SafeWind

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Abstract: An assessment of the lidar datasets measured in Task 2.2 is performed. Generally high quality is found in comparison with co-located mast measurements. Results from an inter-comparison of two lidars show similar bias after the necessary filtering has been applied. Methods for identifying possibly cloud-corrupted data for a CW lidar are described. Results from an inter-comparison between a sodar and a measuring mast show disappointing results due to the too close positioning of the sodar with respect to the mast.

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[1] **The authors of this document are solely responsible for its content, which does not represent the opinion of the European Community and the European Community is not responsible for any use that might be made of data appearing therein.**

[2] **VERSION NAMING : V0.x** draft before peer-review approval, **V1.0** at the approval, **V1.x** minor revisions, **V2.0** major revision

Contents

1. Assessment of the Windcube lidar data sets

The Windcube lidar and the Høvsøre measuring site were described in [1].

In order to assess the suitability for use in other SafeWind tasks, we here present the overview information of the four lidar datasets (already presented in [1]) together with comparison of the direction (one level) and speed (two levels, low and high) with mast mounted instruments.

For the direction comparisons, only wind speeds exceeding 4 m/s are used and only periods with a lidar availability of 100%. For the speed comparisons, all speeds are included but only wind directions between 230° and 300° (to avoid mast and wind turbine wakes) and lidar availability of 100%.

1.1 Period 1

Location: 56°26'25.51"N, 8° 9'3.02"E (116m met mast)
Instrument: Windcube WLS-7-02

Heights, data periods and availability:

Height	Count(Name)	Avg(Available)	min(Name)	Max(Name)
40	10693	99.84964	200712121700	200802250910
60	10693	99.08634	200712121700	200802250910
80	10693	98.78024	200712121700	200802250910
100	10693	97.88331	200712121700	200802250910
116	10693	96.65042	200712121700	200802250910
130	10693	95.34797	200712121700	200802250910
160	10435	90.28374	200712122200	200802231900
200	10435	77.62792	200712122200	200802231900
250	9134	64.86672	200712220820	200802231900
300	9134	50.60702	200712220820	200802231900

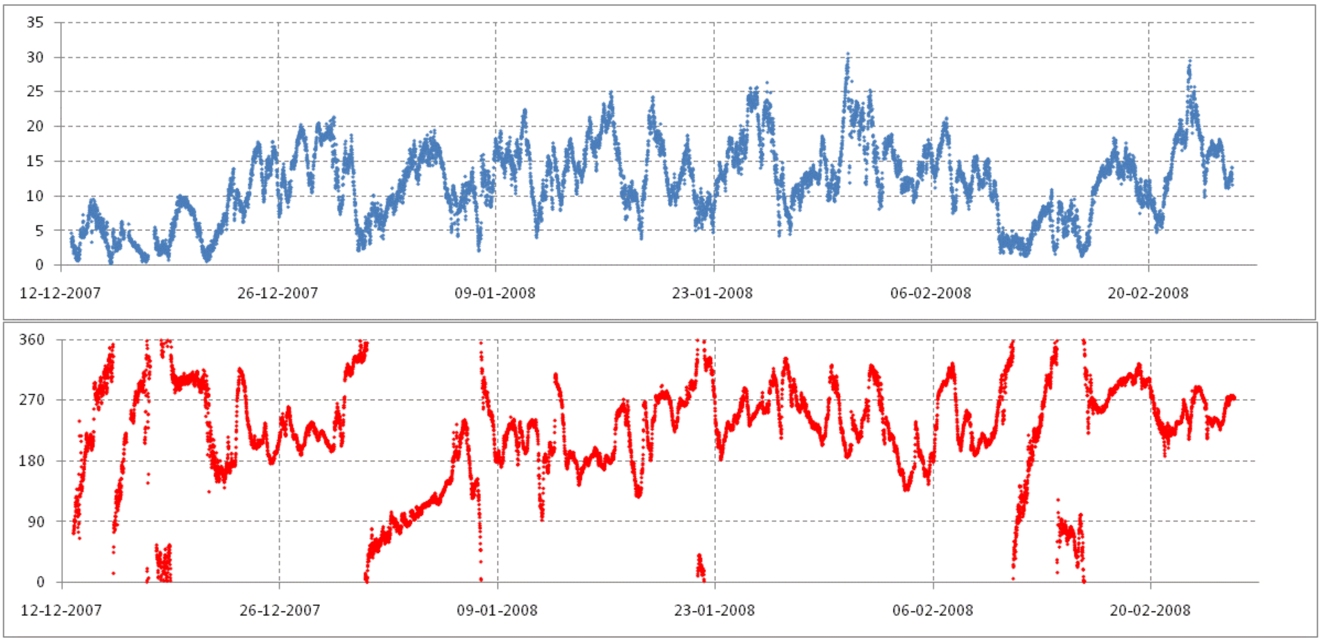


Figure 1 Time series of wind speed at 100m (blue) and wind direction (red) for Period 1.

Comments

This was the initial test period for the newly acquired Leosphere WLS7-02 Windcube lidar, described in more detail in [1]. The lidar was positioned close to the foot of the measurement mast at Høvsøre. The performance and availability in this period were generally good although there was some slight non-linearity in the wind speed measurement, apparent in the region 5-10 m/s (Figures 4 and 5).

