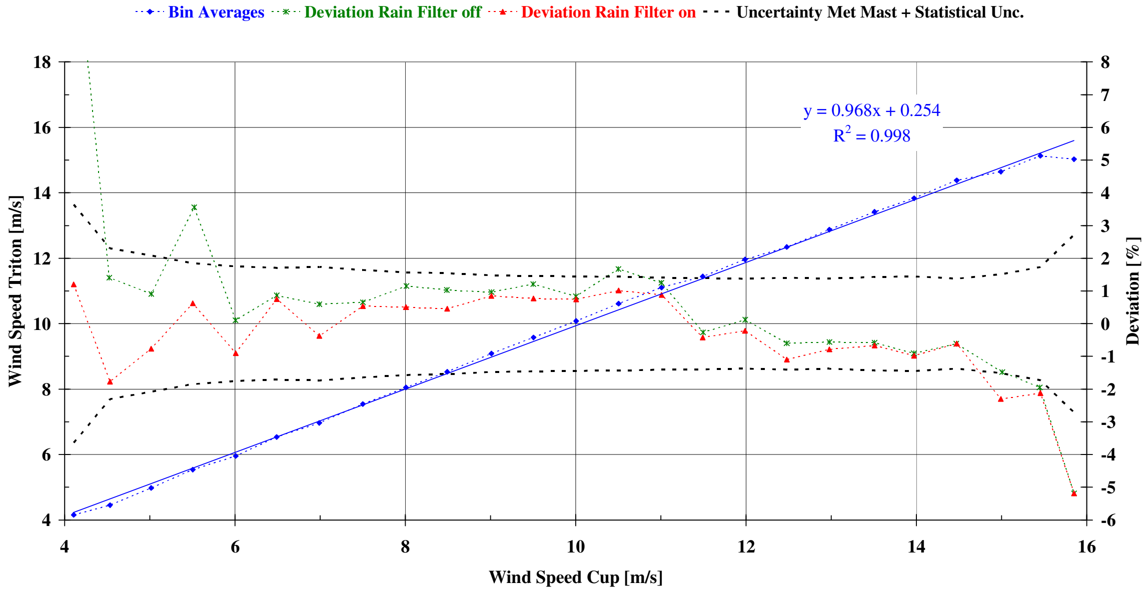


Figure 10: Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 135.12 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton.

Table 6: Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 135.12 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$v_{Metmast}$	v_{Triton}	number of data sets	v_{Triton} maximum	v_{Triton} minimum	v_{Triton} sigma	v_{Triton} sigma/sqrt(N)	deviation	$v_{Metmast}$ uncertainty	v_{Triton} uncertainty
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]
4.107	4.157	8	4.99	3.85	0.352	0.125	1.2	1.8	3.7
4.532	4.452	42	5.43	3.12	0.378	0.058	-1.8	1.8	2.8
5.015	4.977	66	6.21	3.36	0.416	0.051	-0.8	1.7	2.2
5.505	5.539	111	7.24	4.70	0.370	0.035	0.6	1.7	1.9
6.009	5.955	163	8.81	4.85	0.404	0.032	-0.9	1.7	2.0
6.490	6.539	133	8.08	5.36	0.407	0.035	0.8	1.6	1.9
6.990	6.964	127	8.12	2.70	0.581	0.052	-0.4	1.6	1.8
7.502	7.542	144	9.63	5.39	0.529	0.044	0.5	1.6	1.8
8.008	8.048	180	10.27	5.11	0.497	0.037	0.5	1.6	1.7
8.491	8.530	177	10.20	5.45	0.522	0.039	0.5	1.5	1.7
9.010	9.087	238	10.55	7.76	0.417	0.027	0.8	1.5	1.8
9.504	9.577	232	11.09	8.41	0.441	0.029	0.8	1.5	1.7
10.005	10.080	268	12.57	7.88	0.526	0.032	0.7	1.5	1.7
10.503	10.609	235	13.78	8.12	0.588	0.038	1.0	1.5	1.8
11.009	11.106	223	12.69	9.59	0.518	0.035	0.9	1.5	1.7
11.492	11.443	273	14.53	8.10	0.604	0.037	-0.4	1.5	1.6
11.988	11.962	226	13.23	9.92	0.523	0.035	-0.2	1.5	1.5
12.479	12.342	151	14.39	10.62	0.673	0.055	-1.1	1.4	1.9
12.978	12.876	110	14.34	11.51	0.534	0.051	-0.8	1.4	1.7
13.509	13.419	101	15.87	11.53	0.767	0.076	-0.7	1.4	1.7
13.973	13.836	60	15.10	11.60	0.676	0.087	-1.0	1.4	1.8
14.473	14.385	56	15.49	13.35	0.494	0.066	-0.6	1.4	1.6
14.991	14.645	29	15.59	13.02	0.635	0.118	-2.3	1.4	2.8
15.456	15.128	22	16.86	13.54	0.842	0.180	-2.1	1.4	2.8
15.851	15.029	8	16.51	13.48	1.076	0.380	-5.2	1.4	5.9

4.2.2 Accuracy of Triton in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 104.08 m Measurement Height (v104)

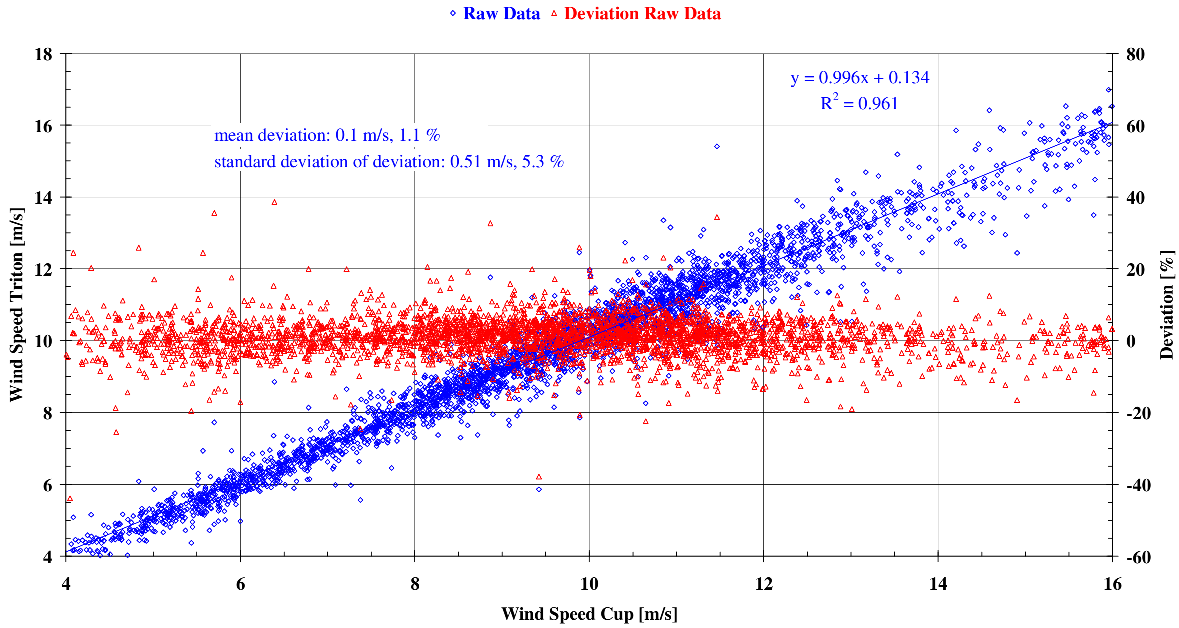


Figure 11: Scatter plot of horizontal wind speed component as measured by Triton against cup anemometer readings at 104.08 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

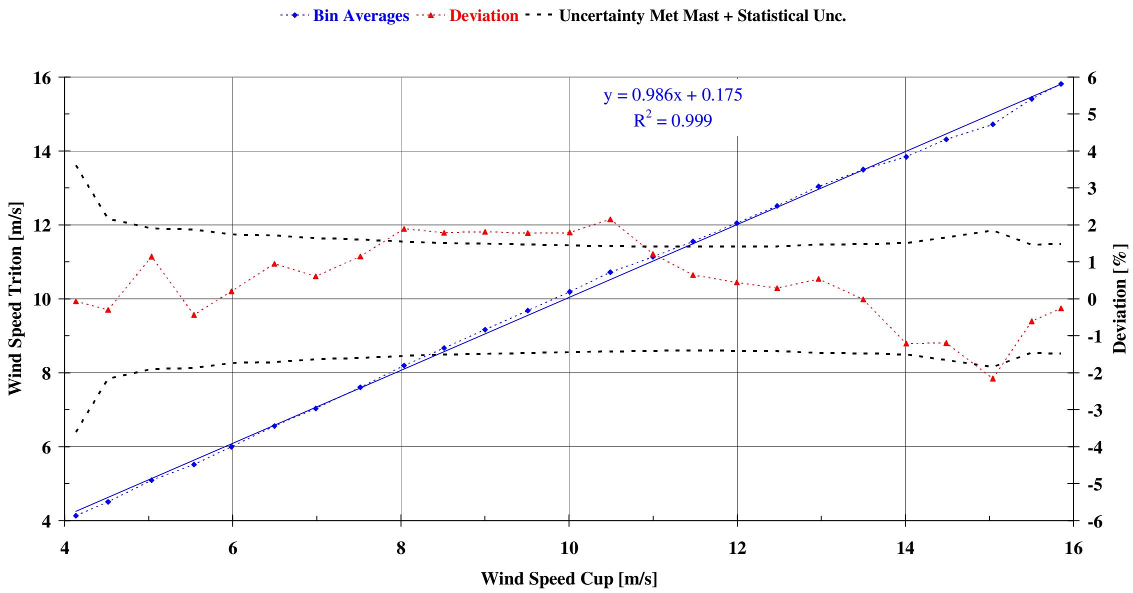


Figure 12: Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 104.08 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton.

Table 7: Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 104.08 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$v_{Metmast}$	v_{Triton}	number of data sets	v_{Triton} maximum	v_{Triton} minimum	v_{Triton} sigma	v_{Triton} sigma/sqrt(N)	deviation	$v_{Metmast}$ uncertainty	v_{Triton} uncertainty
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]
4.133	4.130	19	5.08	2.27	0.539	0.124	-0.1	1.8	3.5
4.517	4.503	55	5.17	3.41	0.337	0.045	-0.3	1.8	2.1
5.034	5.091	102	6.09	4.42	0.294	0.029	1.1	1.8	2.2
5.537	5.513	111	7.72	4.37	0.412	0.039	-0.4	1.7	1.9
5.983	5.995	129	6.93	4.97	0.321	0.028	0.2	1.7	1.8
6.496	6.558	117	8.85	5.89	0.391	0.036	0.9	1.7	2.0
6.985	7.028	126	8.65	5.99	0.363	0.032	0.6	1.6	1.8
7.517	7.603	143	8.60	5.56	0.422	0.035	1.1	1.6	2.0
8.038	8.190	183	9.82	7.21	0.415	0.031	1.9	1.6	2.5
8.512	8.665	233	10.26	7.30	0.412	0.027	1.8	1.6	2.4
9.000	9.163	231	11.76	7.64	0.487	0.032	1.8	1.5	2.4
9.510	9.679	266	11.24	5.86	0.550	0.034	1.8	1.5	2.4
10.008	10.187	234	12.45	7.85	0.528	0.035	1.8	1.5	2.4
10.490	10.716	267	12.73	8.26	0.545	0.033	2.2	1.5	2.6
10.998	11.131	270	13.35	9.02	0.581	0.035	1.2	1.5	2.0
11.473	11.547	211	15.40	9.87	0.599	0.041	0.6	1.5	1.7
11.995	12.048	139	13.17	10.35	0.606	0.051	0.4	1.5	1.6
12.474	12.510	105	13.89	10.43	0.605	0.059	0.3	1.5	1.6
12.967	13.037	83	14.69	10.52	0.747	0.082	0.5	1.5	1.7
13.498	13.495	54	15.18	11.93	0.660	0.090	0.0	1.5	1.6
14.009	13.839	39	15.85	12.45	0.662	0.106	-1.2	1.4	2.0
14.486	14.312	35	16.41	12.63	0.885	0.150	-1.2	1.4	2.1
15.039	14.715	23	16.06	12.44	0.955	0.199	-2.2	1.4	2.9
15.503	15.409	35	16.53	13.93	0.635	0.107	-0.6	1.4	1.7
15.852	15.811	30	16.98	13.49	0.652	0.119	-0.3	1.4	1.6

4.2.3 Accuracy of Triton in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 71.66 m Measurement Height (v72)

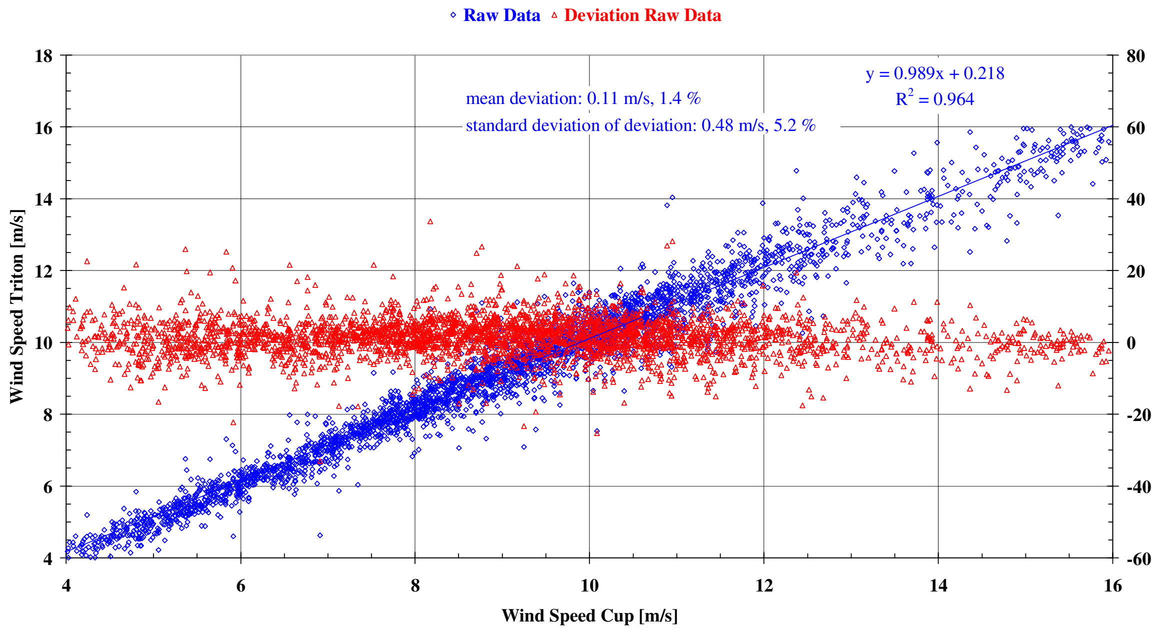


Figure 13 Scatter plot of horizontal wind speed component as measured by Triton against cup anemometer readings at 71.66 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

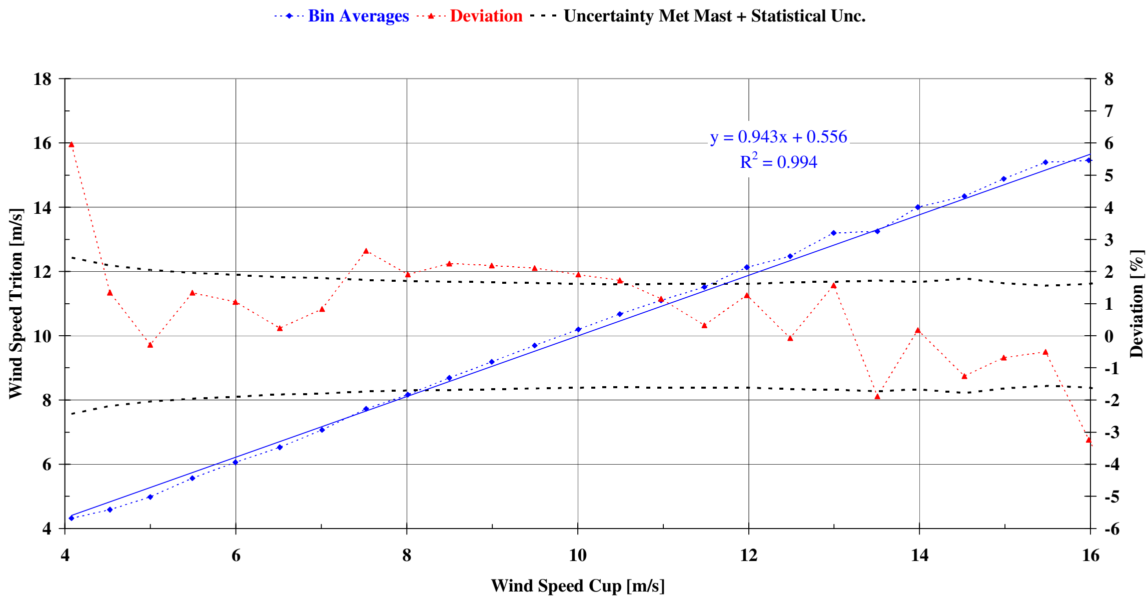


Figure 14 Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 71.66 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton.

Table 8: Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 71.66 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$v_{Metmast}$	v_{Triton}	number of data sets	v_{Triton} maximum	v_{Triton} minimum	v_{Triton} sigma	v_{Triton} sigma/sqrt(N)	deviation	$v_{Metmast}$ uncertainty	v_{Triton} uncertainty
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]
4.076	4.319	27	5.20	4.00	0.239	0.046	6.0	2.0	6.4
4.526	4.587	67	5.37	4.01	0.284	0.035	1.3	2.0	2.5
4.997	4.983	109	5.84	4.22	0.304	0.029	-0.3	1.9	2.0
5.491	5.565	146	6.76	4.82	0.343	0.028	1.3	1.9	2.4
5.996	6.059	139	7.31	4.60	0.357	0.030	1.1	1.9	2.2
6.514	6.529	143	7.98	5.77	0.325	0.027	0.2	1.8	1.9
7.009	7.067	158	8.13	4.63	0.409	0.033	0.8	1.8	2.1
7.523	7.723	184	9.17	6.04	0.367	0.027	2.6	1.8	3.2
8.014	8.166	248	10.93	6.82	0.425	0.027	1.9	1.8	2.6
8.498	8.689	224	10.87	7.06	0.459	0.031	2.3	1.8	2.9
8.994	9.190	256	11.12	7.09	0.518	0.032	2.2	1.8	2.8
9.495	9.695	252	11.32	7.57	0.511	0.032	2.1	1.7	2.8
10.007	10.197	264	11.64	7.53	0.524	0.032	1.9	1.7	2.6
10.493	10.674	264	12.18	8.65	0.506	0.031	1.7	1.7	2.5
10.975	11.101	186	14.04	9.32	0.625	0.046	1.1	1.7	2.1
11.483	11.520	141	13.05	9.73	0.624	0.053	0.3	1.7	1.8
11.979	12.130	97	13.87	10.46	0.592	0.060	1.3	1.7	2.2
12.485	12.477	78	14.78	10.26	0.724	0.082	-0.1	1.7	1.8
12.994	13.198	45	14.59	11.66	0.629	0.094	1.6	1.7	2.4
13.507	13.252	35	15.27	12.19	0.672	0.114	-1.9	1.7	2.7
13.979	14.004	35	15.56	12.64	0.598	0.101	0.2	1.7	1.8
14.524	14.341	28	15.85	12.52	0.751	0.142	-1.3	1.7	2.3
14.986	14.884	40	15.95	12.82	0.657	0.104	-0.7	1.7	1.9
15.474	15.396	37	16.00	13.53	0.467	0.077	-0.5	1.6	1.8
15.980	15.463	16	15.94	14.41	0.411	0.103	-3.2	1.6	3.7
16.521	15.533	6	15.99	14.53	0.524	0.214	-6.0	1.6	6.3
16.940	15.682	3	15.99	15.49	0.269	0.155	-7.4	1.6	7.7

4.2.4 Accuracy of Triton in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 35 m Measurement Height (v35S)

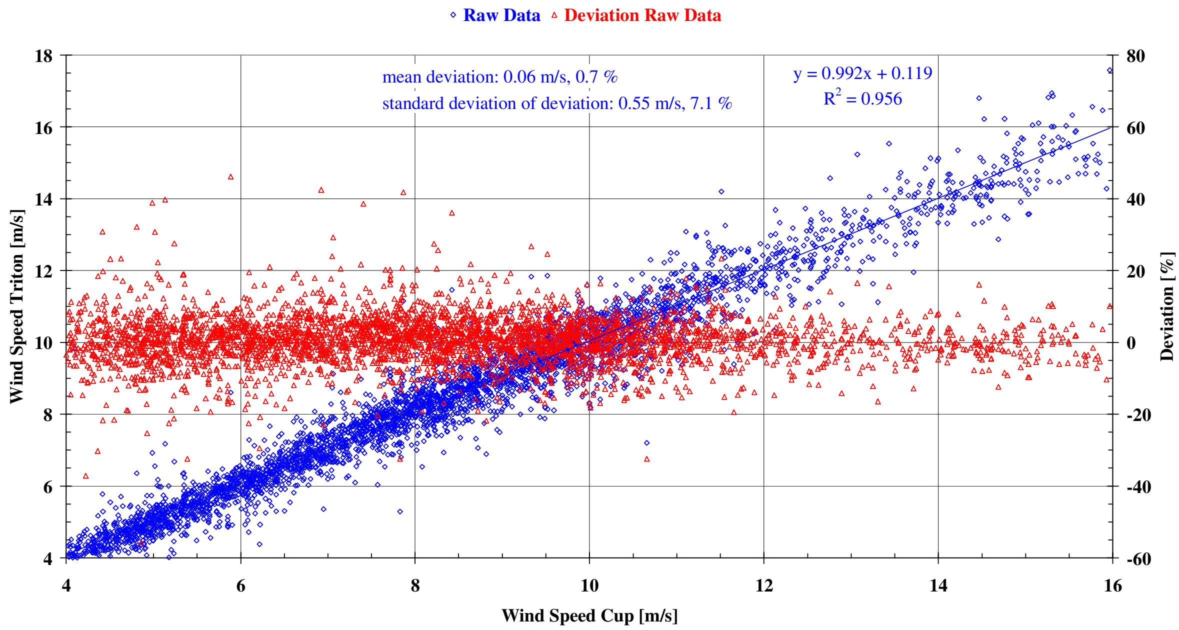


Figure 15 Scatter plot of horizontal wind speed component as measured by Triton against cup anemometer readings at 35 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

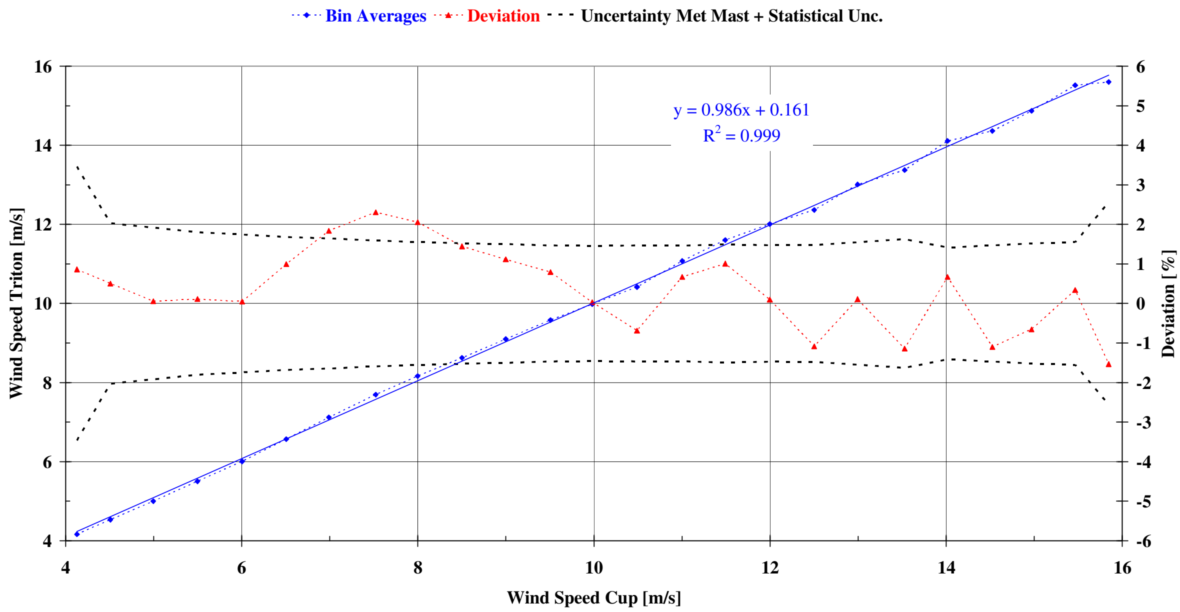


Figure 16 Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 35 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton.

Table 9: Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 35 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$v_{Metmast}$	v_{Triton}	number of data sets	v_{Triton} maximum	v_{Triton} minimum	v_{Triton} sigma	v_{Triton} sigma/sqrt(N)	deviation	$v_{Metmast}$ uncertainty	v_{Triton} uncertainty
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]
4.129	4.164	60	9.81	1.12	0.902	0.116	0.9	1.8	3.5
4.510	4.532	172	5.78	3.04	0.395	0.030	0.5	1.8	2.0
4.995	4.998	251	7.17	2.15	0.481	0.030	0.1	1.7	1.9
5.497	5.503	214	6.41	3.64	0.387	0.026	0.1	1.7	1.8
6.004	6.007	231	8.60	4.38	0.451	0.030	0.0	1.7	1.7
6.506	6.571	221	7.91	5.26	0.439	0.030	1.0	1.6	2.0
6.989	7.118	228	9.86	5.36	0.507	0.034	1.8	1.6	2.5
7.523	7.697	246	10.26	6.04	0.498	0.032	2.3	1.6	2.8
7.998	8.163	294	11.15	5.29	0.560	0.033	2.1	1.6	2.6
8.501	8.624	283	11.46	6.94	0.563	0.033	1.4	1.6	2.2
8.998	9.098	234	10.85	6.89	0.564	0.037	1.1	1.5	1.9
9.506	9.582	288	11.86	7.88	0.569	0.034	0.8	1.5	1.8
9.980	9.983	257	11.78	8.19	0.592	0.037	0.0	1.5	1.6
10.489	10.417	186	12.30	7.20	0.680	0.050	-0.7	1.5	1.7
11.002	11.076	148	13.08	9.21	0.672	0.055	0.7	1.5	1.7
11.490	11.605	107	14.20	9.39	0.746	0.072	1.0	1.5	1.9
11.997	12.009	72	13.68	10.24	0.611	0.072	0.1	1.5	1.6
12.501	12.365	65	13.73	11.03	0.646	0.080	-1.1	1.5	1.9
12.994	13.008	45	15.23	11.06	0.702	0.105	0.1	1.4	1.7
13.528	13.374	41	15.53	11.12	0.833	0.130	-1.1	1.4	2.1
14.015	14.109	44	15.35	13.30	0.507	0.076	0.7	1.4	1.7
14.524	14.364	44	16.80	12.87	0.666	0.100	-1.1	1.4	1.9
14.968	14.870	38	16.22	13.44	0.743	0.120	-0.7	1.4	1.8
15.464	15.516	27	16.94	14.46	0.700	0.135	0.3	1.4	1.7
15.846	15.602	9	17.58	14.28	1.056	0.352	-1.5	1.4	3.0

4.3 Accuracy of Triton in Terms of Wind Shear

Wind shear exponents have been calculated for each 10-minute period from the measurements of the Triton and the measurements of the met mast at approximately same measurement heights as explained in chapter 3.3.2. The applied measurement heights of the Triton and the cup anemometers are summarised in Table 10.

