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ZephIR 300M wind lidar firmware intercomparison

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Abstract

We have performed an intercomparison between two ZephIR 300M wind lidars instrument at the Cabauw site, in order to verify the new ZX firmware in comparison to the old ZP firmware. In general, within the specified accuracy of the manufacturer no significant differences where observed in the output of the two wind lidars, considering the 10-minute averaged data of the horizontal wind speed and wind direction. Additional features of the ZX firmware are also discussed, such as the quality controlled unaveraged data, and consequences in the filesize and MODBUS application.

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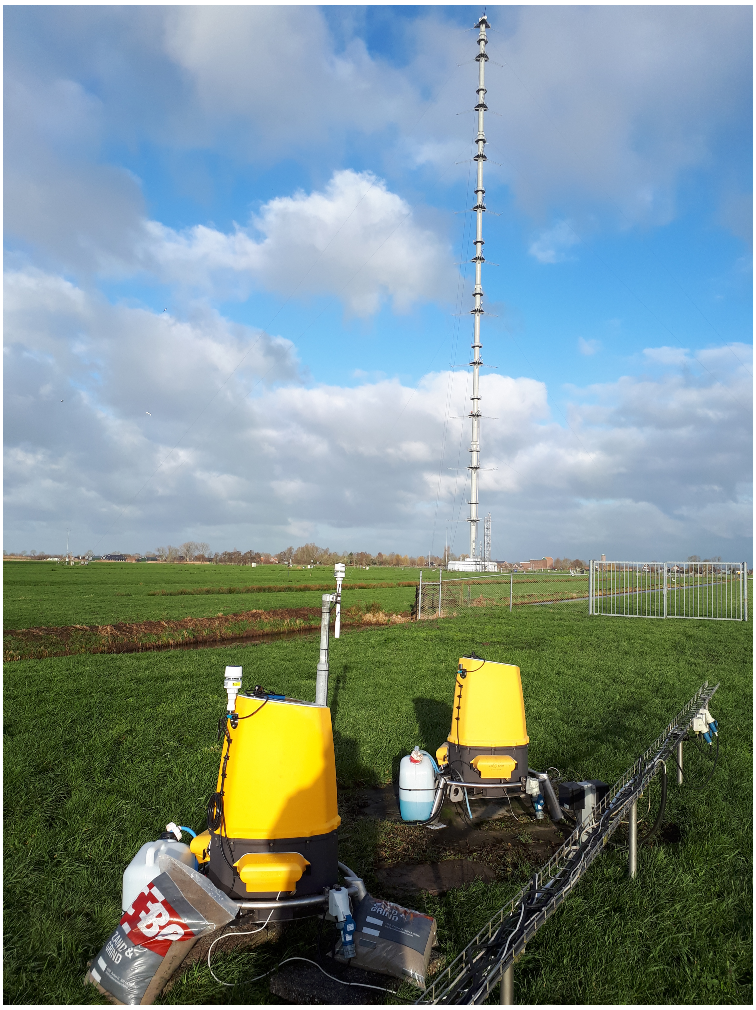

Figure 1: Photo of the two ZephIR 300 wind lidar instruments (ZX973 left, ZP738 right) at the Cabauw site, with the 213-m tall A-mast in the back.

1 Introduction

The ZephIR 300M wind lidar (ZX Lidars, UK) has been selected to be installed on offshore substations within the offshore wind farms in the Dutch North Sea (Borssele, Hollandse Kust Zuid, Hollandse Kust Noord). Its main purpose is to continuously measure the wind speed and direction at hub height, such that in the event of an unavailable offshore electricity grid compensation can be determined on basis of the actual wind conditions. Currently wind lidars are operational at platform Borssele Alpha (since July 2019) and Borssele Beta (since June 2020), and three more are planned (Hollandse Kust Zuid Alpha and Beta, Hollandse Kust Noord) in the coming two years.

In this context the KNMI carried out a two-year measurement campaign (Feb. 2018 - Feb. 2020) of this particular ZephIR 300M instrument at the Cabauw site [1]. The (height-dependent) data availability of the wind lidar under various meteorological conditions and the data quality of 10-minute averaged horizontal wind speed and wind direction via a comparison with in situ wind measurements at several levels in the 213-m tall meteorological mast was studied. The mean bias in the horizontal wind speed was found to be within 0.1 m/s with a high correlation between the mast and wind lidar measurements, although under some specific conditions (very high wind speed, fog or low clouds) larger deviations are observed. The mean bias in the wind direction was within 2°, which is on the same order as the combined uncertainty in the alignment of the wind lidars and the mast wind vanes. The well-known 180° error in the wind direction output occurred about 9 % of the time (3 % when considering wind speeds at 10 m above 4 m/s). The instrument used in this study was part of the first batch of wind lidars, delivered by the end of 2017, which contained the ZP firmware. The output is quality controlled 10-minute averaged wind data, and unfiltered unaveraged data.