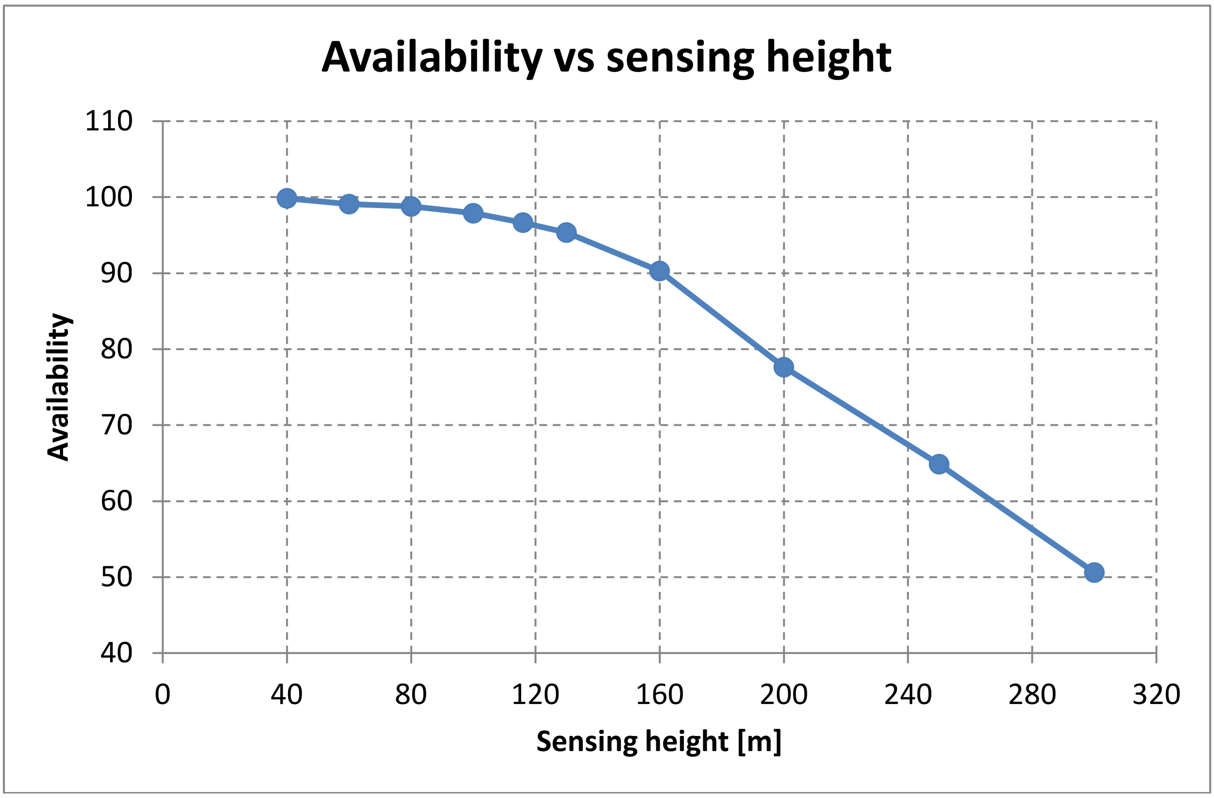


Figure 2 Availability versus sensing height - Period 1

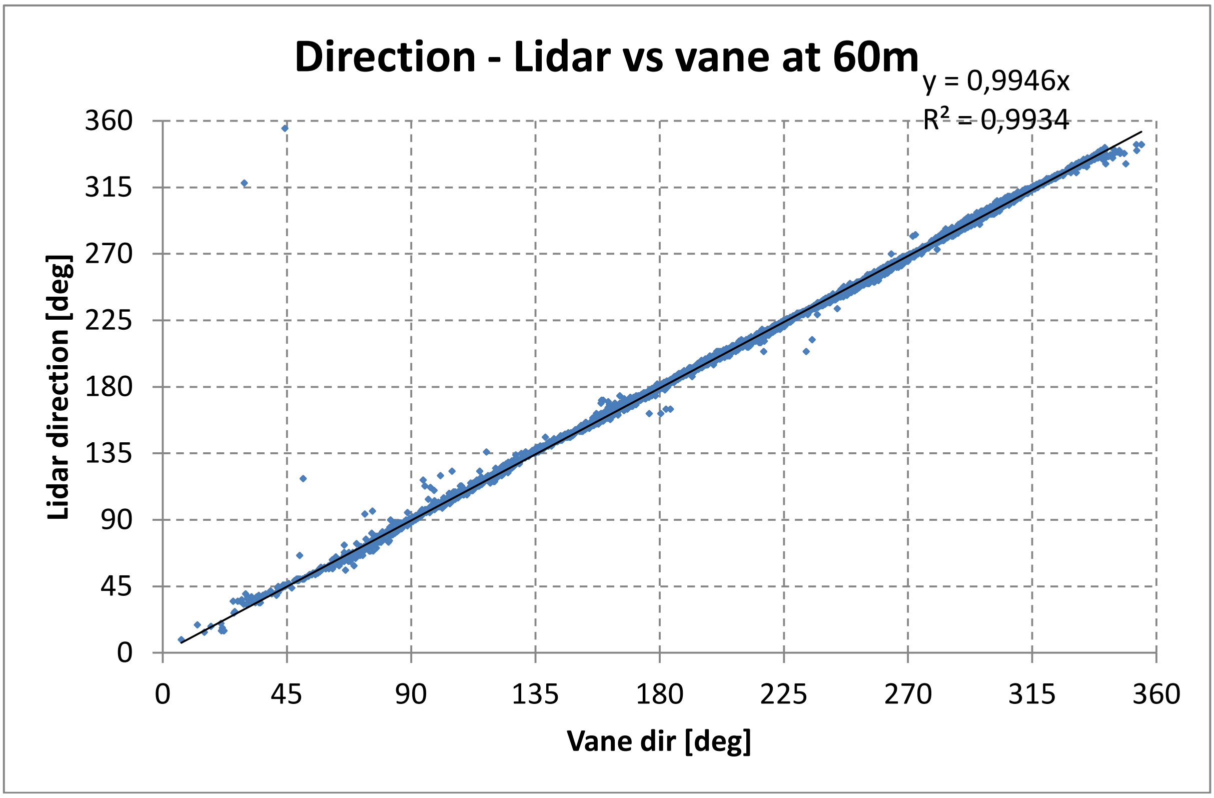


Figure 3 Lidar direction versus wind vane at 60m - Period 1

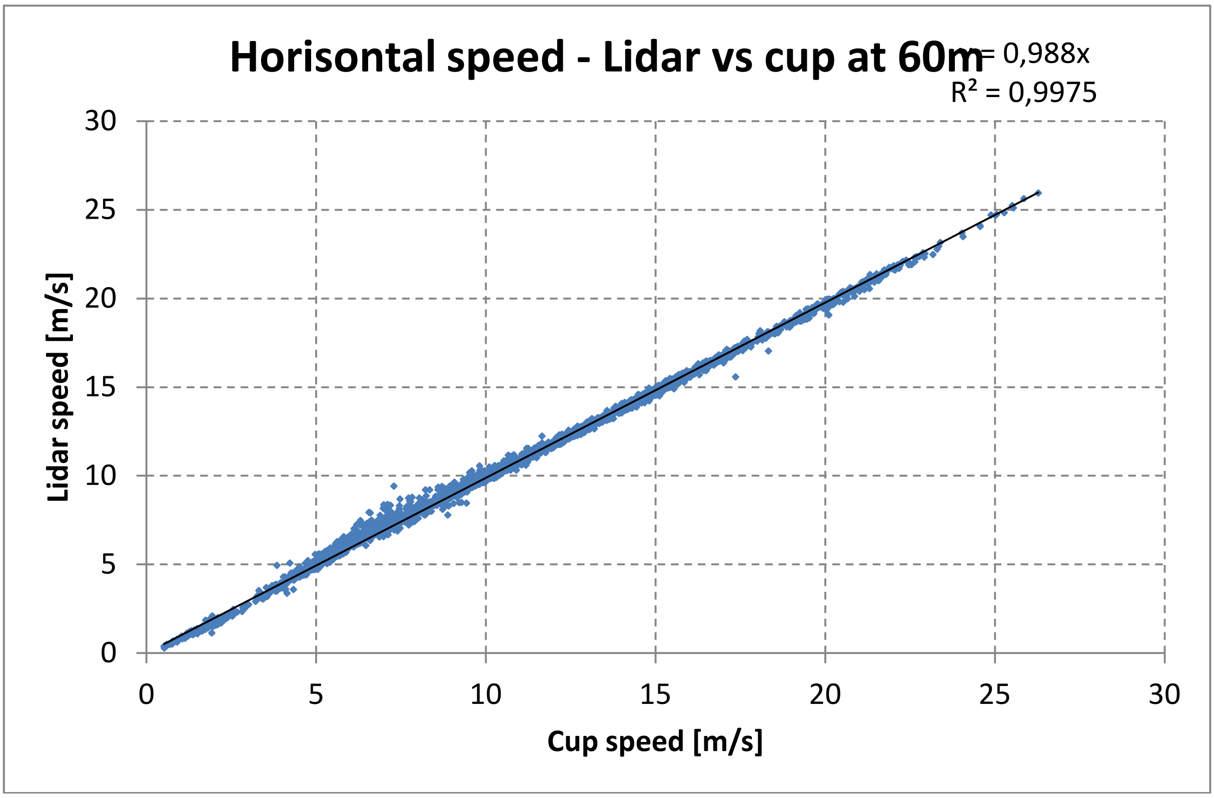


Figure 4 Lidar speed versus cup speed at 60m – Period 1

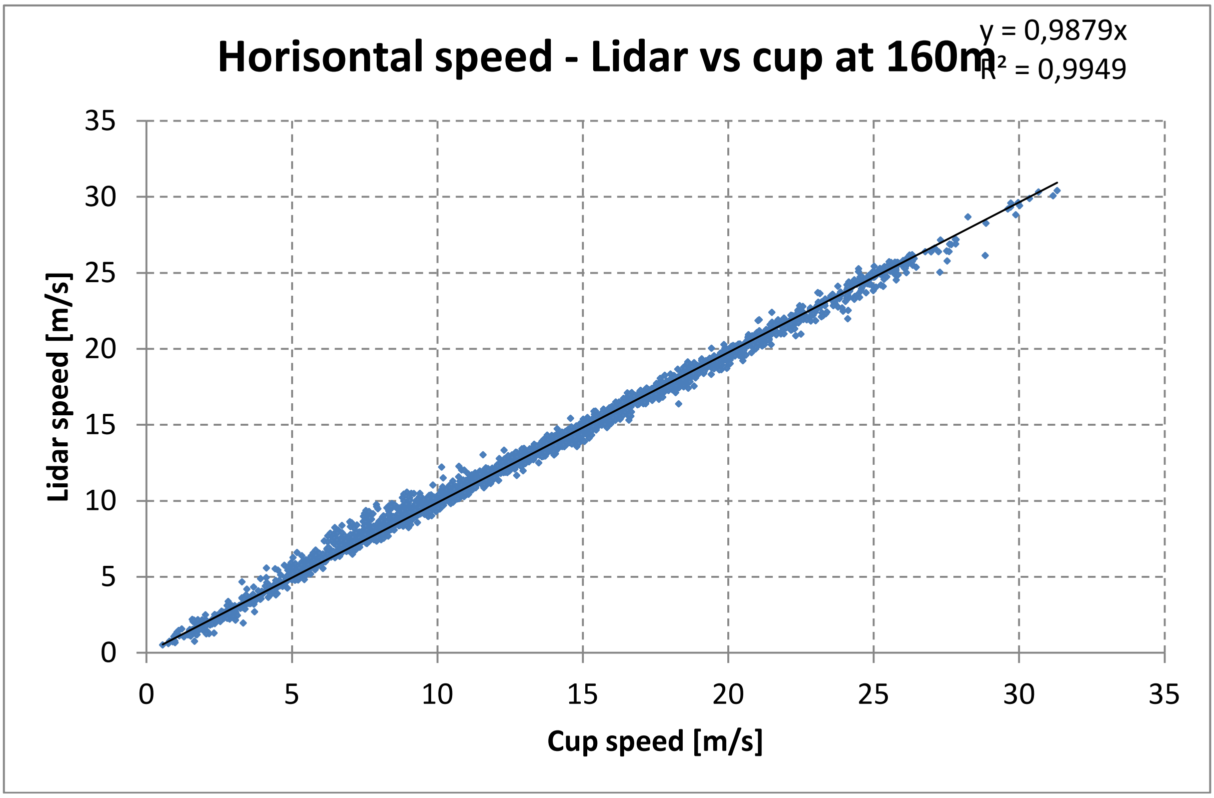


Figure 5 Lidar speed versus cup speed at 160m - Period 1. Note that the reference speed is the boom mounted cup on the OMS mast.

1.2 Period 2

Location: 56°26'56.23"N, 8° 8'50.28"E (half way between stand2 and stand 3 masts)
Instrument: Windcube WLS-7-02

Heights, data periods and availability:

Height	Count(Name)	Avg(Available)	min(Name)	Max(Name)
40	19897	99.75748	200802251440	200807160930
42	967	99.80394	200807091630	200807160930
50	12017	99.52773	200802251440	200807091700
60	19898	99.01717	200802251440	200807160930
70	12016	99.15714	200802251440	200805211500
80	19898	99.12899	200802251440	200807160930
90	12016	99.22796	200802251440	200805211500
100	19898	98.37912	200802251440	200807160930
110	12016	97.55342	200802251440	200805211500
120	19898	96.39679	200802251440	200807160930
130	12052	94.56763	200802251440	200806121350
140	19898	92.10251	200802251440	200807160930
150	12016	87.48746	200802251440	200805211500
160	19898	80.71838	200802251440	200807160930
200	19898	56.61632	200802251440	200807160930
250	12052	40.27814	200802251440	200806121350
300	19898	24.97763	200802251440	200807160930

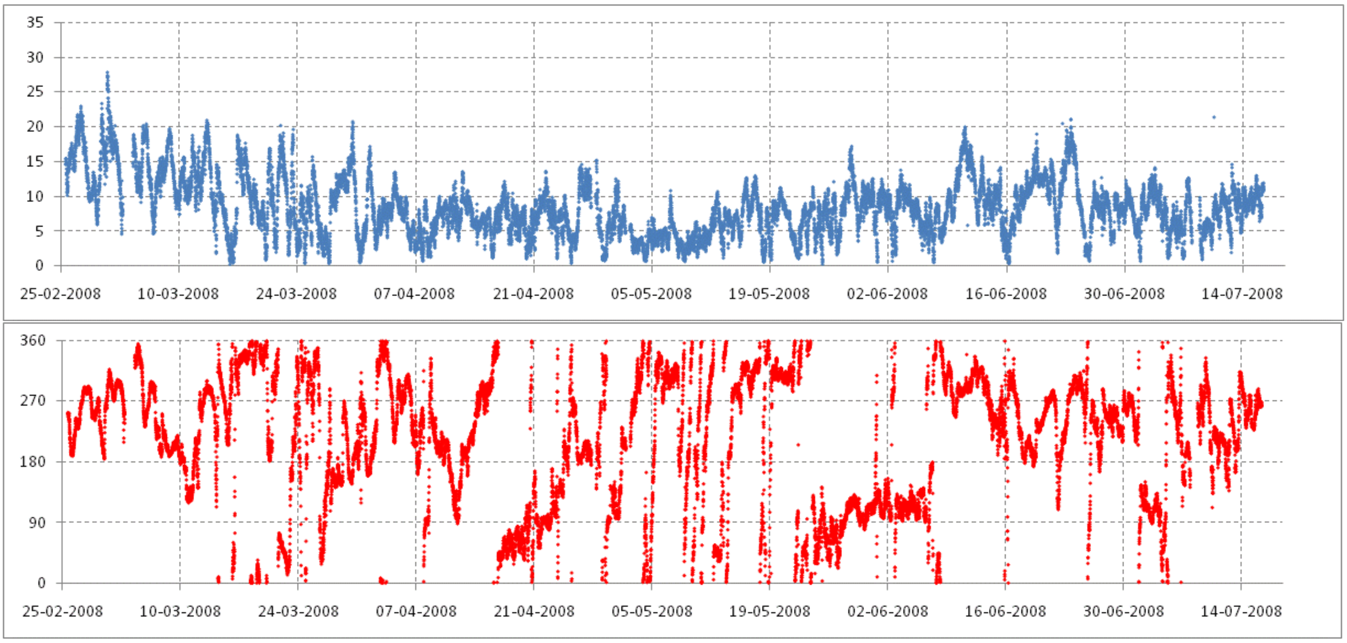


Figure 6 Time series of wind speed at 100m (blue) and wind direction (red) for Period 2.

Comments
Immediately following period 1, the Windcube WLS7-02 was moved to a location half way between the stand2 and stand3 metmasts at Høvsøre. Here the lidar was used to perform a power curve measurement [3].

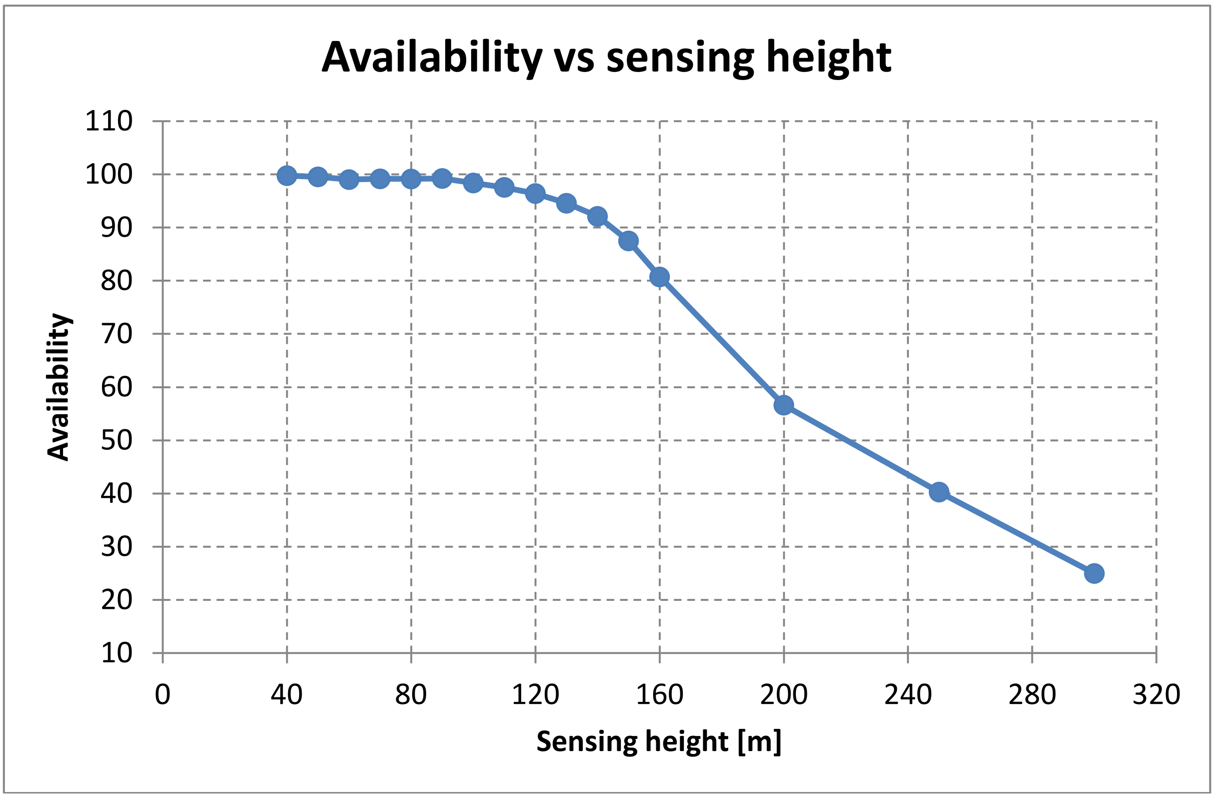


Figure 7 Availability versus sensing height - Period 2

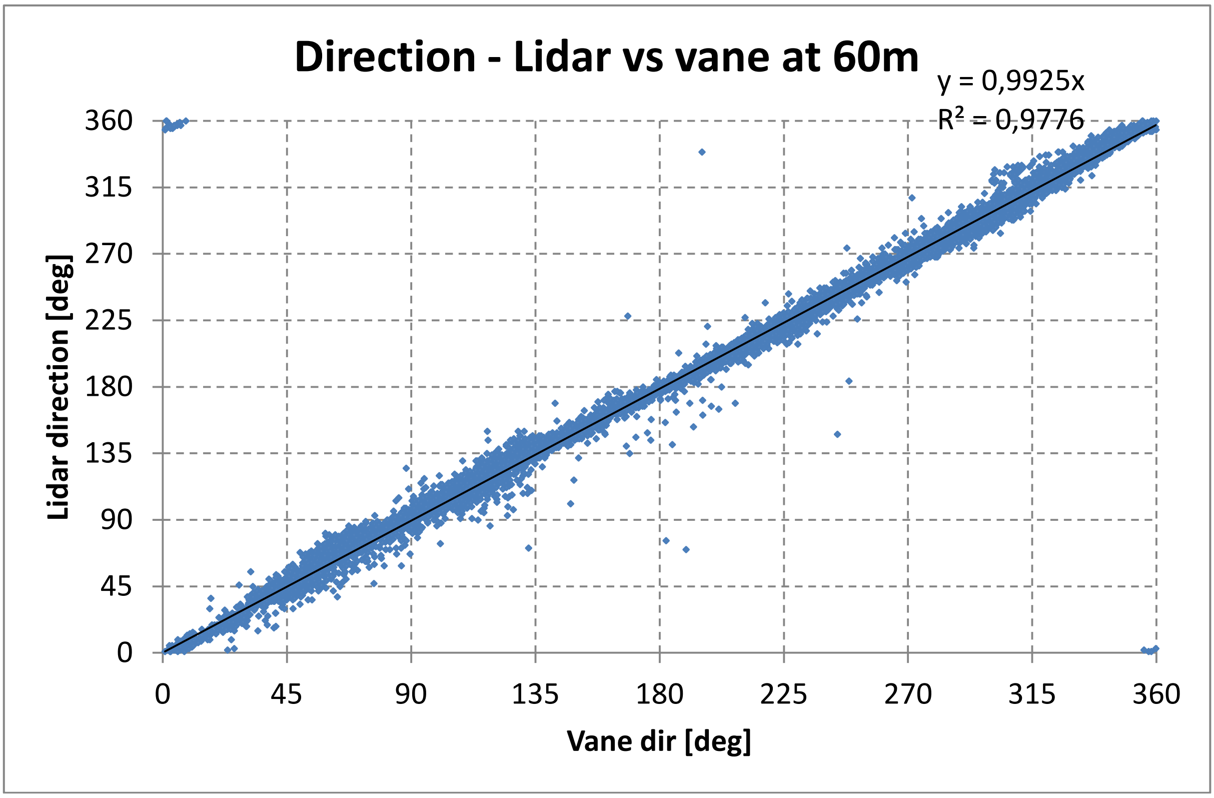


Figure 8 Lidar direction versus metmast vane direction at 60m - Period 2. Note that the reduced correlation is due to the separation between the lidar location and the metmast.

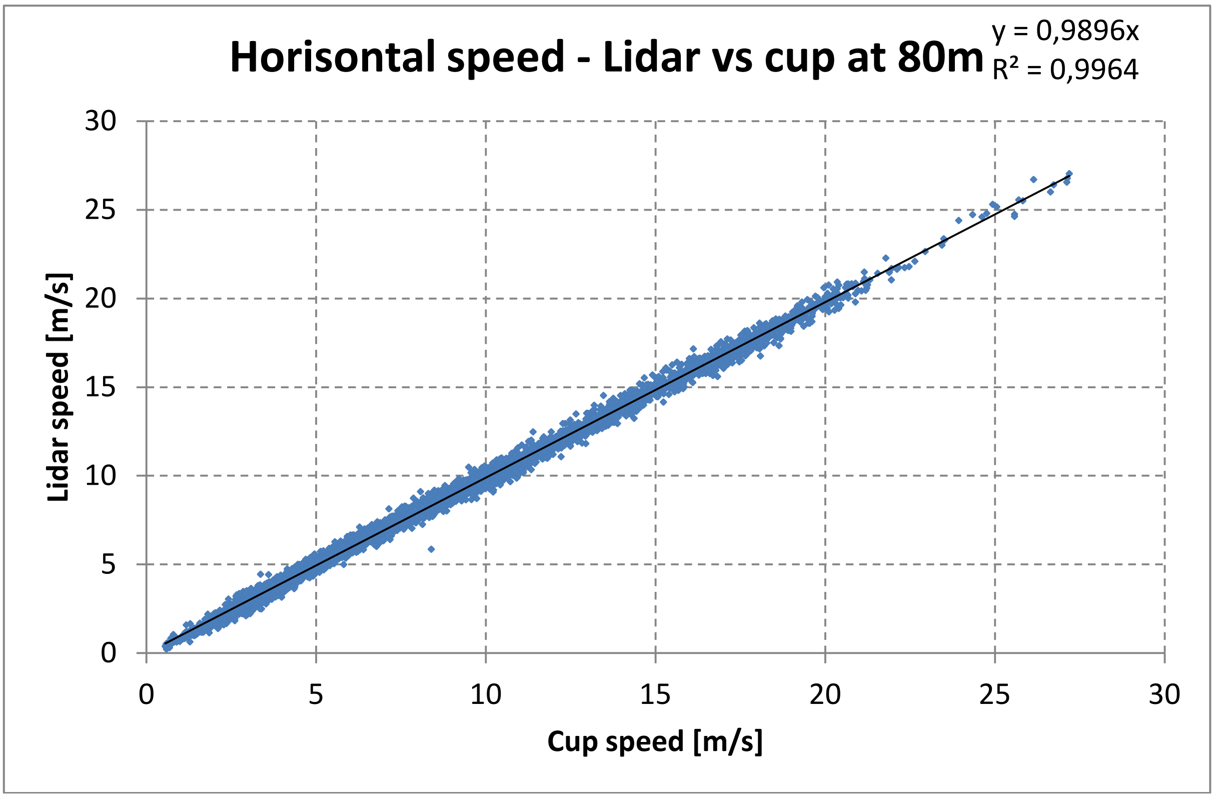


Figure 9 Lidar speed versus cup speed at 80m - Period 2. Note that the reference speed is the top-mounted cup on mast 2.

