Intercomparison of cup anemometer and sonic anemometers on site at Uccle/Belgium

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Abstract

The Royal Meteorological Institute of Belgium (RMIB) has a network of automatic synoptic stations disseminated around the country. Sonic anemometers have recently received mixed reviews about their reliability and bird disturbance. In this paper our experience of field comparison is discussed. The anemometer and wind vane of our AWS network (Siggelkow LISA and RITA) are compared to two Thies sonic anemometers (Ultrasonic Anemometer 2D and Ultrasonic Anemometer Compact). The comparison is done for instantaneous and mean values for wind speed, wind direction and gusts at different time scales. A set of transformations is computed to allow transition from cup anemometer measurement to sonic anemometers measurement.

1 Introduction

There are several reasons to test new instruments for the RMIB network: the used anemometers and wind vanes at RMIB do not comply to WMO recommendation [4], the total price of purchase and maintenance is expected to be lower for sonic anemometers[2] and more recently the firm Siggelkow has gone bankrupt[1]. The choice of instruments for comparison has been based on previous work done at KNMI[3] taking also into account the price of the devices. The choosen anemometer for comparison is the Thies 2D with the optionnal fence against birds developped by Thies in collaboration with KNMI. It has also been decided to test the Thies 2D Compact because of its price and its construction which should avoid bird disturbance despite the fact that it does not answer to WMO recommendation on measuring range. The WMO recommendation is 75m/s but the maximum gust speed ever measured in Belgium is 47 m/s. More details about the choice can be found in [2]. The scope of this test is to assess the possibility to use sonic anemometers without creating a break point in our time series. This discontinuity might in the future impede to detect any climatological trend.

2 Description of Anemometers and Test Field

2.1 Wind Speed Devices Description

In table 1, the charactesristics of the three instruments tested and the WMO requirements for wind speed are listed. There are also different WMO requirements for gusts speeds but they are not appropriate for the Belgian operational network (range is 0.1-150m/s which is clearly too high for Belgium): those requirements are not listed. It should be noted that the three instruments are heated. The WMO recommendation on accuracy should be understood as a global accuracy taking into account the environment and the acquisition system. As the instrument is better, there is more room for environmental influence.

Brand Type	WMO	Siggelkow LISA	Thies 2D 4.3820.32.300	Thies 2D Compact 4.3871.02.300
Measuring Range	0-75 m/s	0-60 m/s	0-75 m/s	0-60 m/s
Accuracy	0.5m/s for ≤ 5m/s 10% for > 5m/s	+/- 1%	0.1m/s for ≤ 5m/s (rms, mean over 360°) 2% for > 5m/s (rms, mean over 360°)	0.5m/s for ≤ 5m/s (rms, mean over 360°) 2% for > 5m/s (rms, mean over 360°)
Threshold of Measuring	-	0.3 m/s	(resolution)	0.01 m/s
Operating Temperature	-	-35° - +70°C	-50° - +70° C	-40° - +60° C
Response length	2 - 5 m	˜5 m	NA	NA
Sampling	1 Hz	(4 Hz as implemented at RMIB)	10 Hz (Max)	100 Hz (Max)
Version	7th edition		310	160
Resolution	0.5 m/s	0.001m/s (as implemented in this test)	0.001m/s (as implemented in this test)	0.001m/s (as implemented in this test)
Heating	-	y	y	y

Table 1: Description of tested instruments and WMO recommendations for wind speed

Brand Type	WMO	Siggelkow Rita	Thies 2D 4.3820.32.300	Thies 2D Compact 4.3871.02.300
Measuring Range	360°	1-360°	0-360°	0-360°
Accuracy	+/- 5°	+/- 2°	+/- 1°	+/- 2° (wind speed > 1m/s)
Detection limit	0.5 m/s	0.1 m/s	NA	NA
Operating Temperature		-35° - +70°C	-50° - +70° C	-40° - +60° C
Undamped wavelength	<10	<10	NA	NA
Damping ratio	[0.3,0.7]	˜0.62	NA	NA
Sampling	4 Hz	(1 Hz as implemented at RMIB)	10 Hz (Max)	100 Hz (Max)
Version	7th edition		310	160
Resolution	1°	0.1° (as implemented in this test)	0.1° (as implemented in this test)	0.1° (as implemented in this test)
Heating	-	y	y	y

Table 2: Description of tested instruments and WMO recommendations for wind direction

2.2 Wind Direction Devices Description

In the table 2, the charactesristics of the three instruments tested and the WMO requirements for wind direction are listed.