In 2018, with the change in name from ZephIR Lidar to ZX Lidars, the manufacturer also introduced a new ZX firmware. The main additional feature compared to the ZP firmware is the reporting of quality controlled (i. e. filtered) unaveraged wind data. In order to verify its performance compared to the ZP firmware, an intercomparison was set up at the Cabauw (Feb. 2020 - June. 2020). In this report the results of this intercomparison are presented. Main point is the verification of the most commonly used output for meteorology and wind energy purposes: 10-minute averaged horizontal wind speed and wind direction. Also some practical differences between the two firmwares are discussed.

2 ZephIR 300M and ZP/ZX firmwares

The ZephIR 300M is a CW focusing vertical profiling wind lidar, which measures the wind at several heights above the instrument. The manufacturer specifies the wind speed and wind direction accuracies as better than 0.1 m/s and 0.5°, respectively, and a wind speed range from <1 m/s to 80 m/s, for a height range up to 200 m, but in the Waltz software a range up to 300 m can be selected. A laser beam is transmitted through a constantly rotating prism (wedge) to perform a so-called velocity azimuth display (VAD) scan. There is a maximum of 10 user-configurable measuring heights, besides a pre-fixed height of 38 m above the instrument. These heights are measured sequentially by changing the focus of the laser beam after each VAD scan. For each height one complete rotation takes 1 s, in which 50 measurements of 20 ms are taken, from which the 3D wind vector is reconstructed (i. e. horizontal and vertical wind speed, and wind direction). These 1-s wind measurements (also called "packets" by the manufacturer) are the unaveraged wind data, which is reported in the "Wind_..." day file. The instrument also outputs quality controlled (QC) 10-minute averaged wind data in the "Wind10_..." day file. For wind speed the mean is taken to derive the 10-minute averaged data, for wind direction vector averaging is applied. If a 10-minute averaged data does not pass QC, a "9998" or "9999" code is given in the "Wind10_..." day file, depending on the reason why the data did not pass QC.

The fundamental change in the new ZX firmware is that the quality control is performed already at the 1-s wind measurement level. Thus, the unaveraged wind data is quality controlled, and the "9998" or "9999" codes are also given in the "Wind_..." day file. Only those 1-s measurements that passed QC are used for the 10-minute averaged wind data. QC 10-minute averaged wind data requires either 8 or 25% (whichever is greater) of QC 1-s measurements available within the 10-minute period. In contrast, in the ZP firmware no QC is applied to the 1-s measurements, which all are used to construct the 10-minute averaged wind data, only after which the QC is performed.

3 Measurement campaign

The intercomparison was set up at the Cabauw site in Feb. 2020, as an extension of the two-year measurement campaign that started in Feb. 2018. Unit ZP738 (firmware 2.1027 ZP300) was installed at Cabauw in February 2018 and had been running continuously. Unit ZX973 (firmware 2.2029 ZX300) was installed directly next to unit ZP738 on Feb. 19, 2020 (see Fig. 1). Both instruments were de-installed on June 8, 2020. Therefore this intercomparison campaign encompassed Feb. 20 to June 7, 2020.

The same measuring height configuration as the ZP738 was applied to the ZX973, containing the maximum amount of 11 measuring heights, ranging between 11 m and 300 m above ground level. The estimated accuracy of the alignment of the wind lidar instruments is about 1°. No maintenance (other than the automatic wiper system) was applied to the wind lidars during the measurement campaign. The meteo station of the ZP738 was re-located from a separate pole to its original position on top of the wind lidar on March 6, 2020. More information on the Cabauw site and the in situ wind measurements (cup anemometers and wind vanes) can be found in Ref. [1].

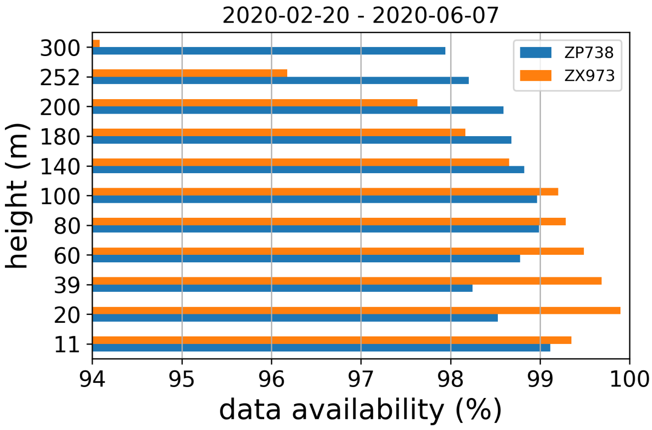

Figure 2: Overall availability of QC averaged wind lidar data for the different vertical levels.