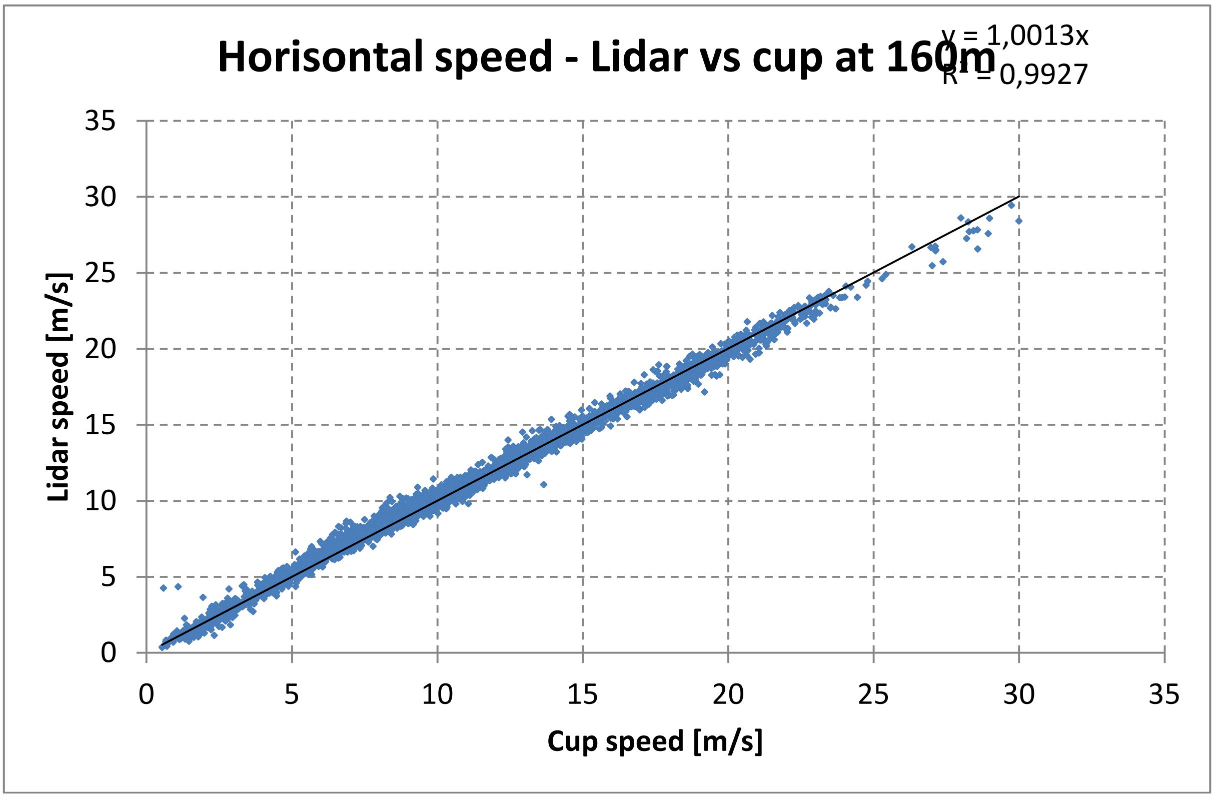


Figure 10 Lidar speed versus cup speed at 160m. Note that the reference speed is the boom mounted cup on the OMS mast.

1.3 Period 3

Location: 56°26'25.51"N, 8° 9'3.02"E (116m met mast)
Instrument: Windcube WLS-7-02

Heights, data periods and availability:

Height	10 mins	Availability	min(Name)	Max(Name)
40	13975	99.07651	201002020750	201005202350
60	13975	98.80054	201002020750	201005202350
80	13975	98.56525	201002020750	201005202350
100	13975	98.25073	201002020750	201005202350
116	13975	97.60857	201002020750	201005202350
130	13975	96.35682	201002020750	201005202350
160	13975	92.25889	201002020750	201005202350
200	13975	85.1495	201002020750	201005202350
250	13975	71.08944	201002020750	201005202350
300	13975	54.66423	201002020750	201005202350

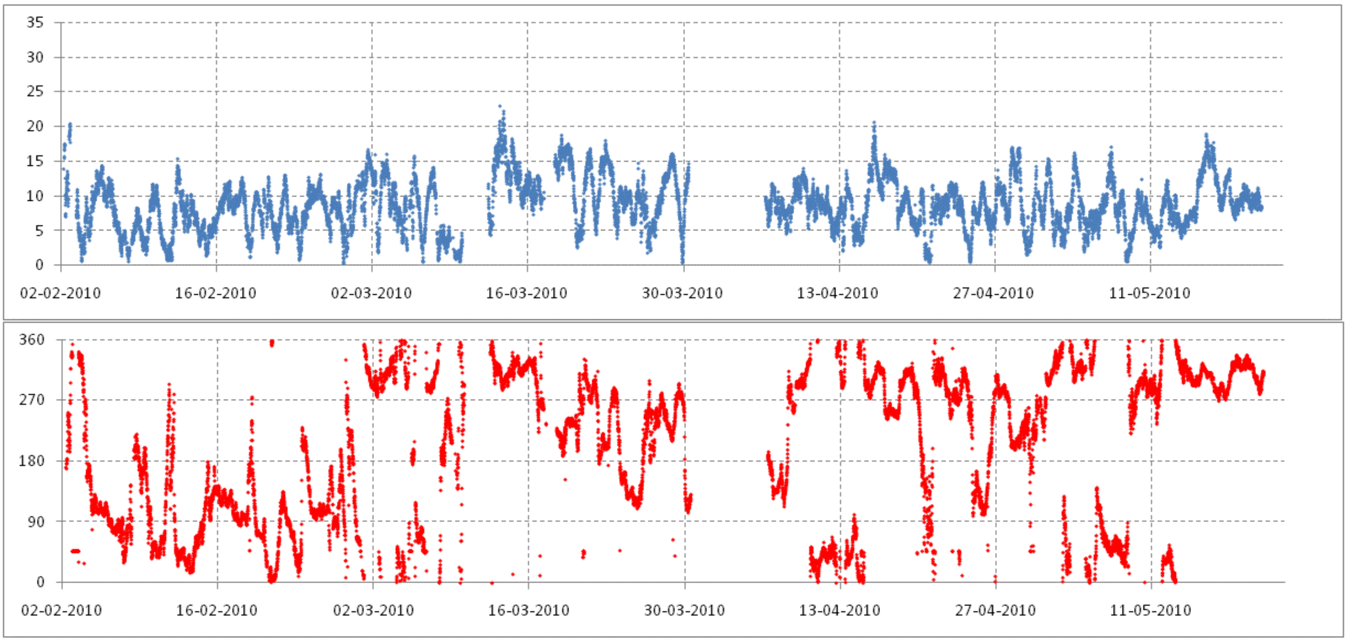


Figure 11 Time series of wind speed at 100m (blue) and wind direction (red) for Period 3.

Comments

For this period the Windcube WLS7-02 was returned to the metmast for the purpose of making reference flat terrain measurements for the SafeWind project. Prior to deployment, the lidar firmware was upgraded to version 2.1.58.1. The most important improvement is the removal of the slight non-linearity present in earlier versions and visible in the data for periods 1 and 2.