Table 10: Selected heights for calculation of wind shear from met mast and Triton data

	Anemometer	**Triton**
	height in [m]	**height in [m]**
Wind shear exponent α	35.00 – 71.66	40 – 80
	71.66 – 104.08	60 – 100
	104.08 – 135.12	100 – 140

Detailed results of the comparison of shear exponents are presented in the following sub chapters.

The following conclusions can be drawn:

- The comparison of the shear exponents derived from the measurements of the Triton and the cup anemometer measurements for each 10-minute period shows large scatter (Figure 17, Figure 19, Figure 21). The square of the correlation coefficient is only about 0.42 to 0.48 in the different height ranges.
- The bin-averaged wind shear exponents derived from the measurements of the Triton and the cup anemometer measurements show a high correlation with a squared correlation coefficient of about 0.97 to 0.98 (Figure 18, Figure 20, Figure 22).
- The mean shear exponents gained by the Triton between the measurement heights 40 m and 80 m and 60 m and 100 m agree well with the corresponding mean shear exponents derived from the cup anemometers (mean deviation about 0.01). However, the mean shear exponent evaluated from the Triton between the measurement heights 100 m and 140 m is much lower than the mean shear exponent gained from the mast (mean deviation about -0.05).
- The standard deviation of the deviations of the shear exponents determined by the Triton and by the cup anemometer measurements is high (about 0.09 at the lower height ranges 40 m-80 m and 60 m-100 m, about 0.14 in the upper height range 100 m-140 m).
- In the low height range 40 m-80 m, the mean shear exponents determined by the Triton and by the cup anemometers agree well in a large range of shear exponents from about 0.05 to 0.6 (Figure 18). At lower shear exponents as determined by the cup anemometers, the Triton significantly overestimates the wind shear in this height range.
- Also in the height range 60 m-100 m, the Triton overestimates the mean shear determined by the cup anemometers significantly at wind shears below 0.05. In this height range, the wind shear is in tendency underestimated by the Triton at wind shears above 0.2 (Figure 20).
- In the upper height range 100 m-140 m, the Triton systematically underestimates the wind shear determined by the cup anemometers at shear exponents above 0.25 (Figure 22).
- In general, there is a down shifting of the bin-wise comparison of the wind shear determined by the Triton and determined by the cup anemometers with increasing measurement height visible.

The comparison of the shear exponents measured by the cup anemometers and by the Triton can be used in order to define an uncertainty of the measurement of the wind shear of the Triton. The following components have been considered in order to evaluate this uncertainty:

- Wind tunnel calibration of cup anemometers
- Classification of the cup anemometers according to IEC 61400-12-1
- Cup anemometer mounting effects
- Uncertainty of correction of mast effects on anemometers
- Bin wise deviation of Triton and cup anemometer measurements in terms of the wind shear

- Statistical uncertainty of bin average of deviation of Triton and cup anemometer measurements in terms of the wind shear
- Statistical uncertainty of wind shear determined from measurements with the Triton per wind speed bin

The respective uncertainties of the two cup anemometer measurements applied to evaluate the reference wind shear have been cumulated under careful and conservative consideration of the correlation of the uncertainties between the cup anemometers. The uncertainty components listed above have then been treated as independent uncertainties for the evaluation of the total uncertainty of the wind shear measurement by the Triton as gained from the comparison.

The resulting wind shear dependent uncertainties of the Triton measurements in terms of the wind shear are about 0.02 to 0.04 for a shear range of 0.05 to 0.60 in the lower height range 40 m-80 m. This is considered as good. However, at lower and higher wind shear exponents, the uncertainty of the Triton increases significantly to values up to 0.09 in this height range (Table 11). In the height range 60 m-100 m, large uncertainties above 0.05 arise for the shear ranges below 0.05 and above 0.25 (Table 12). In the height range 100 m-140 m, the shear measurement of the Triton has high uncertainties almost in the entire shear range (Table 13).

4.3.1 Accuracy of Triton in Terms of Wind Shear between 40 m and 80 m

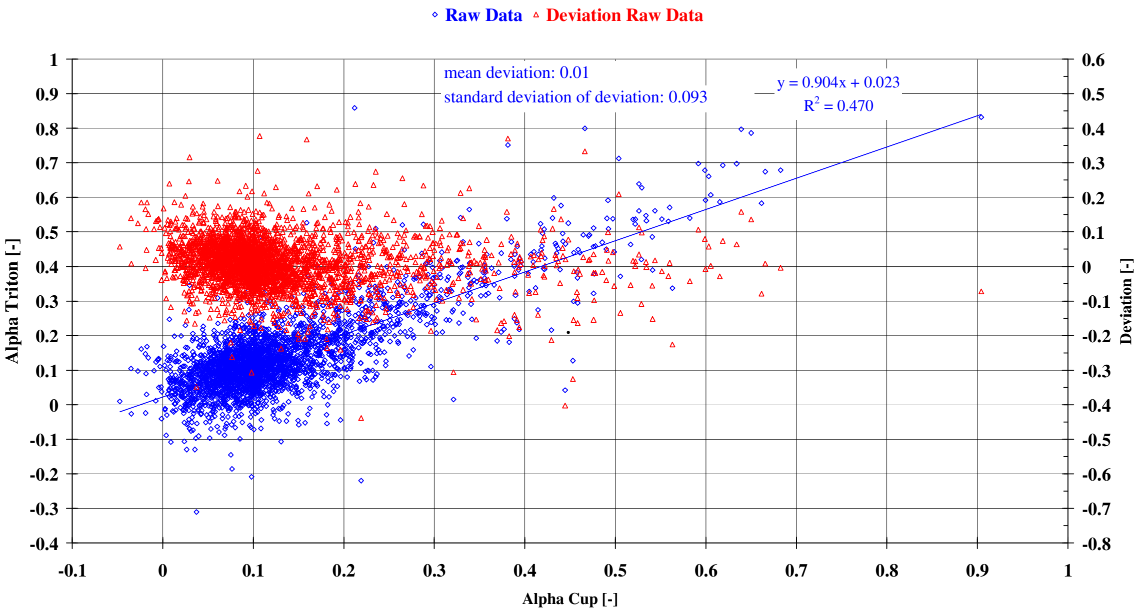


Figure 17 Scatter plot of shear exponents as measured by Triton between 40 m and 80 m height against cup anemometer measurements between 35.00 m and 71.66 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

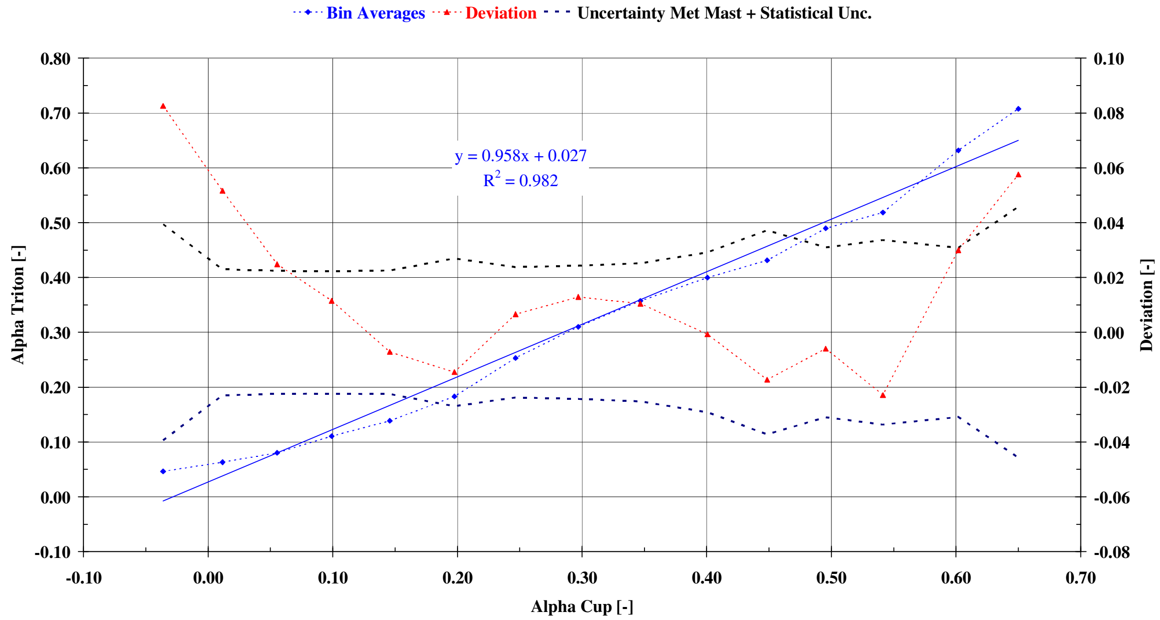


Figure 18 Bin analysis of shear exponents measured by Triton between 40 m and 80 m against cup anemometer measurements between 35.00 m and 71.66 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton.

Table 11: Bin analysis of shear exponents measured by Triton between 40 m and 80 m against cup anemometer measurements between 35.00 m and 71.66 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$\alpha_{Metmast}$	α_{Triton}	number of data sets	α_{Triton} maximum	α_{Triton} minimum	a_{Triton} sigma	α_{Triton} sigma/sqrt(N)	deviation	$\alpha_{Metmast}$ uncertainty	α_{Triton} uncertainty
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.04	0.05	4	0.10	-0.03	0.06	0.03	0.08	0.02	0.09
0.01	0.06	128	0.25	-0.11	0.06	0.01	0.05	0.02	0.06
0.06	0.08	722	0.35	-0.31	0.06	0.00	0.02	0.02	0.03
0.10	0.11	1149	0.49	-0.21	0.06	0.00	0.01	0.02	0.03
0.15	0.14	498	0.53	-0.11	0.07	0.00	-0.01	0.02	0.02
0.20	0.18	239	1.58	-2.79	0.23	0.02	-0.01	0.02	0.03
0.25	0.25	117	0.52	0.07	0.09	0.01	0.01	0.02	0.02
0.30	0.31	74	0.52	0.02	0.08	0.01	0.01	0.02	0.03
0.35	0.36	46	0.56	0.18	0.08	0.01	0.01	0.02	0.03
0.40	0.40	35	0.75	0.18	0.11	0.02	0.00	0.02	0.03
0.45	0.43	26	0.80	0.04	0.15	0.03	-0.02	0.02	0.04
0.50	0.49	18	0.71	0.32	0.09	0.02	-0.01	0.02	0.03
0.54	0.52	13	0.64	0.34	0.09	0.02	-0.02	0.02	0.04
0.60	0.63	8	0.70	0.54	0.06	0.02	0.03	0.02	0.04
0.65	0.71	5	0.80	0.58	0.09	0.04	0.06	0.02	0.07

4.3.2 Accuracy of Triton in Terms of Wind Shear between 60 m and 100 m

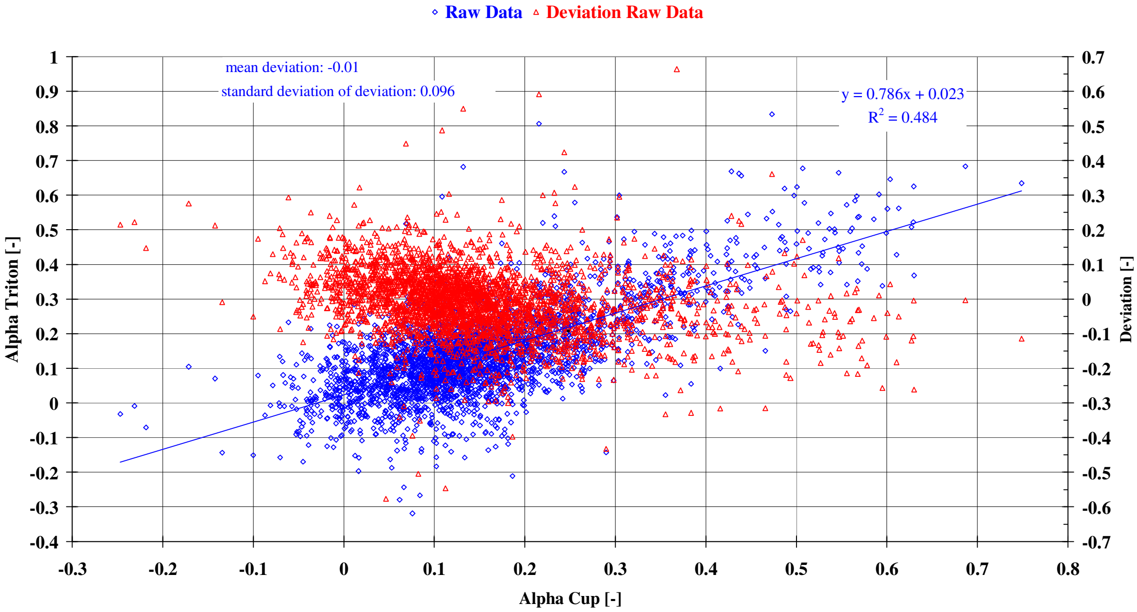


Figure 19 Scatter plot of shear exponents as measured by Triton between 60 m and 100 m height against cup anemometer measurements between 71.66 m and 104.08 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

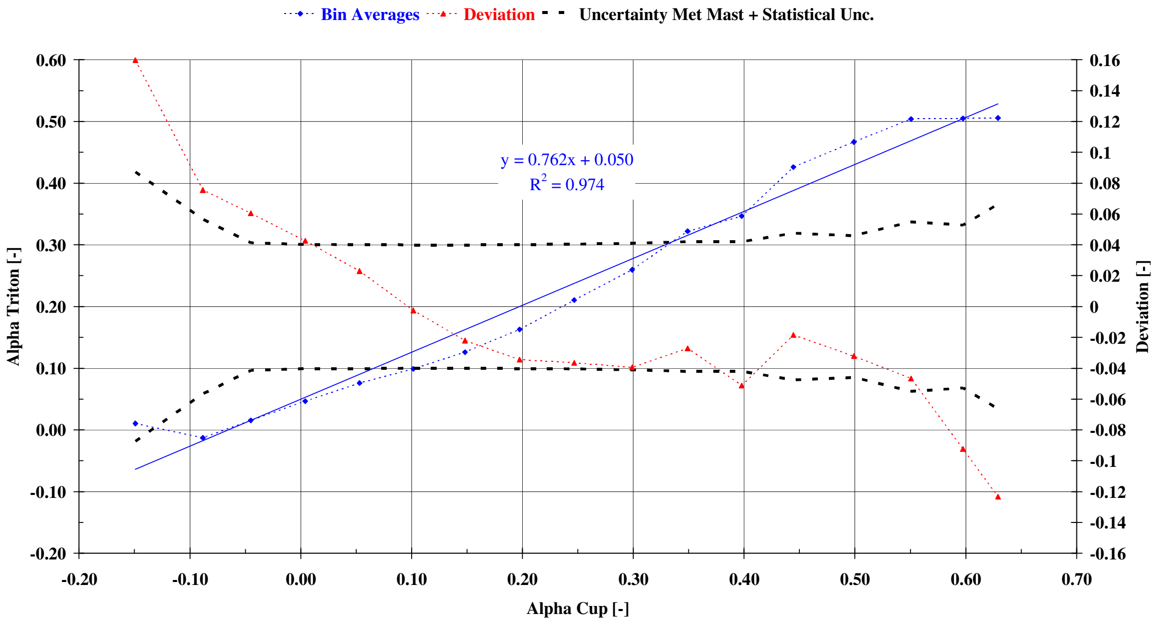


Figure 20 Bin analysis of shear exponents measured by Triton between 40 m and 80 m against cup anemometer measurements between 71.66 m and 104.08 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton.

Table 12: Bin analysis of shear exponents measured by Triton between 40 m and 80 m against cup anemometer measurements between 71.66 m and 104.08 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$\alpha_{Metmast}$	α_{Triton}	number of data sets	α_{Triton} maximum	α_{Triton} minimum	a_{Triton} sigma	α_{Triton} sigma/sqrt(N)	deviation	$\alpha_{Metmast}$ uncertainty	α_{Triton} uncertainty
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.15	0.01	3	0.10	-0.14	0.13	0.08	0.16	0.04	0.18
-0.09	-0.01	5	0.08	-0.15	0.09	0.04	0.08	0.04	0.09
-0.05	0.02	61	0.23	-0.17	0.08	0.01	0.06	0.04	0.07
0.00	0.05	230	0.34	-0.20	0.08	0.01	0.04	0.04	0.06
0.05	0.08	414	0.52	-0.53	0.09	0.00	0.02	0.04	0.05
0.10	0.10	716	0.60	-0.43	0.09	0.00	0.00	0.04	0.04
0.15	0.13	648	0.68	-0.16	0.08	0.00	-0.02	0.04	0.05
0.20	0.16	369	0.81	-0.21	0.09	0.00	-0.03	0.04	0.05
0.25	0.21	239	0.67	0.01	0.10	0.01	-0.04	0.04	0.05
0.30	0.26	120	0.60	-0.14	0.11	0.01	-0.04	0.04	0.06
0.35	0.32	86	1.03	0.02	0.12	0.01	-0.03	0.04	0.05
0.40	0.35	52	0.53	0.06	0.09	0.01	-0.05	0.04	0.07
0.44	0.43	31	0.83	0.15	0.14	0.03	-0.02	0.04	0.05
0.50	0.47	23	0.68	0.26	0.11	0.02	-0.03	0.04	0.06
0.55	0.50	28	1.43	0.34	0.20	0.04	-0.05	0.04	0.07
0.60	0.51	9	0.65	0.34	0.10	0.03	-0.09	0.04	0.11
0.63	0.51	4	0.63	0.37	0.11	0.05	-0.12	0.04	0.14

4.3.3 Accuracy of Triton in Terms of Wind Shear between 100 m and 140 m

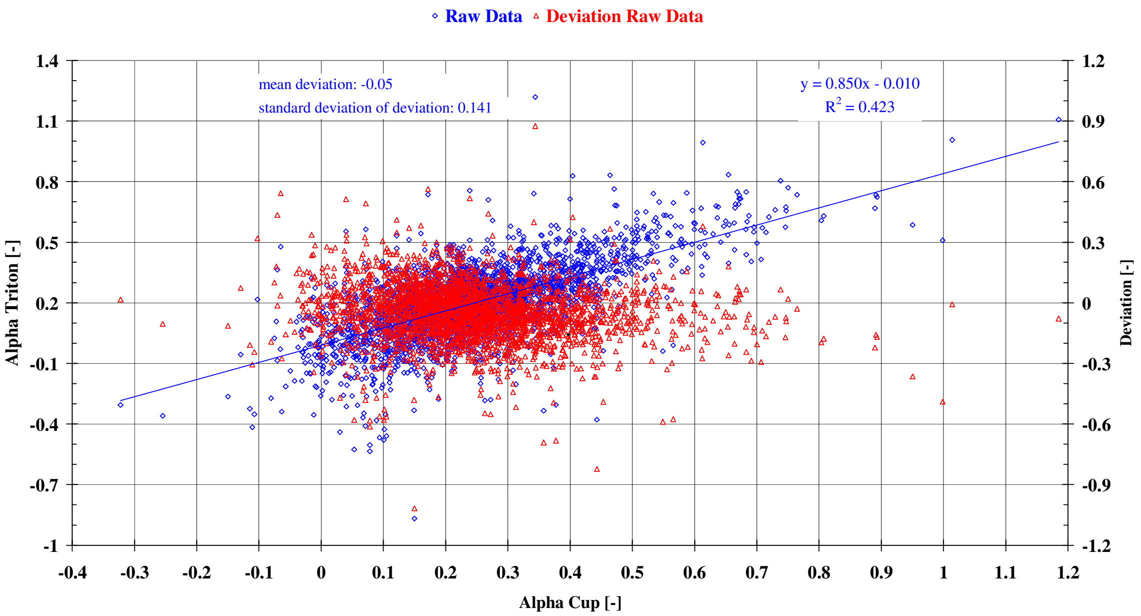


Figure 21: Scatter plot of shear exponents as measured by Triton between 60 m and 100 m height against cup anemometer measurements between 104.08 m and 135.12 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

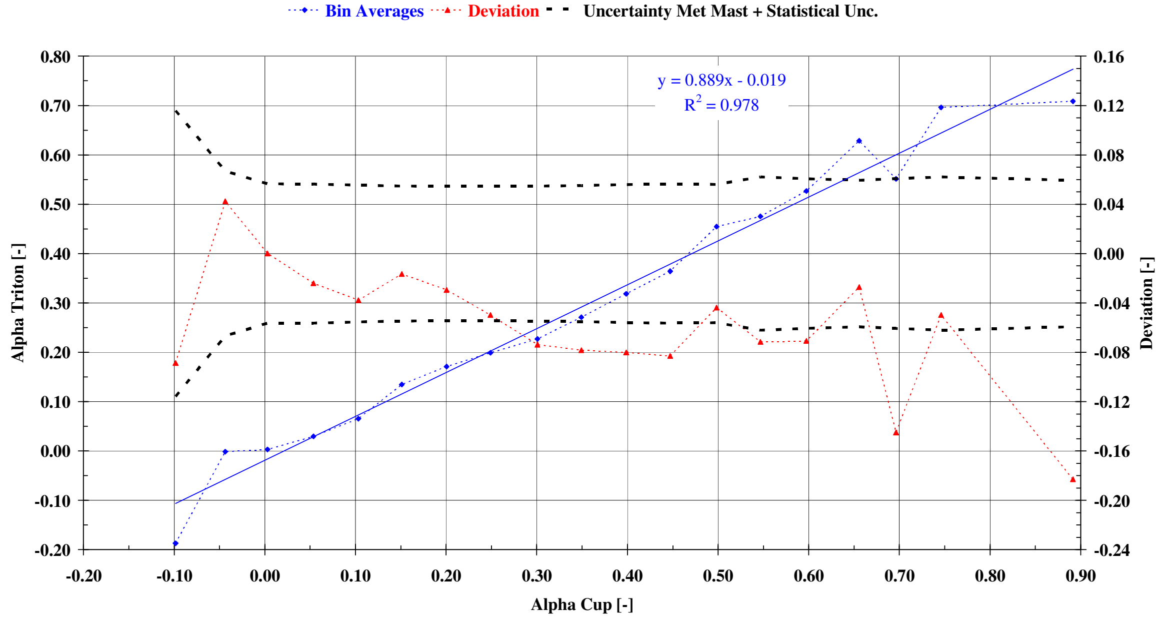


Figure 22: Bin analysis of shear exponents measured by Triton between 40 m and 80 m against cup anemometer measurements between 104.08 m and 135.12 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton.

Table 13: Bin analysis of shear exponents measured by Triton between 40 m and 80 m against cup anemometer measurements between 104.08 m and 135.12 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$\alpha_{Metmast}$	α_{Triton}	number of data sets	α_{Triton} maximum	α_{Triton} minimum	a_{Triton} sigma	α_{Triton} sigma/sqrt(N)	deviation	$\alpha_{Metmast}$ uncertainty	α_{Triton} uncertainty
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.10	-0.19	6	0.22	-0.42	0.25	0.10	-0.09	0.05	0.15
-0.04	0.00	22	0.48	-0.34	0.18	0.04	0.04	0.05	0.08
0.00	0.00	81	0.32	-0.35	0.14	0.02	0.00	0.05	0.06
0.05	0.03	136	0.56	-0.53	0.18	0.02	-0.02	0.05	0.06
0.10	0.07	225	0.53	-0.53	0.17	0.01	-0.04	0.05	0.07
0.15	0.13	361	0.74	-0.87	0.14	0.01	-0.02	0.05	0.06
0.20	0.17	520	0.49	-0.28	0.13	0.01	-0.03	0.05	0.06
0.25	0.20	497	0.76	-0.28	0.12	0.01	-0.05	0.05	0.07
0.30	0.23	360	0.61	-0.20	0.12	0.01	-0.07	0.05	0.09
0.35	0.27	221	1.22	-0.33	0.14	0.01	-0.08	0.05	0.10
0.40	0.32	161	0.83	-1.04	0.17	0.01	-0.08	0.05	0.10
0.45	0.36	100	0.83	-0.38	0.15	0.02	-0.08	0.05	0.10
0.50	0.45	61	0.68	0.15	0.10	0.01	-0.04	0.05	0.07
0.55	0.48	35	0.74	-0.04	0.18	0.03	-0.07	0.05	0.09
0.60	0.53	26	0.99	0.34	0.14	0.03	-0.07	0.05	0.09
0.66	0.63	20	0.83	0.40	0.11	0.02	-0.03	0.05	0.07
0.70	0.55	13	0.75	0.40	0.10	0.03	-0.14	0.05	0.16
0.75	0.70	7	0.80	0.57	0.08	0.03	-0.05	0.05	0.08
0.89	0.71	3	0.73	0.67	0.03	0.02	-0.18	0.06	0.19

4.4 Accuracy of the Triton in Terms of Wind Direction

The wind directions as measured by the Triton and by the met mast are compared for different measurement heights in the following sub chapters. A summary for all wind directions is shown in Figure 23. The following conclusions can be drawn:

- The wind directions as measured by the Triton and by the vanes correlate very well at the measurement heights 133 m , 104 m and 72 m with squared correlation coefficients of at least 0.99. At these heights, hardly any outlier data is observed in the respective scatter plots.
- The Triton shows a mean deviation to the measurements with vanes at 133 m and 104 m of -2.6 ° and -4.6 °, respectively.
- For the measurement height of 72 m the wind direction signal of the ultra sonic anemometer was used. Here the mean deviation is -5.9°.
- At 35 m measurement height, the mean deviation between Triton and wind vane is 3.7 °.
- Overall, the wind direction measurements of the Triton are considered as fine.

It is noted that the vane on the mast at 72 m is significantly influenced by the flow distortion caused by the mast. Thus, this vane has not been applied for the evaluation (also not for the evaluation of the accuracy of the Triton in terms of the measurement of the wind speed and wind shear).

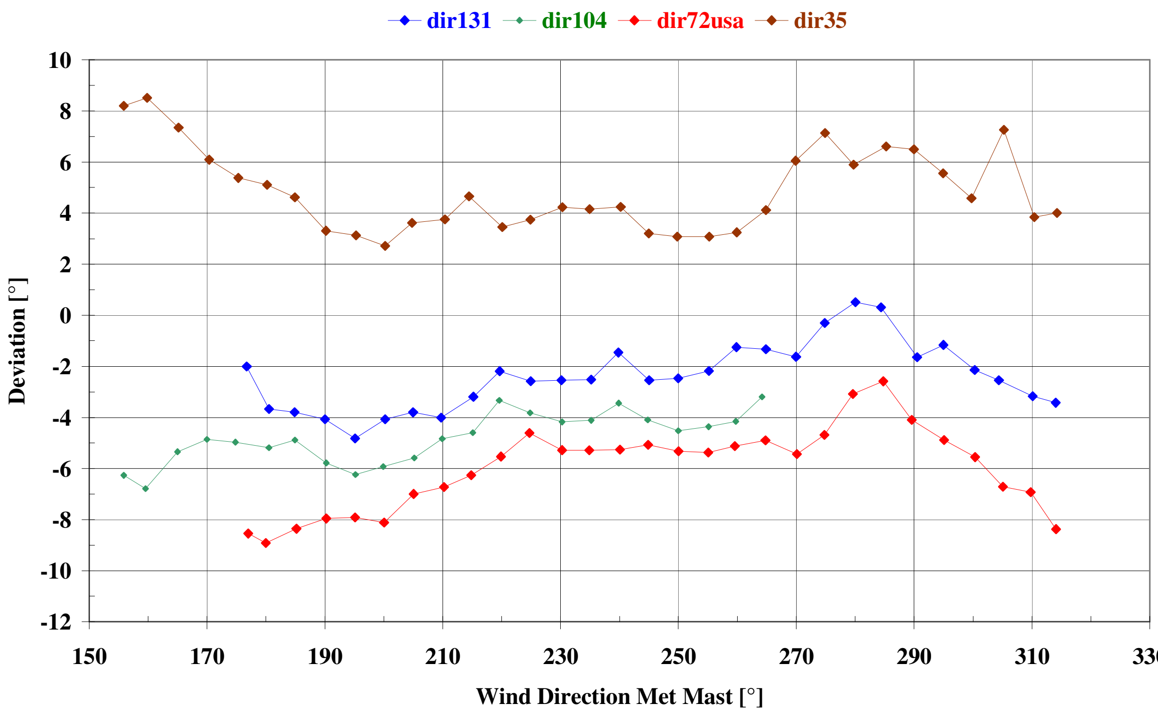


Figure 23 Bin averages of deviation of wind directions as measured by Triton and vanes on the met mast.