4 Results 10-minute averaged wind data

In this section the main wind data output, the quality controlled 10-minute averaged horizontal wind speed and wind direction, is discussed. A direct comparison between ZP738 and ZX973 is given, as well as a comparison with the mast measurements for some selected heights.

In Fig. 2 the overall availability of the QC 10-minute averaged wind data is shown. For the ZP738 data availability ranges between about 98 % and 99 % over the full height range, similar as in Ref. [1]. The ZX973 has more than 99 % availability up to 100 m, above the availability goes down with height, having just above 94 % at 300 m. According to ZX lidars [2], both differences can be explained by properties of the new firmware. There is a more stringent quality control in case of low clouds and fog, which is relevant for the upper levels. Therefore the lower data availability of the ZX firmware at those higher heights, should be accompanied by a better quality of the data. The quality control on the 1-s level results in a less rigid rejection of data during rain episodes, which explain the higher data availability of the ZX firmware at the lower heights.

4.1 Wind speed

The horizontal wind speed data of the ZP738 and ZX973 instruments are compared for all heights. Scatterplots are presented in Fig. 3. Linear regression fits are shown and the correlation coefficient R^2 is provided, for both one- and two-parameter fits. In addition, the mean bias and standard deviation are given. Bias is defined as ZX973-ZP738. For visualization purposes the scatterplots are presented as density plots with finite bin sizes, with a logarithmic color scale. The fits and biases are related to the individual data points.

For the one-parameter linear regression we find the slope ranging from 0.997 to 1.006 with R^2 better than 0.997. For the two-parameter linear regression the results are similar up to 140 m, above which they get a bit worse with height, with a smaller R^2 and for instance a larger offset. The mean bias is between -0.04 m/s and 0.04 m/s for all heights, except 300 m, where the mean bias is 0.09 m/s. The standard deviation is about 0.2 m/s up to 140 m, above which it increases up to 0.6 m/s at 300 m. These results are considering the full wind speed range. The mean biases are within the specified accuracy of 0.1 m/s.

In Fig. 4 the horizontal wind speed data of the the ZP738 and ZX973 wind lidars at 200 m are compared with the cup anemometers in the mast. The mean bias and deviation from unity slope have the same magnitude (but opposite sign), the ZX973 shows a slightly higher correlation (R^2) and smaller