2.3 Acquisition System

The four instruments are connected to a datalogger from Campbell Scientific (CR1000). The Siggelkow LISA anemometer is connected to the pulse counter of the datalogger. The other instruments are connected to a voltage input after a signal conditionner. The signal conditionner is a simple voltage divider composed by two resistances (7k5Ω and 2k49 Ω of 0.1% accuracy at 25°C and 15ppm/°C temperature coefficient).

2.4 Test Field

The test has been carried out at Uccle in Brussels. The environment is urban. It is not an ideal situation but doing the test in a better place would required an amount of time to place a new mast and we would have lost the flexibilty to make the tests just aside the RMIB headquarters. Anyway this place is the historical weather station of Belgium for which most of weather statistics about Belgium since 1833 is available.

Figure 2.1: The four devices from left to right: Thies 2D compact, Siggelkow LISA, Thies 2D, Siggelkow RITA. The photo has been taken facing south direction.

The three anemometers and the wind vane have been placed on a platform at the height of 12.35 m above ground. The 4 instruments are placed each on individual mast at 2.05 m above the platform. The distance between them is 1.50m. The instruments have been placed in a row with orientation east/west. The platform is mainly built using iron grids: the wind is only sligthy perturbed. The surrounding trees and buildings are at a distance which is at least 10 times their height above the anemometers.

2.5 Data Description

The test has been started on January 18 2012 13:50:00 (UTC). In this study the used data is from the beginning of the test to August 3 2012 10:20:00 (UTC). The test is still ongoing. During this period the availability of data has been better than 99.9%. The lost data is because it has been decided to retrieve manually the data and a few data has been lost during the acquisition procedure tuning.

10 min data
Description
Acquisition Time
Scalar mean wind speed
Scalar mean wind direction
Scalar standard deviation of wind direction
Vector mean wind speed
Vector mean wind direction
Vector standard deviation of wind direction
Maximum 1 minute sliding mean wind speed during the 10 minutes acqusition period
Maximum 3 seconds sliding mean wind speed during the 10 minutes acquisition period (gust)
Time of occurence of gust
Mean direction of gust

Table 3: Description of 10 minutes data

1 minute data
Description
Acquisition Time
Scalar mean wind speed
Maximum 3 seconds sliding mean wind speed during the 1 minute acquisition period (gust)
Mean direction of gust

Table 4: Description of 1 minute data

The data has been recorded on three different periods: averaged 10 minutes data, averaged 1 minute data and raw speed measurements. Since the amount of record memory is limited, the higher frequency data has less parameters and the raw data is only recorded during four hours twice a month and only for two instruments (Siggelkow LISA and Thies 2D). In the tables 3,4 and 5, all the recorded parameters are described. The sampling frequency of data is 4Hz for wind speed and 1Hz for wind direction. The two Thies instruments are making a sliding average of 1 second. The time width of this moving average can be changed for both Thies anemometers.

0.25 second data (raw data)
Description
Acquisition Time
Wind speed

Table 5: Description of raw data

The Siggelkow wind vane has suffered deterioration during this period. The wing is made of foam and the birds are destroying it. Visual estimation on 20120706 showed that about 20% disappeared and on 20120822 50% disappeared (see figure 2.2). The foam has been changed on 20120822. There is a different wing made of stainless steel but with this wing the characteristics (undamped wavelength and damping ratio) are not complying to WMO recommendation.

Figure 2.2: Siggelkow wind vane wing foam deterioration on 20120822

3 Comparison Results

3.1 10 minutes Wind Speed

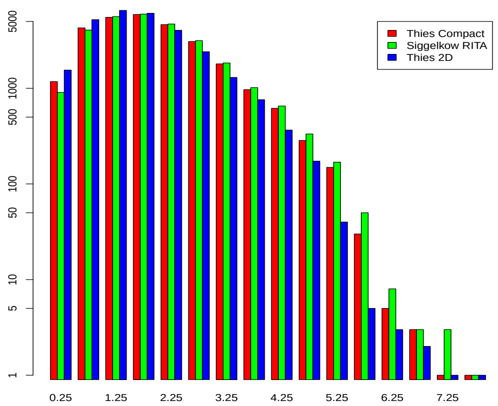


Figure 3.1: Histogram of 10 minutes wind speed scalar mean

In figure 3.1, the histogram of wind speed is showed. The maximum 10 minutes mean wind speed during the test period is less than 8 m/s. According to results of χ^2 test for distribution equality, the three distribution are statistically different (p-value $<$ 6.384e-08). As already noted in the literature, the difference in the histogram for higher speed is mostly related to the overspeeding. Overspeeding is a non-linear response to fluctuating winds which is a disadvantage of cup anemometers.