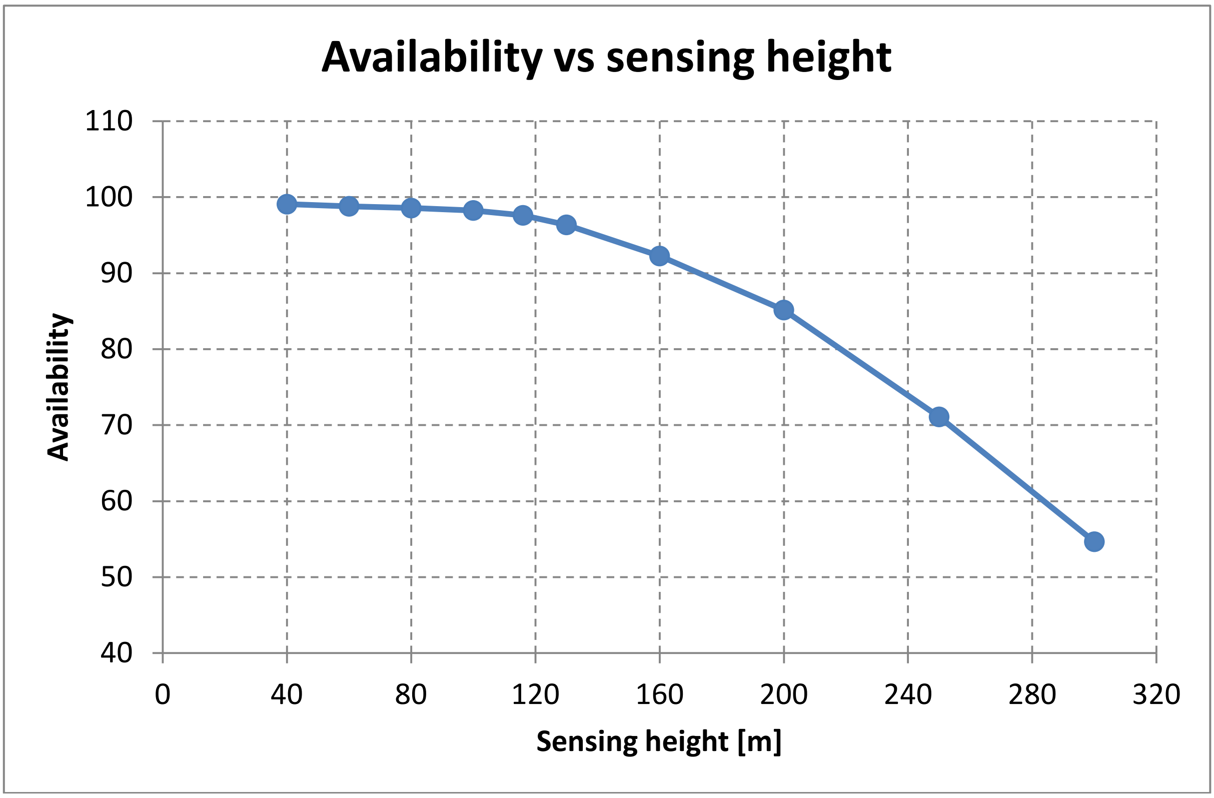


Figure 12 Availability versus sensing height - Period 3

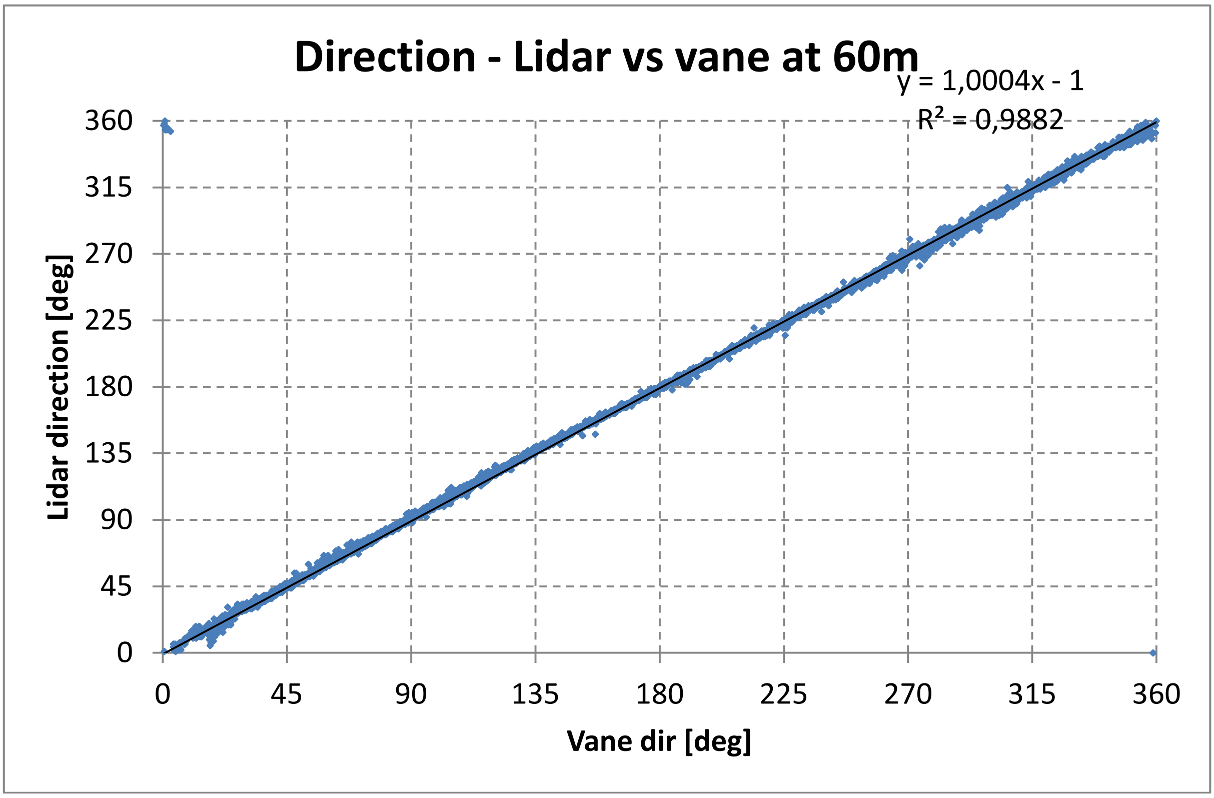


Figure 13 Lidar direction versus wind vane direction at 60m - Period 3

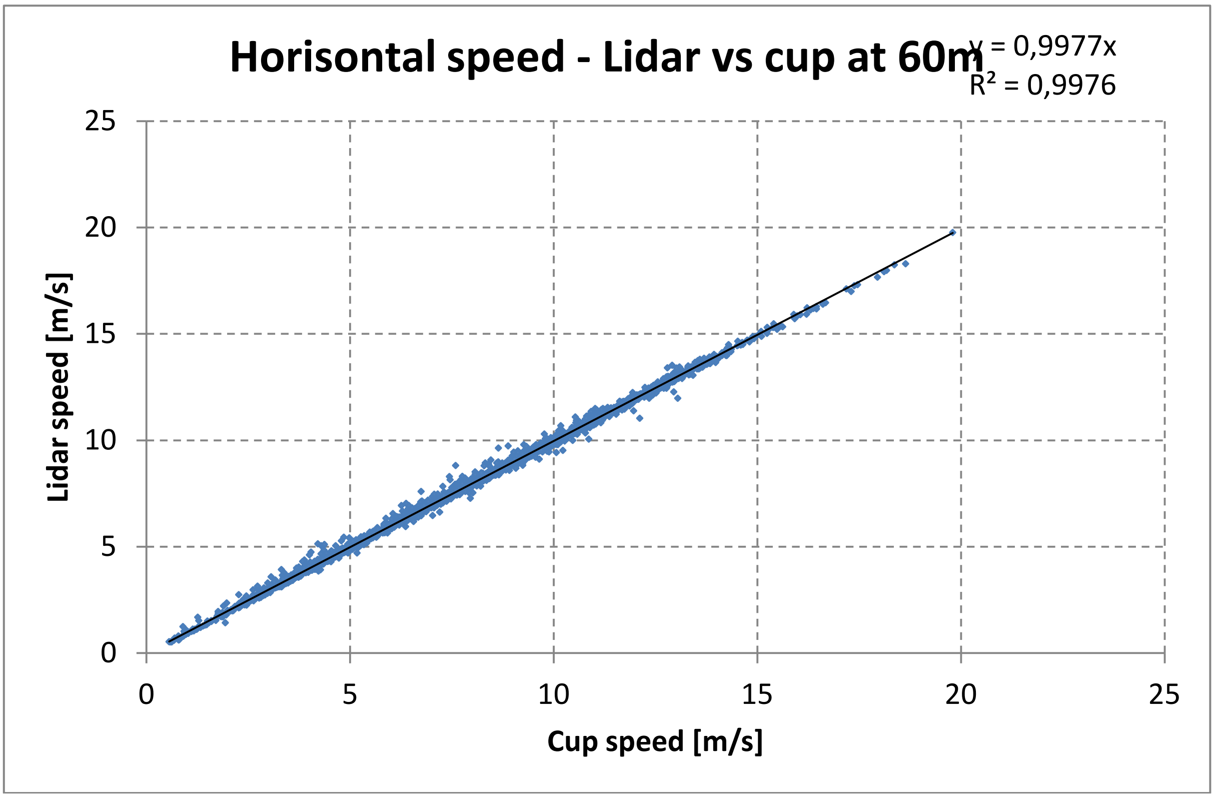


Figure 14 Lidar wind speed versus cup wind speed at 60m - Period 3.

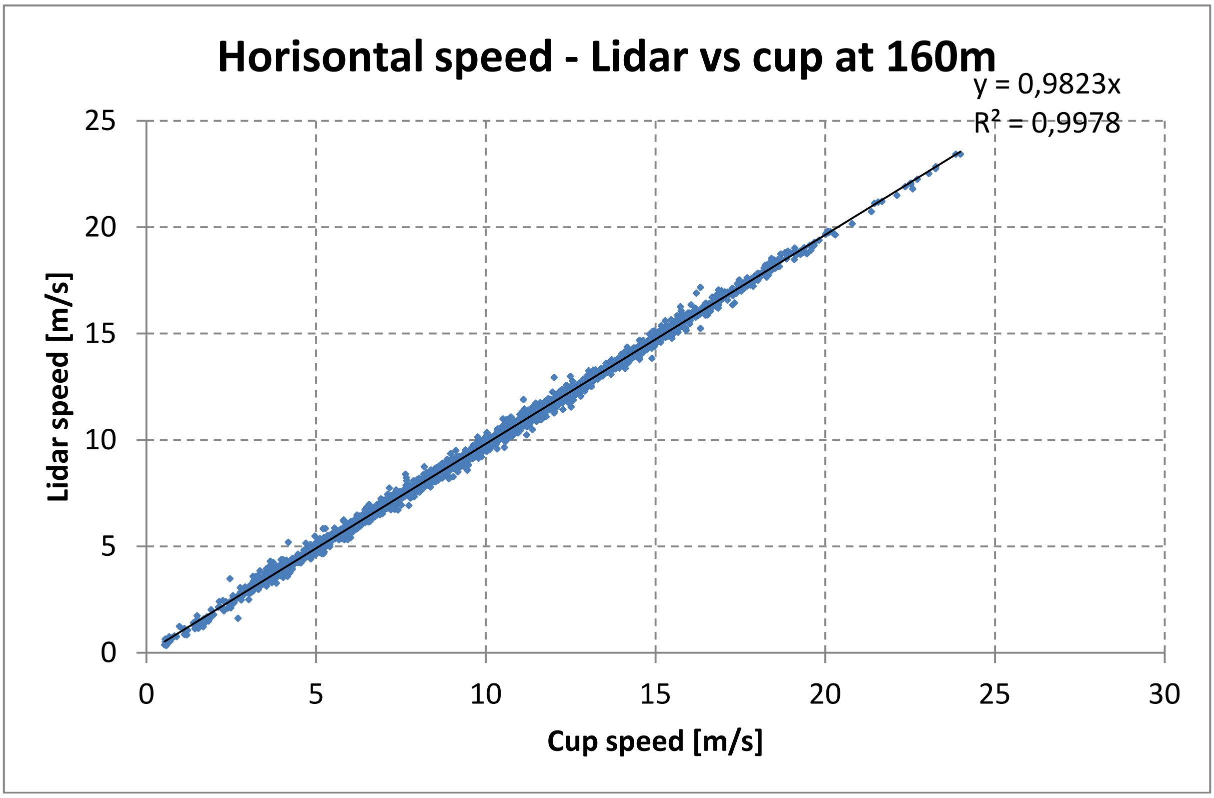


Figure 15 Lidar wind speed versus cup wind speed at 160m - Period 3. The reference cup anemometer is boom-mounted on the OMS mast.

1.4 Period 4

Location: 56°26'50.37"N, 8° 8'38.23"E (Mast 3B)
Instrument: Windcube WLS-7-02

Heights, data periods and availability:

Height	Count(Name)	Avg(Available)	min(Name)	Max(Name)
50	17563	98.09605	201005211050	201009240050
70	17563	97.49909	201005211050	201009240050
90	17563	97.05348	201005211050	201009240050
100	17563	96.75819	201005211050	201009240050
116	17563	96.02827	201005211050	201009240050
130	17563	95.13312	201005211050	201009240050
160	17563	91.74037	201005211050	201009240050
200	17563	83.64077	201005211050	201009240050
250	17563	67.41212	201005211050	201009240050
300	17563	51.07944	201005211050	201009240050

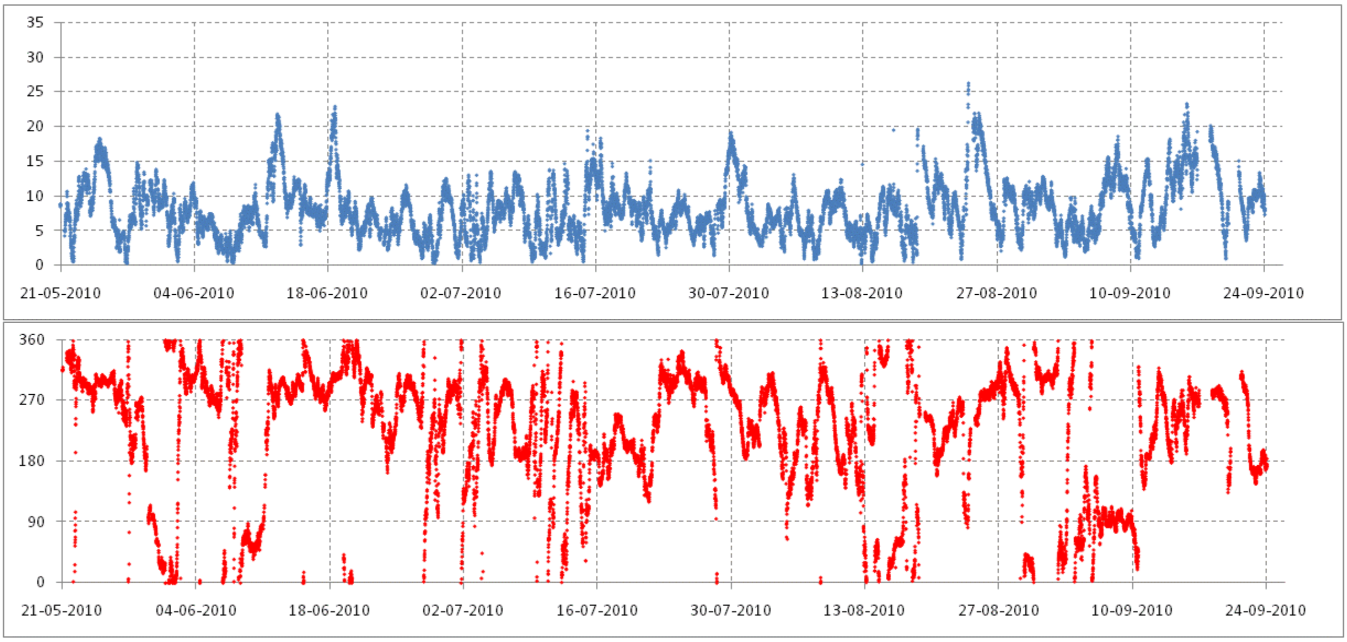


Figure 16 Time series of wind speed at 100m (blue) and wind direction (red) for Period 4 (Windcube lidar).

Comments
Immediately following period 3, the Leosphere Windcube WLS7-02 was moved to mast 3b at Høvsøre for the purpose of carrying out an inter-comparison of the 3 remote sensing instruments to be deployed at the Alaiz test site for task 2.3 of the project. Results of the inter-comparison are reported in sections 2 and 3. Here we present the data in a similar format as periods 1-3 so that the suitability of the period for other tasks within SafeWind can be assessed.