4.4.1 Wind Direction at133 m Height

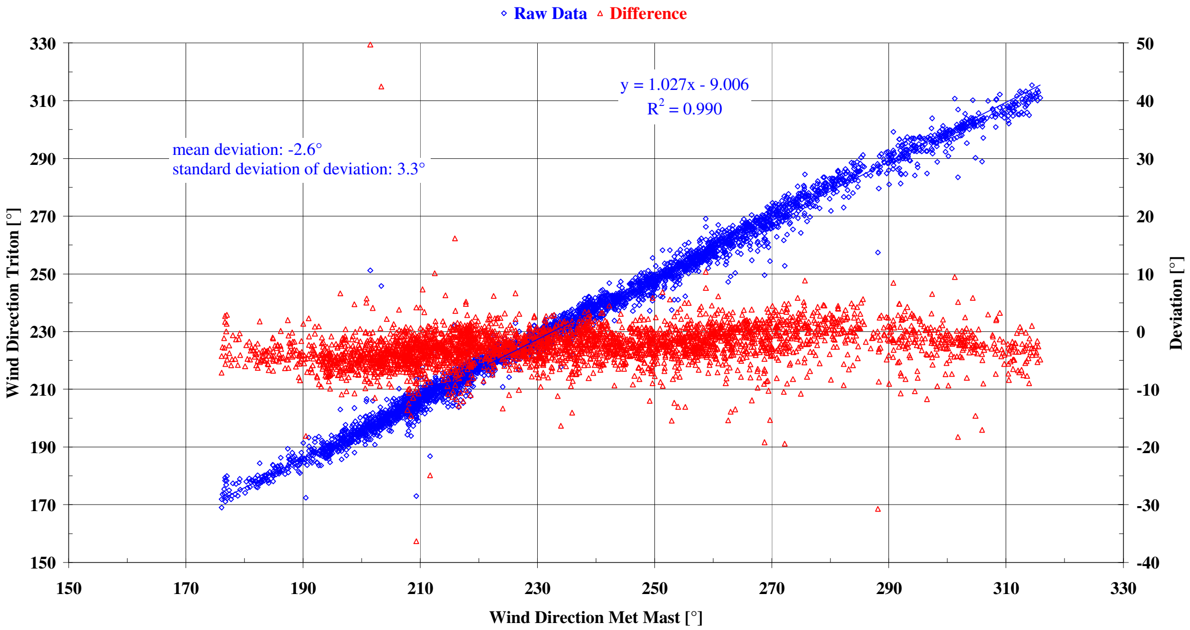


Figure 24 Scatter plot of wind direction as measured by Triton at 140 m height above ground against vane readings at 130.92 m measurement height.

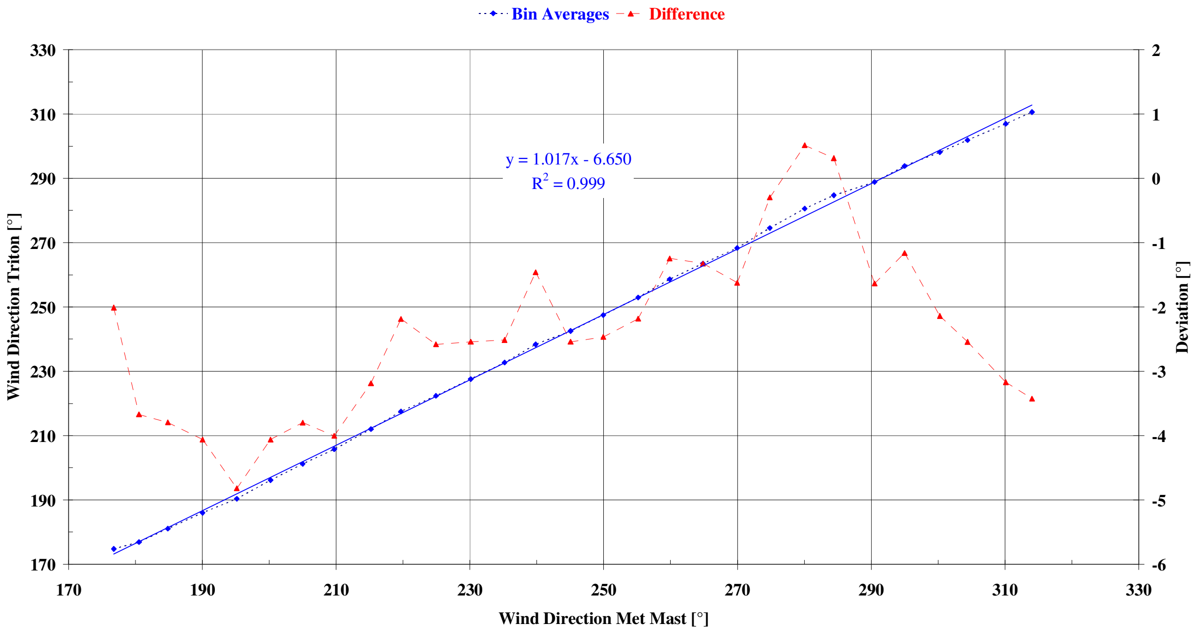


Figure 25 Bin analysis of wind direction as measured by Triton at 140 m height above ground against vane readings at 130.92 m measurement height.

4.4.2 Wind Direction at 104 m Height

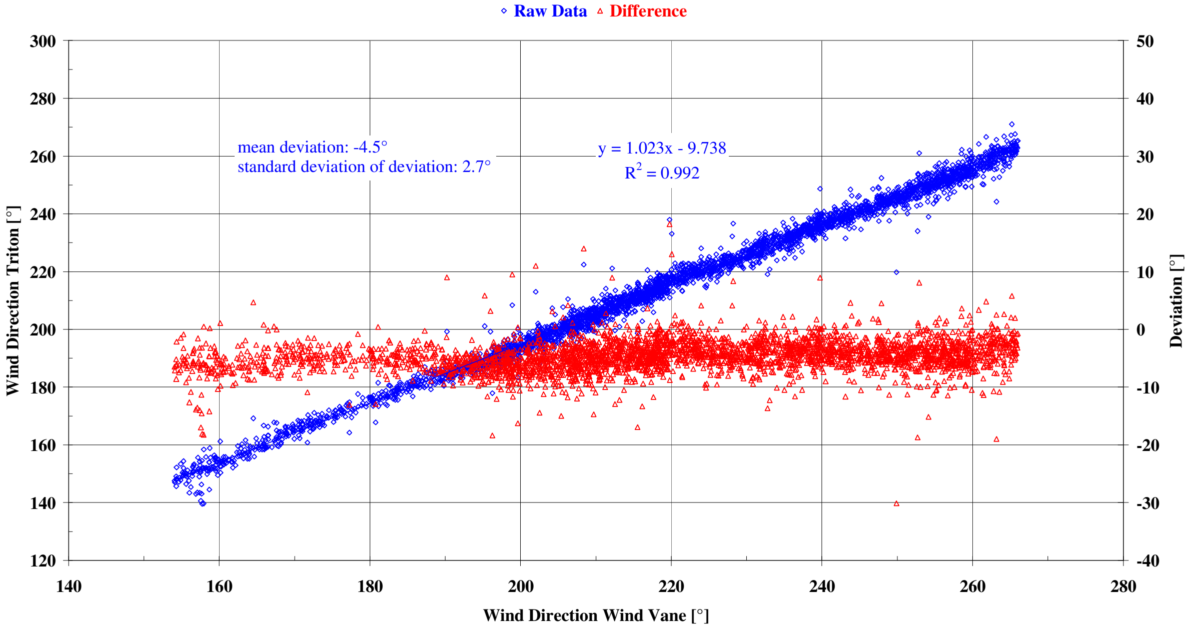


Figure 26 Scatter plot of wind direction as measured by Triton at 100 m height above ground against vane readings at 104.08 m measurement height.

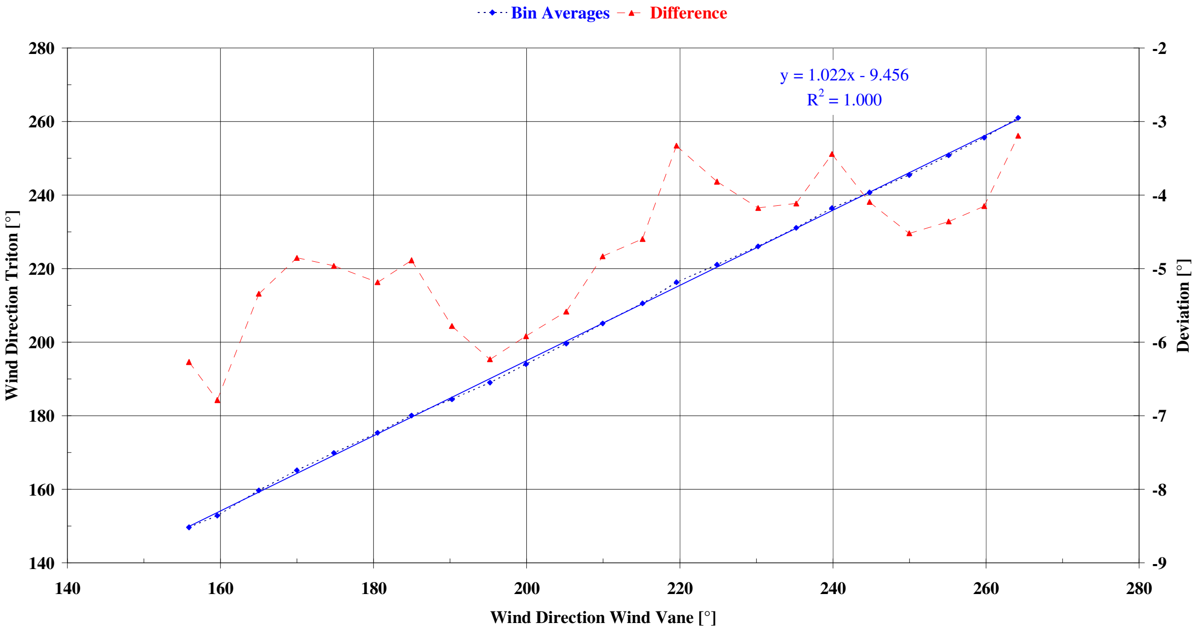


Figure 27 Bin analysis of wind direction as measured by Triton at 100 m height above ground against vane readings at 104.08 m measurement height.

4.4.3 Wind Direction at 72 m Height

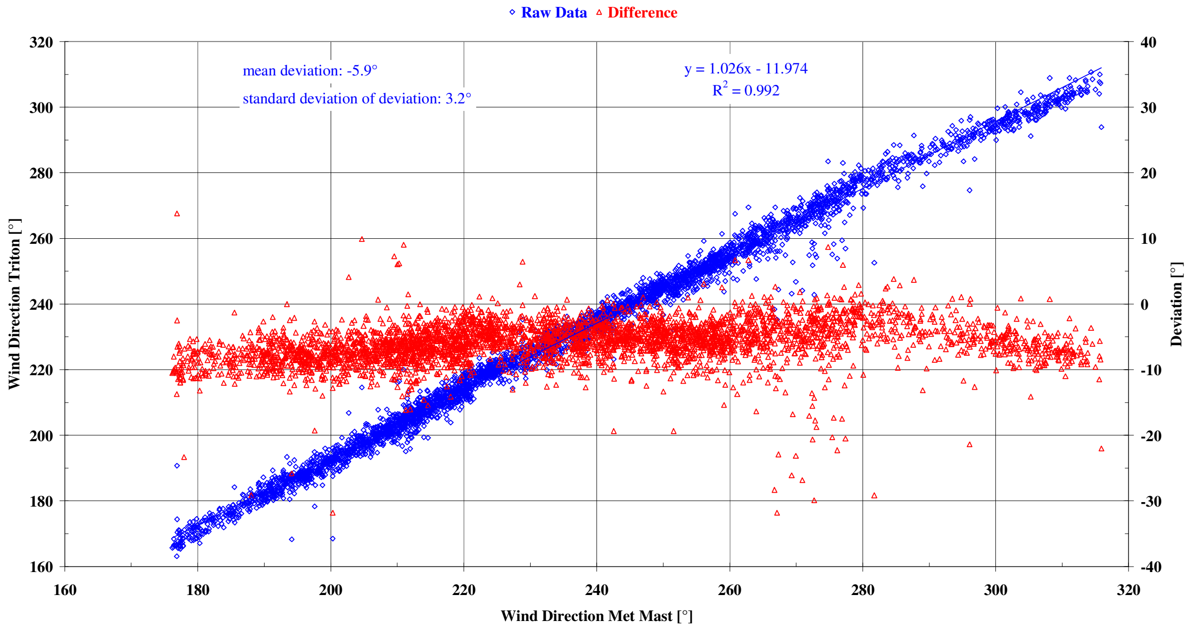


Figure 28 Scatter plot of wind direction as measured by Triton at 80 m height above ground against wind direction signal of ultra sonic anemometer readings at 71.66 m measurement height.

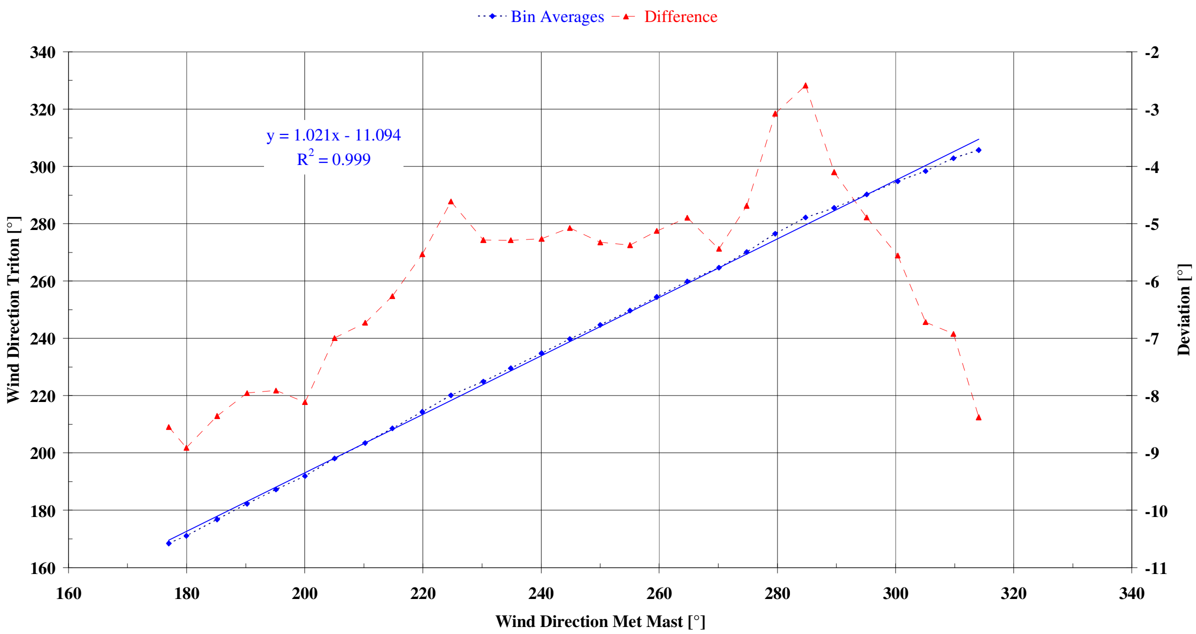


Figure 29 Bin analysis of wind direction as measured by Triton at 80 m height above ground against wind direction signal of ultra sonic anemometer readings at 71.66 m measurement height.

4.4.4 Wind Direction at 35 m Height

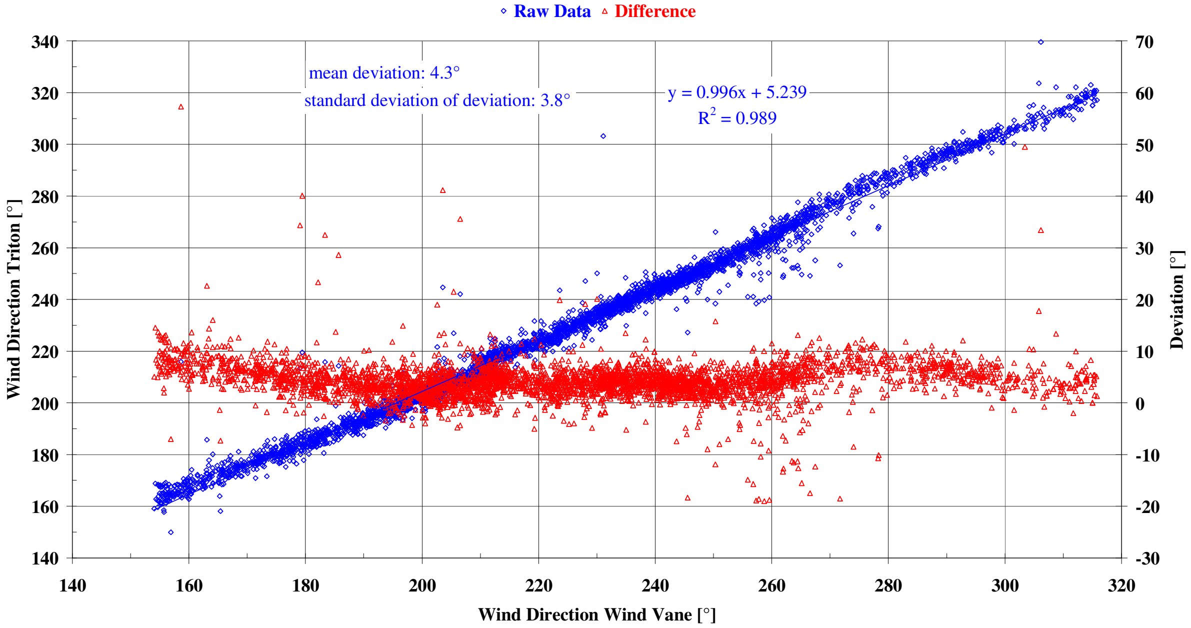


Figure 30 Scatter plot of wind direction as measured by Triton at 40 m height above ground against vane readings at 35 m measurement height.

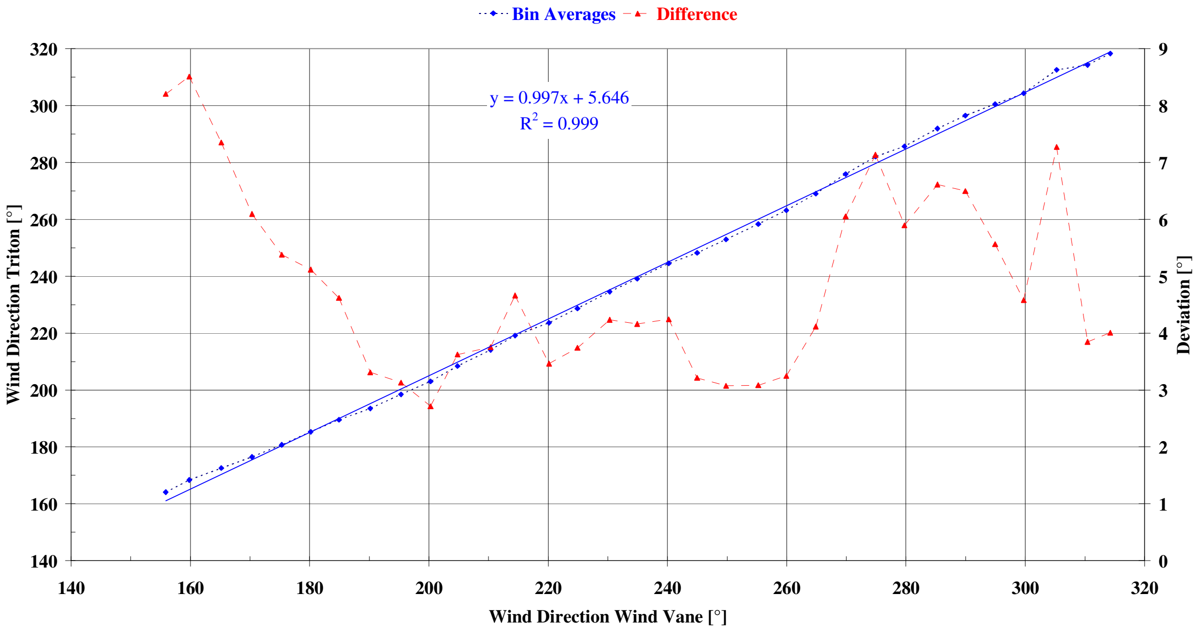


Figure 31 Bin analysis of wind direction as measured by Triton at 40 m height above ground against vane readings at 35 m measurement height.

4.5 Accuracy of Triton in Terms of Turbulence Intensity

For the evaluation of the accuracy of the turbulence intensity of the horizontal wind speed component per 10-minute period as measured by Triton, the same data filtering as described in chapter 3.4 has been applied. Detailed results of the comparison at all measurement heights of the mast are shown for cup anemometers as references in the following sub chapters. Key results are:

- The correlation of the turbulence intensity as determined by the Triton and the turbulence intensity as determined from cup and sonic anemometers is poor (squared correlation coefficient of 0.04 to 0.05) The respective scatter plots show many outliers (Figure 32, Figure 34, Figure 36, Figure 38).
- The mean turbulence intensity determined by the Triton deviates between 0.021 to -0.017 from the reference measurements at the different measurement heights. The mean deviation is systematically increases with increasing measurement height.
- The standard deviation of the deviations of the turbulence intensities determined by the Triton and by the cup anemometers varies from 0.04 to 0.06 in the different measurement heights.
- The bin averages of the turbulence intensity as determined by the Triton correlate reasonably well with the bin averages of the turbulence intensities determined with the reference sensors at the measurement heights 135.12 m and 104.08 m with squared correlation coefficients above 0.9. In the lower measurements heights, the correlation is poor (0.52 at 71.66 m, 0.38 at 35.00 m).
- The Triton clearly overestimates the turbulence intensity at low turbulence values. In addition, at the lower measurement heights the Triton clearly underestimates the turbulence intensities at high turbulence values.
- Overall, the Triton is hardly capable to determine the turbulence intensity.

4.5.1 Accuracy of Triton in Terms the Turbulence Intensity at 135.12 m Measurement Height

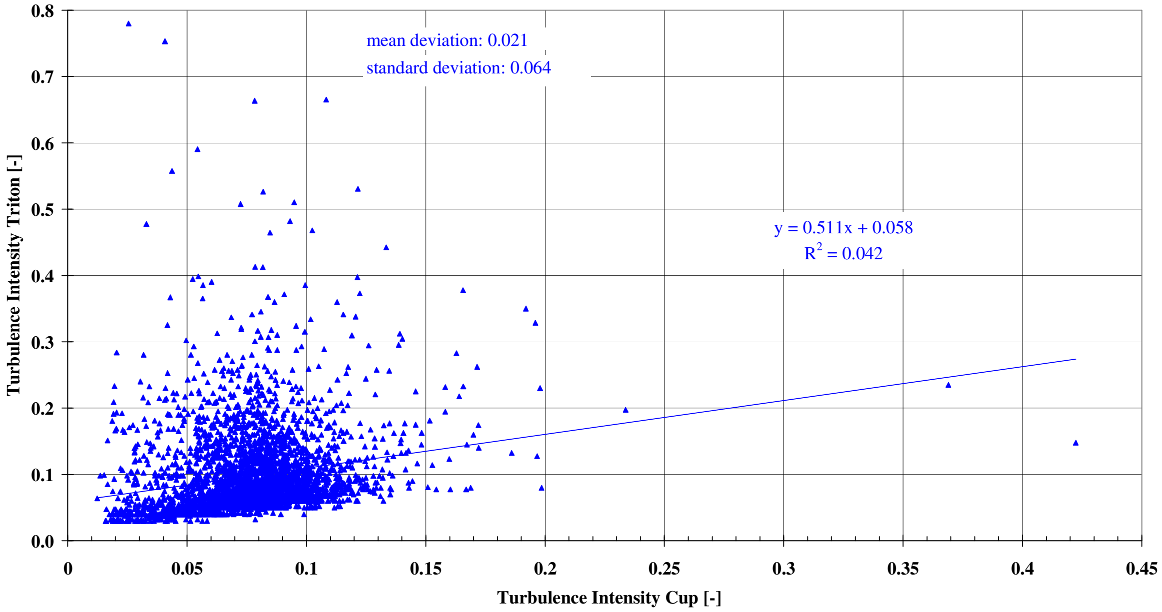


Figure 32 Scatter plot of turbulence intensity of the horizontal wind speed component as measured by Triton against cup anemometer measurements (v135S) at 135.12 m height above ground.

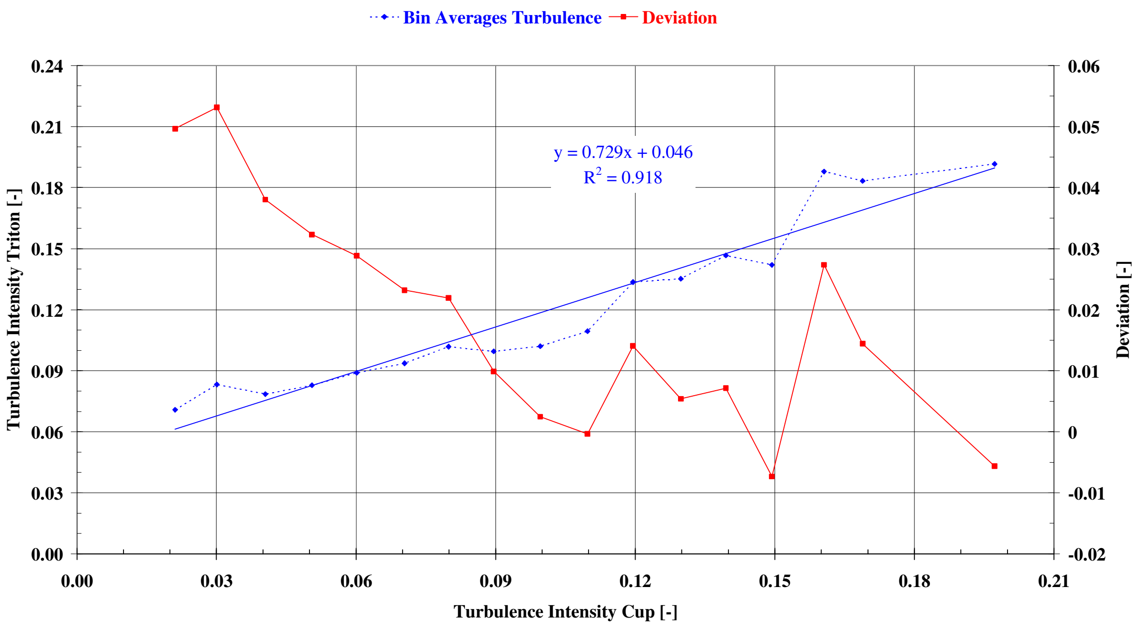


Figure 33 Bin analysis of turbulence intensity of the horizontal wind speed component measured by Triton against cup anemometer measurements (v135S) at 135.12 m height above ground.