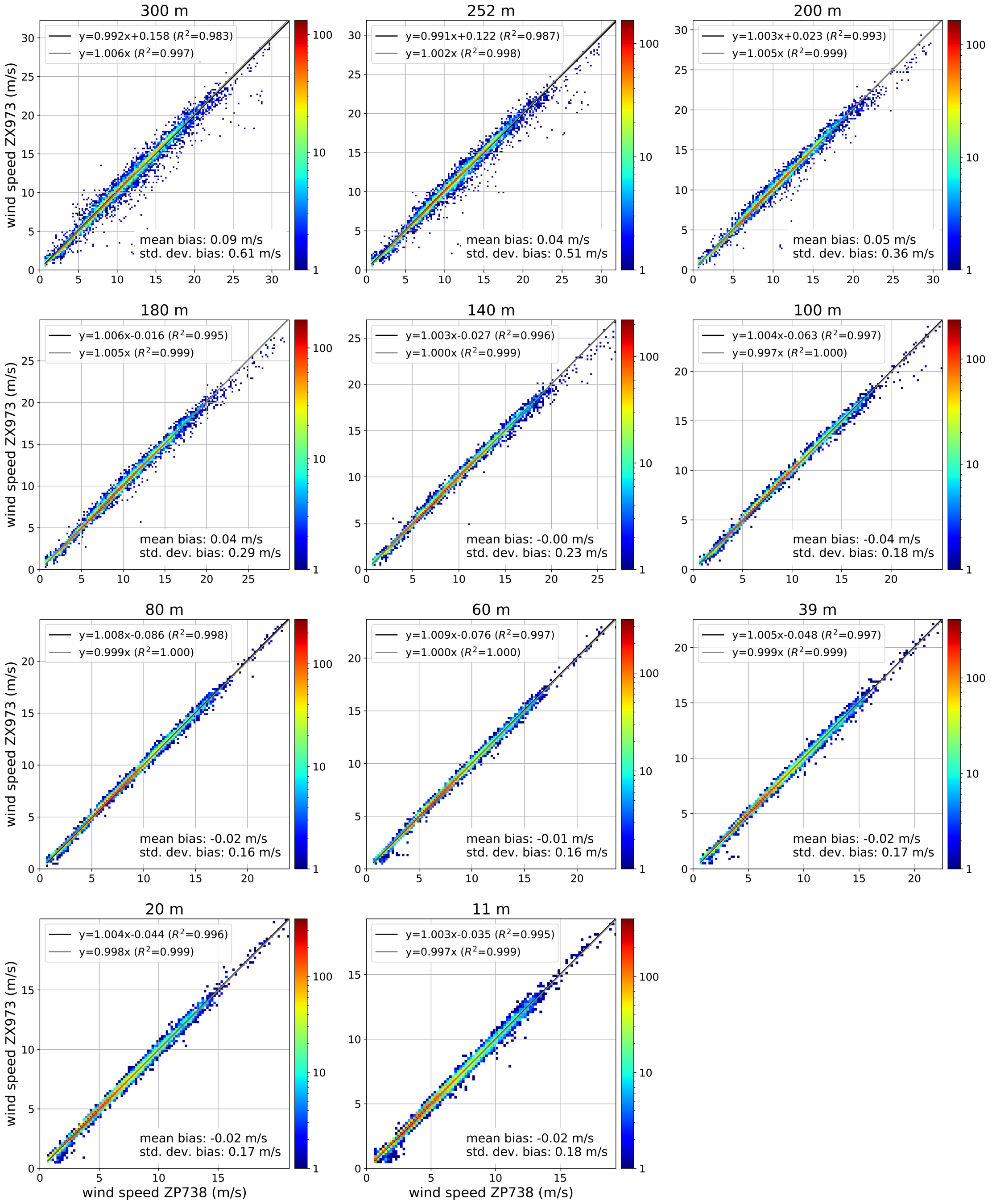

Figure 3: Wind speed comparison between ZP738 and ZX973 for the different heights. The results of a linear regression analysis (with and without offset), and the mean bias and standard deviation in the bias are indicated in each panel.

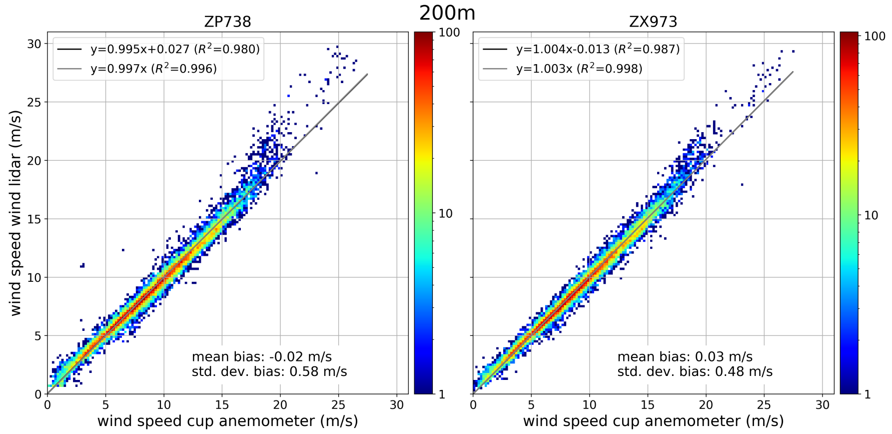

Figure 4: Wind speed comparison between the wind lidars and the mast at 200 m. The results of a linear regression analysis (with and without offset), and the mean bias and standard deviation in the bias are indicated in each panel.

standard deviation. At high wind speeds (>20 m/s) the wind lidars seems to overestimate the wind speed, which was also observed in Ref. [1]. An example of a time-series of wind speed data, comparing the wind lidars and the mast, is shown in Fig. 5. During these days the mast measurements reported the highest reported wind speeds during the measurements campaign. Indeed, at 200 m both wind lidars overestimates the wind speed at the peaks, but the ZX973 clearly less than the ZP738. This trend is confirmed in Fig. 6, where the results of the (one-parameter) linear regression and the bias between the mast en wind lidar measurements for different wind speed classes are shown, for 80 m, 140 m and 200 m. In terms of mean bias, only the highest wind speed class (>20 m/s) shows a significant difference between the two instruments, with the ZX973 showing a smaller bias. For the wind speed class most relevant to wind energy applications, 4-16 m/s, the results of the two instruments are essentially the same and well within the specified accuracy of 0.1 m/s.

Finally, we have observed a small but distinct difference in the lowest reported wind speed, namely 0.6 m/s an 0.4 m/s for the ZP738 and ZX973, respectively. As the ZephIR 300M is a homodyne wind lidar, a high-pass filter needs to be applied to remove very low frequencies in the backscatter signal, which means that very small Doppler shifts (corresponding to very small wind speeds) cannot be measured. According to ZX lidars, the ZX firmware has some advancements in signal processing compared to the ZP firmware, such the minimum wind speed that can be reliably detected is lower [2].

