Weather Forecasts
Renewable Energies
Air and Climate
Environmental Information Technology

METEOTEST Cooperative
Fabrikstrasse 14, CH-3012 Bern
Tel. +41 (0)31 307 26 26
Fax +41 (0)31 307 26 10
office@meteotest.ch, www.meteotest.ch

Bern, 31 May 2012

Validation Study of the Lufft Ventus Wind Sensor

Test Measurement and Validation on La Dôle in the Jura Mountains, Switzerland

Customer:

G. LUFFT
Mess- und Regeltechnik GmbH
Klaus Hirzel
Gutenbergstrasse 20
70736 Fellbach
GERMANY

Prepared by:

Dr. Stefan Müller

Contents

1 Introduction **3**
2 Measuring Instruments and Arrangement **4**
2.1 Measurement Data 7
3 Data Analysis **8**
3.1 General Meteorological Situation 8
3.2 Data Availability 10
3.3 Wind Measurement Data 10
4 Case Studies **15**
4.1 Case 1: 10.1.2012 15
4.2 Case 2: 21.4.2012 17
5 Conclusion **19**

Version	Date	Contents	Prepared by	Checked by
1.0	8.5.2012	Validation Study of the Lufft Ventus Wind Sensor	SM	RC, 31.5.2012

1 Introduction

Icing of measuring instruments is a common problem in meteorological measurement. Icing causes erroneous measurements leading to the misinterpretation of measurement data and sensor failure.

METEOTEST was commissioned by G. Lufft GmbH to carry out a validation study of its wind sensor, *Ventus*, under icing conditions. In the winter of 2011/2012, a test measurement was performed on La Dôle in the Jura Mountains, Switzerland, at an altitude of 1,670 meters above sea level. This is probably one of the locations in Switzerland most severely affected by icing.

A station belonging to the automatic monitoring network of the Federal Office of Meteorology and Climatology, MeteoSwiss, is also located on La Dôle. A heated Metek USA-1 ultrasonic anemometer is currently installed on La Dôle. According to MeteoSwiss, at present this is the reference instrument for wind measurement under icing conditions. The Ventus was installed and operated by MeteoSwiss.

In this report, the collected measurement data are analyzed and compared with the reference instrument. At the same time, an evaluation of the entire measurement period is performed. In addition, two case studies are described.

2 Measuring Instruments and Arrangement

La Dôle lies in the Swiss Jura Mountains at an altitude of 1,670 m above sea level (Figure 1). It is the highest elevation in the vicinity and hence, due to its exposed position, it is particularly open to the wind and, accordingly, prone to icing. A station belonging to Switzerland's official meteorological measuring network, SwissMetNet, which is operated by MeteoSwiss, is located on La Dôle. Information about this station is presented in Table 1.

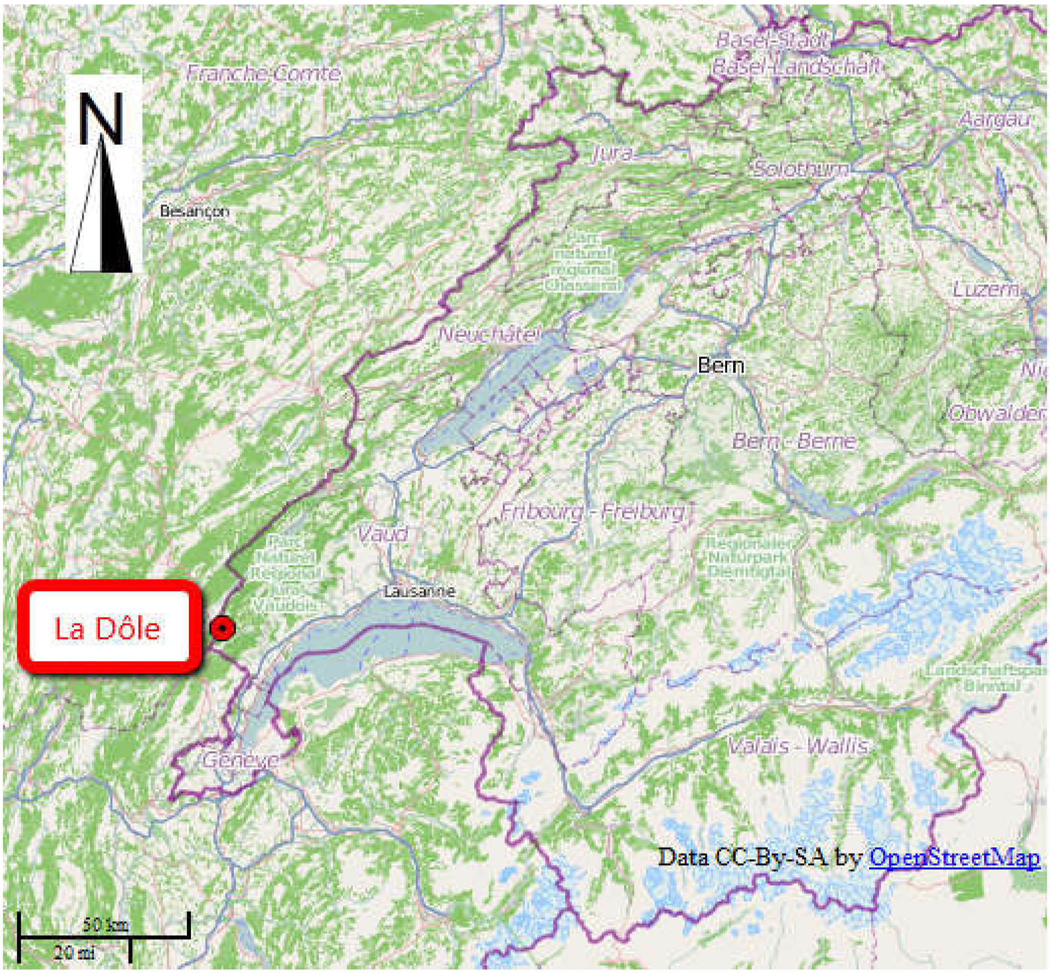

Figure 1: The La Dôle station is located in the Jura Mountains in the west of Switzerland, north of Geneva.