4.5.2 Accuracy of Triton in Terms the Turbulence Intensity at 104.08 m Measurement Height

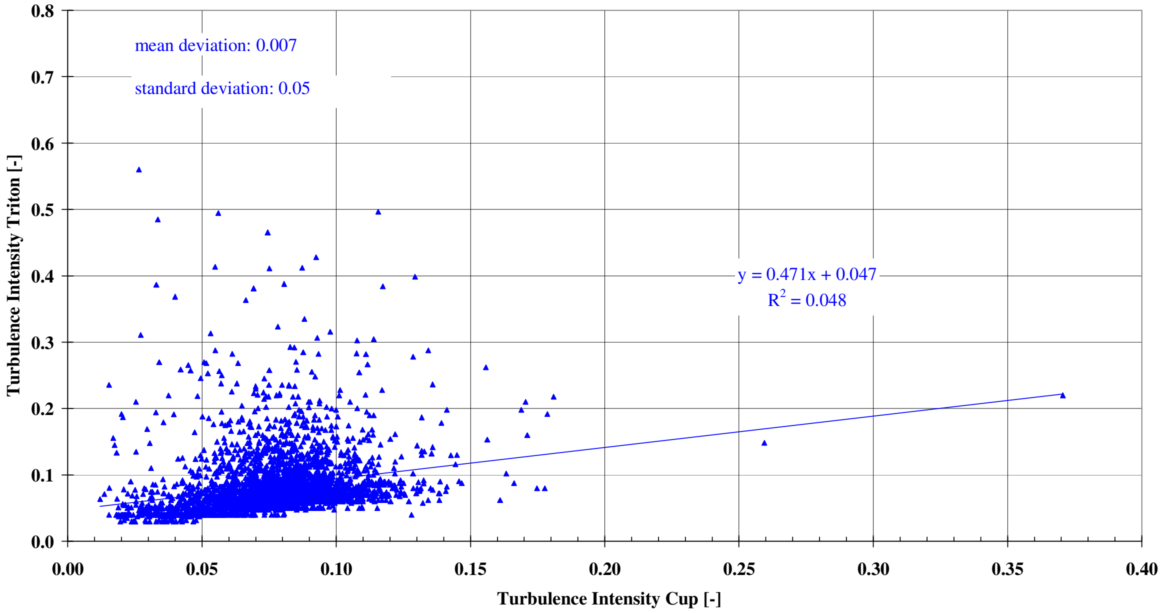


Figure 34 Scatter plot of turbulence intensity of the horizontal wind speed component as measured by Triton against cup anemometer measurements (v104) at 104.08 m height above ground.

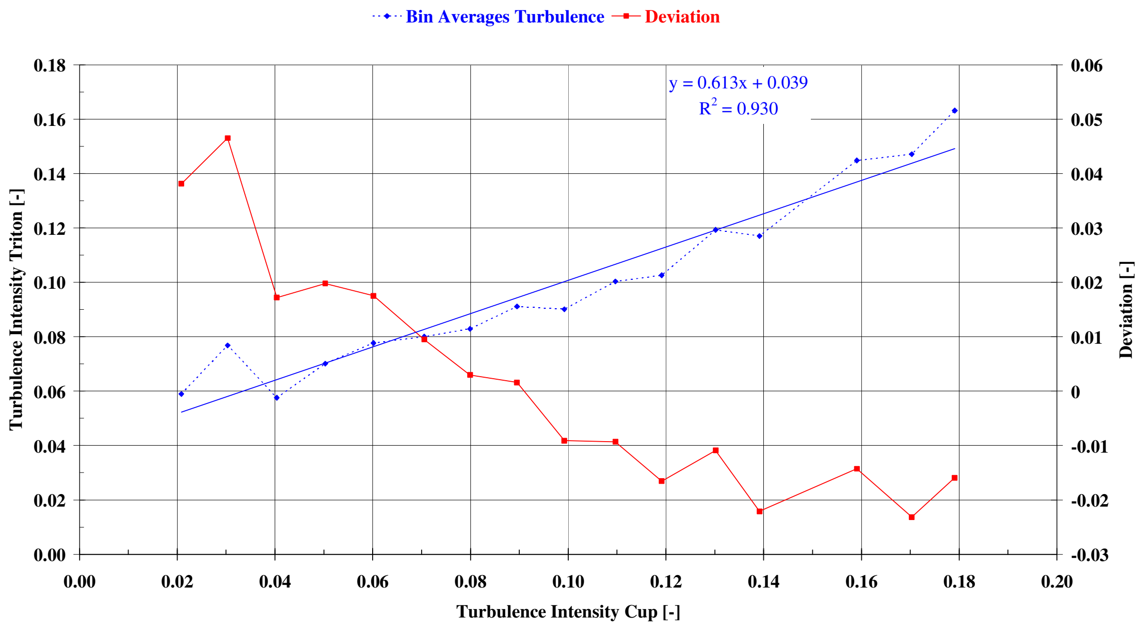


Figure 35 Bin analysis of turbulence intensity of the horizontal wind speed component measured by Triton against cup anemometer measurements (v104) at 104.08 m height above ground.

4.5.3 Accuracy of Triton in Terms the Turbulence Intensity at 71.66 m Measurement Height

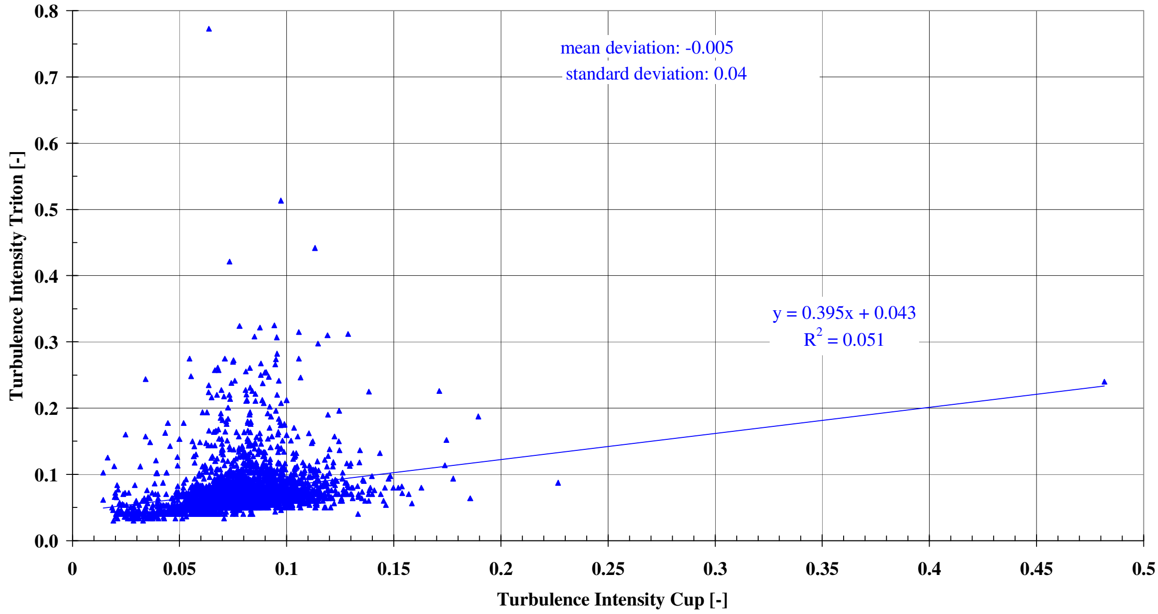


Figure 36 Scatter plot of turbulence intensity of the horizontal wind speed component as measured by Triton against cup anemometer measurements (v72) at 71.66 m height above ground.

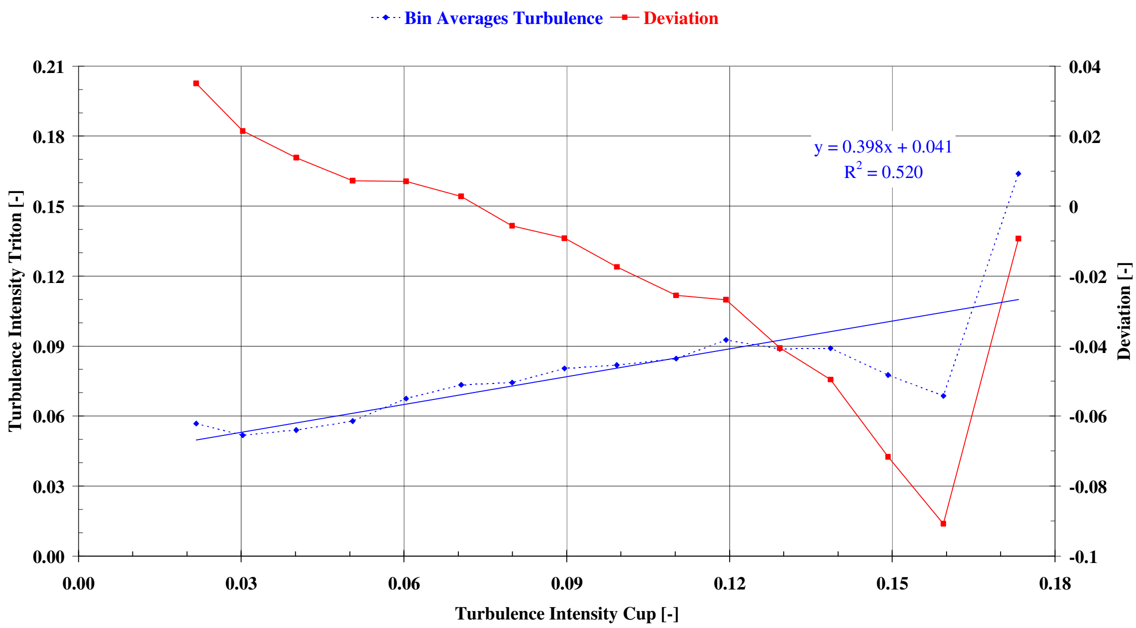


Figure 37 Bin analysis of turbulence intensity of the horizontal wind speed component measured by Triton against cup anemometer measurements (v72) at 71.66 m height above ground.

4.5.4 Accuracy of Triton in Terms the Turbulence Intensity at 35.00 m Measurement Height

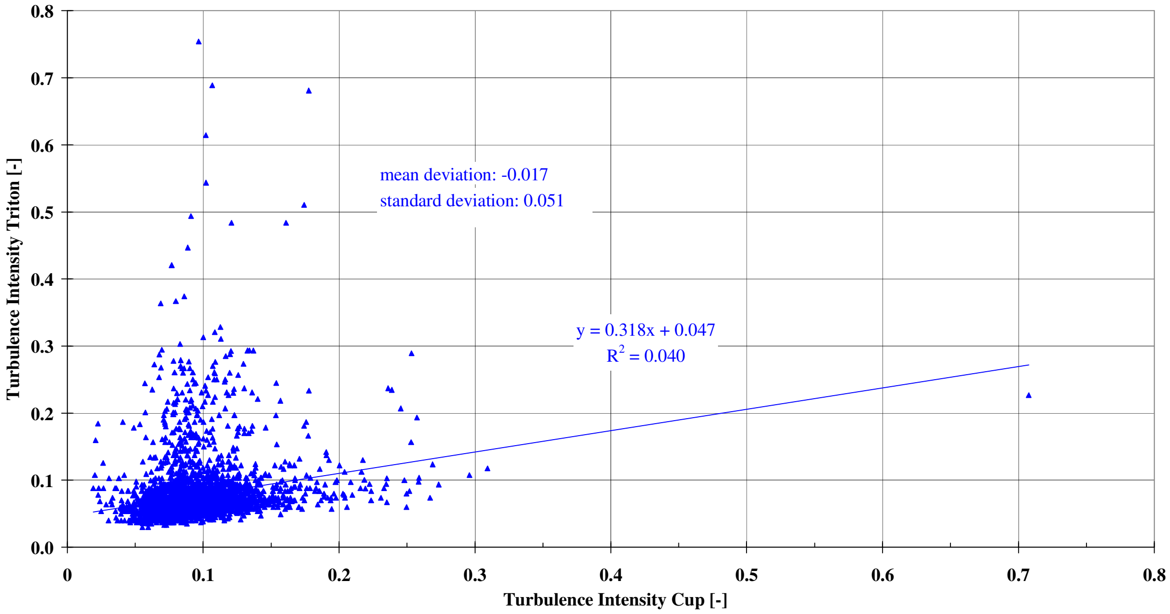


Figure 38 Scatter plot of turbulence intensity of the horizontal wind speed component as measured by Triton against cup anemometer measurements (v35S) at 35.00 m height above ground.

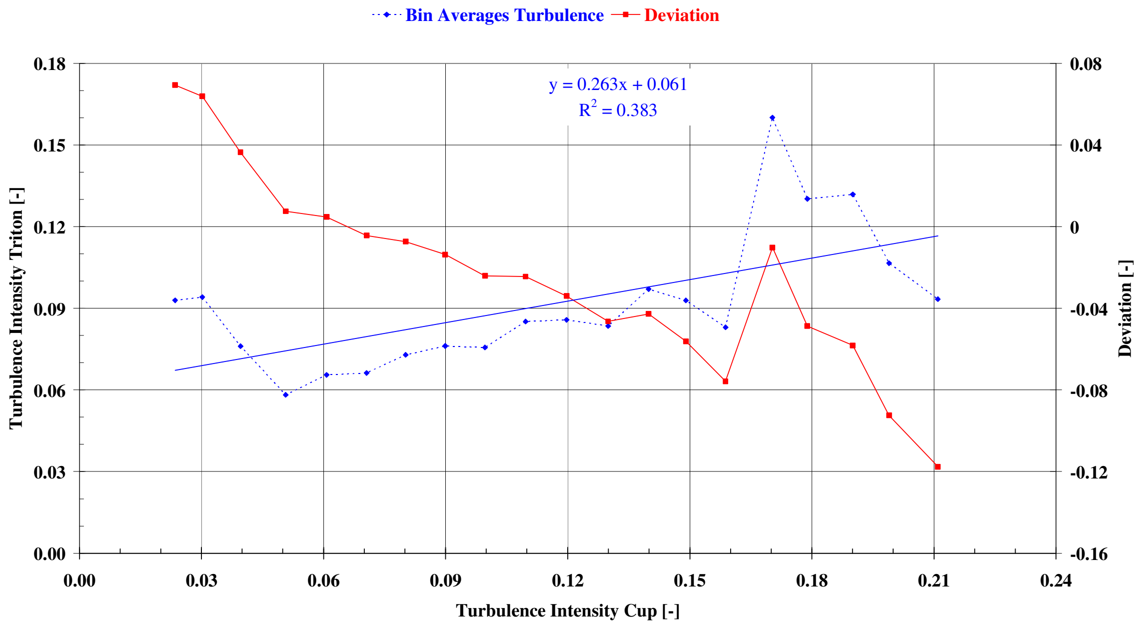


Figure 39 Bin analysis of turbulence intensity of the horizontal wind speed component measured by Triton against cup anemometer measurements (v35S) at 35 m height above ground.

4.6 Accuracy of Triton in Terms of Vertical Wind Speed Component

The mean vertical wind speed component per 10-minute period as measured by the Triton has been compared to the measurements with the ultra sonic anemometers at 72 m and 133 m measurement height (Figure 40.and Figure 41). Key result are:

- The 10-minute mean values of the vertical flow component as measured by the Triton does not correlate with the data of the ultra sonic anemometers.
- The vertical flow component determined by the Triton seems to have a negative bias as nearly all bin-averaged values are at negative wind speeds.

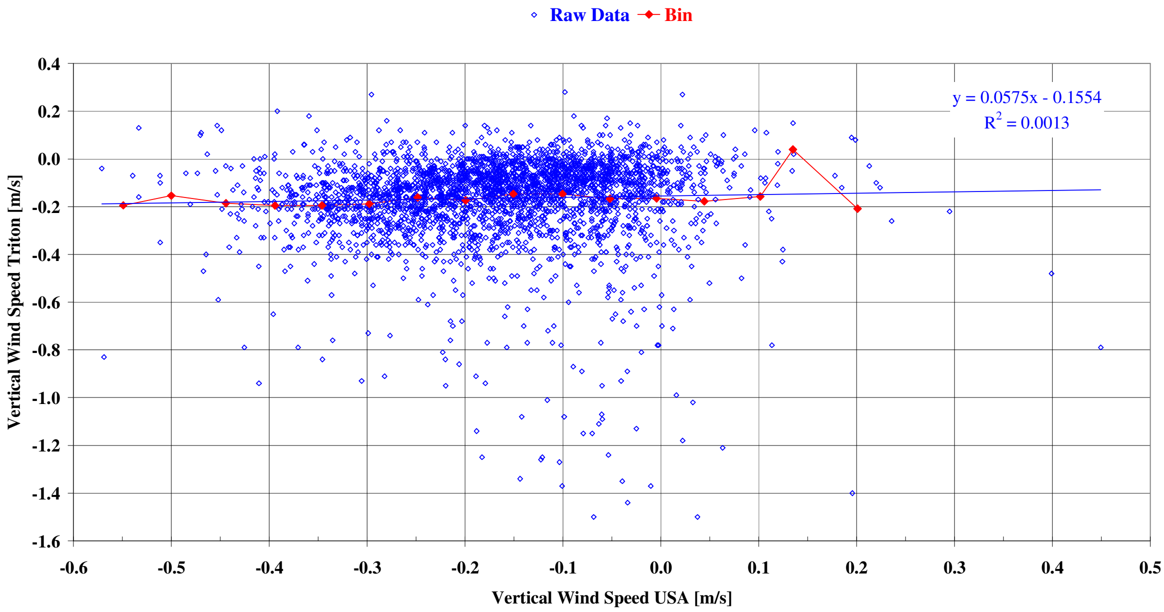


Figure 40 Scatter plot of vertical wind speed as measured by Triton at 80 m height against ultra sonic anemometer readings at 71.66 m

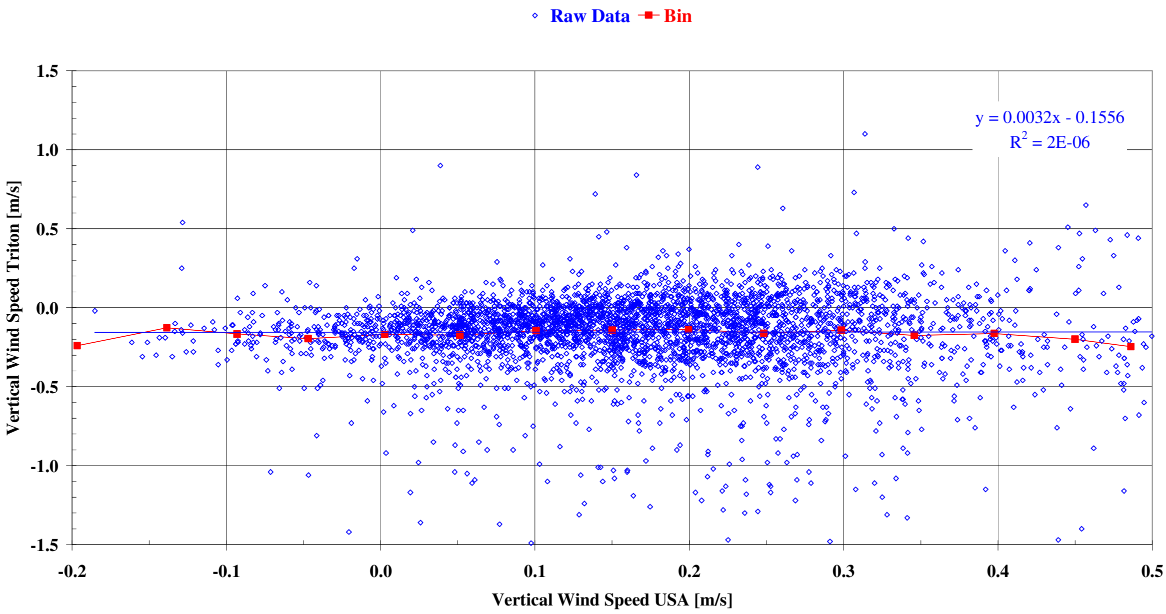


Figure 41 Scatter plot of vertical wind speed as measured by Triton at 140 m height against ultra sonic anemometer readings at 132.62 m

5 Conclusions

The accuracy of a sodar of type Triton Wind Profiler has been tested against a 135 m high met tower in flat terrain. The met mast is equipped with cup anemometers of high accuracy class, vanes and 3D-ultasonic anemometers at height levels of about 135 m, 104 m, 72 m and 35 m. All anemometers have been calibrated according to MEASNET by Deutsche WindGuard Wind Tunnel Services GmbH. The respective wind tunnel of Deutsche WindGuard is applied by the German Authority for the standardisation of units, Physikalisch-Technische Bundesanstalt (PTB), as German reference for the definition of the unit m/s in airflow measurements. A more accurate reference for cup anemometers is not available. The anemometers on the mast are mounted according to IEC 61400-12-1. Mast influences at the lower measurement heights like blockage and flow acceleration effects have been corrected empirically. Wind directions with the sensors of the mast or with the sodar in wakes have been excluded from the test.

The main results of this test are:

- The Triton has shown a good data availability of more than 95 % at measurement heights up to 80 m. At larger measurement heights, the availability decreases significantly with increasing measurement height.
- The Triton shows a reasonable correlation to cup anemometer measurements in terms of 10-minute averages of the horizontal wind speed component in all compared measurement heights from 35 m above ground to 135 m above ground (square of correlation coefficient about 0.96). Obvious outlier data is hardly present in the scatter plots of wind speeds measured by the Triton and wind speeds measured by the met mast.
- The mean deviation of the measurements of the horizontal wind speed component measured by the Triton and by the reference cup anemometers is very low (between 0.0 m/s and 0.1 m/s in the different measurement heights).The horizontal wind speed component is in tendency slightly overestimated for medium wind speeds of about 7-11 m/s and in tendency underestimated at wind speeds higher than about 13 m/s by the Triton. A linear correction (calibration) of the measurement data of the Triton has been tested, but did not help to successfully remove these tendencies.
- The standard uncertainty of the Triton in terms of the measurement of the horizontal wind speed component has been evaluated to be in the order of 2-3 % for the most wind speed bins and for all measurement heights from 35 m to 135 m above ground. In certain wind speed bins and measurement heights, the standard uncertainty varies from 1.5 % up to 7.7 %.
- The wind shear exponents determined by the Triton per 10-minute period show a relatively low correlation to the wind shear exponents determined by the reference met mast.
- The mean shear exponents as determined by the Triton calculated over the complete measurement period agrees very well with the mean wind shear derived from the cup anemometers in the height range up to 100 m above ground (mean deviation below 0.01)). In the height range 100 m to 140 m, the Triton underestimates the mean wind shear significantly (mean deviation about -0.05).
- The bin averages off the wind shear exponents determined by the Triton agree well with the bin averaged shear exponents gained form the cup anemometer measurements in the height range 40 m to 80 m in a large range of shear values form about 0.05 to 0.6. In case of wind shears below 0.05, the Triton tends to overestimate the wind shear significantly in the height range up to 100 m. In addition, the Triton tends to underes-

timate the wind shear significantly in the height ranges 60 m to 100 m and 100 m to 140 m at shear ranges above 0.25.

- The standard uncertainty of the measurement of the wind shear exponent by the Triton has been evaluates of being about 0.02 to 0.04 for a shear range of 0.05 to 0.60 in the lower height range 40 m-80 m, what is considered as good. At lower and higher wind shears, the uncertainty of the Triton increases significantly to values up to 0.09 in this height range. In the height range 60 m-100 m, large uncertainties above 0.05 arise for the shear ranges below 0.05 and above 0.25. In the height range 100 m-140 m, the shear measurement of the Triton has high uncertainties almost in the entire shear range.
- The wind direction as measured by the Triton correlates very well with the wind direction as measured by vanes on the met masts at all height levels up to 135 m. Overall, the measurement of the wind direction is considered as fine.
- The turbulence intensity of the horizontal wind speed component as measured by the Triton shows a poor correlation with the turbulence intensity measured by cup anemometers or ultrasonic anemometers. At low turbulence intensities, the Triton has a tendency to significantly overestimate the turbulence intensity. At high turbulence intensities, the Triton clearly tends to underestimate the turbulence intensity at the measurement heights up to 72 m. Overall, the Triton is hardly capable to determine the turbulence intensity.
- The 10-minute mean of the vertical wind speed component as measured by the Triton shows a very poor correlation to the measurements with sonic anemometers. In addition, the vertical wind speed component as determined by the tested Triton seems to have a negative offset.

It is noted that the evaluated accuracy of the Triton can be expected only if no rain or snow is present and if only data with values of the internal quality filter of at least 85 are considered.

It is further pointed out that this accuracy test does not cover an investigation of the sensitivity of the accuracy of the Triton on meteorological variables like e.g. wind shear, turbulence intensity, wind veer and others. A possible dependency of the accuracy of the Triton on such variables should be taken into account for an application of the system. In addition, a systematic measurement error of the Triton can result from the assumption of equal wind conditions in the three scanning volumes at an application in complex terrain. Guidance on how to deal with these issues is provided in reference [1]. Additional uncertainties can result from the mounting alignment and from ambient noise.

6 Literature

[1] A. Albers, A.W. Janssen, J. Mander: How to Gain Acceptance for Lidar Measurements, proceedings of German Wind Energy Conference 2010, Bremen

[2] J. Gottschall, M. S. Courtney, P. Lindelöw, A. Albers; Classification of lidar profilers or: how to introduce lidars for power performance testing, proceedings of European Wind Energy Conference 2010, Warsaw

[3] IEC 61400-12-1, Wind turbines, Part 12-1: Power performance measurements of electricity producing wind turbines, 2005

[4] A. Albers, A.W. Janssen, J. Mander: Comparison of Lidars, German test Station for remote Wind Sensing Devices, proceedings of European Wind Energy Conference 2009, Marseille

[5] T.F. Pedersen, J.-A. Dahlberg, P. Busche; ACCUWIND – Classification of Five Cup Anemometers According to IEC 61400-12-1, Risoe National Laboratory Denmark, report Risoe-R-1556(EN), May 2006

[6] MEASNET; Cup Anemometer Calibration Procedure, Version 2, October 2009

[7] MEASNET, Evaluation of Site-specific Wind Conditions, Version 1, November 2009

[8] F. Bingöl, J. Mann, D. Foussekis; Lidar performance in complex terrain modelled by WAsP Engineering, Proceedings of European Wind Energy Conference 2009, Marseille

7 Acknowledgement

Thanks belong to Enercon, especially Mr. Jürgen Stoltenjohannes and Mr. Rolf Rohden, to make available the test site and met mast for the measurements.

8 Appendix A: Detailed Results of Further Reference Sensors

This chapter presents detailed comparisons of the Triton with additional reference sensors on the met mast.

8.1 Results from Northward Cup Anemometer at 135 m Height (V135N)

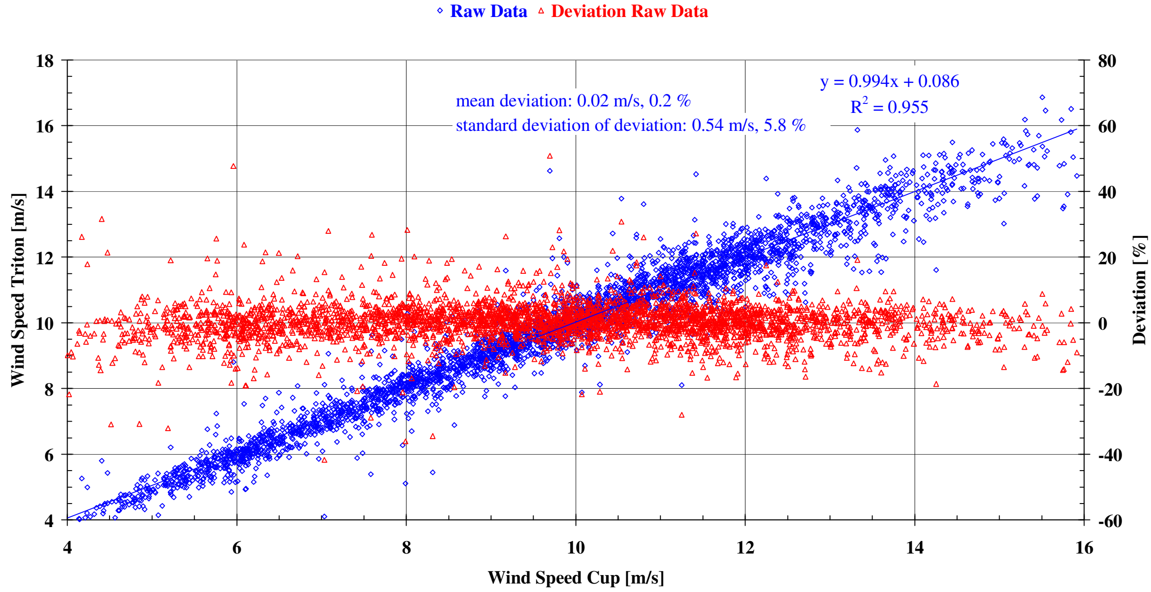


Figure 42 Scatter plot of horizontal wind speed component as measured by Triton against cup anemometer (v135N) readings at 135.12 m height above ground and the difference between both values in percent of the wind speed.