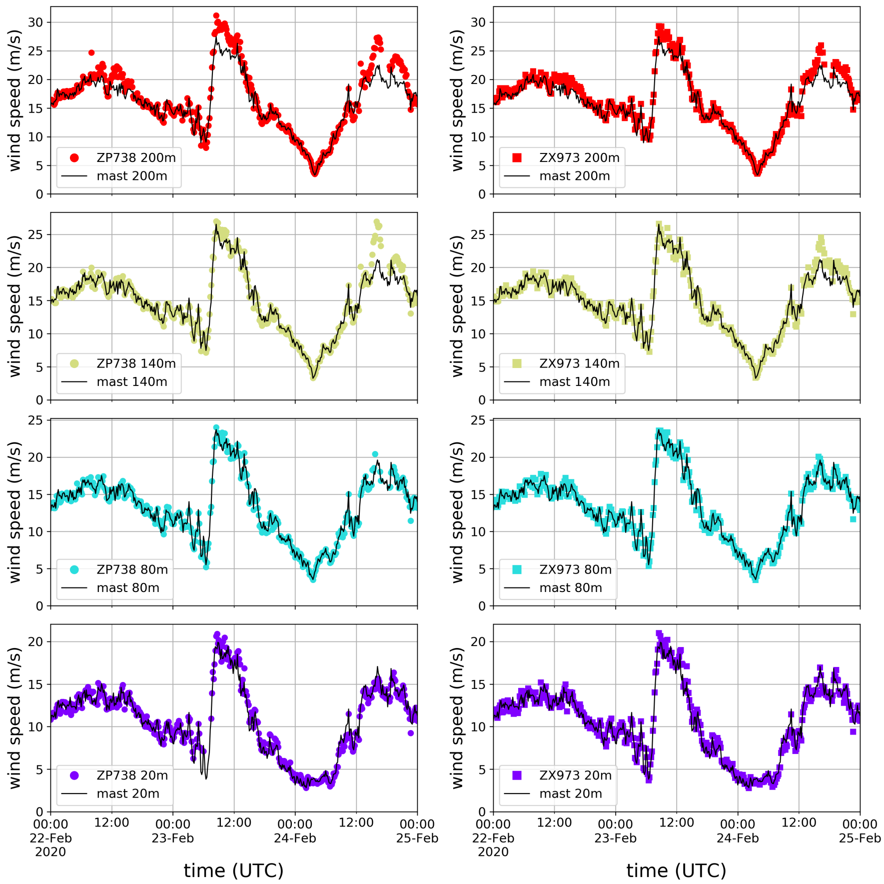

Figure 5: Wind speed measurements of February 22-24, 2020, comparing the 10-min averaged data of the mast (black solid lines) and the (a) ZP738 and (b) ZX973 wind lidars (colored symbols), for different heights (indicated on top of each panel).

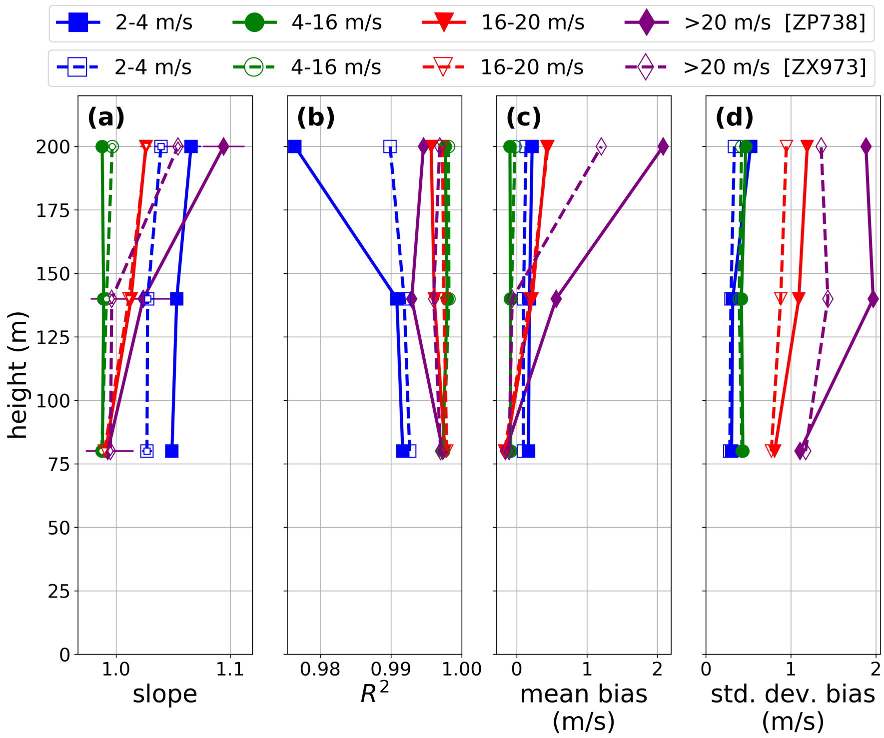

Figure 6: Profiles of linear regression analysis results and biases in the wind speed, applied to four different wind speed classes: 2-4 m/s (blue squares), 4-16 m/s (green circles), 16-20 m/s (red triangles) and >20 m/s (purple); solid symbols ZP738, open symbols ZX973. Panels (a) and (b) shows the parameters for a linear regression without offset (slope and R^2), and panels (c) and (d) the mean bias and standard deviation of the bias. The error bars in panel (a) indicate the standard uncertainties of the parameter estimates (often smaller than symbol).