Table 1: Information about the La Dôle station as provided by www.meteoschweiz.ch.

Parameter	Description
WMO number:	06702
National station number:	8280
Coordinates:	46.4247N / 6.099478E
Altitude:	1,670 m above sea level
In operation since:	1981
Parameters measured:	Global irradiance Relative humidity Sunshine duration Wind speed Wind direction Air pressure Temperature Precipitation

Table 2 shows the list of the wind sensors used for the comparison. The measurement station's reference instrument is installed on the top of the meteo mast at a height of 10 m. The Ventus wind sensor made by Lufft was installed on a lateral arm, attached to the mast in an east-west direction, approximately 1.5 m lower down. The precise alignment of the arm is 92°. Figure 2 shows a photograph of the meteo mast with an indication of the geographical alignment. The Lufft Ventus wind sensor was installed on the western side of the mast in November 2011. Figure 3 shows the top of the mast in detail with the two installed sensors.

The Lufft Ventus wind sensor is a first generation device. For organizational reasons (access to mast not possible due to ice accumulation; MeteoSwiss technicians unavailable), it was only possible to install the new version, with enhanced heating, on the eastern side of the mast on 15.3.2012.

MeteoSwiss installed, operated and collected the data from the Ventus. MeteoSwiss also provided the measurements from the reference sensors.

Table 2: Installed wind sensors.

Manufacturer	Measuring Instrument
G. Lufft Mess- und Regeltechnik GmbH	VENTUS Ultrasonic Wind Sensor (test instrument)
METEK – Meteorologische Messtechnik GmbH	USA-1 (reference instrument)

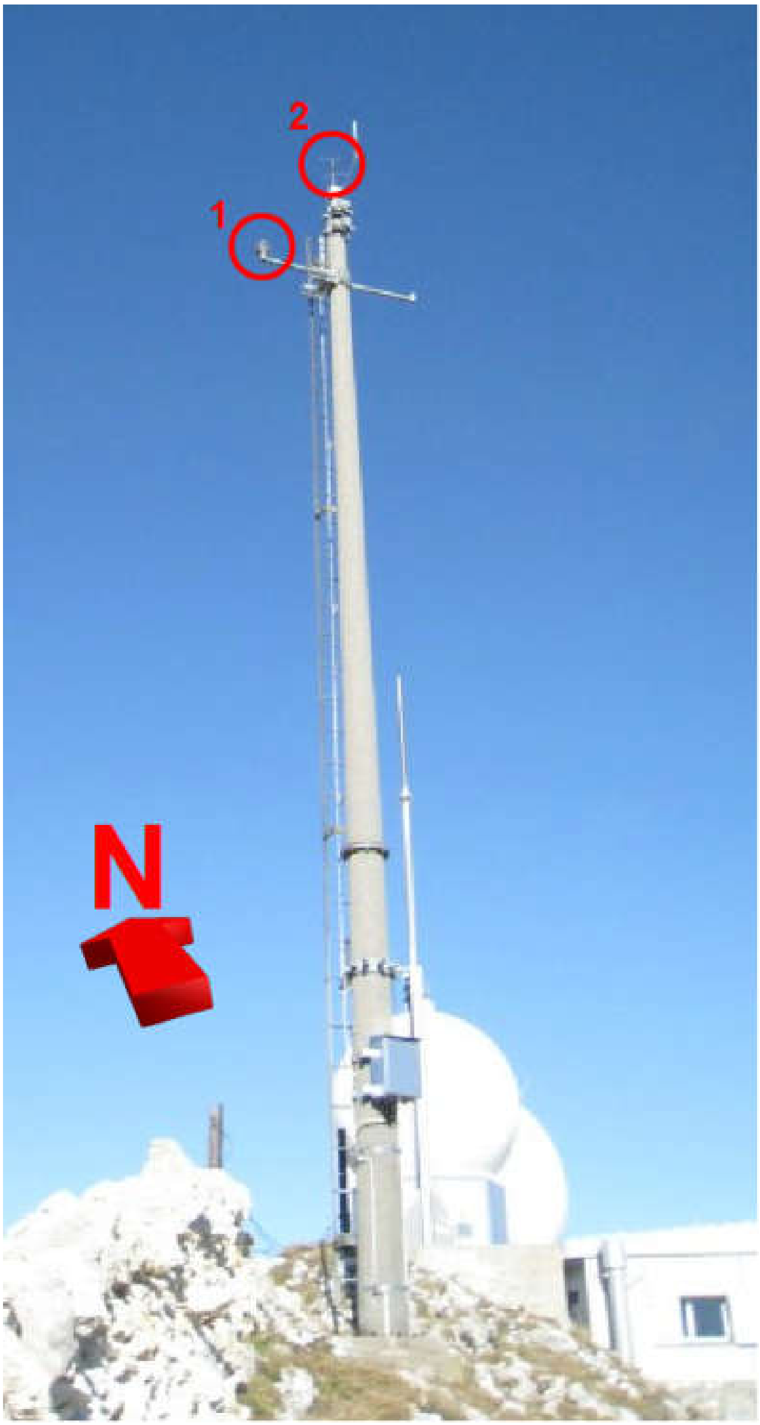

Figure 2: Meteo mast on La Dôle in the Swiss Jura Mountains at an altitude of 1,670 m above sea level. The red arrow shows the geographical alignment. The two sensors are circled in red (1: Lufft Ventus, 2: METEK USA-1).