If the 10 minutes data is reported to the same instrument using the linear fitting (see below), the histograms of the speed between the Siggelkow and the Thies 2D (showed in figure 3.2) are not statistically different anymore. This is not true for the Thies Compact histogram which remains different from the two other histograms.

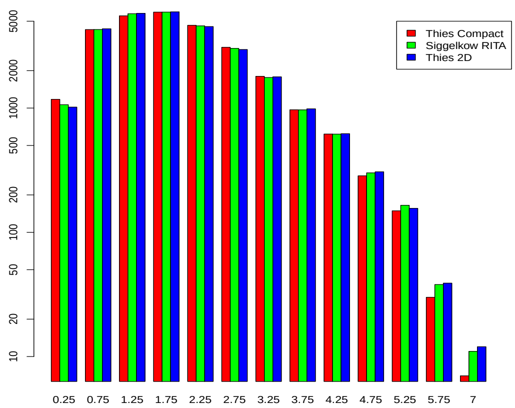
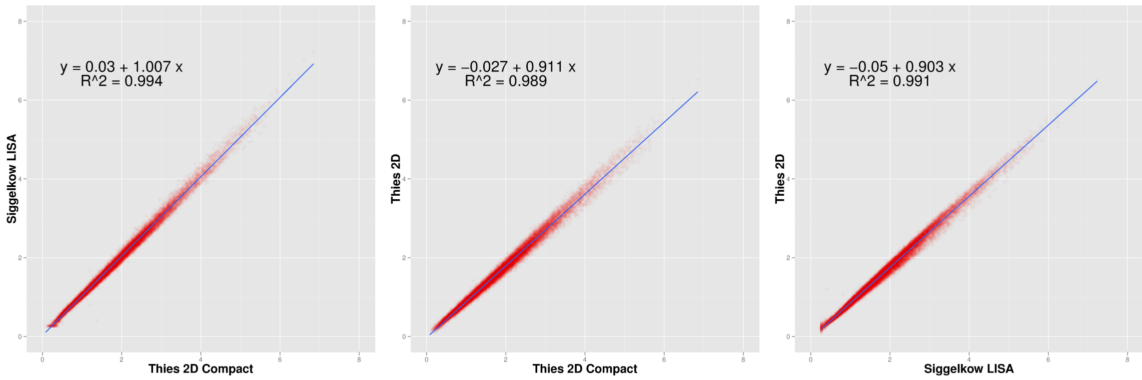


Figure 3.2: Histogram of 10 minutes wind speed scalar mean after rescaling to Thies Compact using linear fitting

The maximum difference of 10 minutes average of wind speed is 0.50m/s bewteen Thies Compact and Siggelkow LISA and 0.47m/s between Thies 2D and Siggelkow LISA.

In figure 3.3, the linear fitting between the three instruments is showed for the 10 minutes mean wind speed. As already mentioned in the literature, the slope between the cup anemometer and the Thies 2D is less than 1 (0.903). This is not the case for the slope between the cup anemometer and the Thies Compact which is very close to one (1.007). The linear fitting between the different instruments showed a good correlation coefficient (∼0.99) but a closer look to the residuals and to the QQ-plot showed as expected heteroscedasticity and a probably non-linear relation which can be related to overspeeding again.



(a) (b) (c)

Figure 3.3: Linear fitting of the 10 minutes mean wind speed

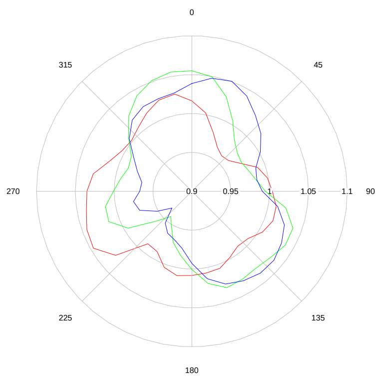


Figure 3.4: Regression slope ratio according to the direction ((Red=Thies 2D Compact,Green=Siggelkow,Blue=Thies 2D)

The dependence of the linear fitting according to the direction of the wind speed is displayed in figure 3.4. The value reported is the regression slope ratio according to the angle. The wind speed data has been first binned into 10° wind direction. Then the regression has been computed for each bin. The ratio between the slope of those regressions and the one computed using all the data has been reported in a polar plot. If the regression is independent from the angle we should have a perfect circle of radius one. The origin of this difference is unknown.