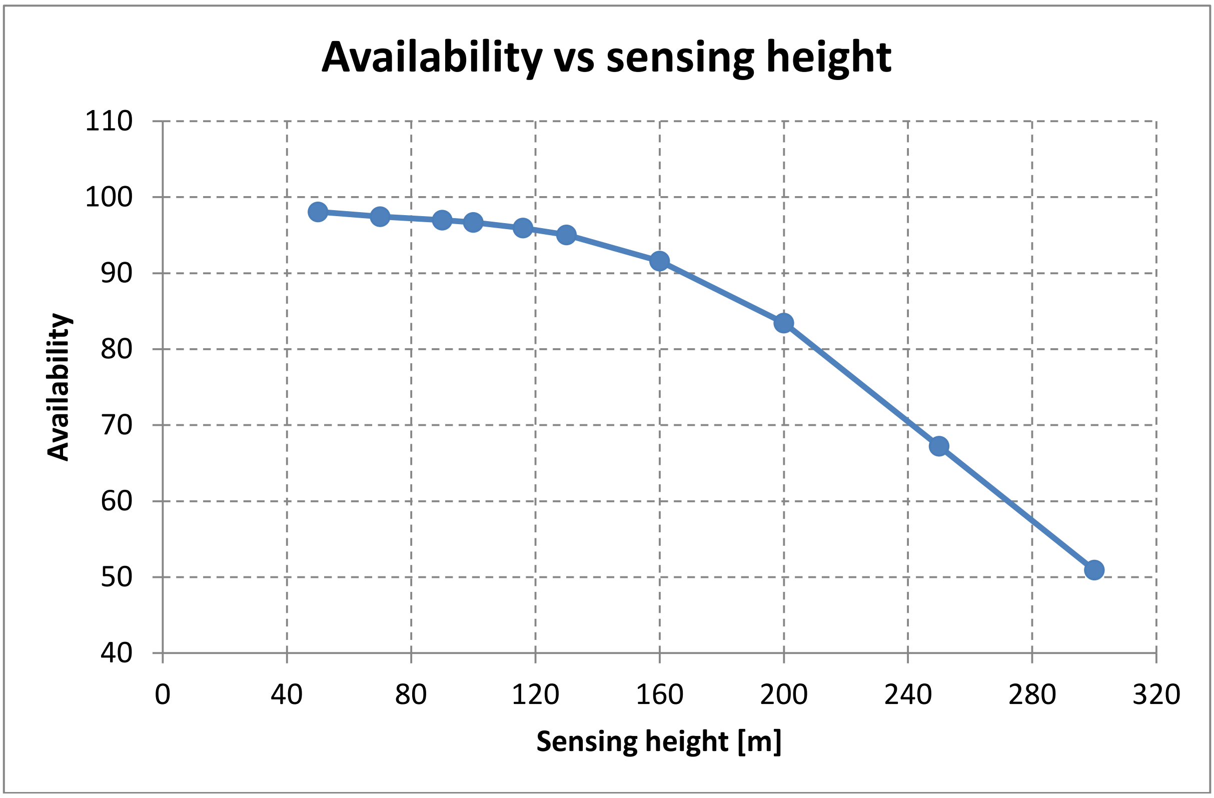


Figure 17 Availability versus sensing height - Period 4

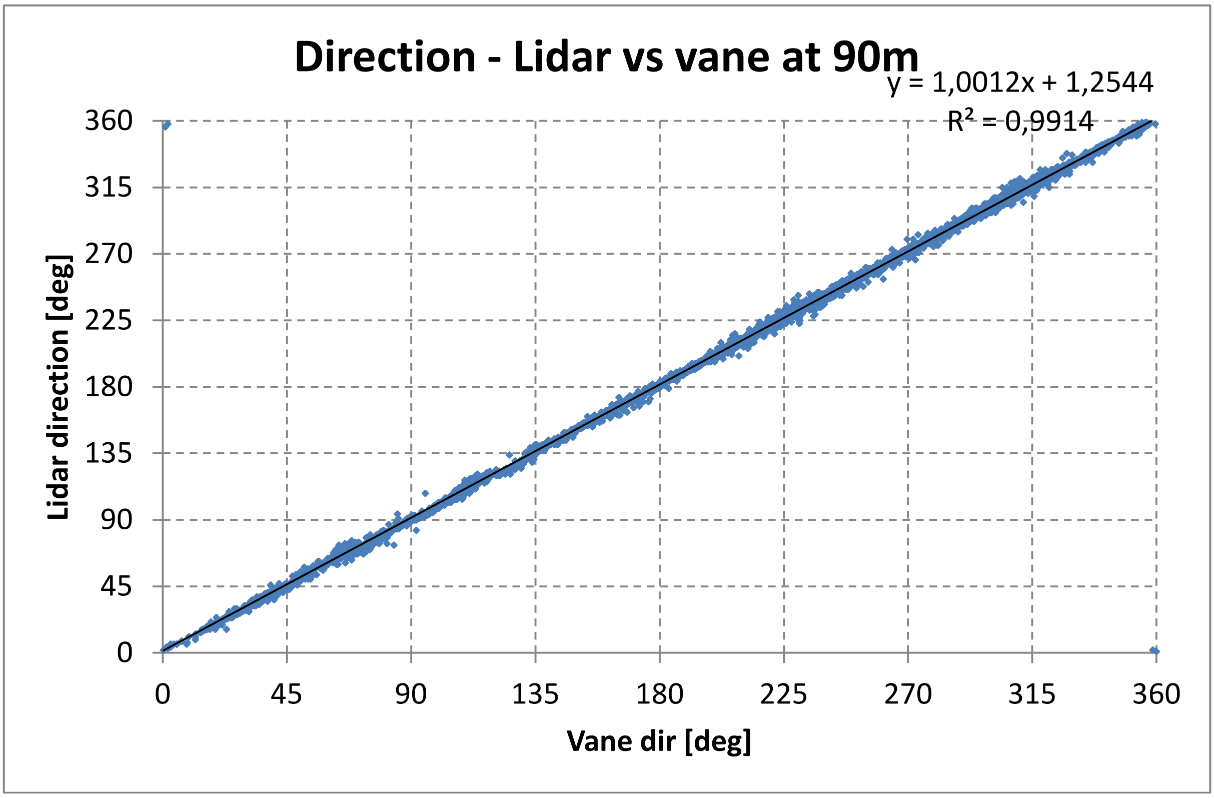


Figure 18 Lidar speed versus cup wind speed at 90m - Period 4

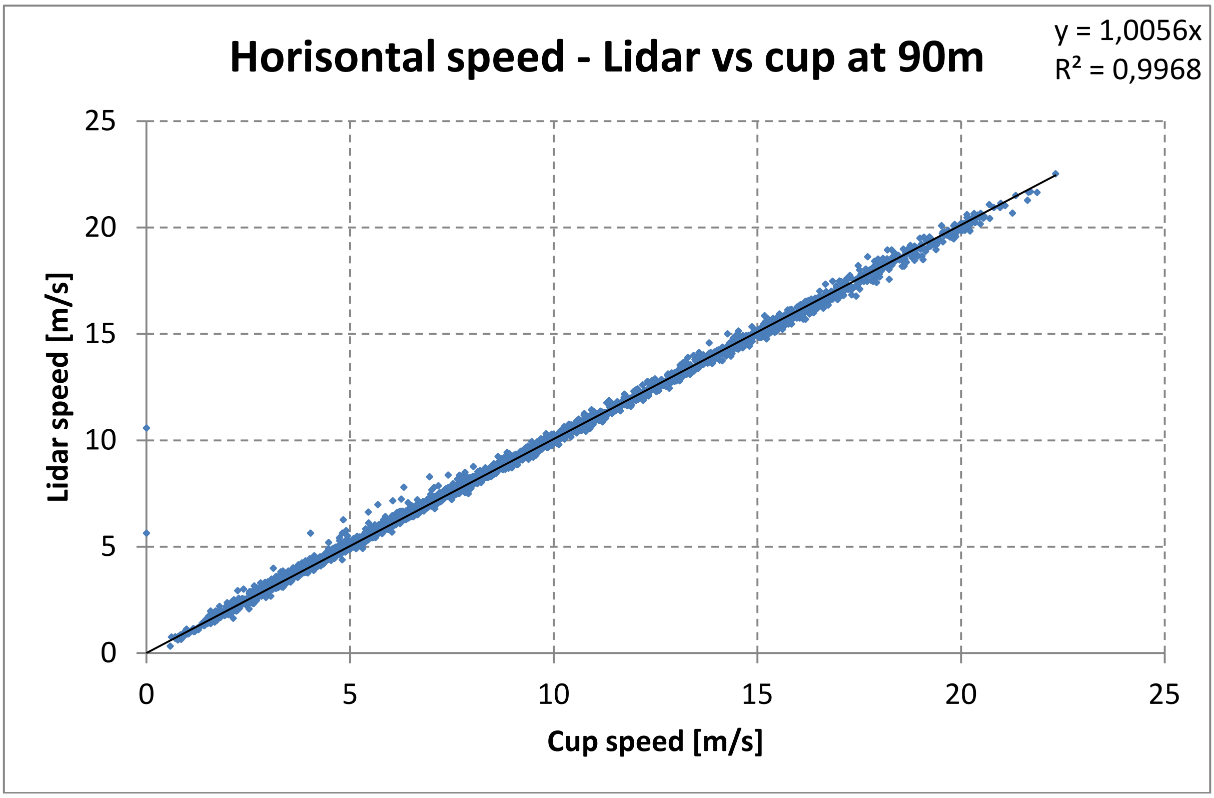


Figure 19 Lidar speed versus cup speed at 90m - Period 4. The reference instrument is top-mounted on mast 3B at Høvsøre.

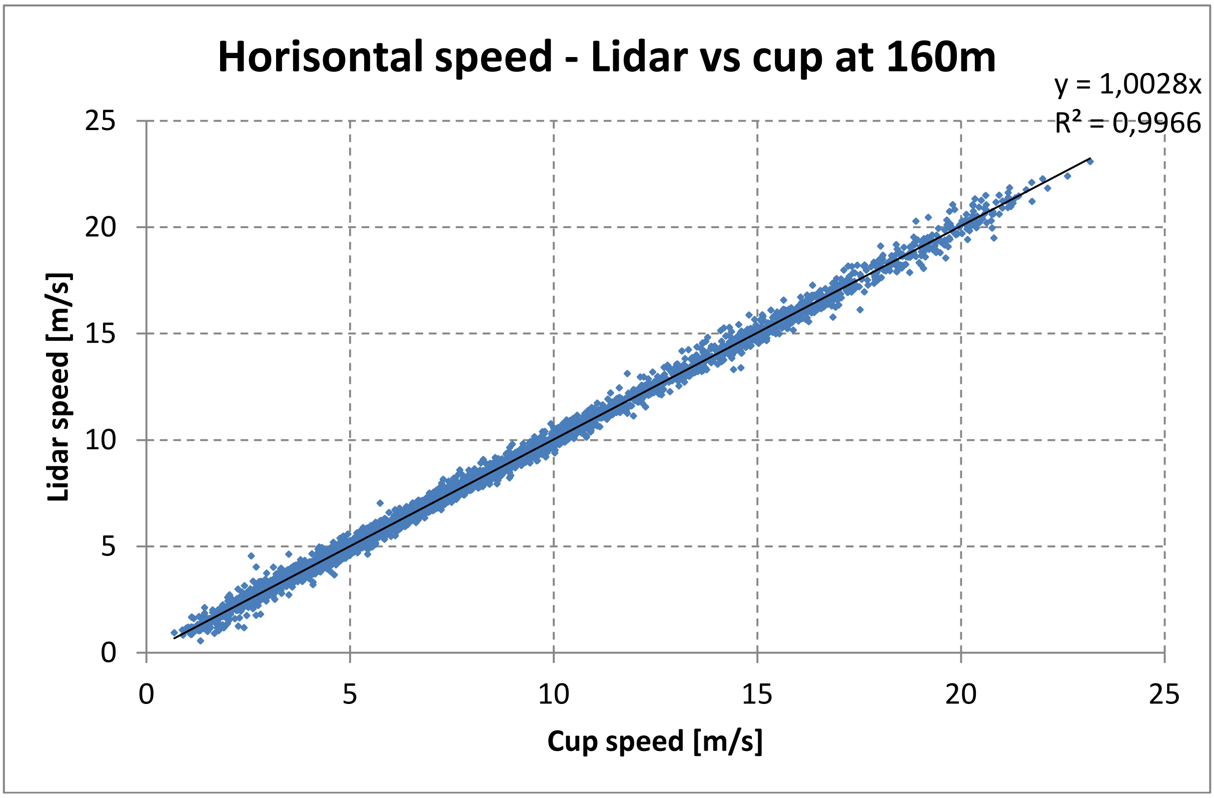


Figure 20 Lidar speed versus cup speed at 160m - Period 4. The reference instrument is a boom-mounted cup anemometer on the OMS mast at Høvsøre.

2. Lidar performance in flat terrain

2.1 Introduction

In the coming sections, lidar performance in flat terrain has been studied. Data from the measuring campaign was used to compare the measurements from the lidars with cup anemometers installed at several heights. Not only the horizontal wind speed, but also the vertical wind speed, cloud effects on measurements and sensitivity to extreme wind shear has been addressed.

The study is essentially a comparison of the Windcube pulsed lidar and the ZephiR CW lidar, both described in [2]. Most of the comparisons are for a 90m sensing height. In the following section the Windcube measurements are denoted *w90* and the ZephIR denoted *z90* (for 90m height).

2.2 Horizontal wind speed measurements

The ZephIR lidar performance compared to the met mast is presented in Figure 1-1. This figure presents a correlation between the horizontal wind speed sensed by the lidars compared to the measurements from a cup anemometer installed at the same height, in this case, at 90m height.

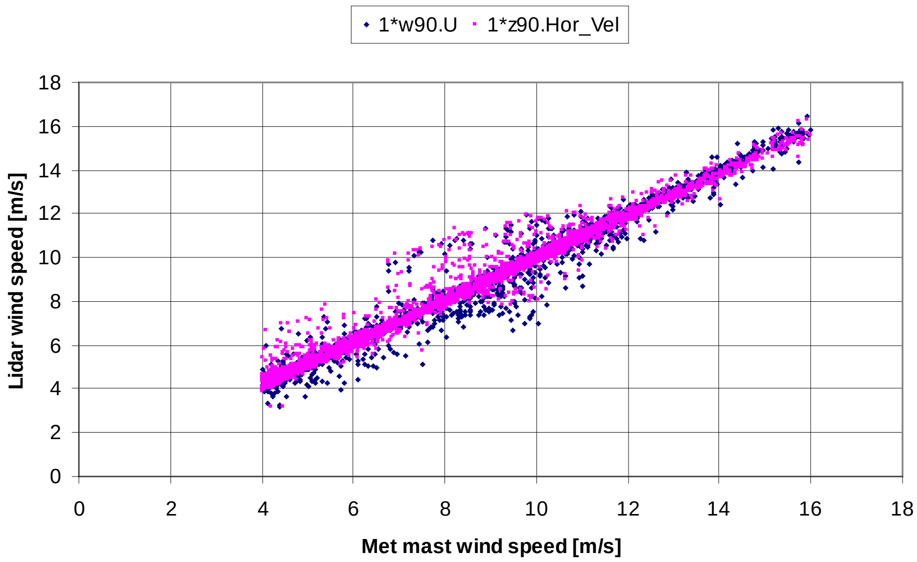


Figure 2-1. Lidars vs. met mast: Correlation horizontal wind speed at 90 m. 1*w90.U are measurements of a Windcube lidar and the 1*z90.Hor_Vel are measurements of the ZephIR lidar.

This correlation corresponds to a measurement period of a month and a week. The data were previously filtered using the following conditions:

- No rain
- 4 m/s < Met mast wind speed <16 m/s

- ZephIR points in fit > 105

The periods where rain was present are discarded since rain introduces a vertical speed component that affects the measurements. Also, water drops can retain memory from horizontal wind speed coming from higher altitudes. Moreover, if very heavy rain is present, the laser beam can be blocked at the lidar window.

Since the ZephIR lidar is affected by signal noise at lower wind speeds and also the cup anemometers are calibrated to a certain range of wind speed, the data have been filtered for wind speed between 4 m/s and 16 m/s.

In this measurement campaign, the ZephIR was programmed to scan three consecutive circles per height. Therefore a nominal amount of 150 radial velocities per height are expected. The actual number of successful radial speed measurements per height may be lower however, since the backscatter can be affected by low aerosol concentration or blocked by dense fog. For this reason, only periods where at least 105 points have been received are taken into account.

By applying the mentioned filters, from the total of 4833 records, 3389 remain corresponding to 70 % of the initial amount. Note in Figure 1-1 that despite the applied filters, still a considerable scatter is present in the graph. The reason is that there are other environmental conditions that affect the lidar and cup anemometer performance. A function defined as the lidar error (wind speed sensed by the lidar minus the wind speed sensed by the cup anemometer) was used in order to develop a sensitivity study of the environmental conditions over the lidar performance compared to the cup anemometer. From this study, it was found that surrounding obstacles produced a large bias in wind speed measurements, as shown in Figure 1-2.

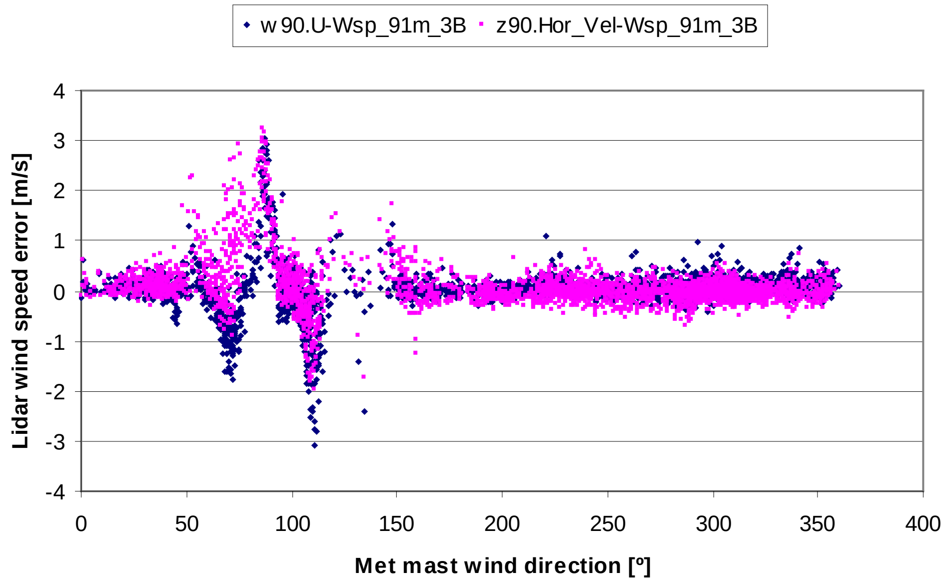
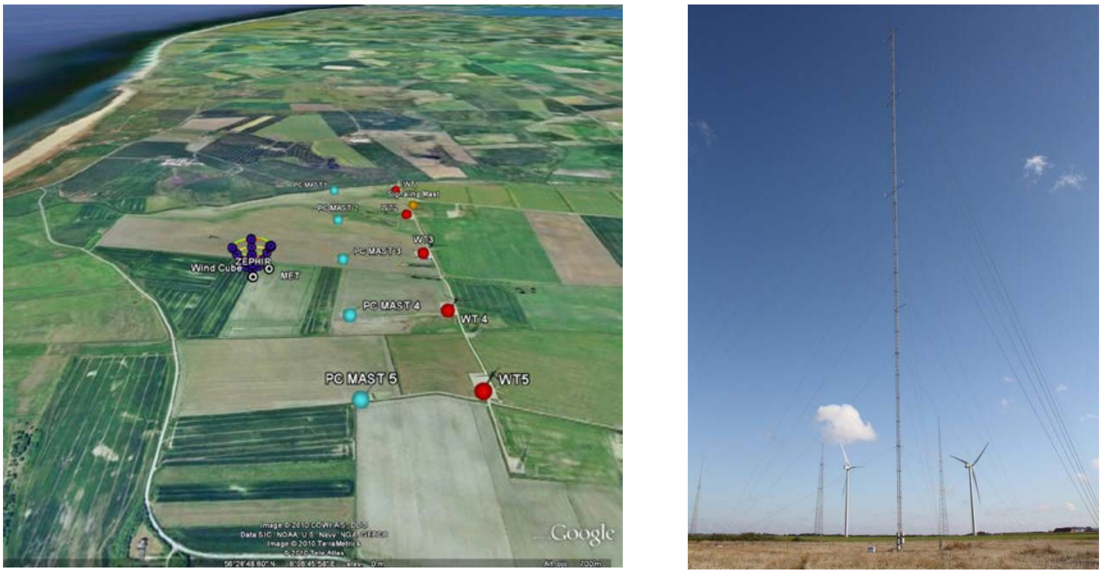


Figure 2-2. Correlation horizontal wind speed error vs. wind direction, at 90 m (top mounted). The wind speed error is defined as the wind speed sensed by the lidar minus the wind speed sensed by the cup anemometer.