Figure 3: Top of the meteo mast with the wind sensors: ① Lufft Ventus, ② METEK USA-1. (Date: November 2011)

2.1 Measurement Data

The Ventus was installed in November 2011. Measurement data are available from 1.12.2011. Data samples are collected every second and averaged to provide 10 minute values. Each 10 minute data report contains the minimum, maximum, standard deviation and number of valid samples for the respective 10 minute period. In the case of wind speed, the maximum for the period corresponds to the peak gust at the second level.

3 Data Analysis

3.1 General Meteorological Situation

December 2011 was characterized by wet and windy weather. Winds from a westerly direction brought moist, mild air masses. On 16 December, the severe storm known as “Joachim” passed over Switzerland, bringing peak gusts of up to 175 km/h. Subsequently, large amounts of fresh snow fell on the mountains.
(Released by: MeteoSwiss 2011: Climate Bulletin December 2011, Zurich.)

At the beginning of January, strong westerly winds again prevailed. On 5 January 2012, the storm front named “Andrea” reached Switzerland with peak wind speeds of up to 170 km/h in the Jura Mountains. Large amounts of fresh snow fell at the same time. At the end of January, an icy breeze set in and temperatures fell to well below freezing point throughout the whole of Switzerland.
(Released by: MeteoSwiss 2011: Climate Bulletin January 2012, Zurich.)

The first half of February 2012 was characterized by a cold spell with temperatures down to -20°C on the plains, with smaller inland lakes freezing over and winds from an easterly direction bringing cold air from Russia to Central Europe. The cold spell ended in mid February and temperatures again rose above freezing point.
(Released by: MeteoSwiss 2011: Climate Bulletin February 2012, Zurich.)

After a warm and sunny start to March, a storm again brought snow to low-lying areas. A similar event occurred on 18/19 March. Otherwise, March was mild with temperatures above zero even at higher altitudes.
(Released by: MeteoSwiss 2011: Climate Bulletin March 2012, Zurich.)

After a warm start to April, a low pressure system brought cool, wet weather. Only at the end of the month did the nature of the weather change back to warm and sunny.
(Released by: MeteoSwiss 2011: Climate Bulletin April 2012, Zurich.)

Figure 4 shows the measurements from the SwissMetNet station on La Dôle. The general weather situation on the northern side of the Alps in Switzerland, described above, is also reflected in the measurements on La Dôle. The marked drop in pressure, which was caused by the two storm fronts Joachim and Andrea, is clearly visible. At the same time, we also have the strongest wind speeds in this period. During the period of high rainfall the wind direction was westerly; during the cold spell with temperatures of -20°C in February the wind direction turned to easterly. At temperatures below zero, precipitation falls in the form of snow, which is why the snow depth increases. The snow cover melts when temperatures are above zero.