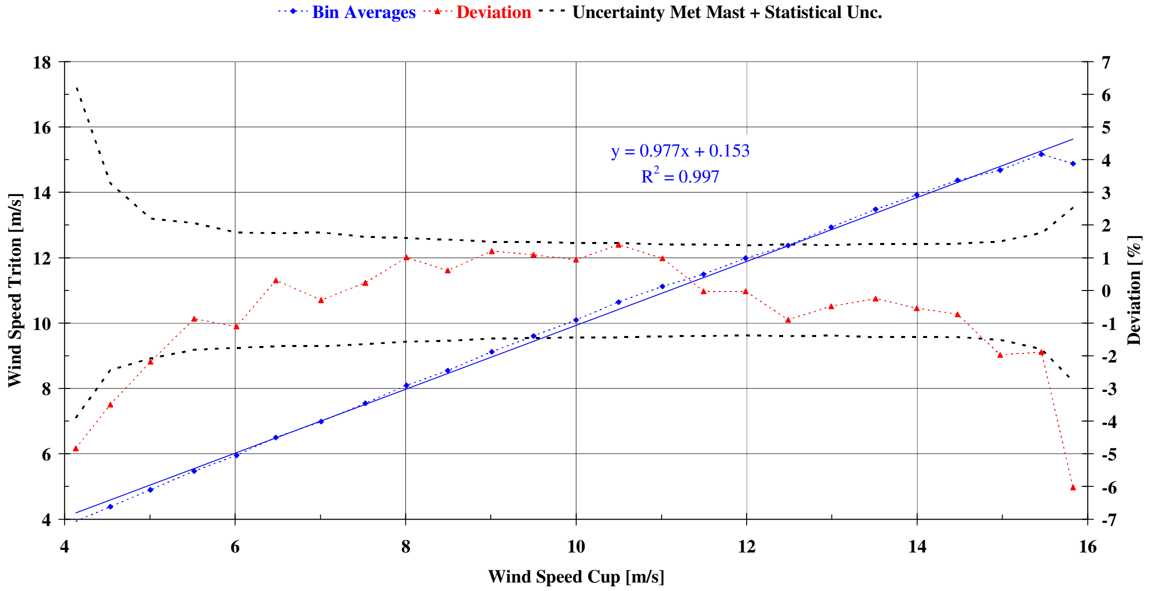


Figure 43 Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer (v135N) measurements at 135.12 m height above ground.

Table 14: Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 135.12 m height above ground (v135N). A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$v_{Metmast}$	v_{Triton}	number of data sets	v_{Triton} maximum	v_{Triton} minimum	v_{Triton} sigma	v_{Triton} sigma/sqrt(N)	deviation	$v_{Metmast}$ uncertainty	v_{Triton} uncertainty
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]
4.134	4.042	12	5.26	3.15	0.582	0.168	-2.2	1.8	5.0
4.532	4.420	34	5.80	3.12	0.460	0.079	-2.5	1.8	3.5
5.008	4.886	67	6.21	3.36	0.421	0.051	-2.4	1.7	3.2
5.520	5.471	114	6.76	4.69	0.322	0.030	-0.9	1.7	2.0
6.018	5.961	160	8.81	4.85	0.437	0.035	-1.0	1.7	2.0
6.478	6.498	137	8.08	5.36	0.416	0.036	0.3	1.6	1.8
7.008	7.001	144	9.06	2.70	0.595	0.050	-0.1	1.6	1.8
7.527	7.544	141	9.63	5.39	0.533	0.045	0.2	1.6	1.7
8.010	8.091	181	10.27	5.11	0.505	0.038	1.0	1.6	1.9
8.494	8.546	180	10.20	5.45	0.529	0.039	0.6	1.5	1.7
9.011	9.129	240	11.59	7.76	0.453	0.029	1.3	1.5	2.0
9.501	9.625	234	14.62	8.03	0.592	0.039	1.3	1.5	2.0
9.999	10.093	270	12.57	7.88	0.512	0.031	0.9	1.5	1.8
10.497	10.644	231	13.78	8.12	0.607	0.040	1.4	1.5	2.1
11.011	11.132	240	13.61	9.59	0.534	0.034	1.1	1.5	1.9
11.493	11.492	266	14.53	8.10	0.612	0.038	0.0	1.5	1.5
11.989	11.985	223	14.39	9.92	0.548	0.037	0.0	1.5	1.5
12.487	12.374	150	13.93	10.62	0.652	0.053	-0.9	1.4	1.8
12.992	12.929	108	14.34	11.51	0.534	0.051	-0.5	1.4	1.6
13.512	13.480	100	15.87	11.53	0.780	0.078	-0.2	1.4	1.6
13.993	13.935	61	15.10	12.46	0.612	0.078	-0.4	1.4	1.6
14.474	14.368	50	15.49	11.60	0.624	0.088	-0.7	1.4	1.7
14.977	14.675	31	15.59	13.02	0.639	0.115	-2.0	1.4	2.6
15.466	15.182	22	16.86	13.48	0.877	0.187	-1.8	1.4	2.6
15.823	15.063	8	16.51	13.54	1.097	0.388	-4.8	1.4	5.6

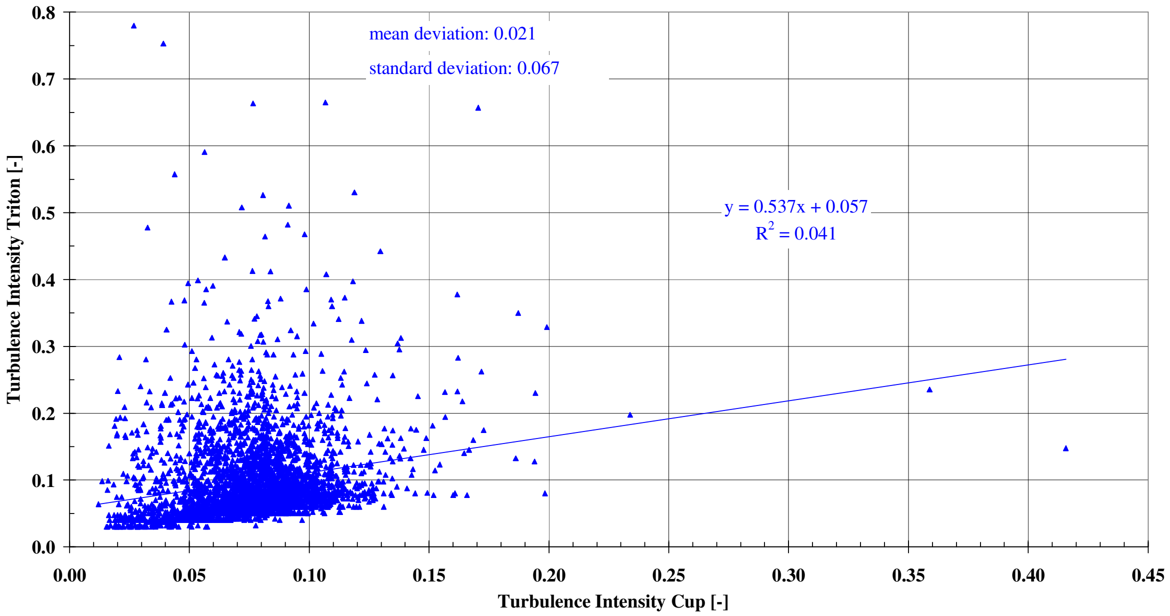


Figure 44 Scatter plot of turbulence intensity of the horizontal wind speed component as measured by Triton against cup anemometer (v135N) readings at 135.12 m height above ground.

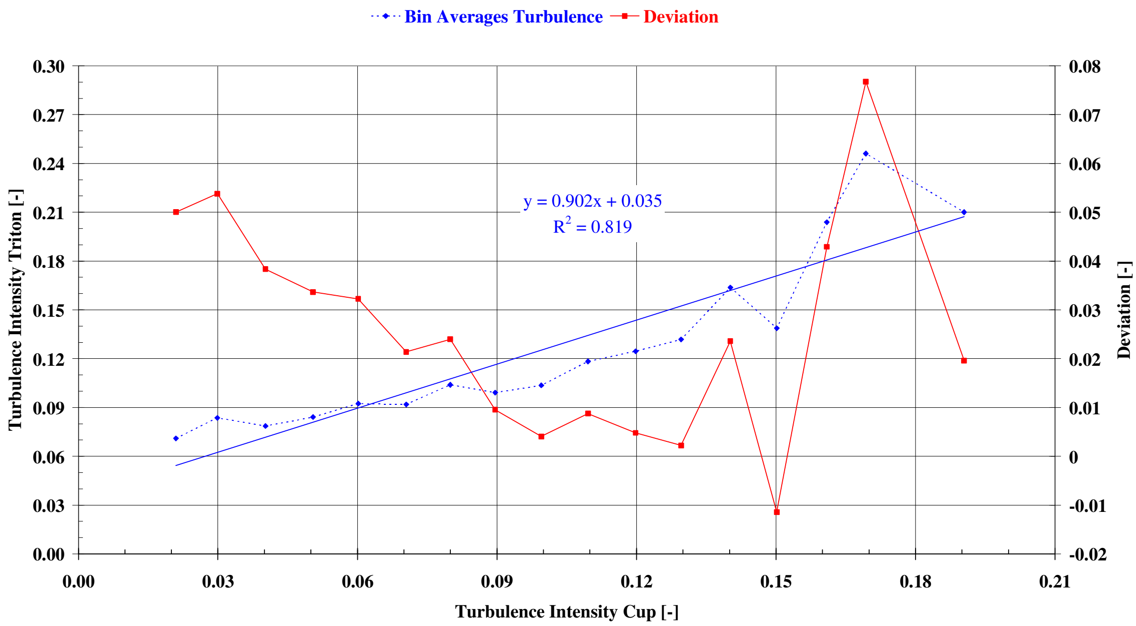


Figure 45 Bin analysis of turbulence intensity of the horizontal wind speed component measured by Triton against cup anemometer (v135N) measurements at 135.12 m height above ground.

8.2 Results from Cup Anemometer at 133 m Height (V133)

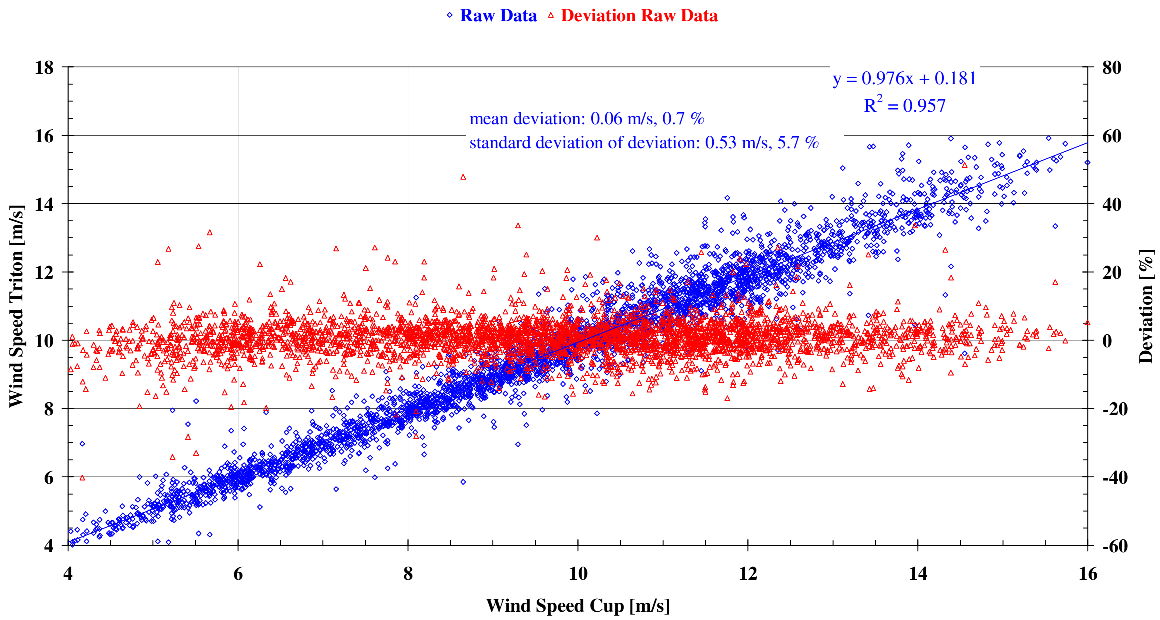


Figure 46 Scatter plot of horizontal wind speed component as measured by Triton against cup anemometer (v133) readings at 132.62 m height above ground and the difference between both values in percent of the wind speed.

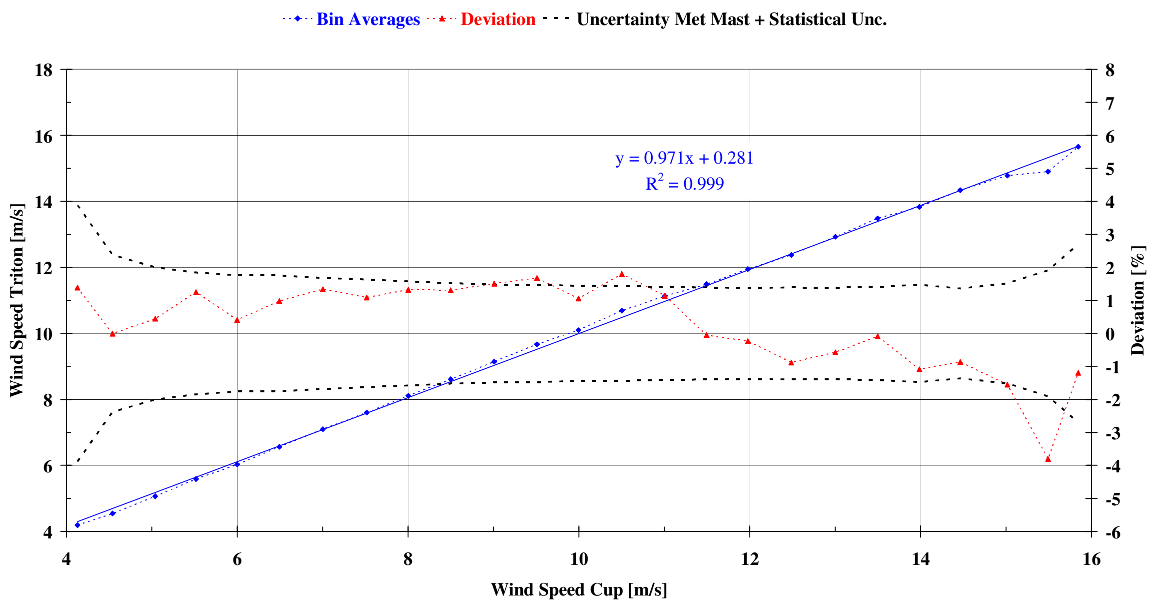


Figure 47 Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer (v133) measurements at 132.62 m height above ground.

Table 15 Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 132.62 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$v_{Metmast}$	v_{Triton}	number of data sets	v_{Triton} maximum	v_{Triton} minimum	v_{Triton} sigma	v_{Triton} sigma/sqrt(N)	deviation	$v_{Metmast}$ uncertainty	v_{Triton} uncertainty
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]
4.132	4.190	12	5.18	3.73	0.475	0.137	1.4	1.8	4.0
4.541	4.541	45	5.67	3.05	0.435	0.065	0.0	1.8	2.3
5.042	5.064	76	6.26	3.57	0.377	0.043	0.4	1.7	2.0
5.519	5.588	112	7.15	4.82	0.367	0.035	1.3	1.7	2.2
6.000	6.025	169	8.65	4.84	0.433	0.033	0.4	1.7	1.8
6.495	6.558	134	8.19	3.05	0.512	0.044	1.0	1.6	2.0
7.003	7.097	132	9.30	4.17	0.477	0.041	1.3	1.6	2.2
7.517	7.599	146	9.39	5.41	0.514	0.043	1.1	1.6	2.0
8.003	8.109	184	10.22	5.23	0.536	0.039	1.3	1.6	2.1
8.500	8.612	182	10.14	7.11	0.444	0.033	1.3	1.5	2.1
9.009	9.145	247	11.45	7.74	0.448	0.028	1.5	1.5	2.2
9.510	9.670	232	14.55	8.48	0.597	0.039	1.7	1.5	2.3
9.995	10.101	272	11.98	7.86	0.497	0.030	1.1	1.5	1.9
10.502	10.691	221	13.97	9.07	0.595	0.040	1.8	1.5	2.4
11.007	11.132	239	12.53	8.10	0.561	0.036	1.1	1.5	1.9
11.495	11.488	268	14.32	9.54	0.580	0.035	-0.1	1.5	1.5
11.979	11.950	203	14.39	9.94	0.547	0.038	-0.2	1.5	1.5
12.486	12.376	157	13.76	10.64	0.626	0.050	-0.9	1.5	1.7
13.003	12.929	99	14.25	11.49	0.522	0.052	-0.6	1.4	1.6
13.497	13.485	100	15.61	11.49	0.721	0.072	-0.1	1.4	1.5
13.985	13.833	54	15.12	11.76	0.702	0.096	-1.1	1.4	1.9
14.463	14.337	52	15.25	13.30	0.431	0.060	-0.9	1.4	1.7
15.015	14.782	30	15.99	13.12	0.659	0.120	-1.6	1.4	2.2
15.491	14.902	19	16.72	13.43	0.957	0.219	-3.8	1.4	4.3
15.843	15.654	6	16.92	14.39	0.922	0.376	-1.2	1.4	3.0

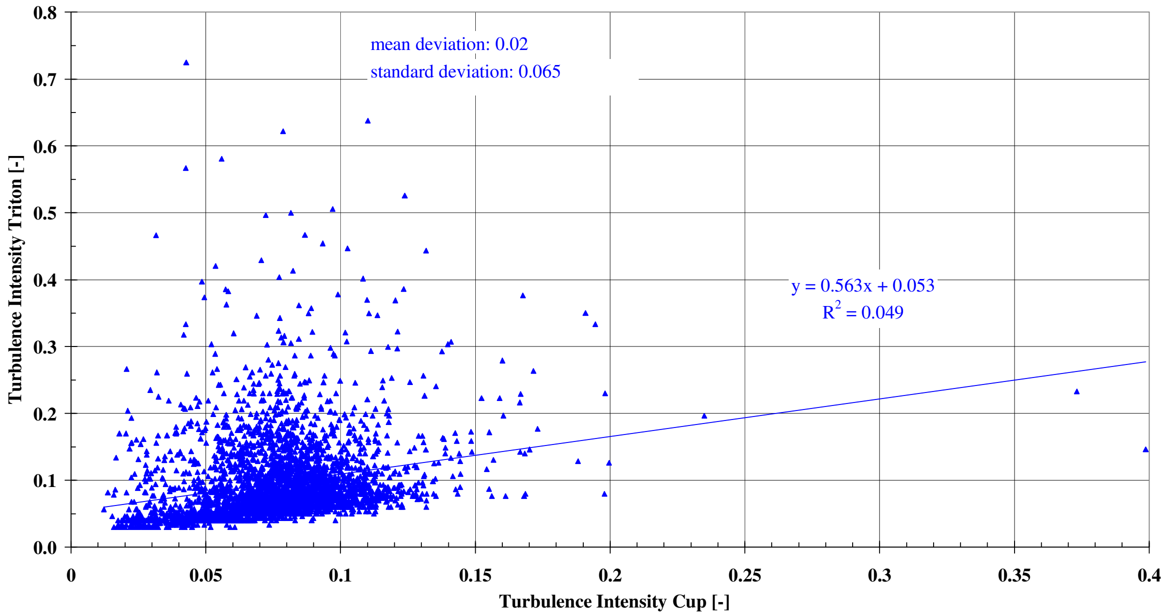


Figure 48 Scatter plot of turbulence intensity of the horizontal wind speed component as measured by Triton against cup anemometer (v133) readings at 132.62 m height above ground.

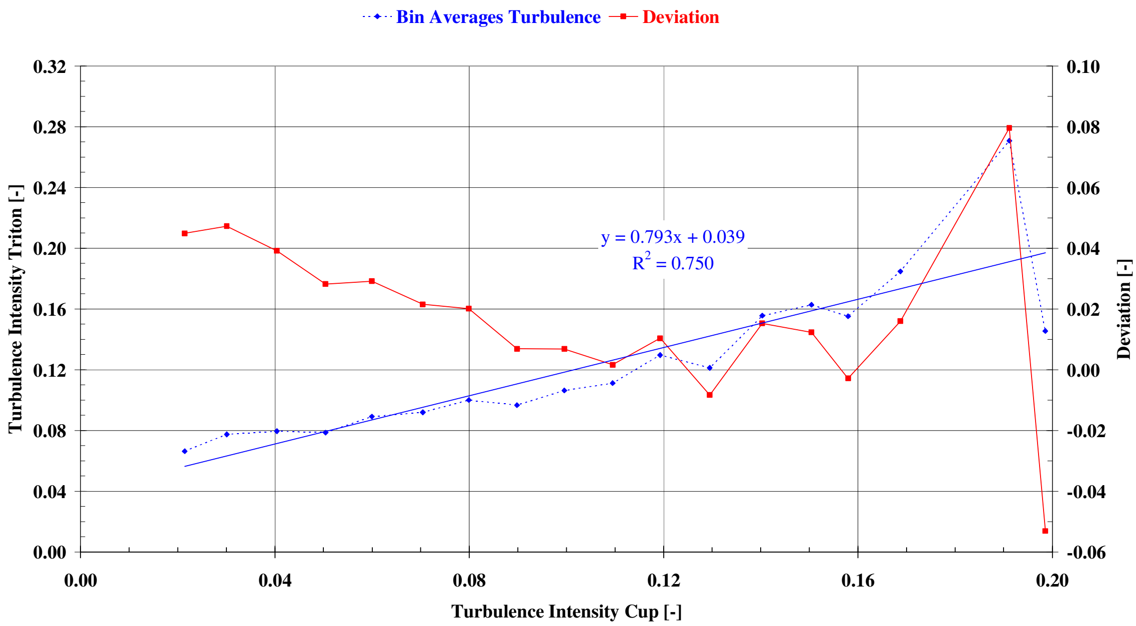


Figure 49 Bin analysis of turbulence intensity of the horizontal wind speed component measured by Triton against cup anemometer (v133) measurements at 132.62 m height above ground.

8.3 Results from Sonic Anemometer at 133 m Height (USA133)

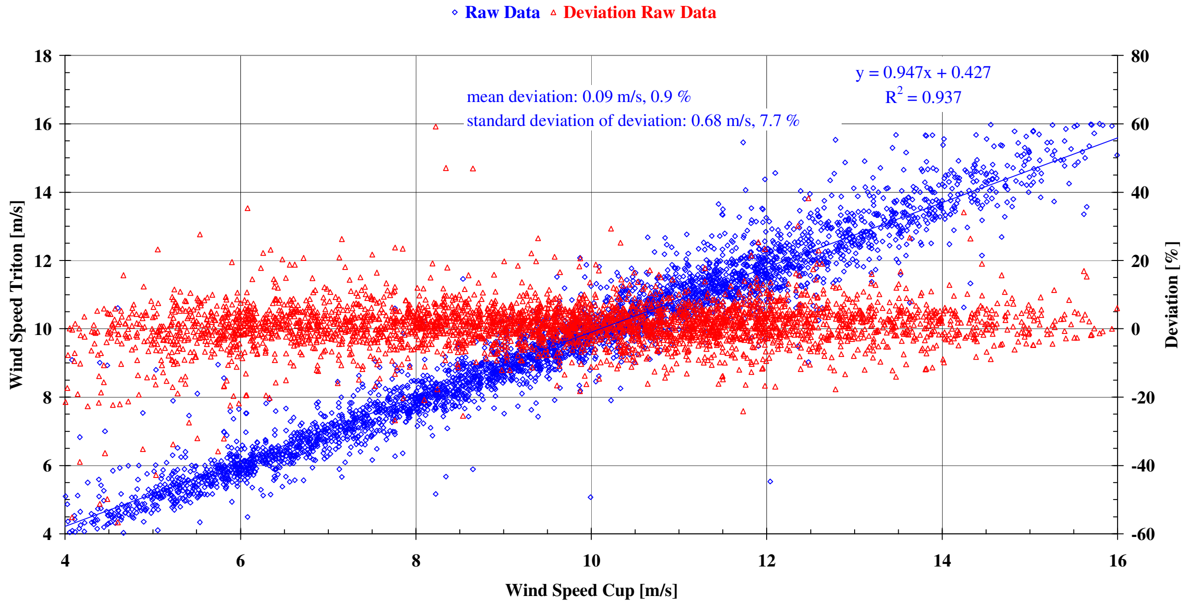


Figure 50: Scatter plot of horizontal wind speed component as measured by Triton against ultrasonic anemometer (USA133) measurements at 132.62 m height above ground.

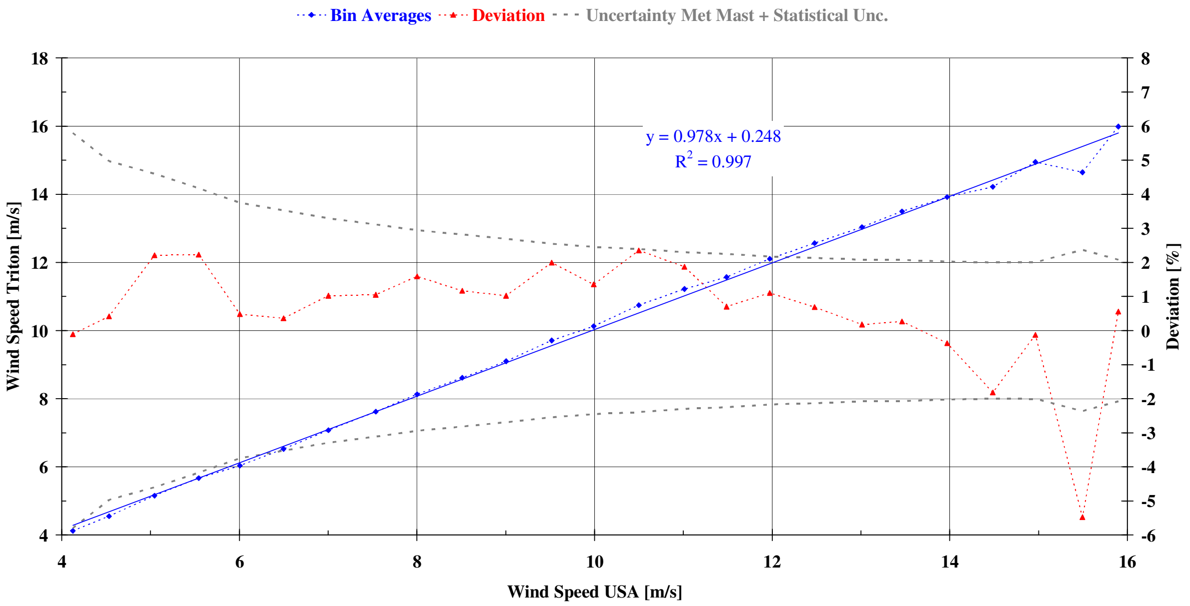


Figure 51: Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against ultrasonic anemometer (USA133) measurements at 132.62 m height above ground.