4.2 Wind direction

The wind direction data of the the ZP738 and ZX973 wind lidars are compared for all heights. Scatterplots are presented in Fig. 7. The mean bias and standard deviation are given. Bias is defined as ZX973-ZP738. The mean bias is around -1°, which is within the (combined) alignment accuracy of the instruments. The standard deviation is about 5°, which depends on the wind speed range considered. When omitting small wind speed (<4 m/s), the standard deviation is at most 2° up to 200 m, but 4° at 300 m. In Fig. 8 the wind direction data of the the ZP738 and ZX973 wind lidars at 200 m are compared with the wind vanes in the mast. The mean bias is below 1°, well within the (combined) alignment accuracy of the wind lidars and the wind vanes. The standard deviation is about 6°, which reduces to 3° when omitted wind speeds below 4 m/s.

In Fig. 8, but also in Fig. 7, wind direction measurements that are off by 180° can be recognized. This is a well-known issue of the ZephIR 300, and explained in depth in Ref. [1]. In order to quantify the occurrence of these "wrongly assigned" wind direction measurements, we consider events for which the absolute difference between the wind lidar and the wind vane (at the same measuring height), denoted Δ, is more than 90° ($\Delta > 90°$). In the analysis above, these $\Delta > 90°$ events are omitted in determining the mean bias and standard deviation. In Fig. 8 the percentages of $\Delta > 90°$ events are also indicated: 4.1% for the ZP738 and 1.6% for the ZX973. In Ref. [1] it was found that $\Delta > 90$ depends on wind speed and wind direction, and occurs more often in low wind situations or when the wind flow towards the meteo station is obstructed. Therefore it is not so useful to make a comparison with the previous results of the ZP738 in Ref. [1], as the wind conditions are not the same. However, the present direct comparison indicates that the ZX973 has clearly less wrongly assigned wind direction measurements than the ZP738.

This can be further investigated by considering the amount of $\Delta > 90°$ events for the different wind sectors, which is shown in Fig. 9. Here the lowest measuring height of the wind lidars (11 m) is considered, and as a reference the 10-m D- (or AWS-)mast is used, which is closest to the wind lidars. Data is considered after March 6, 9:15 UTC, at which the meteo station of ZP738 put back to it original position, to provide equal condition for both wind lidars. Both wind lidars show similar behavior with wind directions, i. e. $\Delta > 90°$ mostly caused by Southerly wind due to flow obstructions from the remote sensing site, but the ZX973 suffers much less than the ZP738. Especially when omitting low wind speeds, occurrence for the ZX973 is almost zero. According to ZX Lidars [2], this is due to the improved internal algorithm in the ZX firmware, in which additional information from the wind lidar is used, besides the wind information from the meteo station, for the determination of the correct wind direction.