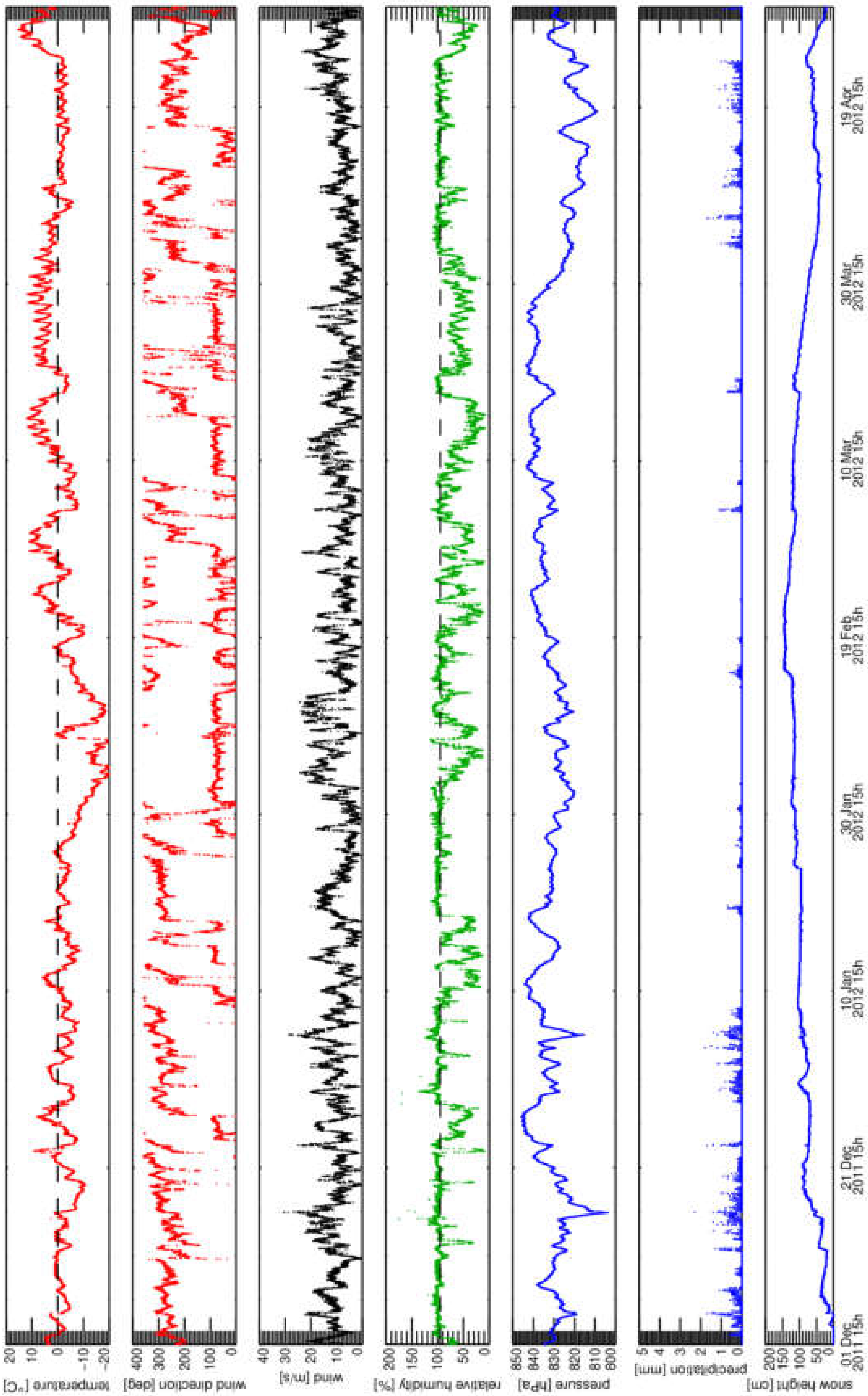

Figure 4: Measurement data from the La Dôle station. The chart covers the entire winter.

3.2 Data Availability

For the validation of data availability, the number of samples was compared to the maximum possible number of samples per month (at a rate of 1 sample per second). As far as data sampling is concerned, the Ventus shows excellent availability throughout the entire measurement period.

Table 3: Number of recorded data samples. 100% corresponds to complete data acquisition at a rate of 1 sample per second. ff indicates wind speed; dd indicates wind direction.

Month	Ventus ff	Reference ff	Ventus dd	Reference dd
2011/12	100.0%	99.7%	100.0%	99.7%
2012/01	99.9%	99.8%	99.9%	99.8%
2012/02	99.9%	99.8%	99.9%	99.8%
2012/03	100.0%	100.0%	100.0%	100.0%
2012/04	100.0%	99.7%	100%	99.8%

3.3 Wind Measurement Data

At first glance, the wind speed measurements presented in Figure 5 show very good correlation between the two sensors. However, with an easterly wind the Ventus shows lower wind speeds than the reference sensor. This is clearly identifiable on the scatter plot at Figure 6 and in the chart at Figure 7. With the wind from any direction other than the east (or – following the sensor change on 15.3.2012 - from the west), the wind speeds are very similar, whereas with an easterly wind significant deviations regularly occurred. This indicates a systematic error due to shadowing and not a measurement error.

It can also be seen that the effect of shadowing is not always equally severe. This indicates that other factors, presumably icing, had an effect on measurement during some periods.

A similar picture emerges with regard to wind direction (Figure 8). On the whole, the measurements are very similar. However, in the case of easterly winds there were some periods during which the wind direction measurement was significantly at variance.

So as not to distort the result, the potentially systematic discrepancies in the case of easterly winds (or – following the sensor change on 15.3.2012 – westerly winds) should not be considered in the following statistical analysis (Table 4 and Table 5). For this purpose, a sector of 90° opening was disregarded.

Using the data adjusted in this way, the monthly mean values of the Ventus are up to 0.5 m/s lower than the reference sensor. The mean peak gusts measured with the Ventus are slightly higher than the reference in 3 out of 5 months. The wind measurement of the Ventus correlates very well with the reference. The correlation coefficient is over 0.95. The wind direction correlation is somewhat lower. However, in 4 out of 5 months the correlation coefficient is over 0.80. Only January falls off slightly at 0.61.

Table 4: Monthly mean wind speed measurements (ff) and mean peak gust (fx) excluding systematic shadowing effects.

Month	ff Ventus [m/s]	Reference ff [m/s]	Ventus fx [m/s]	Reference fx [m/s]
2011/12	10.2	10.7	13.9	14.2
2012/01	8.0	8.6	11.0	11.2
2012/02	6.2	6.3	8.8	8.5
2012/03	6.6	7.1	9.7	9.4
2012/04	8.3	8.5	12.6	12.1

Table 5: Correlation coefficients for wind speed (ff), peak gust (fx) and wind direction (dd) excluding systematic shadowing effects.