Table 16 Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against ultra sonic anemometer measurements at 132.62 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$v_{Metmast}$	v_{Triton}	number of data sets	v_{Triton} maximum	v_{Triton} minimum	v_{Triton} sigma	v_{Triton} sigma/sqrt(N)	deviation	$v_{Metmast}$ uncertainty	v_{Triton} uncertainty
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]
4.125	4.120	15	5.06	3.58	0.406	0.105	-0.1	1.8	3.1
4.532	4.551	60	6.08	3.05	0.485	0.063	0.4	1.8	2.3
5.044	5.155	99	9.99	3.03	0.781	0.078	2.2	1.7	3.2
5.542	5.666	127	12.04	3.18	0.793	0.070	2.2	1.7	3.1
6.006	6.035	188	8.65	4.55	0.485	0.035	0.5	1.7	1.8
6.499	6.522	158	7.85	3.05	0.572	0.046	0.4	1.6	1.8
7.002	7.074	152	8.36	4.17	0.514	0.042	1.0	1.6	2.0
7.537	7.616	159	9.39	4.89	0.615	0.049	1.0	1.6	2.0
8.001	8.128	199	10.33	5.23	0.578	0.041	1.6	1.6	2.3
8.511	8.610	201	10.09	1.66	0.708	0.050	1.2	1.5	2.0
9.005	9.097	258	12.48	4.08	0.794	0.049	1.0	1.5	1.9
9.517	9.707	239	12.35	8.48	0.493	0.032	2.0	1.5	2.5
9.991	10.126	243	11.98	7.86	0.499	0.032	1.4	1.5	2.0
10.498	10.745	229	14.25	4.60	0.777	0.051	2.3	1.5	2.8
11.013	11.219	275	13.63	3.33	0.738	0.045	1.9	1.5	2.4
11.487	11.568	242	14.32	2.52	0.881	0.057	0.7	1.5	1.7
11.973	12.105	185	14.45	9.87	0.620	0.046	1.1	1.5	1.9
12.478	12.564	134	14.68	10.64	0.706	0.061	0.7	1.5	1.7
13.012	13.035	106	14.71	11.09	0.655	0.064	0.2	1.4	1.5
13.463	13.499	96	15.65	11.45	0.828	0.084	0.3	1.4	1.6
13.971	13.919	71	15.45	11.76	0.741	0.088	-0.4	1.4	1.6
14.486	14.222	54	15.51	11.98	0.700	0.095	-1.8	1.4	2.4
14.964	14.946	35	16.17	12.89	0.691	0.117	-0.1	1.4	1.6
15.495	14.646	27	16.98	11.73	1.224	0.236	-5.5	1.4	5.9
15.899	15.987	19	17.14	14.55	0.739	0.169	0.6	1.4	1.8

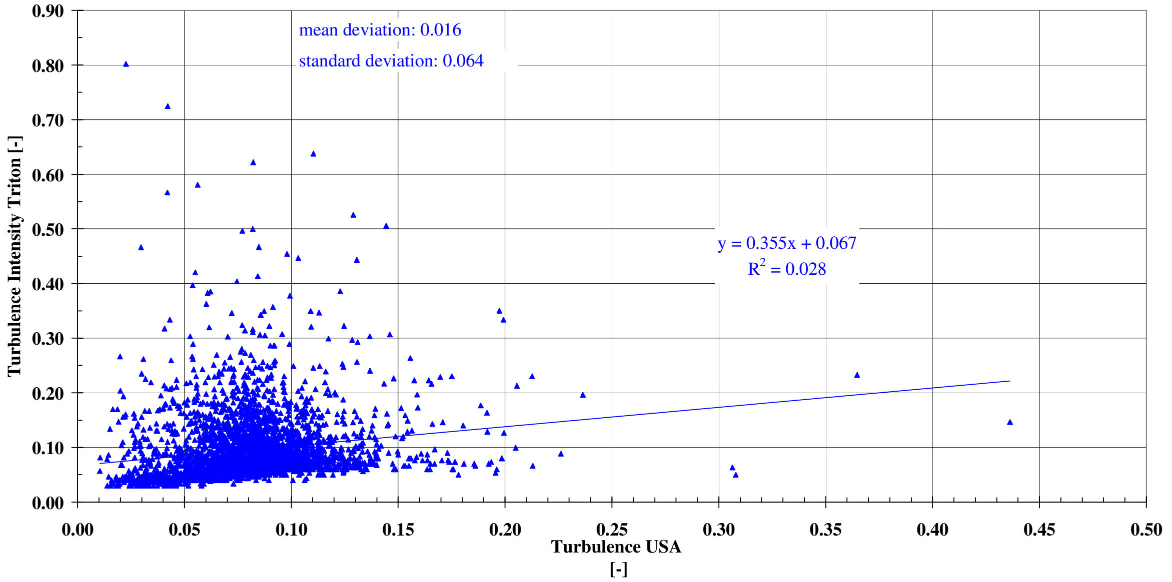


Figure 52: Scatter plot of turbulence intensity of the horizontal wind speed component as measured by Triton against ultrasonic anemometer (USA133) measurements at 132.62 m height above ground.

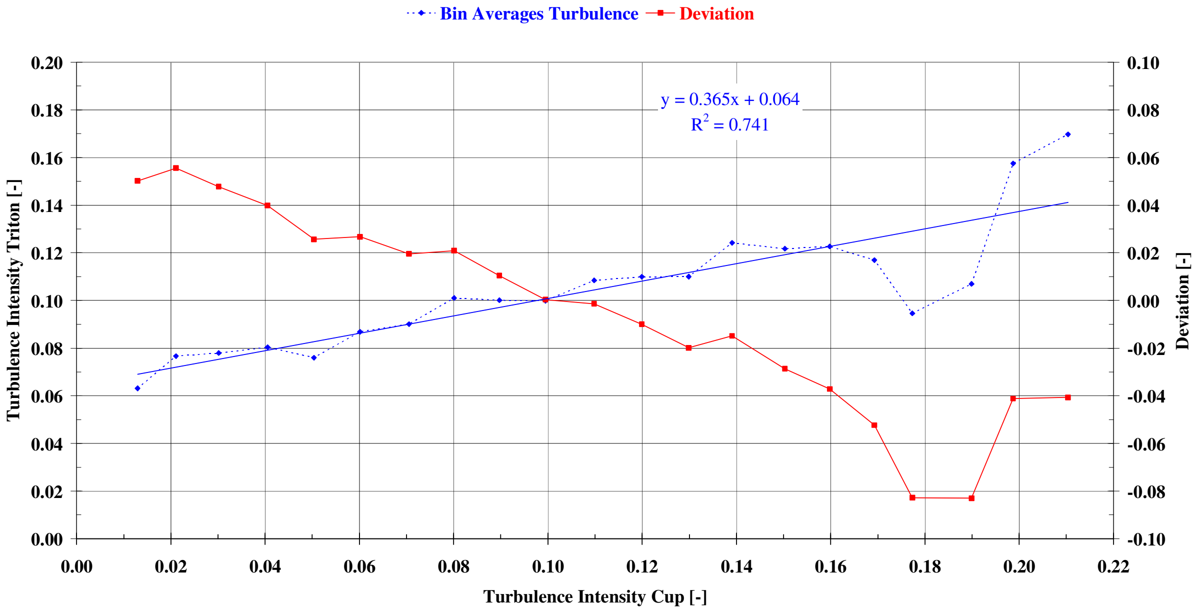


Figure 53: Bin analysis of turbulence intensity of the horizontal wind speed component as measured by Triton against ultrasonic anemometer (USA133) measurements at 132.62 m height above ground.

8.4 Results from Sonic Anemometer at 72 m Height (USA72)

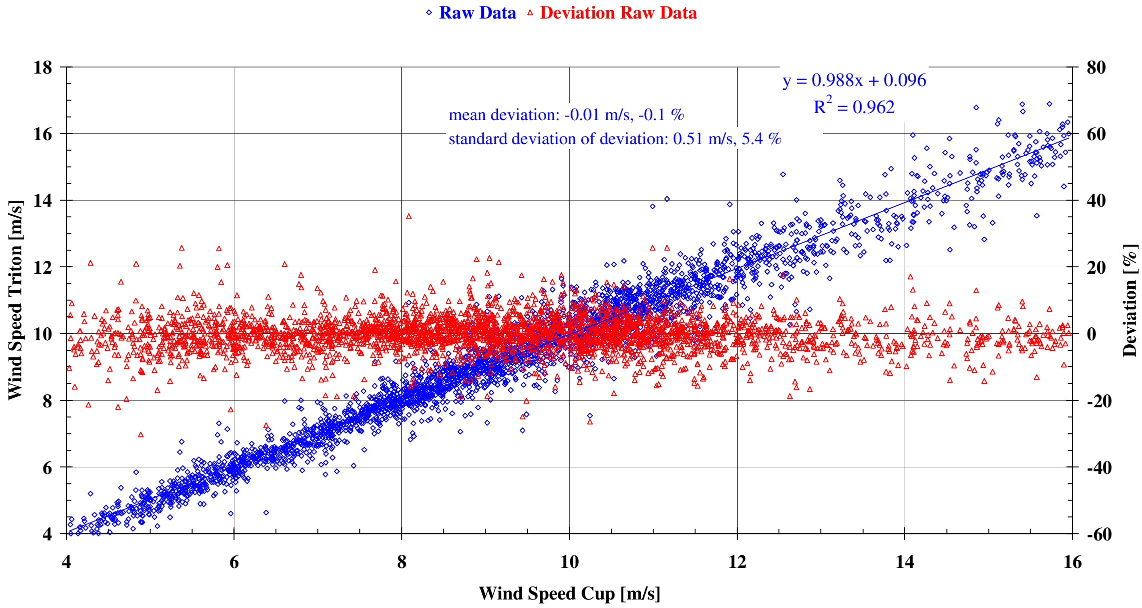


Figure 54 Scatter plot of horizontal wind speed component as measured by Triton against ultrasonic anemometer (USA72) measurements at 71.66 m height above ground.

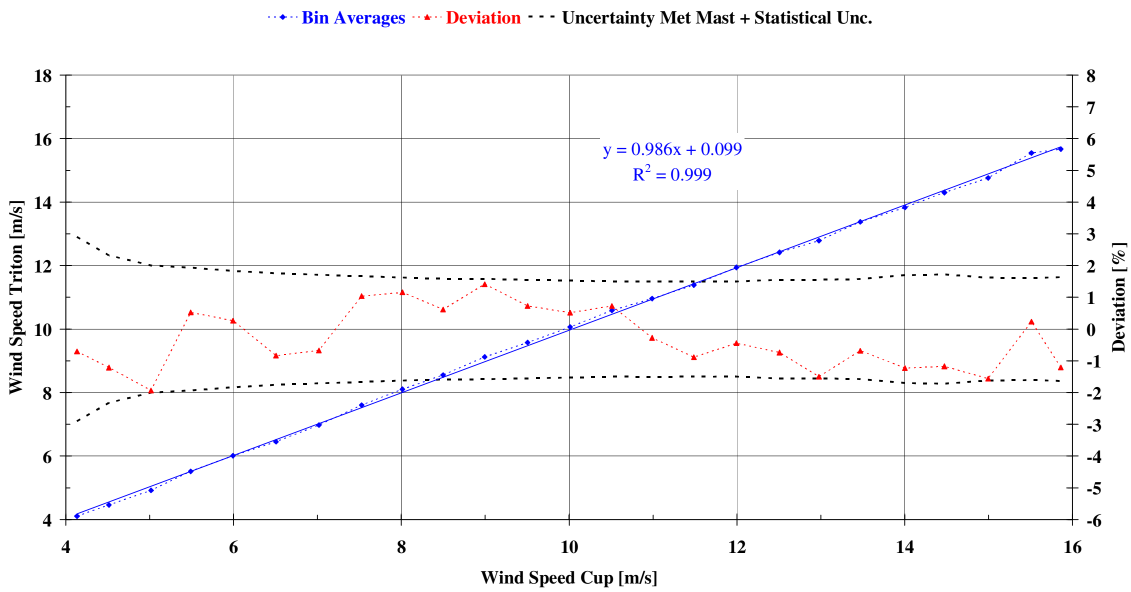


Figure 55 Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against ultrasonic anemometer (USA72) measurements at 71.66 m height above ground.

Table 17 Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against ultra sonic anemometer measurements at 71.66 m height above ground. A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$v_{Metmast}$	v_{Triton}	number of data sets	v_{Triton} maximum	v_{Triton} minimum	v_{Triton} sigma	v_{Triton} sigma/sqrt(N)	deviation	$v_{Metmast}$ uncertainty	v_{Triton} uncertainty
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]
4.135	4.105	19	5.20	3.45	0.369	0.085	-0.7	2.0	2.9
4.516	4.461	54	5.86	3.35	0.410	0.056	-1.2	1.9	2.6
5.017	4.920	95	5.84	3.41	0.352	0.036	-1.9	1.9	2.8
5.490	5.518	130	8.82	4.82	0.449	0.039	0.5	1.8	2.0
5.994	6.010	141	8.55	4.60	0.427	0.036	0.3	1.8	1.9
6.507	6.453	120	8.26	4.63	0.374	0.034	-0.8	1.8	2.0
7.018	6.971	148	8.76	5.77	0.428	0.035	-0.7	1.7	1.9
7.526	7.604	154	9.54	6.04	0.448	0.036	1.0	1.7	2.1
8.013	8.105	216	12.00	6.82	0.497	0.034	1.2	1.7	2.1
8.499	8.551	210	10.71	7.06	0.463	0.032	0.6	1.7	1.8
8.995	9.122	238	12.34	7.32	0.613	0.040	1.4	1.7	2.2
9.504	9.573	211	11.62	7.09	0.582	0.040	0.7	1.7	1.9
10.012	10.064	216	11.64	7.53	0.575	0.039	0.5	1.6	1.8
10.510	10.587	248	14.11	8.65	0.600	0.038	0.7	1.6	1.8
10.990	10.959	199	14.04	9.28	0.650	0.046	-0.3	1.6	1.7
11.487	11.385	141	14.40	9.73	0.618	0.052	-0.9	1.6	1.9
11.995	11.942	107	13.87	10.46	0.597	0.058	-0.4	1.6	1.7
12.508	12.415	74	14.78	10.26	0.711	0.083	-0.7	1.6	1.9
12.977	12.783	55	14.59	10.73	0.654	0.088	-1.5	1.6	2.3
13.470	13.378	39	15.48	12.34	0.627	0.100	-0.7	1.6	1.9
14.004	13.832	42	16.47	12.19	0.898	0.139	-1.2	1.6	2.2
14.473	14.303	26	15.85	12.52	0.765	0.150	-1.2	1.6	2.2
14.994	14.761	41	16.78	12.82	0.832	0.130	-1.6	1.6	2.4
15.511	15.547	43	19.06	13.53	0.873	0.133	0.2	1.6	1.8
15.861	15.668	14	16.34	14.41	0.541	0.145	-1.2	1.6	2.2

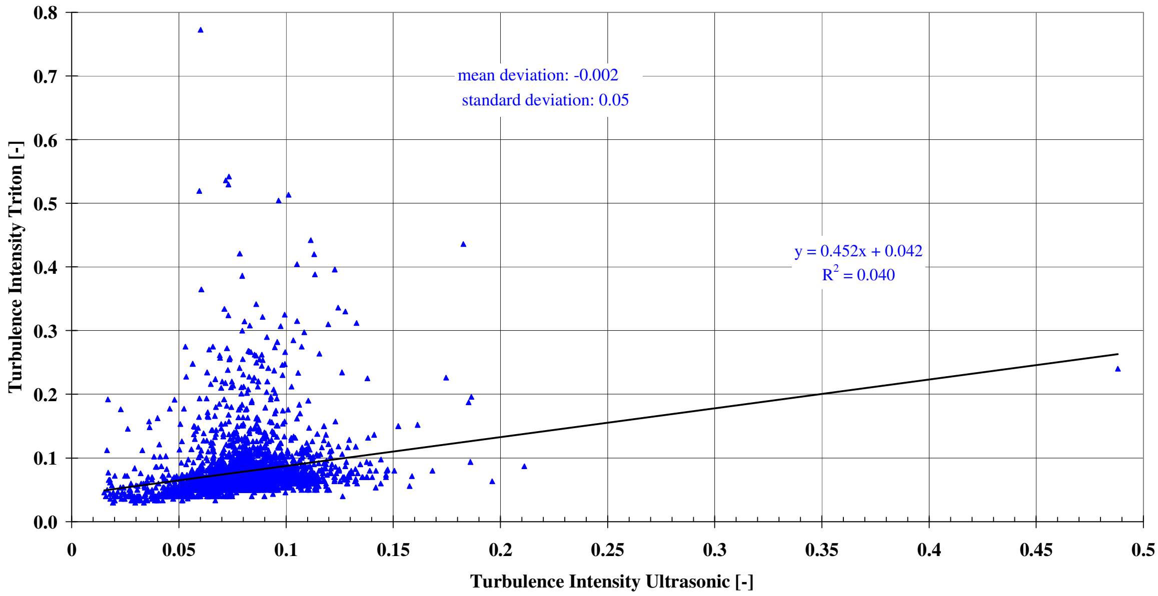


Figure 56 Scatter plot of turbulence intensity of the horizontal wind speed component as measured by Triton against ultrasonic anemometer (USA72) measurements at 71.66 m height above ground.

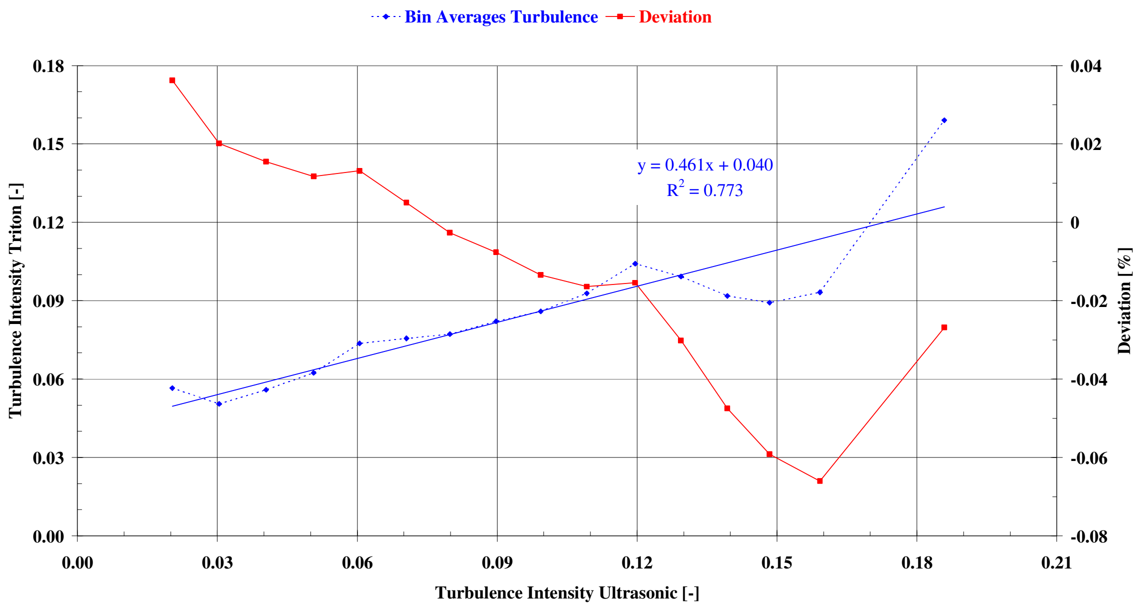


Figure 57 Bin analysis of turbulence intensity of the horizontal wind speed component as measured by Triton against ultrasonic anemometer (USA72) measurements at 71.66 m height above ground.

8.5 Results from Northward Cup Anemometer at 35 m Height (V35)

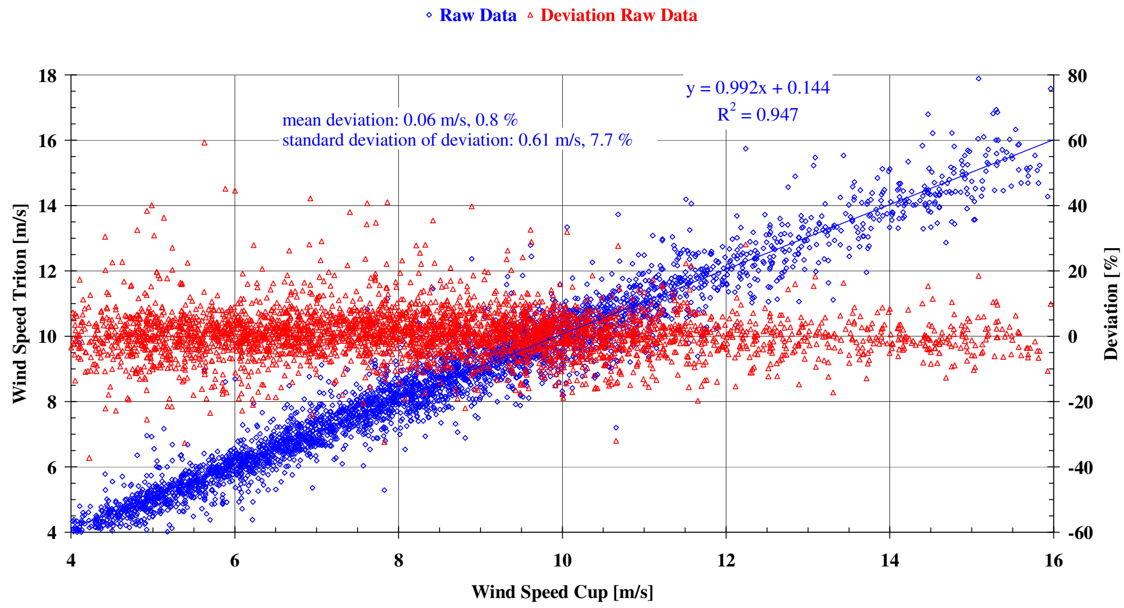


Figure 58 Scatter plot of horizontal wind speed component as measured by Triton against cup anemometer (v35N) readings at 35.00 m height above ground and the difference between both values in percent of the wind speed.

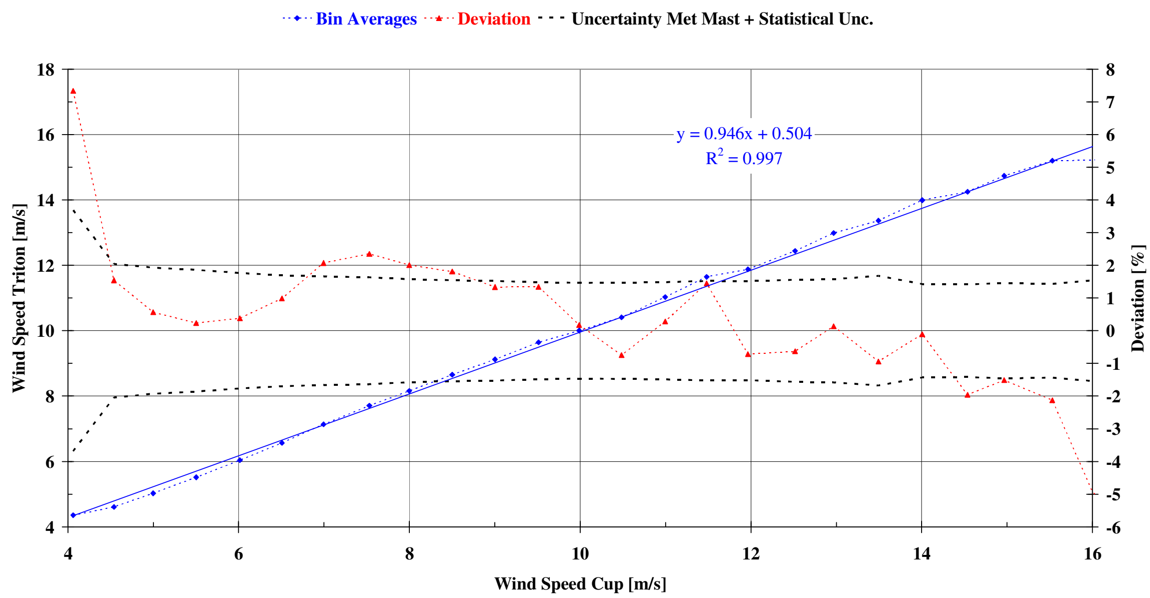


Figure 59 Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer (v35N) measurements at 35 m height above ground.

Table 18: Bin analysis of 10-minute averages of the horizontal wind speed component measured by Triton against cup anemometer measurements at 35 m height above ground (v35N). A positive sign of the shown deviation represents higher values measured by Triton. The right column shows the total standard uncertainty of the Triton as derived from the test.

$v_{Metmast}$	v_{Triton}	number of data sets	v_{Triton} maximum	v_{Triton} minimum	v_{Triton} sigma	v_{Triton} sigma/sqrt(N)	deviation	$v_{Metmast}$ uncertainty	v_{Triton} uncertainty
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]
4.060	4.358	46	9.81	4.01	0.847	0.125	7.3	1.9	8.2
4.539	4.609	111	5.78	4.05	0.339	0.032	1.5	1.8	2.5
4.998	5.026	200	6.96	4.01	0.445	0.031	0.6	1.8	2.0
5.503	5.516	191	8.98	4.12	0.497	0.036	0.2	1.7	1.9
6.014	6.037	223	8.69	4.72	0.496	0.033	0.4	1.7	1.8
6.507	6.571	220	8.48	5.26	0.480	0.032	1.0	1.7	2.0
6.994	7.138	216	9.86	5.36	0.533	0.036	2.1	1.6	2.7
7.530	7.707	219	10.83	6.04	0.616	0.042	2.4	1.6	2.9
7.997	8.158	252	11.15	5.29	0.583	0.037	2.0	1.6	2.6
8.501	8.655	272	11.46	6.94	0.626	0.038	1.8	1.6	2.4
9.002	9.122	228	12.37	6.89	0.623	0.041	1.3	1.6	2.1
9.513	9.641	294	12.79	7.88	0.645	0.038	1.3	1.6	2.1
9.988	10.005	262	13.34	8.19	0.629	0.039	0.2	1.5	1.6
10.485	10.407	191	12.30	7.20	0.688	0.050	-0.7	1.5	1.8
10.996	11.027	150	13.73	9.21	0.754	0.062	0.3	1.5	1.6
11.481	11.648	102	14.20	9.39	0.776	0.077	1.4	1.5	2.2
11.965	11.880	76	13.68	9.99	0.708	0.081	-0.7	1.5	1.8
12.517	12.438	64	15.75	11.03	0.804	0.101	-0.6	1.5	1.8
12.969	12.987	52	15.47	11.06	0.797	0.111	0.1	1.5	1.7
13.494	13.367	39	15.53	11.12	0.870	0.139	-0.9	1.5	2.0
14.006	13.991	53	15.35	12.69	0.584	0.080	-0.1	1.5	1.6
14.536	14.252	43	15.83	12.87	0.534	0.081	-2.0	1.5	2.5
14.966	14.740	39	15.82	13.44	0.626	0.100	-1.5	1.5	2.2
15.530	15.200	21	15.88	14.46	0.453	0.099	-2.1	1.5	2.7
16.003	15.211	12	15.81	14.28	0.472	0.136	-4.9	1.4	5.2
16.514	15.548	4	15.94	15.15	0.324	0.162	-5.9	1.4	6.1

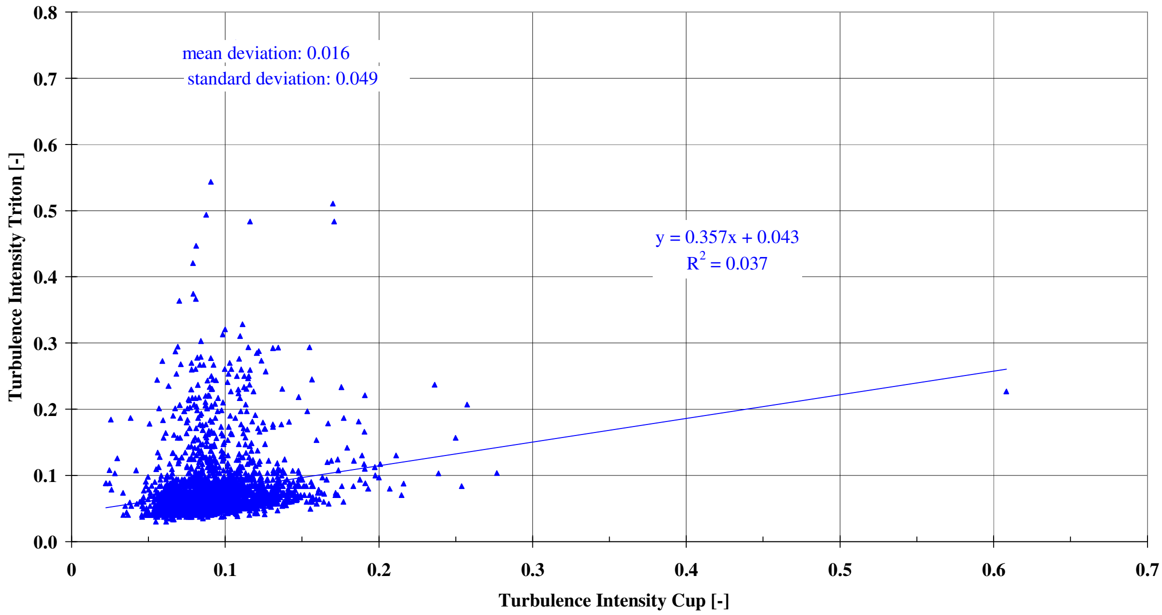


Figure 60 Scatter plot of turbulence intensity of the horizontal wind speed component as measured by Triton against cup anemometer (v35N) readings at 35 m height above ground.