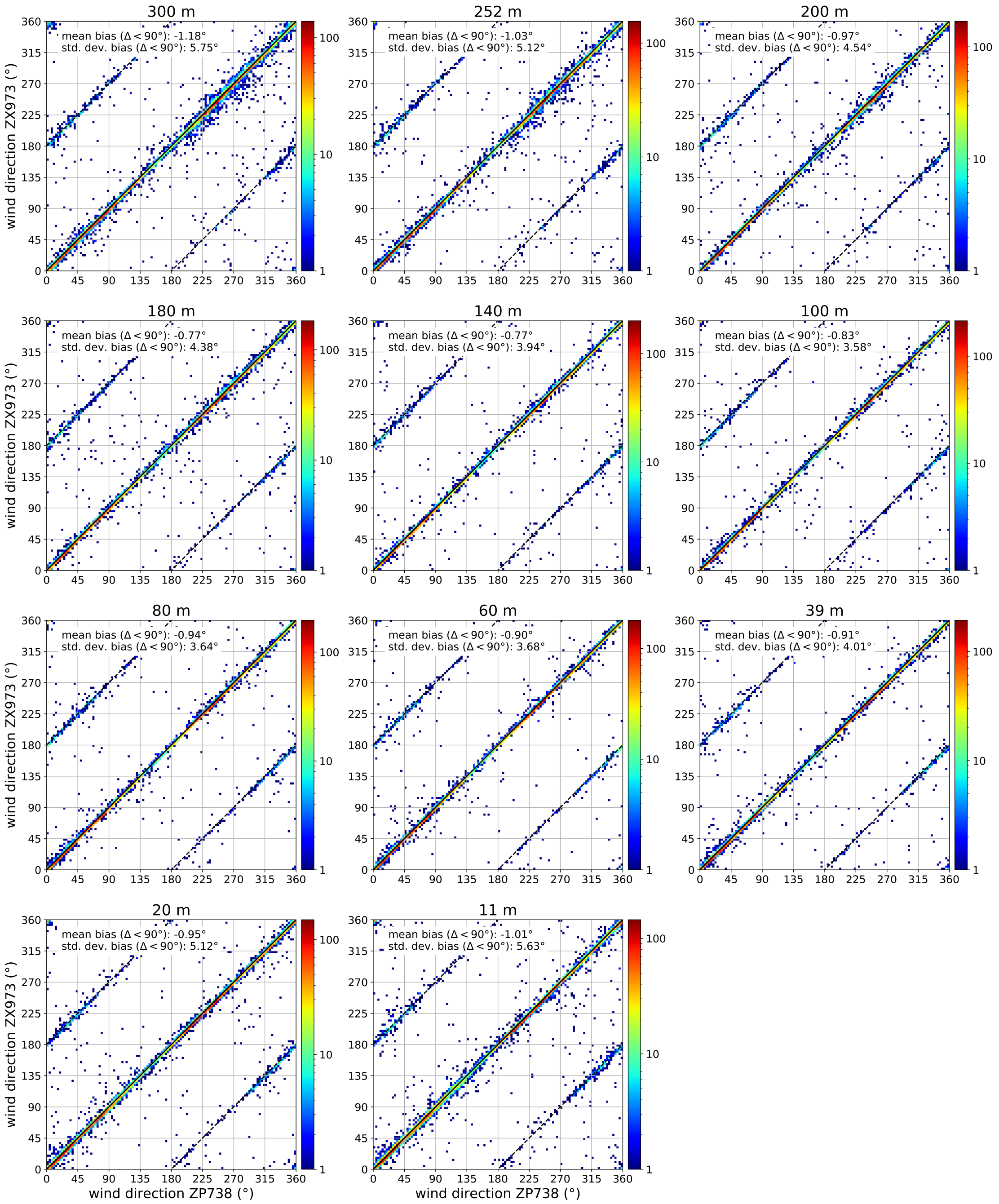

Figure 7: Wind direction comparison between ZP738 and ZX973 for the different heights. The mean bias and standard deviation in the bias are indicated in each panel.

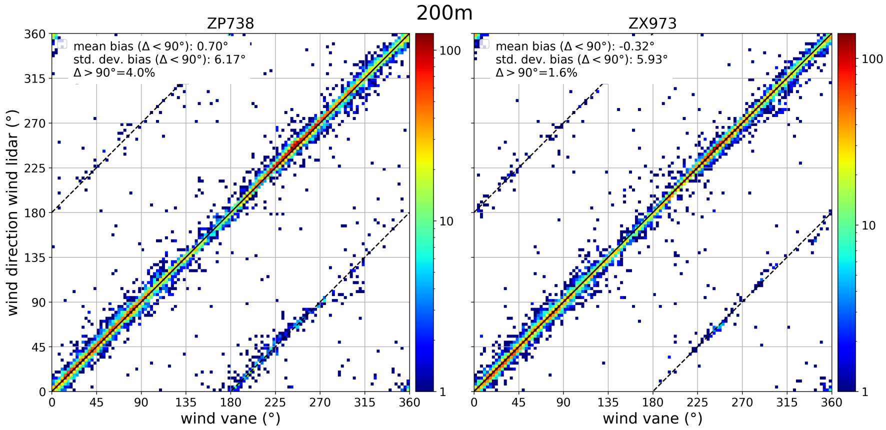

Figure 8: Wind direction comparison between the wind lidars and the mast at 200 m. The mean bias and standard deviation in the bias are indicated in each panel.

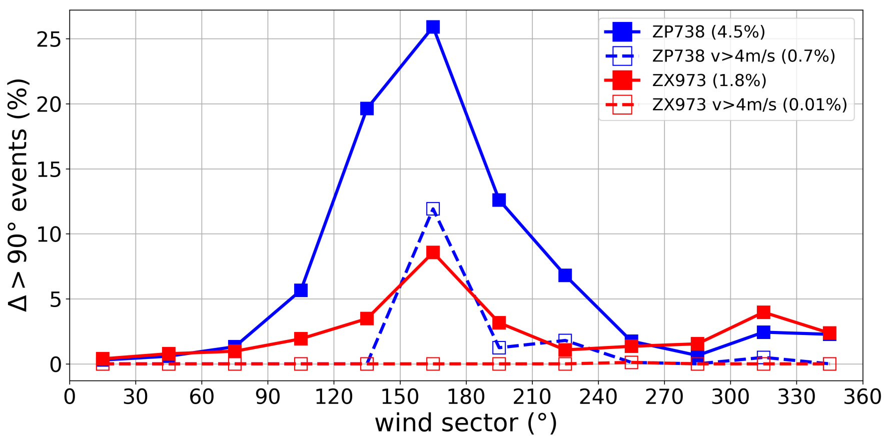

Figure 9: The $\Delta > 90^\circ$ occurrence for the lowest measuring height of 11 m for different wind sectors (binsize 30°), including a wind speed threshold of 4 m/s (as measured at 10 m). Percentage in the legend is the total occurrence of $\Delta > 90^\circ$.