Month	Number of samples	Correlation coefficient for ff	Correlation coefficient for fx	Correlation coefficient for dd
2011/12	3941	0.95	0.96	0.91
2012/01	3376	0.97	0.96	0.61
2012/02	1334	0.98	0.95	0.80
2012/03	3000	0.99	0.91	0.88
2012/04	2488	0.99	0.95	0.90

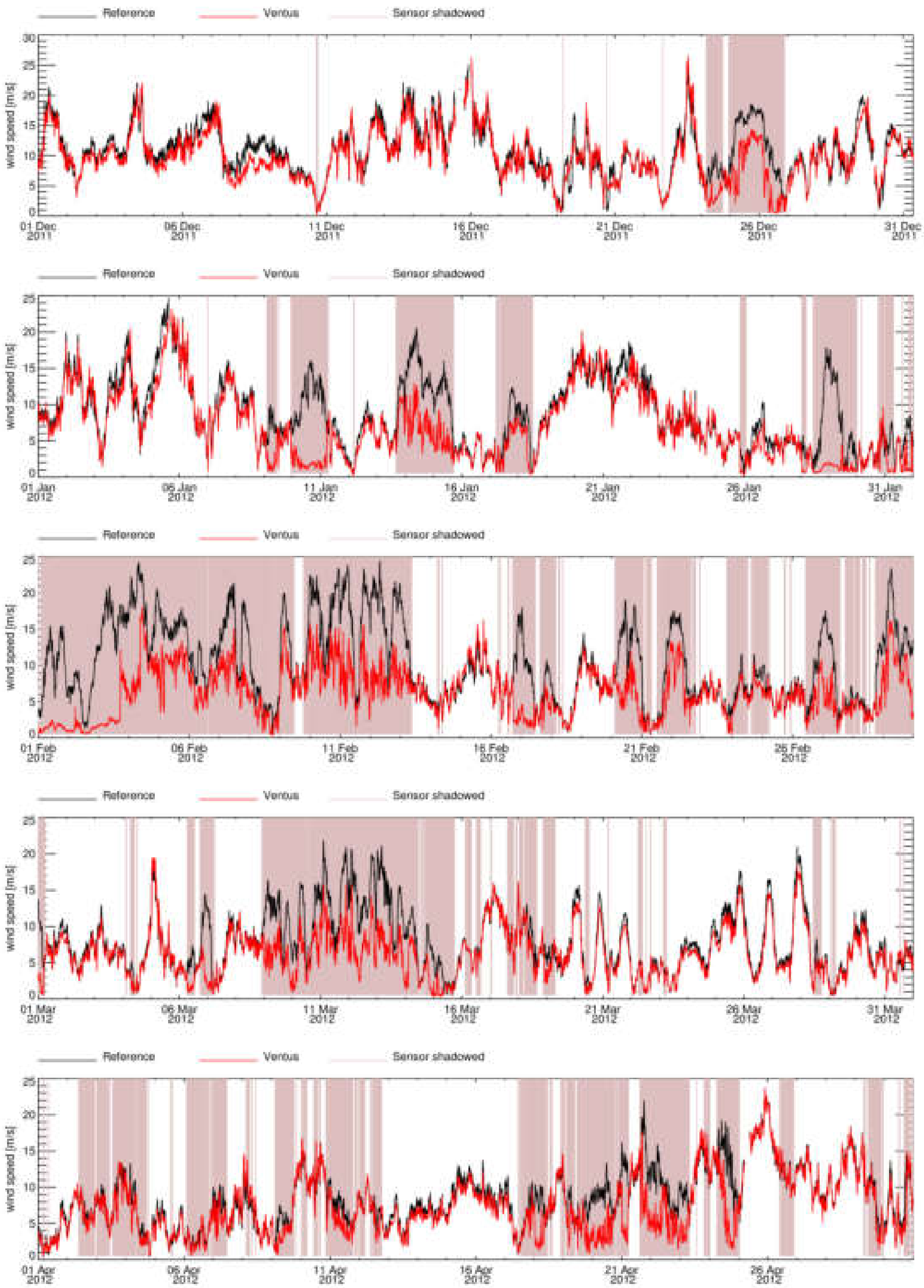

Figure 5: Wind speed measurement of Ventus (red) and reference (black). Periods of shadowing by the meteo mast are highlighted in pink (up to 15.3.2012 with easterly wind; with westerly wind after that date). As a rule, the Ventus indicates lower values than the reference sensor.

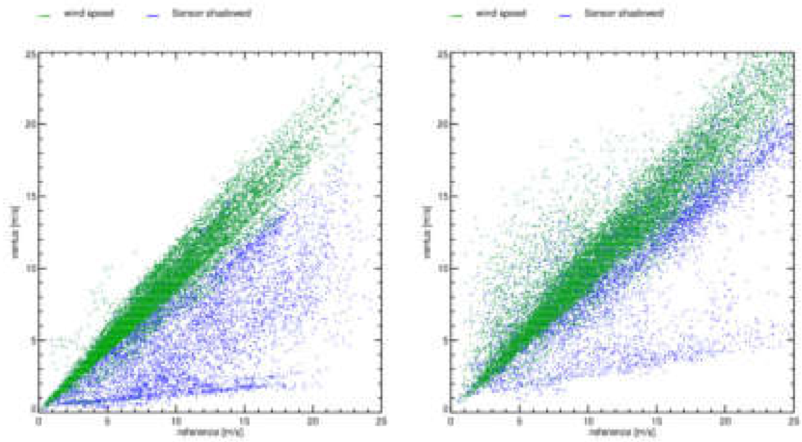

Figure 6: Scatter plot of the measured wind speeds (left) and peak gusts (right) of the Ventus sensor and reference. The measurements which occurred due to shadowing by the mast are shown in blue; the remaining measurements are in green.