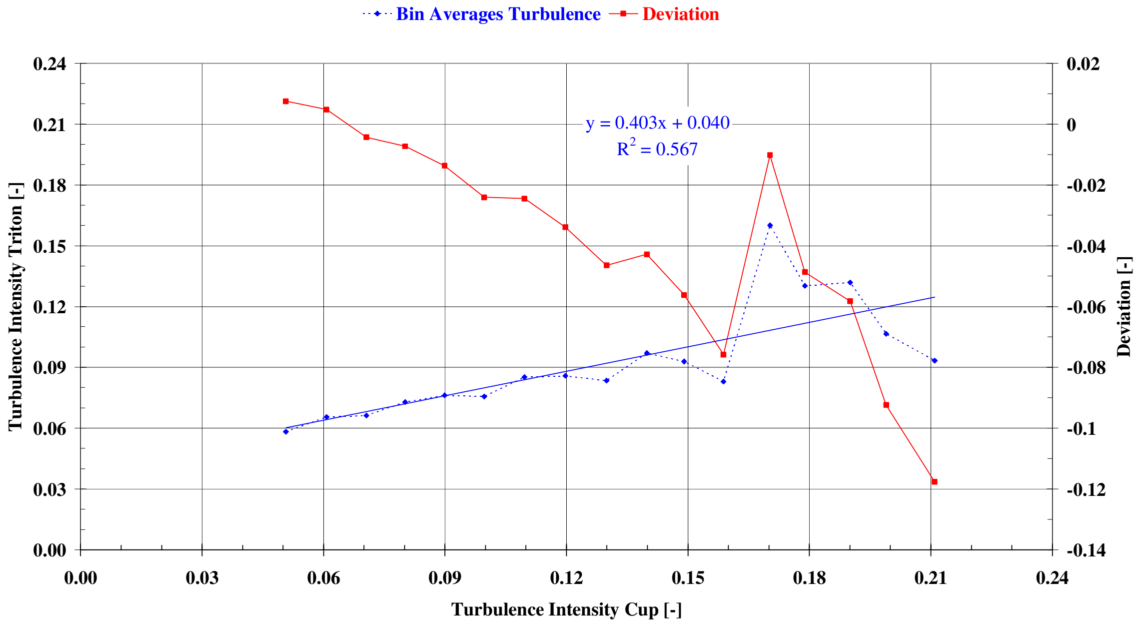


Figure 61 Bin analysis of turbulence intensity of the horizontal wind speed component measured by Triton against cup anemometer (v35N) measurements at 35 m height above ground.

9 Details of Mast Set-Up, Calibrations, Mast Corrections

9.1 Pictures and Drawing of Met Mast Details

Figure 62: Photo of the mast top at about 131 to 135 m above ground

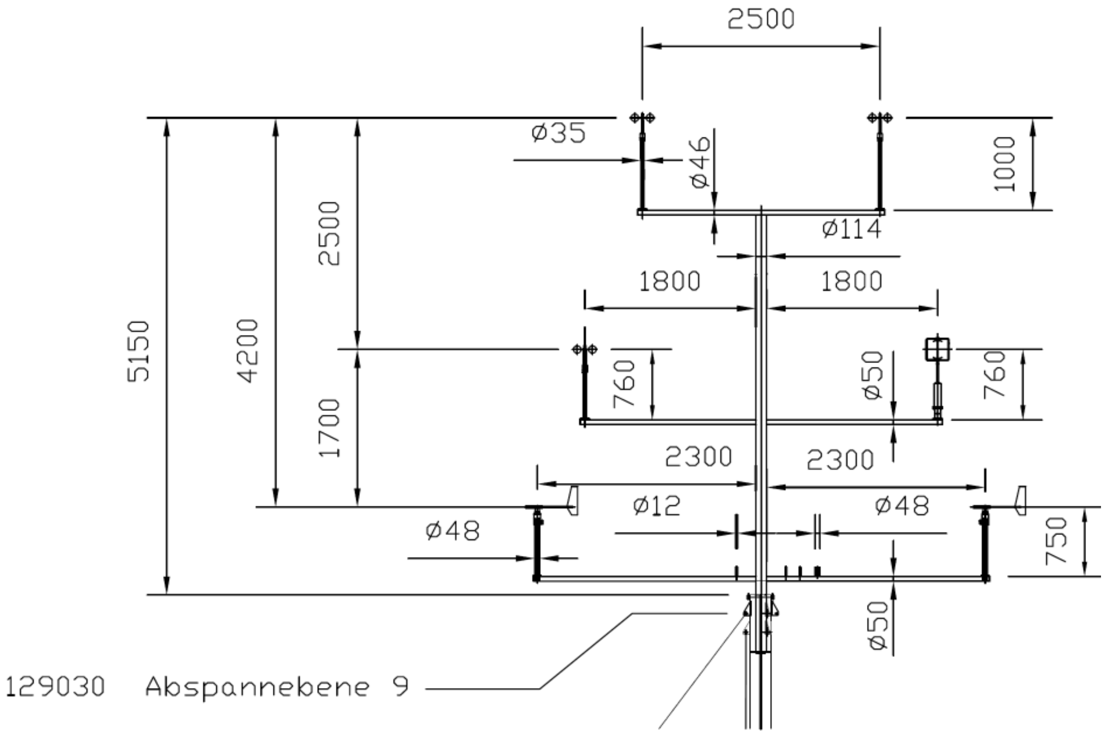


Figure 63: Drawing of the mast top with dimensions in mm

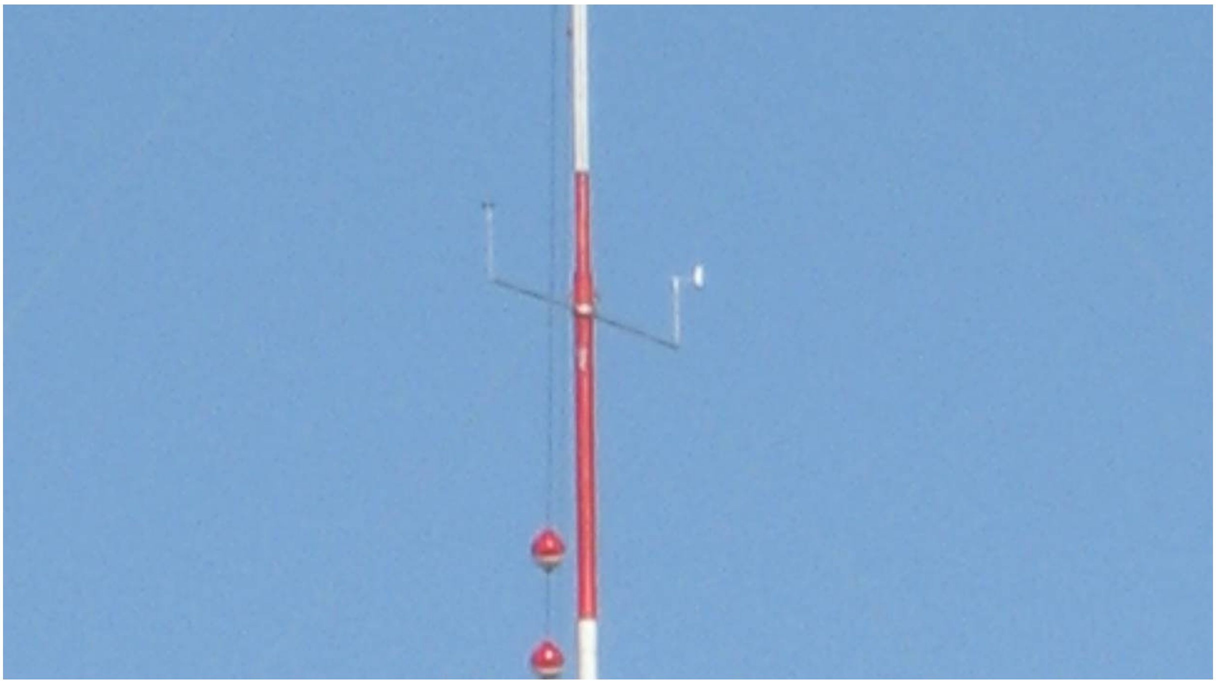


Figure 64: Photo of the sensors and booms at a height of about 104 m above ground

Figure 65: Photo of the sensors and booms at a height of about 72 m above ground

Figure 66: Photo of the sensors and booms at a height of about 35 m above ground

9.2 Calibration Certificates of Anemometers

9.2.1 Calibration Certificate Top-Anemometer (135 m southwards)

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label

10/1894
DKD-K-36801
03/2010

Gegenstand *Object*	4.3350.00.000
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0309119 Cup: 0309119
Auftraggeber *Customer*	Deutsche WindGuard GmbH D 26316 Varel
Auftragsnummer *Order No.*	VT10196
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	26.03.2010

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Akkreditierungsstelle des DKD als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift und Stempel haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Accreditation Body of the DKD and the issuing laboratory. Calibration certificates without signature and seal are not valid.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	26.03.2010	Dipl. Phys. D. Westermann	Dipl. Ing. (FH) Catharina Herold

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Seite 3
Page

10/1894
DKD-K-36801
03/2010

Kalibrierergebnis:
Result:

Test Item (1/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
80.666	4.131	0.05
122.122	6.114	0.05
160.456	7.983	0.05
199.027	9.831	0.05
239.015	11.787	0.05
279.652	13.750	0.05
320.513	15.709	0.05
299.109	14.659	0.05
259.556	12.769	0.05
218.813	10.792	0.05
179.036	8.874	0.05
138.517	6.955	0.05
102.157	5.177	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Anhang
Annex

10/1894

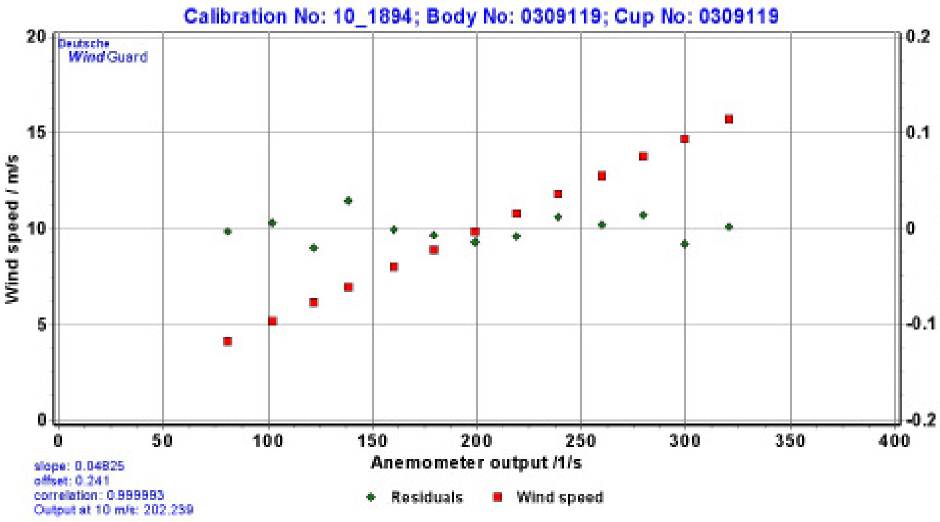
1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	10/1894
Body no.	0309119
Cup no.	0309119
Date	26.03.2010
Air temperature	23.7 °C
Air pressure	1004.4 hPa
Humidity	37.3 %

Linear regression analysis

Slope	0.04825 (m/s)/(1/s) ±0.00005 (m/s)/(1/s)
Offset	0.241 m/s ±0.011 m/s
St.err(Y)	0.013 m/s
Correlation coefficient	0.999993

Remarks no



[1]) According to MEASNET Cup Anemometer Calibration Procedure 09/1997.
Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutscher Kalibrierdienst – DKD (German Calibration Service). Registration: DKD – K – 36801

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0) 4451 9515 0

9.2.2 Calibration Certificate Top-Anemometer (135 m northwards)

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat DAR

DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label

10/1892
DKD-K-36801
03/2010

Gegenstand *Object*	4.3350.00.000
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0209798 Cup: 0209798
Auftraggeber *Customer*	Deutsche WindGuard GmbH D 26316 Varel
Auftragsnummer *Order No.*	VT10196
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	26.03.2010

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Akkreditierungsstelle des DKD als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift und Stempel haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Accreditation Body of the DKD and the issuing laboratory. Calibration certificates without signature and seal are not valid.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	26.03.2010	Dipl. Phys. D. Westermann	Dipl. Ing. (FH) Catharina Herold

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Deutsche WindGuard

Seite 3
Page

10/1892
DKD-K-36801
03/2010

Kalibrierergebnis:
Result:

Test Item (1/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
80.513	4.126	0.05
121.521	6.110	0.05
159.994	7.976	0.05
198.146	9.824	0.05
238.181	11.785	0.05
279.174	13.750	0.05
319.884	15.711	0.05
298.168	14.667	0.05
259.874	12.774	0.05
217.933	10.787	0.05
178.889	8.876	0.05
138.575	6.948	0.05
101.956	5.181	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

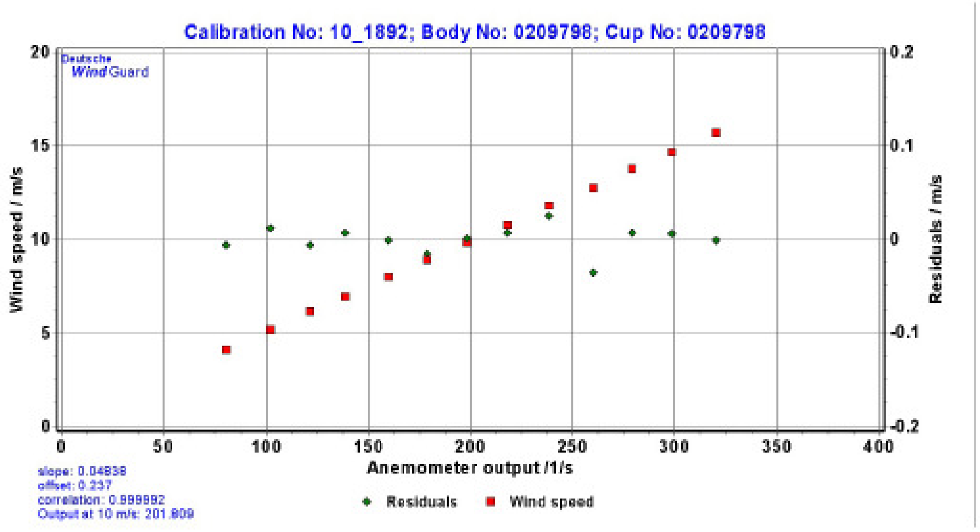
Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0) 4451 9515 0

Anhang
Annex

10/1892

1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	10/1892
Body no.	0209798
Cup no.	0209798
Date	26.03.2010
Air temperature	23.7 °C
Air pressure	1004.7 hPa
Humidity	37.3 %
Linear regression analysis	
Slope	0.04838 (m/s)/(1/s) ±0.00006 (m/s)/(1/s)
Offset	0.237 m/s ±0.012 m/s
St.err(Y)	0.013 m/s
Correlation coefficient	0.999992
Remarks	no



[1]) According to MEASNET Cup Anemometer Calibration Procedure 09/1997.
Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutscher Kalibrierdienst – DKD (German Calibration Service). Registration: DKD – K – 36801

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

9.2.3 Calibration Certificate Backup-Anemometer (133 m)

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label

10/1847
DKD-K-36801
03/2010

Gegenstand *Object*	4.3350.00.000
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0209552 Cup: 0209552
Auftraggeber *Customer*	Deutsche WindGuard GmbH D 26316 Varel
Auftragsnummer *Order No.*	VT10196
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	24.03.2010

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Akkreditierungsstelle des DKD als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift und Stempel haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Accreditation Body of the DKD and the issuing laboratory. Calibration certificates without signature and seal are not valid.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	24.03.2010	Dipl. Phys. D. Westermann	Dipl. Ing. (FH) Catharina Herold

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Seite 3
Page

10/1847
DKD-K-36801
03/2010

Kalibrierergebnis:
Result:

Test Item (1/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
80.867	4.133	0.05
121.525	6.083	0.05
160.656	7.986	0.05
198.345	9.809	0.05
239.657	11.776	0.05
279.534	13.744	0.05
321.249	15.704	0.05
299.645	14.656	0.05
260.177	12.772	0.05
218.650	10.778	0.05
178.548	8.856	0.05
138.987	6.955	0.05
102.253	5.158	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0) 4451 9515 0

Anhang
Annex

10/1847

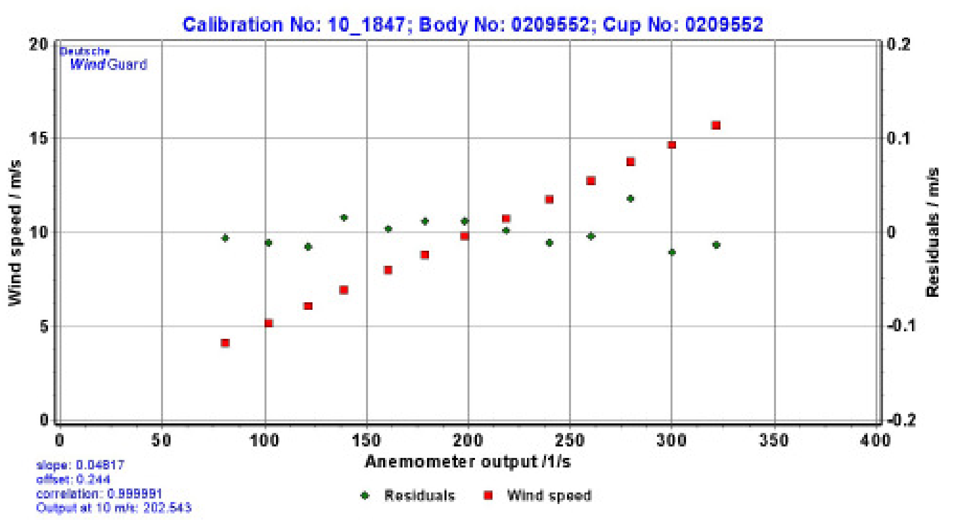
1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	10/1847
Body no.	0209552
Cup no.	0209552
Date	24.03.2010
Air temperature	23.7 °C
Air pressure	1009.2 hPa
Humidity	35.6 %

Linear regression analysis

Slope	0.04817 (m/s)/(1/s) ±0.00006 (m/s)/(1/s)
Offset	0.244 m/s ±0.013 m/s
St.err(Y)	0.015 m/s
Correlation coefficient	0.999991

Remarks no



[1]) According to MEASNET Cup Anemometer Calibration Procedure 09/1997.
Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutscher Kalibrierdienst – DKD (German Calibration Service). Registration: DKD – K – 36801

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0) 4451 9515 0

9.2.4 Calibration Certificate Ultra Sonic Anemometer (133 m)

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

DKD-K- 36801

Kalibrierzeichen *Calibration label*	10/2245 DKD-K- 36801 09/2010

Kalibrierschein
Calibration Certificate

Gegenstand *Object*	Sonic Anemometer
Hersteller *Manufacturer*	Gill Instruments UK-Hampshire S041 9EG
Typ *Type*	1590-PK-020
Fabrikat/Serien-Nr. *Serial number*	Body: 093120 Cup: -
Auftraggeber *Customer*	ENERCON GmbH D 26605 Aurich
Auftragsnummer *Order No.*	VT10557
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	24.08.2010

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	16.09.2010	Dipl. Phys. D. Westermann	Dipl. Ing. (FH) Catharina Herold

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Seite 3
Page

10/2245
DKD-K-36801
09/2010

Kalibrierergebnis:
Result:

Test Item (m/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
3.660	3.767	0.05
5.798	5.979	0.05
7.818	8.061	0.05
9.752	10.063	0.05
11.590	11.972	0.05
13.526	13.977	0.05
15.366	15.890	0.05
14.444	14.937	0.05
12.528	12.953	0.05
10.692	11.049	0.05
8.786	9.079	0.05
6.814	7.045	0.05
4.697	4.862	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Deutsche WindGuard Wind Tunnel Services is accredited according to ISO/IEC 17025:2005 by the Deutscher Kalibrierdienst – DKD and by MEASNET.

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Anhang
Annex

10/2245

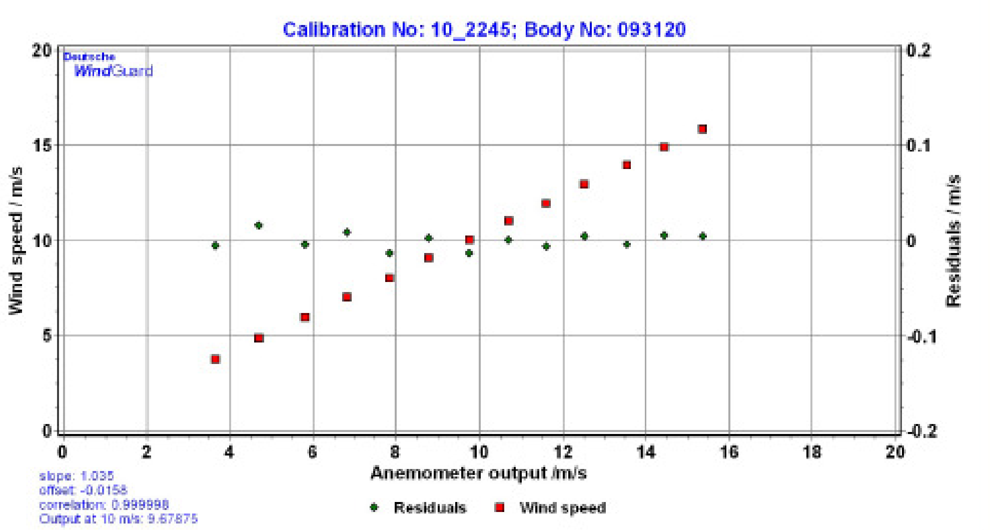
1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	10/2245
Body no.	093120
Cup no.	-
Date	24.08.2010
Air temperature	24.7 °C
Air pressure	1004.3 hPa
Humidity	47.5 %

Linear regression analysis

Slope	1.03482 (m/s)/(m/s) ±0.00069 (m/s)/(m/s)
Offset	-0.016 m/s ±0.007 m/s
St.err(Y)	0.010 m/s
Correlation coefficient	0.999998

Remarks no



[1]) According to MEASNET Cup Anemometer Calibration Procedure.
Deutsche WindGuard Wind Tunnel Services is accredited according to ISO/IEC 17025:2005 by the Deutscher Kalibrierdienst – DKD (German Calibration Service) and by MEASNET.

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

9.2.5 Calibration Certificate Anemometer (104 m)

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

DKD-K- 36801

Kalibrierzeichen / *Calibration label*	10/1891 DKD-K-36801 03/2010

Kalibrierschein
Calibration Certificate

Gegenstand / *Object*	4.3350.00.000
Hersteller / *Manufacturer*	Thies Clima D-37083 Göttingen
Typ / *Type*	4.3350.00.000
Fabrikat/Serien-Nr. / *Serial number*	Body: 0309117 Cup: 0309117
Auftraggeber / *Customer*	Deutsche WindGuard GmbH D 26316 Varel
Auftragsnummer / *Order No.*	VT10196
Anzahl der Seiten des Kalibrierscheines / *Number of pages of the certificate*	3
Datum der Kalibrierung / *Date of calibration*	26.03.2010

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Akkreditierungsstelle des DKD als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift und Stempel haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Accreditation Body of the DKD and the issuing laboratory. Calibration certificates without signature and seal are not valid.