By observing previous graph, it is possible to identify the wind direction sector comprehending between 45º and 150º as a source of large uncertainty in measurements since the error can be asmuch as 6 times larger compared to other directions and sometimes is positive and others is negative. A field visit to the test site helped to identify the presence of 5

big wind turbines at close distance precisely at east side from where the lidar and met mast were located. In Figure 1-3 a) the location of the met mast, the lidar and the wind turbines are indicated. In Figure 1-3 b) the met mast 3B and near wind turbines are shown.



a) ZephIR lidar, met mast 3B and wind turbines (WT).

b) Met mast 3B and wind turbines WT2 and WT3.

Figure 2-3. Location of lidar, met mast and wind turbines at Hovsore test site.

The separation distance between the lidar and the met mast is approximately 43 m. For this reason, depending on the wind direction, the wake of a wind turbine was reaching either the met mast, the lidar measurement volume (totally or partially) or the two of them simultaneously. For this reason the error had different sign and intensity as appreciated in the graph of Figure 1-2.

An additional variable to take into account is the height at which the measurements are obtained. If the same graph form Figure 1-2 is plotted for measurements at 50 m, the result is the graph from Figure 1-4.

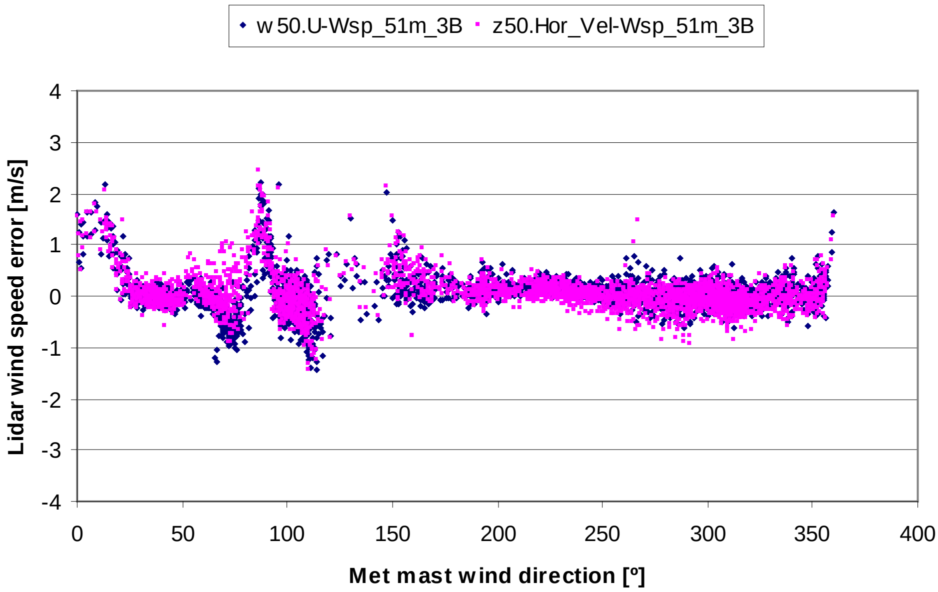


Figure 2-4. Correlation horizontal wind speed error vs. wind direction, at 50 m (southern boom).

When comparing Figure 1-2 and Figure 1-4, there are several differences important to mention. Firstly, there is a high error that appeared in Figure 1-4 when wind blows from directions close to 0º. The reason of this error is the fact that the 50 m cup anemometer is not top mounted, but is installed on a boom facing south. For this reason, when wind comes from the north, the mast wake impacts directly the cup anemometer installed at the southern boom. As a consequence, the cup anemometer senses lower wind speed compared to the lidar that is not affected by the mast wake and the error is positive.

Furthermore, the error magnitude in the sector with turbine wake influence is higher at 90 m (Figure 1-2) than at 50 m height (Figure 1-4). The reason is that the lidar scanning volume at higher heights is more embedded into the wake volume and therefore senses a stronger wind speed deficit.

It was therefore necessary to filter wind directions in order to avoid the sector with influence of wind turbine wakes over the met mast and lidar measurements. Data from wind directions between 30º and 150º were discarded. The application of this filter in addition to those already applied resulted in 50% of all records being discarded. After filtering, the correlation between the lidars and the cup anemometer can be seen in Figure 1-5.

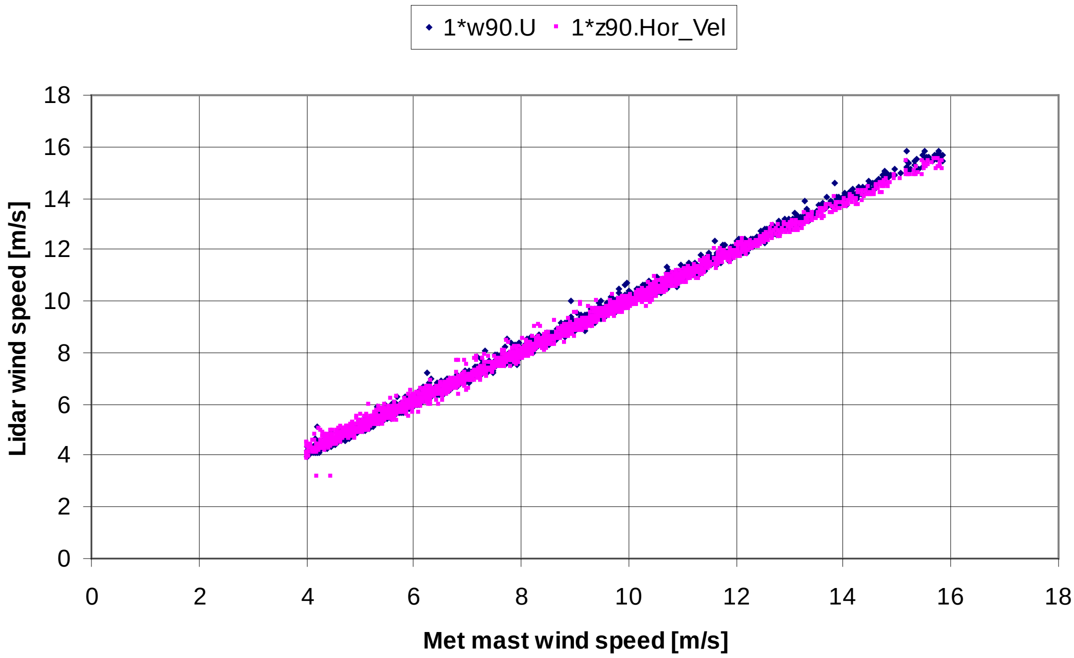


Figure 2-5. Lidars vs. met mast: Correlation horizontal wind speed at 90 m. Wind direction has been filtered to avoid wind coming from the sector between 30º and 150º.

Notice the reduction in the data dispersion when compared to Figure 1-1. Nevertheless, still some dispersion is present. By analyzing other recorded variables, it was found that low cloud base has an impact in the error magnitude. This is in accordance with the cloud effect explained previously. In Figure 1-6, the wind speed error has a generally higher magnitude when the cloud base is lower than approximately 2000 m.

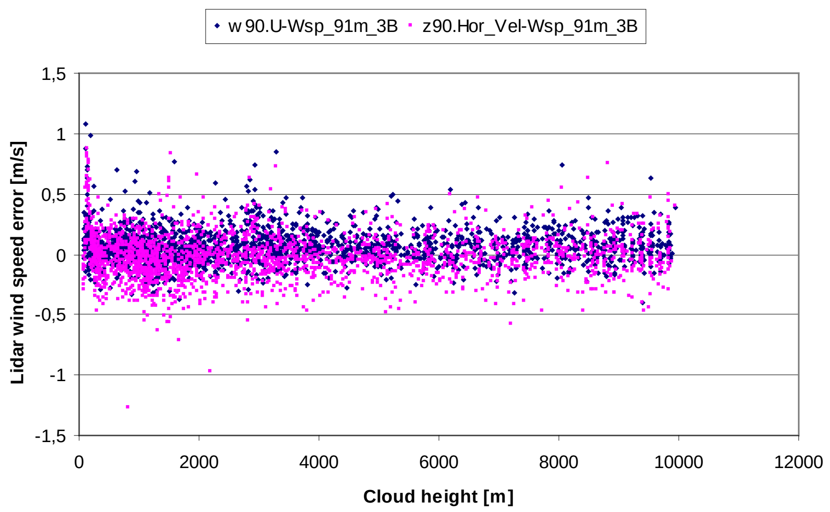


Figure 2-6. Lidars vs met mast: Correlation horizontal wind speed error vs. Cloud height, at 90 m.

A filter has been applied to discard data when the cloud base is lower than 2000 m. The result is shown in Figure 1-7.

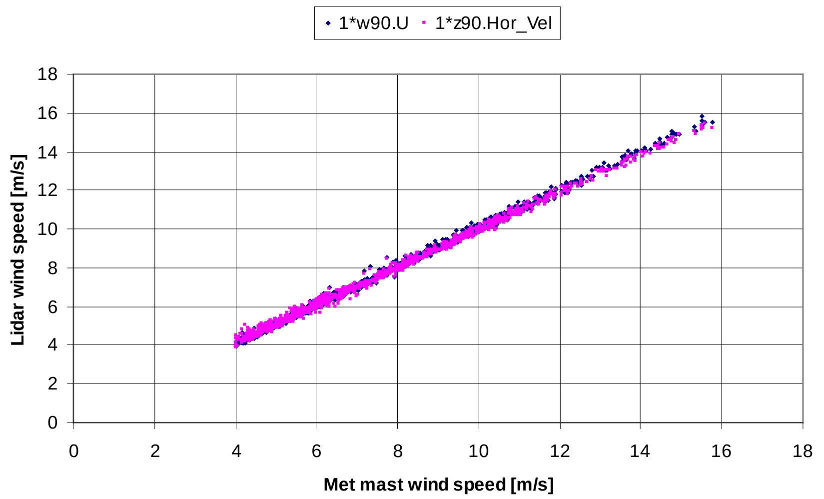


Figure 2-7. Lidars vs. met mast: Correlation horizontal wind speed at 90m. Data where cloud base height was equal or lower than 2000 m have been discarded.

When working with data from cup anemometers installed at the end of met mast booms, it is important to account the effect of these structures in the reduction of the wind speed. This effect is feasible to detect when two cup anemometers are installed in opposite sides of the met mast. By plotting the ratio of their wind speed measurements as function of the wind direction, the error due to boom effects can be assessed. An example of this procedure is presented in Figure 1-8.

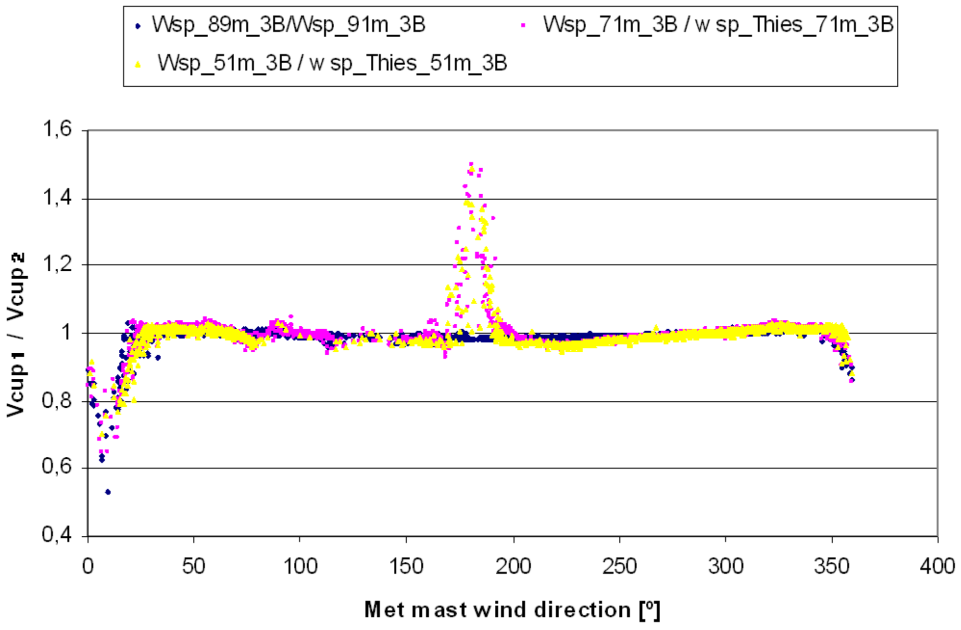


Figure 2-8. Met mast: Correlation cup ratio vs. horizontal wind direction.

Several effects are identifiable from Figure 1-8. First, the ratio of cup anemometer measurements installed on booms at opposite sides of the met mast, present a sinus shape. The reason is that when wind is blowing almost paralleled to the boom, one cup anemometer is sensing low boom interference over the flow while the other is sensing the maximum boom interference. This is a peak in the sinus signal. When wind blows perpendicular to both booms, the effect is the same and the ratio crosses through the unit value. Then, if the direction scan continues, the opposite effect is sensed.

On addition of the explained boom effect, there is the mast wake effect on cup anemometers. In this case, when wind approaches from north or south, one cup anemometer at the time is immersed in the mast wake. This is the reason of the two peaks at around 0º and 180º. For the special case of comparing one boom mounted anemometer and one top mounted anemometer, just one wake effect is present, as in the case of the *Wsp_89m_3B/Wsp_91m_3B* ratio.

In order to avoid the boom effects and the mast wake effects, in addition to avoiding other local terrain obstacles like farm buildings, small groups of trees and some dikes, the wind direction sector was limited to directions between 237º and 323º (mainly from the coast line at west). The final filtering result includes only 18% of the total recorded data, however the linear regression presents much less dispersion as seen in Figure 1-9.

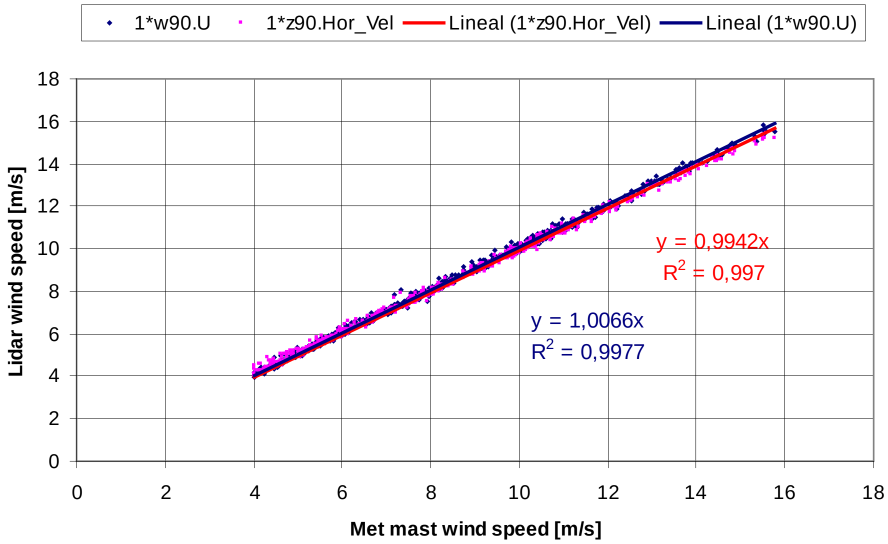


Figure 2-9. Horizontal wind speed correlation for lidars and cup anemometer after filtering data, at 90m

It is important to mention that the wind direction error is very low in general terms. However, in a few cases, the ZephIR lidar reported a wind direction offset by 180º as can be seen in Figure 1-10. This reflects the 180 º ambiguity of the ZephiR in determining the wind direction directly from the radial wind speeds (since the polarity of the radial speeds is unknown, only the magnitude). To resolve this ambiguity, the ZephIR measures the wind direction using a sensor mounted on a short mast above the instrument. In cases where there is large wind veer, the surface direction may not be close to the direction at the lowest sensing height and a 180º error can occur.