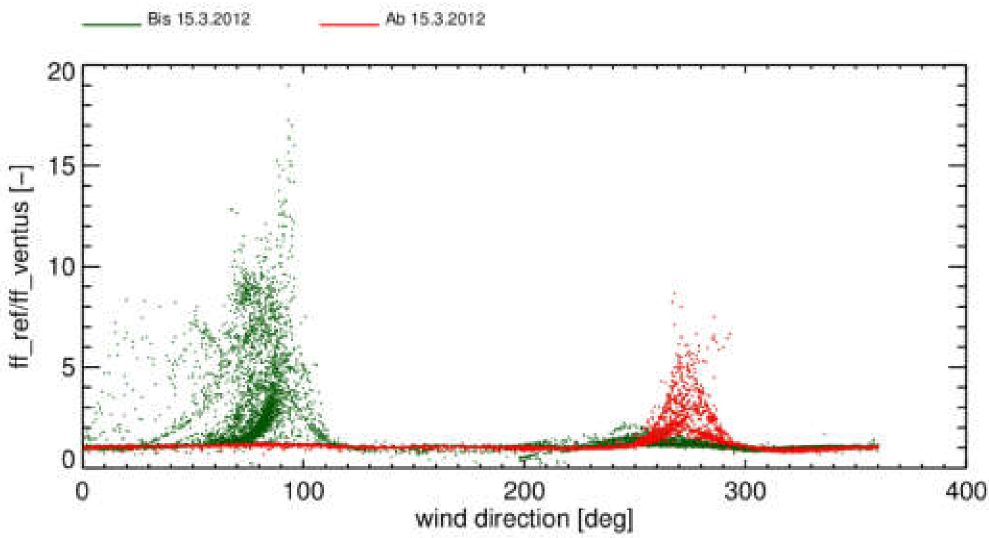

Figure 7: Quotient of wind speed between reference and Ventus in relation to wind direction. Noticeably different measurements arise at angles where the sensor is in the lee of the meteo mast.

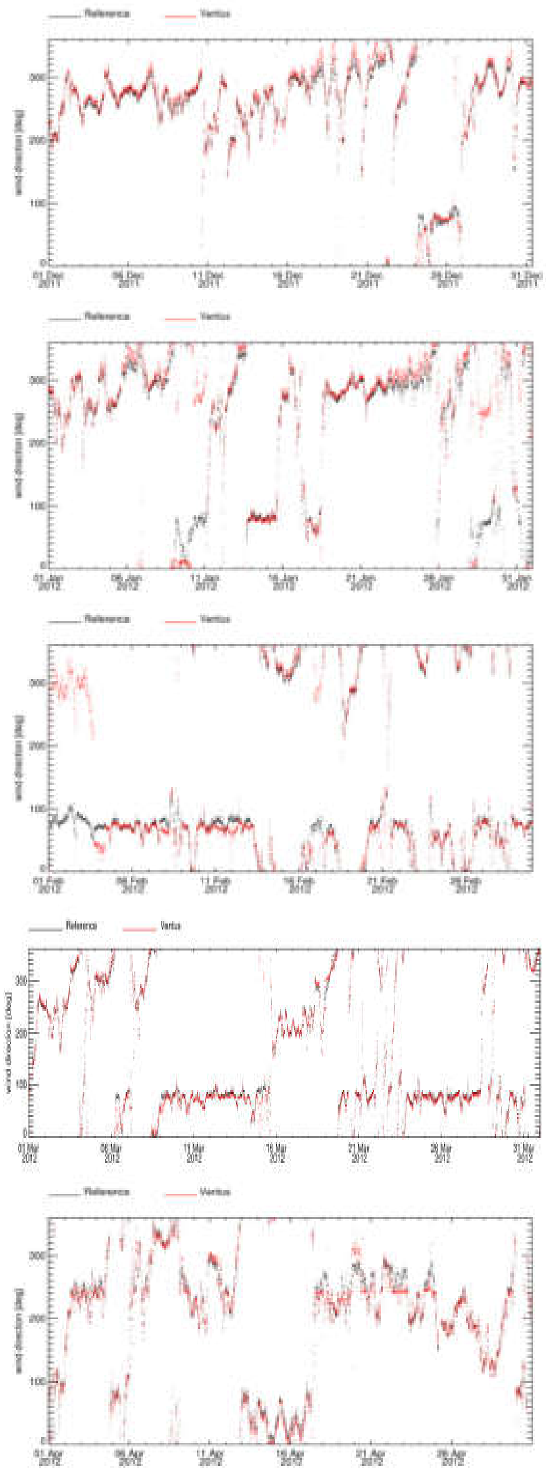

Figure 8: Wind direction measurement of Ventus (red) and reference (black).

4 Case Studies

4.1 Case 1: 10.1.2012

Figure 9 shows a photograph of the top of the mast on the morning of 10.1.2012 during a heavy icing event. There is a strong build-up of ice on the west side of the mast. The reference wind sensor protrudes above the ice whereas on the west side the Ventus wind sensor on the lateral arm is surrounded by ice. Although the actual sensor is ice-free, it reaches very close to the ice on the lateral arm. When the wind blows from the east, the sensor lies in the wind shadow of the ice formation; it is ice-free on the west, north and south sides.

Figure 9: Left: Top of mast during a heavy icing event on 10.1.2012. Right: Zoom on Ventus wind sensor.