3.2 10 minutes Wind Direction

The comparison for the wind direction is done for mean wind speed higher than 0.5 m/s to avoid influence of detection limit of Siggelkow anemometer and wind vane. The scalar wind direction comparison of the three anemometers shows a good agreement except around 200°. The wind rose (figure 3.5) shows a difference that seems not to be linked to a bad orientation of the devices.

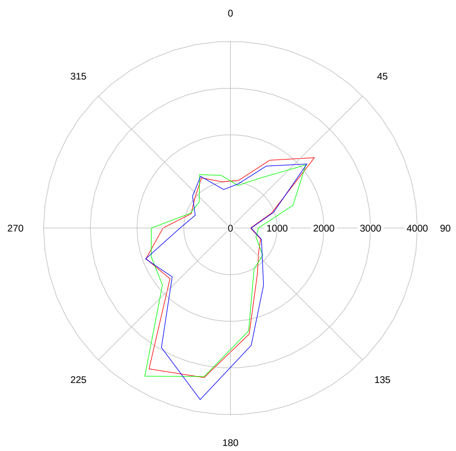


Figure 3.5: Wind Rose of 10 minutes wind direction scalar mean (Red=Thies 2D Compact,Green=Siggelkow,Blue=Thies 2D)

The mean wind direction is computed using the internal function of the datalogger and it is simply the arithmetic mean of the direction. The two closer anemometers are the Siggelkow LISA and the Thies Compact in the test field and in the wind rose but the two closest wind vane are the Siggelkow RITA and the Thies 2D. For the mean scalar wind direction, the wind speed is not used. Anyway we can not exclude that there is some influence from the environment. Additionnal tests will be carried out by changing their position in the test field.

4 Transfer function

The very high sampling of the data has enabled us to try to construct a transfer function. This transfer function is needed for the homogenisation of the climatological measurements. A simple linear transfer function of the type of equation 4.1 where $S[n]$ is the Siggelkow instantaneaous time value and $T[n]$ is the Thies 2D instantaneaous time value does not really improve the statistical 10 minutes data compared to a simple linear regression on the averaged values.

$$S[n] = \sum_i a_i T[n-i] \tag{4.1}$$

It has thus been decided to test some non linear function of the type of equation 4.2 where ϕ is a strongly non linear function (4.3).

$$S[n] = \sum_i a_i T[n-i] + \phi(b + \sum_i b_i T[n-i]) \sum_i d_i T[n-i] \tag{4.2}$$

$$\phi = \frac{1}{1+e^{-x}} \tag{4.3}$$

The idea behind this formulae is to create a model for the overspeeding by having a different linear response depending on the argument of the function ϕ. The results on the 10 min wind speed are improved: the RMSE is improved from 0.1141 to 0.08701 and the maximum difference is improved from 0.35m/s to 0.29 m/s. However the gust speed estimation is not improved. A closer look to the data seems to show that the higher gusts are not well reproduced. The Thies data always seems to give a lower value than the cup anemometer for high gusts. The 1 second averaging of the Thies anemometer is perhaps the reason of this behaviour. A deeper analysis and a change in the averaging period of the Thies would certainly improved our understanding of this issue.

5 Conclusion

The aim of the study is to assess the possibility to use a sonic anemometer to replace our cup anemometer and wind vane. Previous studies have already showed that from a meteorological point of view the transiston is within the WMO specifications. Our results do not differ from previous studies and allow us to use the previous work done on the subject. Nevertheless replacing the cup anemometers by sonic anemometers without having a transfer function could lead us to a discontinuity on our time series. In this scope linear fitting on 10 minutes has its limitation and it is not correct from a statistical point of view. This first results have also raised several issues on the wind direction difference, the fitting slope depending on the wind direction and the window averaging of the Thies. Additionnal tests will be carried out in the next months to have more insight on these issues.

References

[1] `http://www.firmendatenbank.de/Siggelkow_Geraetebau_GmbH_317394575_12081.html`.

[2] Koen De Clercq. Studie van hedendaagse sonische windsensoren ter vergelijking and vervanging van de cup anemometer bij het kmi. Eindverhandeling tot het verkrijgen van de graad van master in industriele wetenschappen: Elektrotechniek, Sint-Lieven Hogeschool, 2011.

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[4] WMO. Guide to meteorological instruments and methods of observation. Technical Report 8, World Meteorological Organisation, 2008.