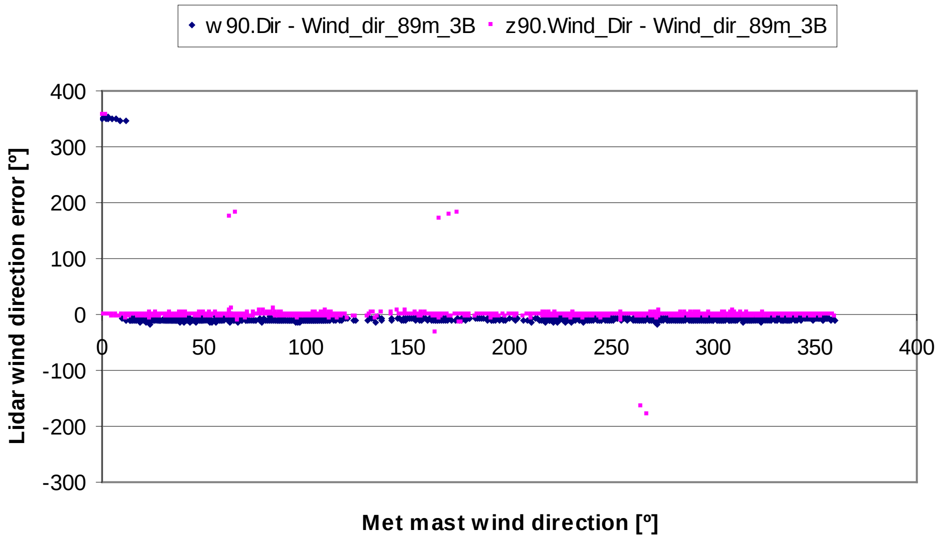


Figure 2-10. Lidars vs. met mast: Correlation horizontal wind direction error vs. wind direction, at 90m. ZephIR error in pink color.

As explained previously, the vertical wind speed has a relevant influence in the lidar error since the vertical wind speed gradient is considered to be a major source of uncertainty. For

this reason, it is important to verify how the devices measure the vertical component of the wind velocity. This is done in the next section.

2.3 Vertical wind speed measurements

In addition to the horizontal wind speed and wind direction, the vertical speed was measured and recorded. In Figure 1-11, a time series of the wind velocity vertical component measured by the ZephIR lidar, the Windcube lidar and the sodar is presented.

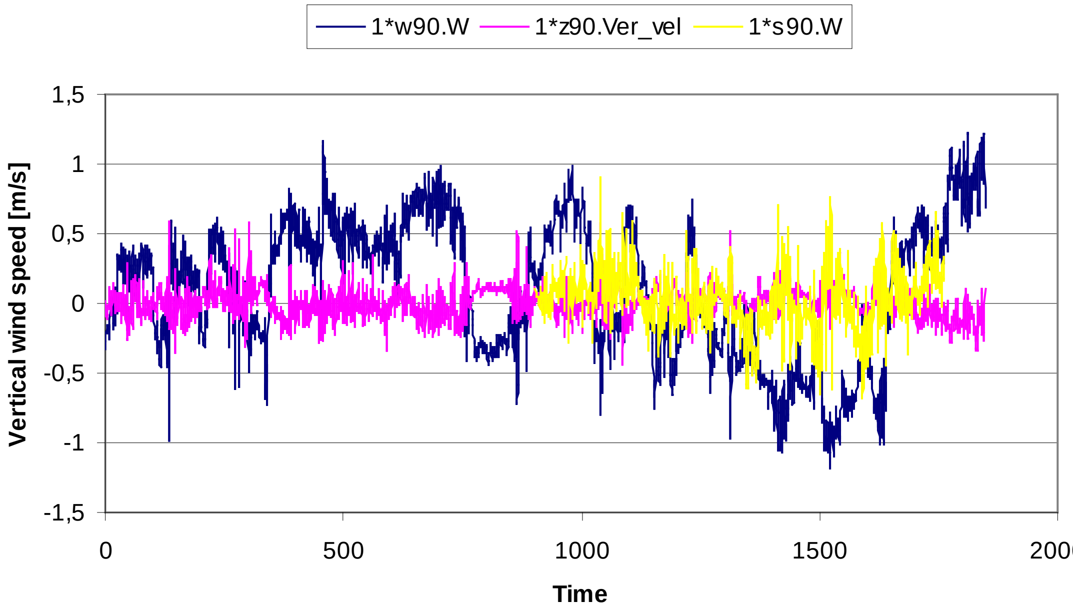


Figure 2-11. Windcube lidar (w90), Zephir lidar (z90) and sodar (s90): Vertical wind speed at 90 m.

Unfortunately, the vertical wind speed was not measured by the met mast instrumentation since there were not installed any vertical anemometer nor sonic anemometers. Only data from the remote sensing devices are available and therefore no error function can be used to verify the performance of each device. The only option is to compare the devices between themselves.

Giving an inspection to Figure 1-11 does not identify any clear correlation between the measurements from three devices. The available data for the sodar is shorter. In this period of time, it is possible to see that sometimes has better agreement with the ZephIR and sometimes with the Windcube. So it is difficult to conclude something based just on this graph. An attempt to obtain further information is to check the correlation of the vertical wind speed with the wind direction. This is given by Figure 1-12.

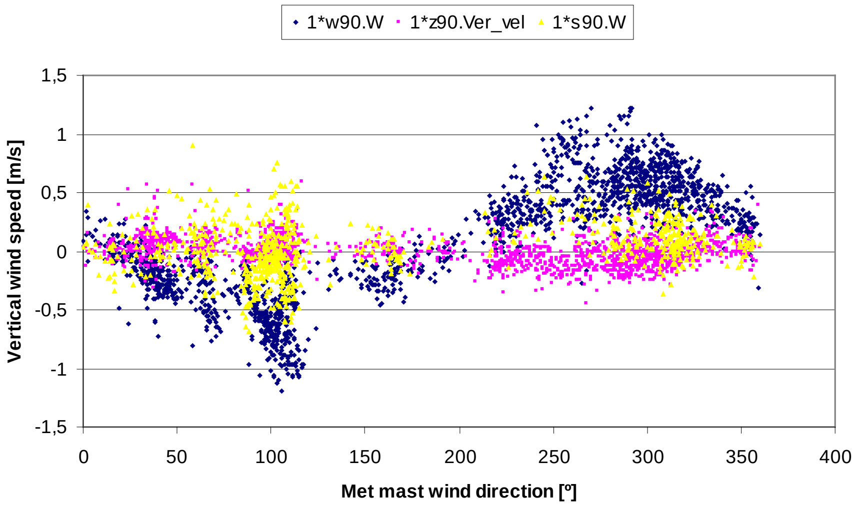


Figure 2-12. Windcube lidar (w90), Zephir lidar (z90) and sodar (s90): Correlation vertical wind speed vs. wind direction, at 90 m.

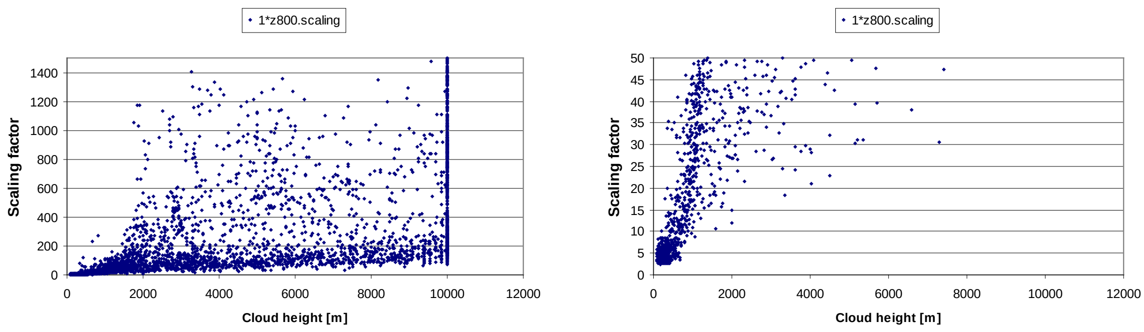
Once again, it is difficult to establish a clear correlation in the vertical wind speed sensed by the three devices. Just one important aspect to mention is that measurements from the Windcube lidar show a sinus shape that suggest a possible vertical misalignment.

2.4 Cloud detection method for the ZephIR lidar at Høvsøre

It is important to mention that thanks to the ceilometer installed at the Høvsøre test site, the cloud base height was measured at all times. This allowed us to assess the impact of low clouds on lidar measurements. However, if the lidar was to be installed at another location without access to ceilometer data, it would be very useful to have a method to detect the presence of low clouds or fog in order to filter out these data. For this reason, a method to detect the presence of fog or very low clouds was developed based on the weather conditions at Høvsøre. Note that this method was mainly developed for research purposes to understand better the influence of low clouds or fog and should not be necessarily taken as valid for other locations or for use with other lidar units. More details are given in the following section.

The ZephIR lidar records a parameter called ‘scaling factor’ that is used in converting from the measured floating point power spectral densities to the stored 8bit integer values of the spectra. The scaling factor is defined as 255/psd_max and therefore a strong backscatter (such as from low clouds or fog) will have low scaling factor values whilst very low backscatter (from very clear) air will be reflected by a very high scaling factor.

By accessing these scaling values, it is possible to correlate their behavior with the cloud base height. For the measurement height at 800 m, the scaling factor as function of the cloud base height is shown in Figure 1-13.



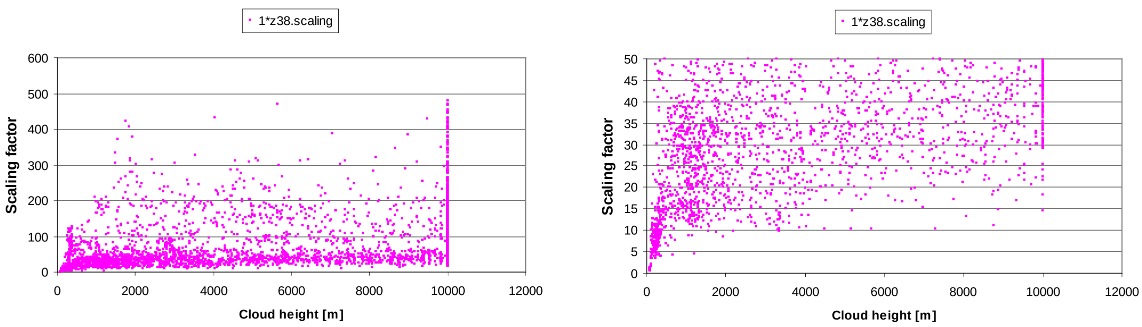
a) Scaling factor vs. cloud base height.

b) Same as left but making a zoom-in at the coordinate origin.

Figure 2-13. Correlation of ZephIR scaling factor at 800 m vs. cloud base height. Based on this information, it was selected a value of z800.scaling < 15 as criterion for low cloud filter.

As can be seen, for low cloud base height, the scaling factor tends to be smaller. The interest is to filter out the cloud base heights lower than 2000 m. For this reason, a filtering criterion of z800.scaling < 15 is defined.

Besides the presence of low cloud, the effects of fog is equally negative to lidar measurements since the laser beam is heavily obstructed before reaching the desired measurement height. For a CW lidar much or all of the received backscatter in these conditions will be from heights below the desired sensing height. The scaling factor at 38 m height is used to detect the presence of foggy conditions. Similarly to the previous case, the impact of the cloud base height over the scaling factor at 38 m is shown in Figure 1-14.

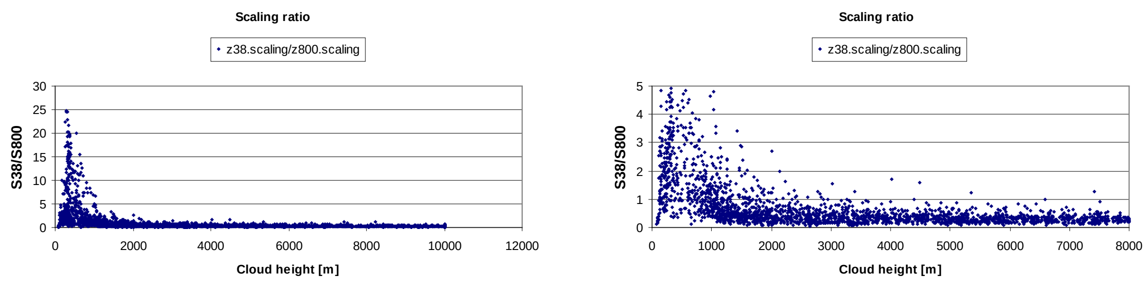


a) Scaling factor vs. cloud base height.

b) Same as left but making a zoom-in at the coordinate origin.

Figure 2-14. Correlation of ZephIR scaling factor at 38 m vs. cloud base height. Based on this information, it was selected a value of z38.scaling < 8.5 as criterion for fog filter.

For the scaling factor at 38 m, a filtering criterion of z38.scaling < 8.5 was selected to avoid the presence of foggy conditions that obstruct the laser beam to reach the desired measuring height. Now if the scaling factor values at the minimum and maximum measuring heights are related to each other, more information could be obtained to detect the presence of low clouds. For this purpose, the ratio of the scaling factor at 38 m divided by the scaling factor at 800 m is plotted against the cloud base height in Figure 1-15.



a) Scaling factor ratio vs. cloud base height.

b) Same as left but making a zoom-in at the coordinate origin.

Figure 2-15. Correlation of ZephIR scaling factor ratio vs. cloud base height. Based on this information, it was selected a value of S38/S800 < 1 as criterion for low cloud base height.

Based on the resultant graph from previous figure, the scaling factor ratio could be used to detect the presence of some low clouds. Then, a filtering criterion of S38/S800 < 1 is defined.

Now that three different criteria have been defined to detect and filter the presence of fog or low clouds, it is necessary to decide how to combine them together. One option is to use a logic OR gate which means that data that fulfill any of these criterion is enough to be discarded. The other option is to use a logic AND instead and then only data that fulfill the three criteria simultaneously should be discarded. The result of applying these different combination methods is shown in Figure 1-16.