Figure 9 is a snapshot which shows the situation on the morning of 10 January 2012. Figure 10 shows the overall meteorological situation before and after. Going back in time, we find on 8 January (①) a north-west wind with moist air and temperatures below freezing point from which the onset of a phase of ice accumulation can be deduced. In phase ② there follows a first east wind phase during which the two sensors are already measuring different wind speeds. Phase ③ with moist, cold winds again shows like wind speeds on both measuring instruments. In phase ④ we come to the situation on 10 January in which the reference sensor measured an east wind of 10-15 m/s while the Ventus in the lee of the ice displayed only around 2 m/s and a west wind. At the end of this phase, the wind turns to the west and the wind speed measured by the Ventus again reaches the reference level. During phase ⑤ temperatures rise to above +5°C, which could possibly lead to melting of the ice. At the end of this phase, icy, moist air masses again reach the location from the north, which in turn lead to an accumulation of ice. During the east wind that that then follows in phase (⑥), the Ventus wind sensor shows wind speed measurements that are lower by a factor of 2. In this case, however, the wind direction is identical. The phase of differing measurements ends with a change of wind direction (⑦).

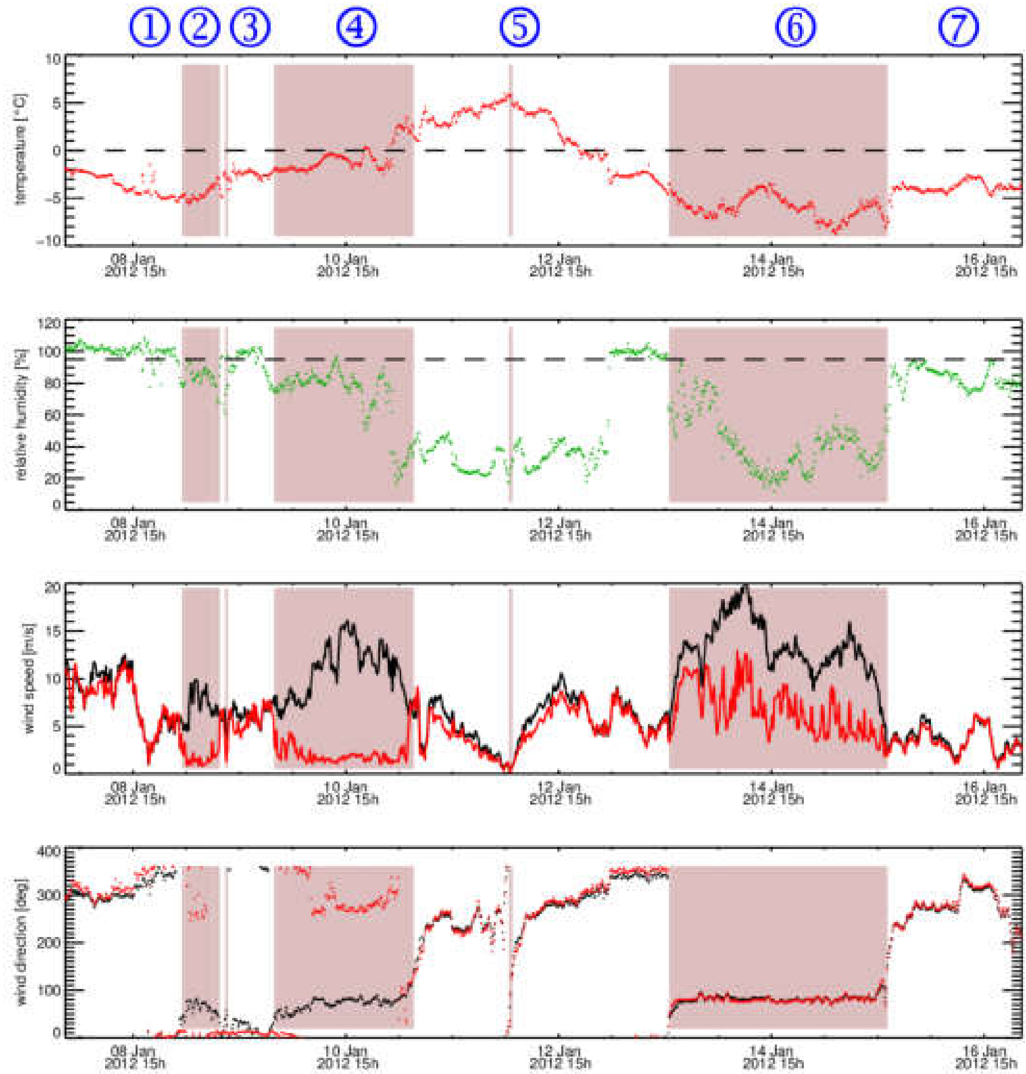

Figure 10: Meteorological situation before and after 10.1.2012. In the two wind charts, the measurements taken with the Ventus are displayed in red; the reference measurement is shown in black. The periods during which the winds were from an easterly direction are highlighted in pink (shadowing by meteo mast).

4.2 Case 2: 21.4.2012

Figure 11 shows the series of measurements from 16.4.2012 to 28.4.2012. At the beginning the winds are blowing from the north-west (①). With very cold, moist air, ice can be expected to form on the mast. However, as the sensor is not in the mast's wind shadow, it is not negatively influenced. On 17.4 (②), clear differences occur between the Ventus and the reference wind measurements. Yet the winds already turned from north-east to west before the deviation commenced. The differences are at their most pronounced when the wind direction reads 270° (west). This may be entirely due to shadowing by the mast. Phases ③ to ⑤ are characterized by very moist, very cold air, mostly from a westerly direction, and events where the Ventus measured considerably lower wind speeds. In interim phases with south-west winds, even wind speeds were measured. With increasing temperatures after phase ⑤, ice is definitely no longer present. The winds come from the south-south-west. Due to the fact that no optical images are available, it is not possible to make a direct statement about the extent of ice formation and its effect.