Stempel / *Seal*	Datum / *Date*	Leiter des Kalibrierlaboratoriums / *Head of the calibration laboratory*	Bearbeiter / *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	26.03.2010	Dipl. Phys. D. Westermann	Dipl. Ing. (FH) Catharina Herold

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0) 4451 9515 0

Seite 3
Page

10/1891
DKD-K-36801
03/2010

Kalibrierergebnis:
Result:

Test Item (1/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
80.824	4.129	0.05
121.689	6.113	0.05
159.917	7.984	0.05
199.257	9.832	0.05
239.660	11.790	0.05
280.514	13.750	0.05
321.907	15.709	0.05
299.284	14.668	0.05
259.914	12.774	0.05
218.703	10.792	0.05
178.644	8.875	0.05
138.910	6.952	0.05
102.138	5.182	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

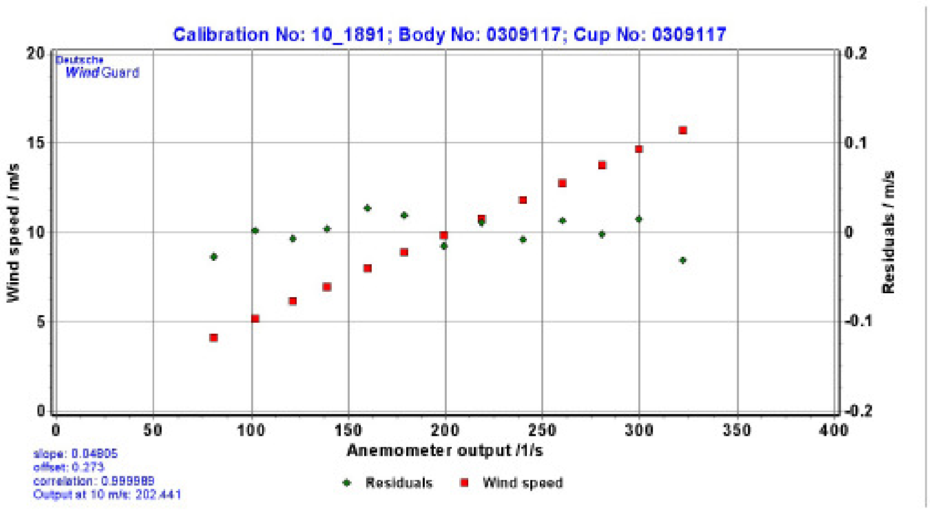
Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Anhang
Annex

10/1891

1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	10/1891
Body no.	0309117
Cup no.	0309117
Date	26.03.2010
Air temperature	23.7 °C
Air pressure	1004.6 hPa
Humidity	37.4 %
Linear regression analysis	
Slope	0.04805 (m/s)/(1/s) ±0.00007 (m/s)/(1/s)
Offset	0.273 m/s ±0.015 m/s
St.err(Y)	0.017 m/s
Correlation coefficient	0.999989
Remarks	no



[1]) According to MEASNET Cup Anemometer Calibration Procedure 09/1997.
Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutscher Kalibrierdienst – DKD (German Calibration Service). Registration: DKD – K – 36801

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0) 4451 9515 0

9.2.6 Calibration Certificate Anemometer (72 m)

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label

10/1893
DKD-K-36801
03/2010

Gegenstand *Object*	4.3350.00.000
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0209542 Cup: 0209542
Auftraggeber *Customer*	Deutsche WindGuard GmbH D 26316 Varel
Auftragsnummer *Order No.*	VT10196
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	26.03.2010

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Akkreditierungsstelle des DKD als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift und Stempel haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Accreditation Body of the DKD and the issuing laboratory. Calibration certificates without signature and seal are not valid.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	26.03.2010	Dipl. Phys. D. Westermann	Dipl. Ing. (FH) Catharina Herold

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

10/1893
DKD-K-36801
03/2010

Kalibrierergebnis:
Result:

Test Item (1/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
80.657	4.125	0.05
121.179	6.113	0.05
159.830	7.979	0.05
199.276	9.823	0.05
239.834	11.778	0.05
279.692	13.747	0.05
320.354	15.701	0.05
299.166	14.655	0.05
260.183	12.766	0.05
218.077	10.786	0.05
178.324	8.874	0.05
138.771	6.947	0.05
102.398	5.178	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Anhang
Annex

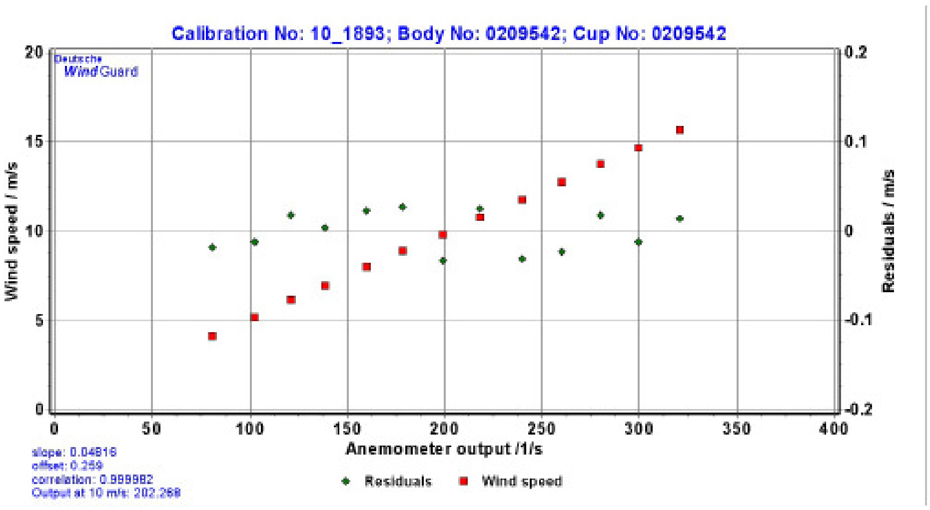
10/1893

1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	10/1893
Body no.	0209542
Cup no.	0209542
Date	26.03.2010
Air temperature	23.7 °C
Air pressure	1005.2 hPa
Humidity	37.3 %

Linear regression analysis

Slope	0.04816 (m/s)/(1/s) ±0.00009 (m/s)/(1/s)
Offset	0.259 m/s ±0.019 m/s
St.err(Y)	0.023 m/s
Correlation coefficient	0.999982
Remarks	no



[1]) According to MEASNET Cup Anemometer Calibration Procedure 09/1997.
Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutscher Kalibrierdienst – DKD (German Calibration Service). Registration: DKD – K – 36801

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

9.2.7 Calibration Certificate Anemometer (35 m southwards)

DEUTSCHER KALIBRIERDIENST **DKD**

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label

10/1849
DKD-K-36801
03/2010

Gegenstand *Object*	4.3350.00.000
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0209539 Cup: 0209539
Auftraggeber *Customer*	Deutsche WindGuard GmbH D 26316 Varel
Auftragsnummer *Order No.*	VT10196
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	25.03.2010

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Akkreditierungsstelle des DKD als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift und Stempel haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Accreditation Body of the DKD and the issuing laboratory. Calibration certificates without signature and seal are not valid.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	25.03.2010	Dipl. Phys. D. Westermann	Dipl. Ing. (FH) Catharina Herold

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0) 4451 9515 0

Deutsche WindGuard

Seite 3
Page

10/1849
DKD-K-36801
03/2010

Kalibrierergebnis:
Result:

Test Item (1/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
80.895	4.135	0.05
121.208	6.084	0.05
160.372	7.986	0.05
198.286	9.816	0.05
238.609	11.780	0.05
279.210	13.738	0.05
320.483	15.701	0.05
300.311	14.664	0.05
259.973	12.770	0.05
217.536	10.778	0.05
178.621	8.877	0.05
139.340	6.954	0.05
102.087	5.182	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

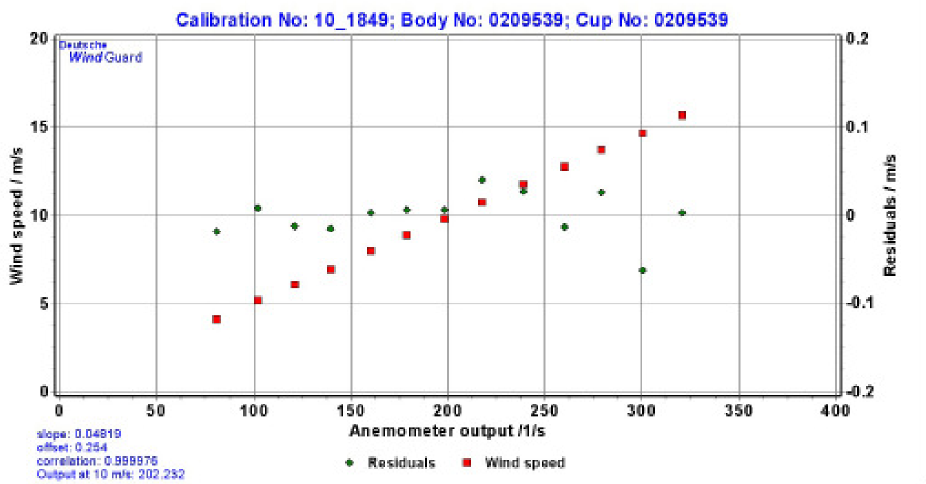
Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Anhang
Annex

10/1849

1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	10/1849
Body no.	0209539
Cup no.	0209539
Date	25.03.2010
Air temperature	23.7 °C
Air pressure	1009.0 hPa
Humidity	35.7 %
Linear regression analysis	
Slope	0.04819 (m/s)/(1/s) ±0.00010 (m/s)/(1/s)
Offset	0.254 m/s ±0.021 m/s
St.err(Y)	0.027 m/s
Correlation coefficient	0.999976
Remarks	no



[1]) According to MEASNET Cup Anemometer Calibration Procedure 09/1997.
Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutscher Kalibrierdienst – DKD (German Calibration Service). Registration: DKD – K – 36801

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel : Tel. ++49 (0) 4451 9515 0

9.2.8 Calibration Certificate Anemometer (ultra sonic anemometer 72 m)

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label

10/2299
DKD-K-36801
09/2010

Gegenstand *Object*	Sonic Anemometer
Hersteller *Manufacturer*	Gill Instruments UK-Hampshire S041 9EG
Typ *Type*	1590-PK-020
Fabrikat/Serien-Nr. *Serial number*	Body: 525 Cup: -
Auftraggeber *Customer*	ENERCON GmbH D 26605 Aurich
Auftragsnummer *Order No.*	VT10557
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	25.08.2010

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	16.09.2010	Dipl. Phys. D. Westermann	Dipl. Ing. (FH) Catharina Herold

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Deutsche WindGuard

Seite 3
Page

10/2299
DKD-K-36801
09/2010

Kalibrierergebnis:
Result:

Test Item (m/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
3.768	3.783	0.05
5.994	6.000	0.05
8.095	8.074	0.05
10.091	10.065	0.05
12.006	11.987	0.05
14.034	13.983	0.05
15.894	15.850	0.05
14.964	14.911	0.05
12.996	12.968	0.05
11.026	11.017	0.05
9.108	9.092	0.05
7.020	7.020	0.05
4.857	4.880	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Deutsche WindGuard Wind Tunnel Services is accredited according to ISO/IEC 17025:2005 by the Deutscher Kalibrierdienst – DKD and by MEASNET.

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Anhang
Annex

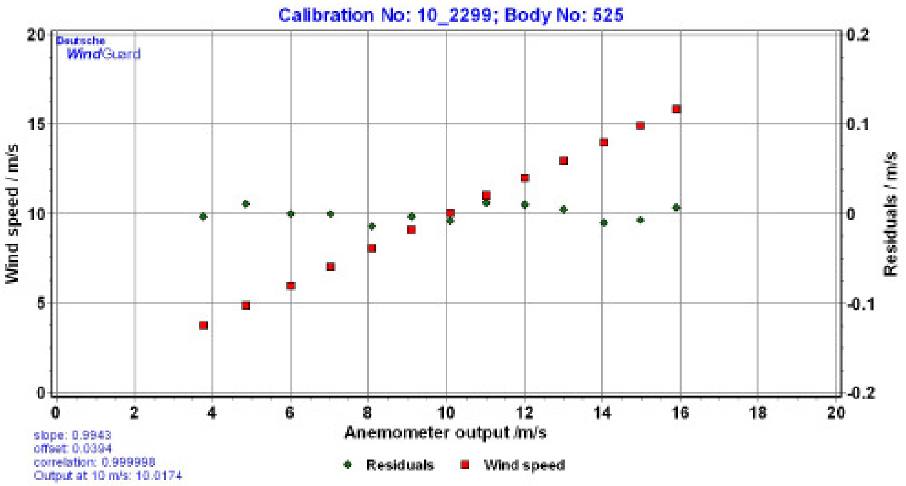
10/2299

1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	10/2299
Body no.	525
Cup no.	-
Date	25.08.2010
Air temperature	22.2 °C
Air pressure	1009.7 hPa
Humidity	50.5 %

Linear regression analysis

Slope	0.99433 (m/s)/(m/s) ±0.00066 (m/s)/(m/s)
Offset	0.039 m/s ±0.007 m/s
St.err(Y)	0.010 m/s
Correlation coefficient	0.999998
Remarks	no



[1]) According to MEASNET Cup Anemometer Calibration Procedure.
Deutsche WindGuard Wind Tunnel Services is accredited according to ISO/IEC 17025:2005 by the Deutscher Kalibrierdienst – DKD (German Calibration Service) and by MEASNET.

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

9.2.9 Calibration Certificate Anemometer (35 m northwards)

DEUTSCHER KALIBRIERDIENST **DKD**

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label

10/1848
DKD-K-36801
03/2010

Gegenstand *Object*	4.3350.00.000
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0309115 Cup: 0309115
Auftraggeber *Customer*	Deutsche WindGuard GmbH D 26316 Varel
Auftragsnummer *Order No.*	VT10196
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	25.03.2010

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Akkreditierungsstelle des DKD als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift und Stempel haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Accreditation Body of the DKD and the issuing laboratory. Calibration certificates without signature and seal are not valid.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	25.03.2010	Dipl. Phys. D. Westermann	Dipl. Ing. (FH) Catharina Herold

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Seite 3
Page

10/1848
DKD-K-36801
03/2010

Kalibrierergebnis:
Result:

Test Item (1/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
80.552	4.132	0.05
121.590	6.119	0.05
160.277	7.986	0.05
197.177	9.816	0.05
239.422	11.784	0.05
278.371	13.750	0.05
319.923	15.703	0.05
297.700	14.666	0.05
259.472	12.768	0.05
218.376	10.791	0.05
178.009	8.855	0.05
139.134	6.963	0.05
101.703	5.159	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel : Tel. ++49 (0) 4451 9515 0

Anhang
Annex

10/1848

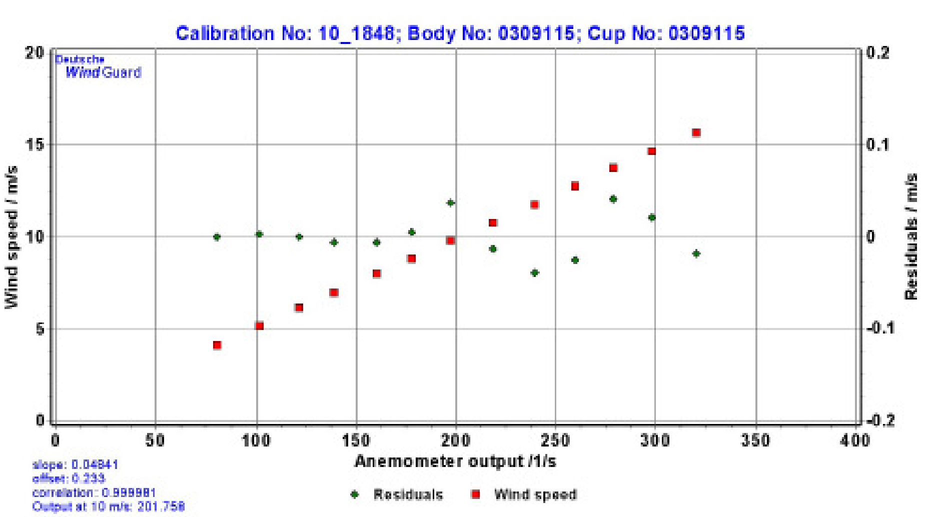
1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	10/1848
Body no.	0309115
Cup no.	0309115
Date	25.03.2010
Air temperature	23.7 °C
Air pressure	1009.1 hPa
Humidity	35.7 %

Linear regression analysis

Slope	0.04841 (m/s)/(1/s) ±0.00009 (m/s)/(1/s)
Offset	0.233 m/s ±0.019 m/s
St.err(Y)	0.024 m/s
Correlation coefficient	0.999981

Remarks	no



[1]) According to MEASNET Cup Anemometer Calibration Procedure 09/1997.
Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutscher Kalibrierdienst – DKD (German Calibration Service). Registration: DKD – K – 36801

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

9.3 Correction of Mast Effects

9.3.1 Mast Correction of v133 and v133usa

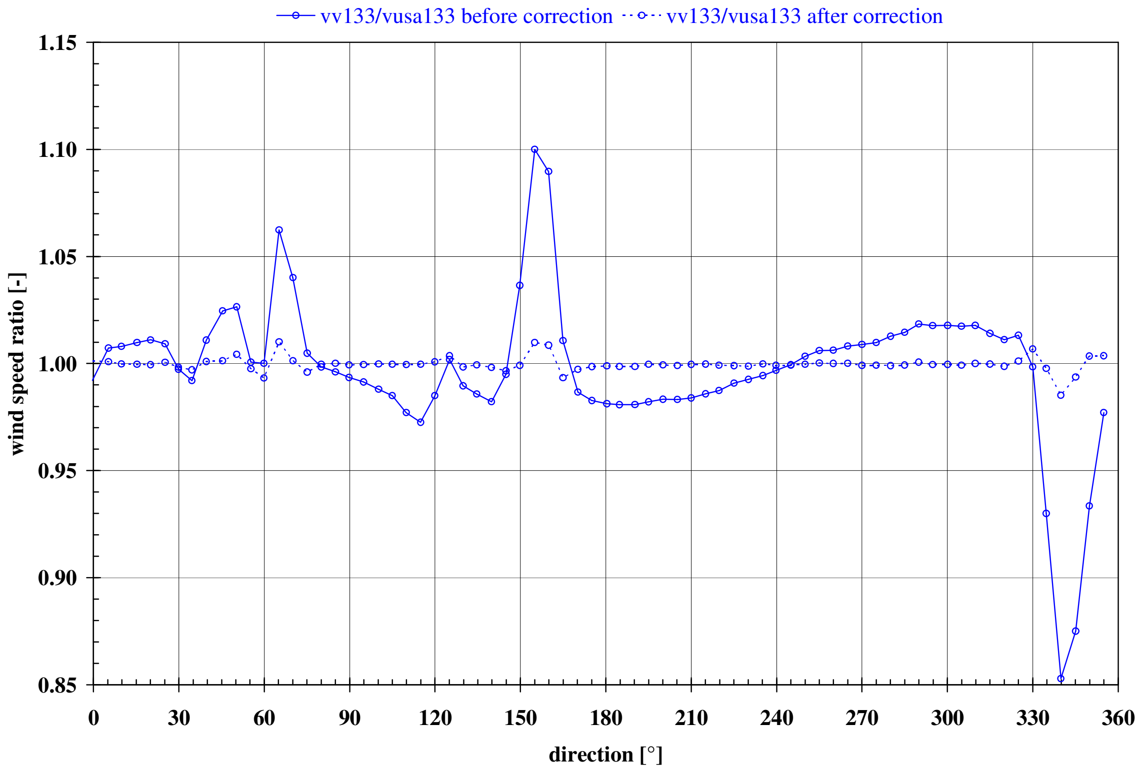


Figure 67: Effect of the wind direction depending wind speed correction at 133 m due to mast effects. The continuous line shows the wind speed ratio between v133 and v133usa before, the doted line the ratio after the application of the empirically determined mast correction function.

9.3.2 Mast Correction of v72 and v72usa

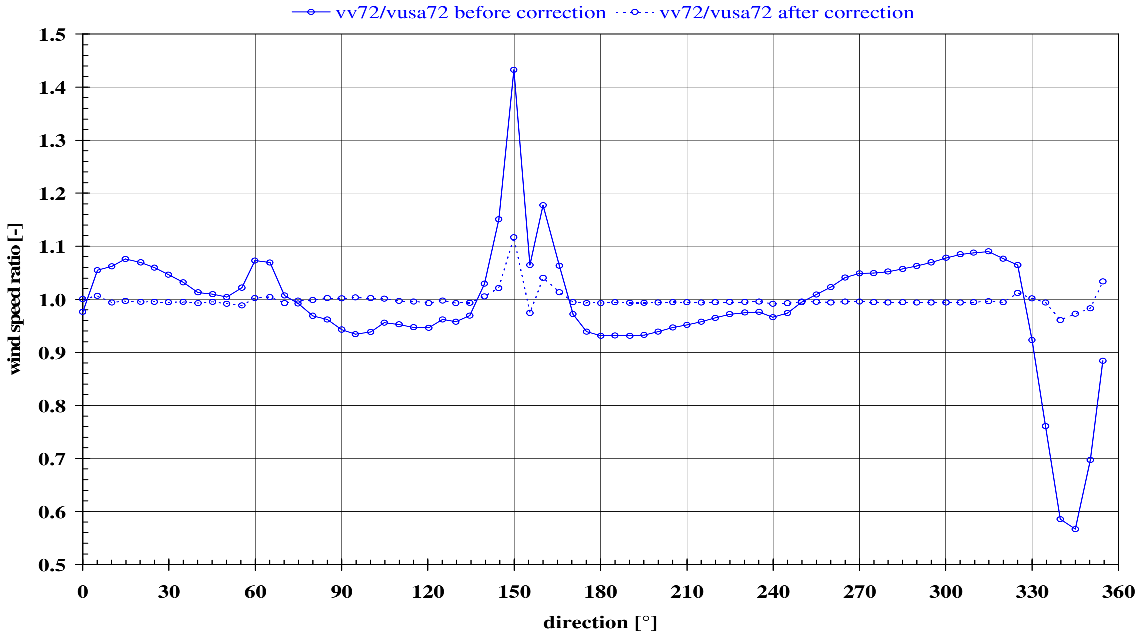


Figure 68: Effect of the wind direction depending wind speed correction at 72 m due to mast effects. The continuous line shows the wind speed ratio between v72 and v72usa before, the doted line the ratio after the application of the empirically determined mast correction function.

9.3.3 Mast Correction of v35N and v35S

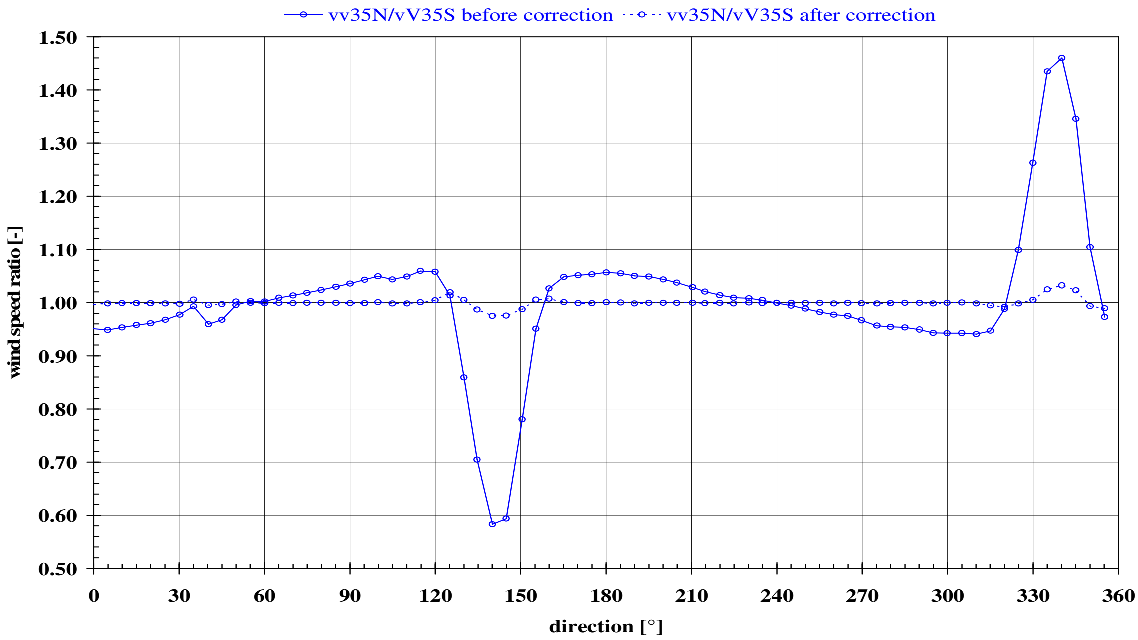


Figure 69: Effect of the wind direction depending wind speed correction at 35 m due to mast effects. The continuous line shows the wind speed ratio between v35N and v35S before, the doted line the ratio after the application of the empirically determined mast correction function.

9.3.4 Table of Wind Speed Correction Factors

Direction [°]	v133	usa133	v72	usa72	v35N	v35S
0	1.012	1.004	1.050	1.027	1.025	0.975
5	0.996	1.004	0.971	1.026	1.026	0.974
10	0.996	1.004	0.967	1.033	1.024	0.977
15	0.995	1.005	0.961	1.040	1.021	0.979
20	0.994	1.006	0.964	1.037	1.020	0.981
25	0.995	1.005	0.969	1.032	1.016	0.984
30	1.001	0.999	0.975	1.026	1.011	0.989
35	1.004	0.996	0.982	1.019	1.003	0.997
40	0.994	1.006	0.991	1.009	1.021	0.980
45	0.988	1.012	0.992	1.007	1.016	0.984
50	0.987	1.013	0.995	1.004	1.002	0.998
55	0.999	1.000	0.986	1.013	0.998	1.002
60	1.000	0.999	0.963	1.038	0.999	1.001
65	0.970	1.030	0.964	1.034	0.995	1.005
70	0.980	1.020	0.994	1.004	0.993	1.007
75	0.997	1.003	1.001	0.997	0.991	1.009
80	1.001	0.999	1.013	0.980	0.988	1.012
85	1.002	0.998	1.017	0.978	0.985	1.015
90	1.003	0.997	1.027	0.965	0.982	1.018
95	1.004	0.996	1.032	0.959	0.979	1.022
100	1.006	0.994	1.029	0.961	0.976	1.025
105	1.007	0.993	1.020	0.977	0.979	1.022
110	1.011	0.988	1.022	0.977	0.976	1.025
115	1.014	0.984	1.025	0.974	0.971	1.030
120	1.007	0.991	1.025	0.974	0.972	1.029
125	0.999	1.001	1.017	0.983	1.014	1.028
130	1.005	0.995	1.019	0.981	1.196	1.028
135	1.007	0.993	1.013	0.986	1.457	1.027
140	1.009	0.991	1.015	1.038	1.759	1.026
145	1.009	1.004	1.017	1.141	1.727	1.026
150	1.009	1.046	1.019	1.380	1.313	1.025
155	1.009	1.109	1.021	1.068	1.077	1.025
160	1.009	1.099	1.023	1.183	0.997	1.024
165	1.009	1.020	1.025	1.086	0.976	1.024
170	1.009	0.996	1.027	1.001	0.975	1.026
175	1.008	0.992	1.029	0.971	0.974	1.027
180	1.009	0.991	1.033	0.968	0.973	1.028
185	1.009	0.991	1.033	0.968	0.973	1.027
190	1.009	0.991	1.033	0.968	0.975	1.025
195	1.009	0.991	1.033	0.969	0.976	1.025
200	1.008	0.992	1.029	0.972	0.979	1.022
205	1.008	0.992	1.025	0.976	0.981	1.019
210	1.008	0.992	1.022	0.978	0.986	1.015
215	1.007	0.993	1.019	0.982	0.990	1.011
220	1.006	0.994	1.015	0.985	0.993	1.007
225	1.004	0.996	1.012	0.989	0.995	1.005
230	1.003	0.997	1.010	0.990	0.996	1.004

235	1.003	0.997	1.009	0.991	0.997	1.003
240	1.001	0.999	1.014	0.986	1.000	1.000
245	1.000	1.000	1.010	0.990	1.003	0.997
250	0.998	1.002	1.000	1.000	1.005	0.995
255	0.997	1.003	0.993	1.007	1.009	0.991
260	0.997	1.003	0.986	1.014	1.011	0.989
265	0.996	1.004	0.977	1.023	1.012	0.988
270	0.995	1.005	0.974	1.027	1.017	0.984
275	0.995	1.005	0.974	1.027	1.022	0.978
280	0.993	1.007	0.972	1.029	1.023	0.977
285	0.993	1.008	0.970	1.031	1.024	0.977
290	0.991	1.009	0.967	1.034	1.026	0.975
295	0.991	1.009	0.964	1.037	1.029	0.971
300	0.991	1.009	0.960	1.041	1.030	0.971
305	0.991	1.009	0.957	1.045	1.030	0.971
310	0.991	1.009	0.956	1.046	1.031	0.970
315	0.993	1.007	0.955	1.047	1.027	0.973
320	0.994	1.006	0.961	1.040	1.027	1.015
325	0.993	1.007	0.966	1.033	1.027	1.127
330	1.007	1.006	1.114	1.032	1.027	1.292
335	1.081	1.006	1.351	1.031	1.026	1.457
340	1.179	1.006	1.754	1.030	1.026	1.466
345	1.148	1.005	1.812	1.029	1.026	1.366
350	1.076	1.005	1.471	1.028	1.026	1.127
355	1.028	1.005	1.160	1.028	1.025	0.997