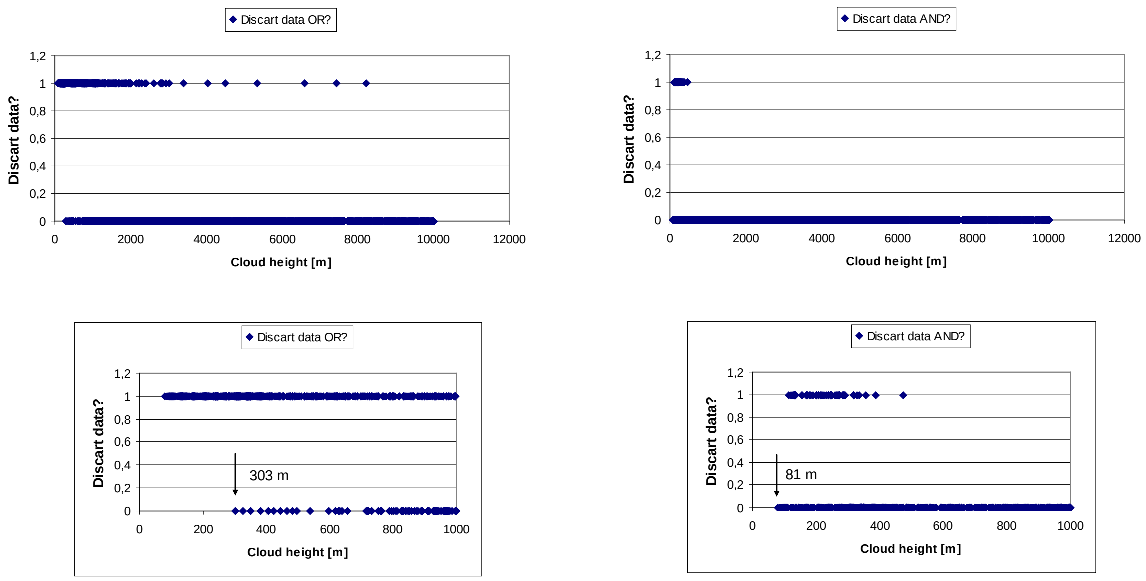


Figure 2-16. Combination methods for fog and low cloud filtering criteria based on ZephIR scaling factors at minimum and maximum measuring heights.

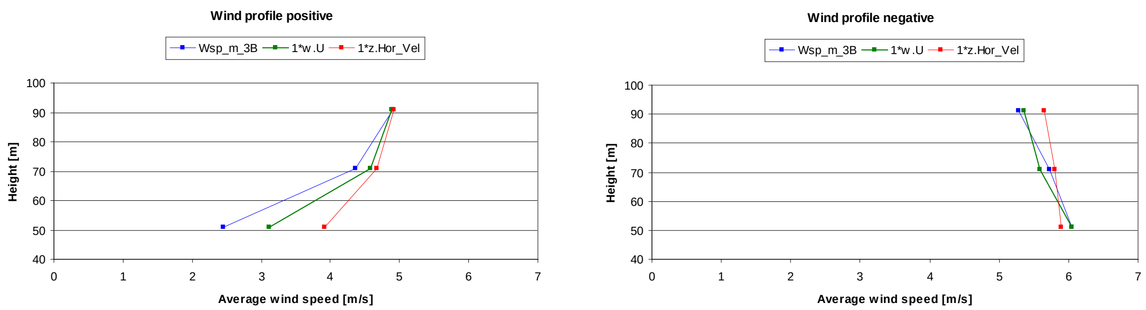
When using a logic OR to combine the two results, more data is discarded in the region where cloud base height is between 0 to 3000 m. Notice that sometimes the discard criteria affects data even when clouds where high up, but just in few cases. With this method, the lowest cloud height remaining by applying this filter is 303 m. On the other hand, if a logic AND is used, the amount of data wrongly filtered out (when cloud base was actually high enough to not disturb lidar measurements) is reduced. However, the lowest cloud height for the remaining data is around 81m, which correspond to the lowest cloud height reported by the ceilometer. This means that this combination method is less effective if weather conditions

with low clouds are desired to be discarded. For the Høvsøre location, the logic OR is the most recommended combination method.

2.5 Measurement of extreme wind shears

The durability of wind turbines is affected by the presence of extreme events. An example of these events is the presence of an extreme wind shear that provokes more loads on the blades when they are at the maximum height and less when passing below aligned with the tower. The opposite tendency, negative wind shear where the wind is higher at lower blade tip height that at hub height, is even more damaging since blade/tower collisions can occur in very extreme events.

Since wind lidars are able to measure wind speed at several heights, they can be used to detect the occurrence of these events. Therefore, it is important to evaluate lidar capability to measure strong wind shears. The flat terrain conditions at Høvsøre make it very appropriate to test this property. The most extreme shear events recorded (after applying previous filters) are plotted in Figure 1-17. Both positive and negative wind shears are compared.



a) Positive wind shear
(wind speed increases with height)

b) Negative wind shear
(wind speed increases with height)

Figure 2-17. Most extreme wind shear events recorded at Høvsøre.

The most extreme positive wind shear (based on 10 minute mean values) is shown in Figure 1-17 a). There is a difference of 2.45 m/s from wind speed at 50 m to 90 m base on cup anemometer data (blue color curve). Within this same shear, note that the biggest speed increase is between 50 m to 70 m and less between 70 m and 90 m. The Windcube lidar is closer to measuring the shear observed by the cup anemometers than the ZephIR lidar. The three devices sensed the same speed at 90 m height.

In the case of negative wind shear, the difference between wind speed at 50 m and 90 m is -0.78 m/s. Once again, the Windcube is better at representing this shear than the ZephiR lidar.

3. Comparison between the Scintec sodar and the mast during the Hovsore campaign

The Scintec SFAS sodar was installed at a distance of 70 m from the 90 m mast 3B (Figure 1). For practical reasons it was not possible to install it at a larger distance, although it would have been necessary in order to avoid strong fixed echoes from the mast. The main parameters of the sodar are indicated in table 1. The pulse duration is 5 m for the highest frequencies, and 15 m for the lowest frequencies.

Number of frequencies	10
Range of frequencies	2500 to 4900 Hz
Number of beams	9
Period of integration	10 min
Pulse duration (m)	5 to 15 m
Height range of measurement	10 to 150 m
Output vertical resolution	5 m

Table 1: Sodar parameters during the Hovsore campaign.

The period of comparison extends from 31st of August to 17th of September 2010. Due to different experimental problems (3G communication, power supply failure, breakdown of the PC at the end of the campaign), the data obtained before the 31st of August could not be included in the analysis. For the same reason, a change of the sodar parameters mid-September could not be tested.

Regarding the possible effect of the mast on the cup anemometers, only the wind direction included in the sector 180° to 330° were selected. Sodar data were kept only when its measurements were validated by Scintec software for all vertical levels between 30 m and 100 m. Finally, the comparison was made using 896 time samples.

Scatter-plots of wind speed measured by the sodar and the cup anemometers at 50 m and 90 m levels are shown on Figure 2, without any other filtering than the one applied by the manufacturer software. At 50 m, the statistical scores of the comparison (Table 2) are similar to what was obtained with the same sodar during other campaigns on flat sites [4], with a bias of - 0.1 m/s, and a R^2 coefficient of 0.954. However, at 70 m and 90 m, the scores are significantly deteriorated with especially a negative bias of about 1 m/s at 90 m, and an increased standard deviation (of differences between mast and sodar). The negative bias is a typical signature of a fixed echoes effect, which is induced here by the close mast. This effect is strongly reduced at 50 m level by the sodar enclosure.

The effect of different additional filters on these statistical scores has then been studied. The main conclusions are:

- There is no significant difference when rain cases are removed. It is consistent with a previous study [4] in which the measurements of the Scintec SFAS sodar were unaffected by rain.
- A slight improvement is observed when sodar data associated with invalidated standard deviation (of one of the horizontal components) are removed (filter 1 in Table 2). The reason could be that an invalidated standard deviation results from a too low number of validated instantaneous measurements within the time integration period, which can lead also to a less reliable averaged value.
- A strong improvement is obtained when sodar data associated with default value of backscattering intensity are removed. This is the case when the peak due to the wind in the Doppler spectrum is not well defined. Applying this filter, the results are improved at all levels and for all statistical scores (filter 2 in Table 2). At 50 m, the R2 coefficient reaches 0.977 and the regression line is closer to the y=x line than without the filter. At 90 m, the bias and standard

deviation are divided by a factor 2, but at the expense of an unacceptable reduction of the sample size.

In summary, the Scintec sodar was strongly affected by the presence of the mast during this campaign, and the statistical scores of the comparison with the cup anemometers above 50 m level indicate much larger differences than in previous campaigns on flat terrain. The sample size was also quite small due to different experimental problems. Lastly, the high number of “default values” of the backscattering intensity, which is observed even at 50 m level, could be an indication of a degraded working of the sodar (maybe due to a hardware problem) during this campaign.

	Without filter			**Filter 1**			**Filter 2**		
	50 m	70 m	90 m	50 m	70 m	90 m	50 m	70 m	90 m
Sample size	896	896	896	501	482	401	471	278	135
Bias (m/s)	-0.10	-0.52	-1.03	-0.10	-0.48	-1.03	-0.05	-0.36	-0.54
SD (m/s)	0.65	0.68	0.92	0.55	0.56	0.76	0.39	0.45	0.50
R^2	0.954	0.956	0.926	0.962	0.963	0.912	0.977	0.968	0.953
slope	0.953	0.934	0.969	0.961	0.947	0.946	0.978	0.923	0.925
Constant (m/s)	0.34	0.11	-0.73	0.25	0.00	-0.55	0.12	0.28	0.01

Table 2: Statistical scores of the comparison between the Scintec SFAS sodar and the cup anemometers of mast 3B on Hovsore site.

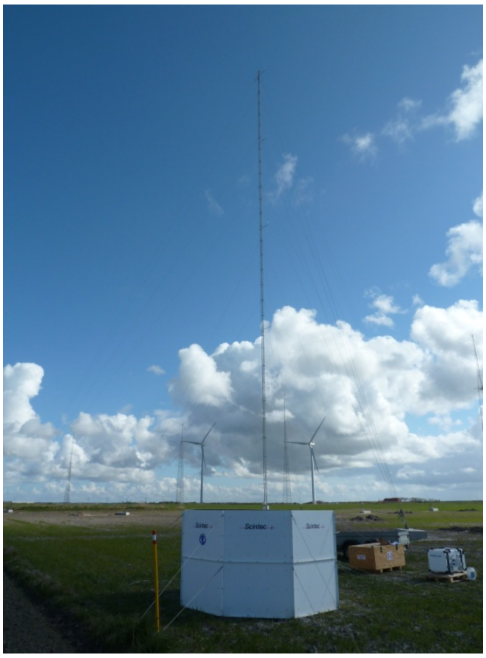
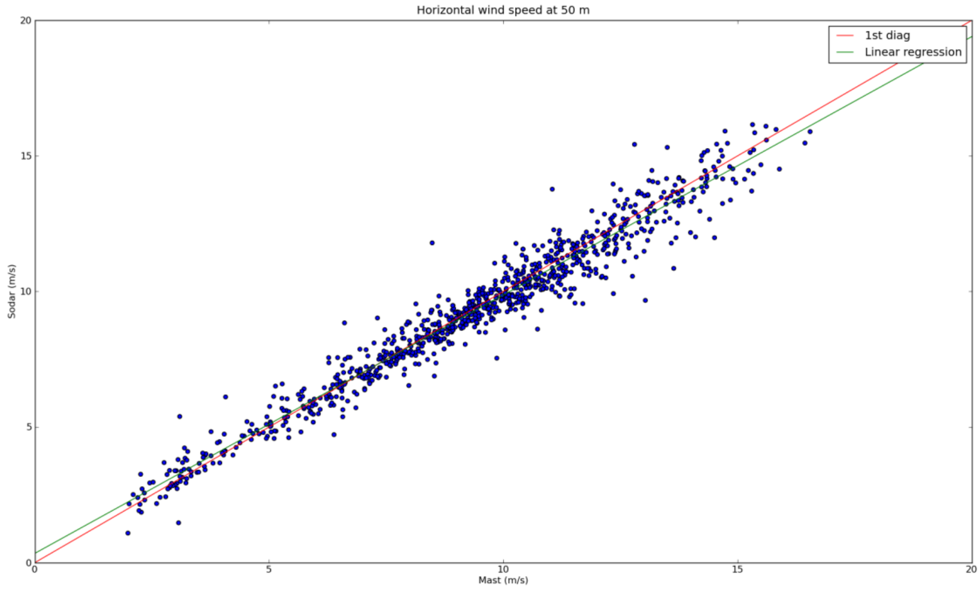


Figure 1: Pictures of the Scintec SFAS sodar during the Hovsore campaign.



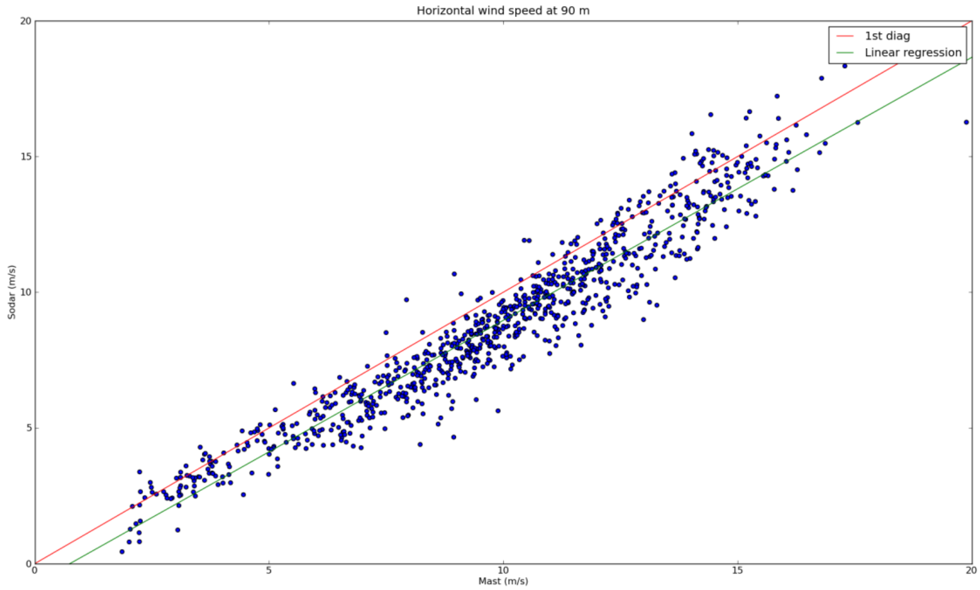


Figure 2: Scatter plots of the comparison between the Scintec SFAS sodar and the cup anemometers of mast 3B, at 50 m (above) and 90 m (below) levels, during the Hovsore campaign.

4. Conclusions

An assessment of the Windcube lidar measurements has shown excellent comparison to co-located mast measurements. All 4 datasets would be suitable for other tasks within the SafeWind project.

The Windcube and ZephiR lidars have been found to have a similar bias in flat terrain, after the necessary filtering has been identified. This result will provide a basis for the future comparison of the instruments in complex terrain (Task 2.3).

Only limited results were obtained from the Scintex sodar due to a number of technical failures. It was found that the sodar was positioned too close to the reference mast, producing fixed echoes at several heights. This significantly de-graded the quality of the measured data. A greater distance between the sodar and reference mast will be implemented in future campaigns but was not possible within the constraints at the Høvsøre test site.

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