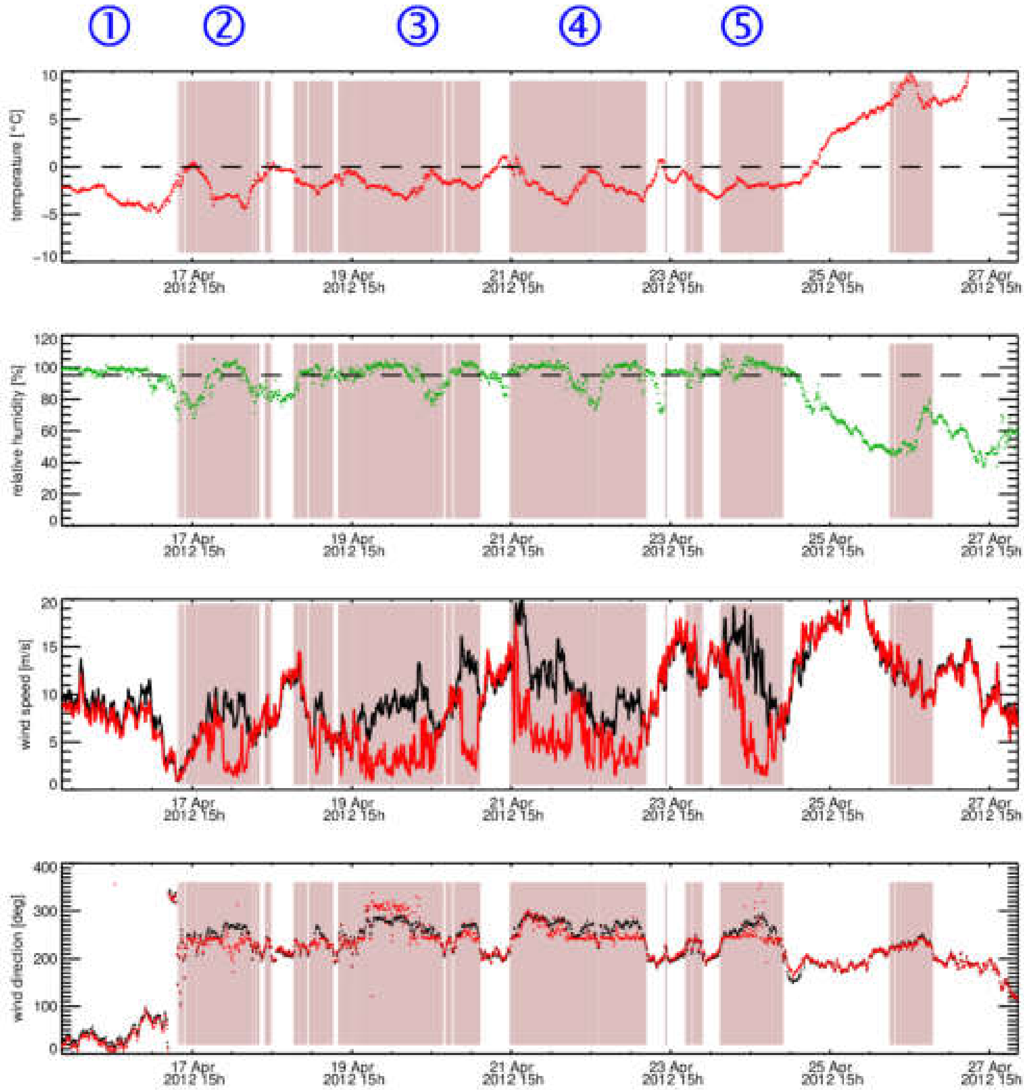

Figure 11: Meteorological situation before and after 21.4.2012. In the two wind charts, the measurements taken with the Ventus are displayed in red; the reference measurement is shown in black. The periods during which the winds were from a westerly direction are highlighted in pink (shadowing by meteo mast).

5 Conclusion

During the measurement period, the Ventus was characterized by excellent data availability and well-correlated readings compared to the reference sensor. The small differences are attributable to the slightly different positioning of the Ventus (on a lateral arm) as opposed to the reference (top of the mast).

At certain wind directions, however, moderate to significant differences can be observed between the two instruments. These differences are due, first and foremost, to the shadowing of the Ventus by the mast. Due to the fact that the effect is not always equally strong, it is assumed that, in some cases, the effect of icing was also partly responsible.

In Case Study 1, this was clearly shown with the aid of photographs. The images demonstrate that, despite severe icing, the Ventus remained ice-free, although heavily influenced by ice formation on the lateral arm.

Unfortunately, no further photographic material of icing events is available, which makes it more difficult to explain the differences. Based on the meteorological conditions obtained from the additional measurements of the remaining meteorological parameters, we can explain differences and deduce icing, as we did in Case Study 2. However, the uneven effect of ice formation compared to the reference instrument remains a supposition.

To obtain more information about sensor behavior under icing conditions, it is recommended to carry out a further test of the sensor including photographs, which allow unequivocal statements to be made about the condition of the instrument.