	ZP firmware		ZX firmware	
	averaged	unaveraged	averaged	unaveraged
.zph	240 kB	6.6 MB	330 kB	10 MB
.csv	230 kB	6.6 MB	440 kB	12 MB
.csv −"checksum"	110 kB	1.9 MB	110 kB	1.8 MB

Table 1: Typical sizes for ZP and ZX firmwares day files, when operating the instruments with maximum amount of measuring heights. In the last row the "checksum" part of the .csv files is removed. Note that the zph2csv conversion of the unaveraged data was done without the "horizontal" mode.

5 Unaveraged wind data

The instrument measures the different heights sequentially, which makes up one measuring cycle. With a maximum number of measuring heights (11), the total duration of the measuring cycle is 17 s. In the "Wind_..." file all measurements of a cycle are given a single timestamp. This means that for the individual measurements there can be an offset in time of at most 17 s. The first data of the dayfile starts around 00:02:00 for ZP738 and 00:04:00 for ZX973, instead of 00:00:00. This is probably because the instrument need some time to process the dayfiles of previous day (including .zph to .csv conversion), which apparently this takes a bit longer for ZX firmware.

With the ZX firmware it is possible to get the individual timestamps for every packet. For this the data needs to be exported or converted in a so-called "horizontal" mode. Then, in the "Wind_..." .csv data file there will be an additional column labeled “height” and each row is an individual packet with a unique timestamp[1]. Application of the "horizontal" mode does lead to a larger .csv filesize (by about 50%).

The ZX firmware has less wind data in the "Wind_..." dayfiles because only the quality controlled unaveraged wind measurements are reported, while for the ZP firmware all the unaveraged data is given. However, knowing that the 1-s measurement are quality controlled makes these data more valuable and useful for research purposes. Note that the unaveraged data is not used for the "compensation scheme".

6 Practical issues

6.1 Filesize

With the ZX firmware the filesizes of "Wind10_..." and "Wind_..." day files are much larger than with the ZP firmware. It turns out that the difference is found in "checksum" part of the data, which has increased in size with the ZX firmware. This checksum is added only for internal diagnostic use by the manufacturer and is not of use for any other purpose. In the .csv file the checksum is a column that can simply be removed[2]. In doing so, the filesizes of the .csv files for the ZX and ZP firmware become nearly the same. In Table 1 an overview of the filesizes is given. Note that removal of the "checksum" data is not possible for the .zph files.

6.2 MODBUS

The ZephIR 300M can also be polled via MODBUS communication. This is an attractive alternative to retrieving the (running) day files via FTP for real-time application of the unaveraged wind data. The

[1] In the KNMI data chain, the unaveraged .csv files are not retrieved via the "horizontal mode", however with the unaveraged .zph files one can apply the zph2csv converter to get this particular form of the data.

[2] In the KNMI data chain, providing the files to the RWS FTP server and the KNMI dataplatform (KDP), the checksum column is indeed removed from the .csv files.

instrument implements a subset of the MODBUS/TCP protocol. This is similar to the standard MODBUS protocol but uses a TCP/IP carrier and has no checksum. The MODBUS server is on the standard MODBUS port 502. The MODBUS implementation is read only, and cannot be used to configure the instrument.

Multiple registers in a single height measurement can be polled at once and this is the recommended mode. For a particular height, the registers will all change simultaneously when the lidar completes a scan. If multiple registers are read in a single read, they are guaranteed to all be from the same measurement. The data is grouped into three blocks of registers: unaveraged data, averaged data and configuration data. A complete list of the registers can be found in the manuals [3].

For most part the MODBUS registers for ZP and ZX firmwares are the same. At the end of the unaveraged data block the ZX firmware has some additional registers (namely 49 to 65). However, in the configuration data block the ZX firmware has one additional register (8225, height #12), with the consequence that the next registers in this block (such as bearing and lens height) are shifted in address. If those registers are actively used in a MODBUS application, it means that is this application is not cross-compatible between the ZP and ZX firmwares.

7 Conclusion

We have performed an intercomparison between two ZephIR 300M wind lidars instrument at the Cabauw site, in order to verify the new ZX firmware in comparison to the old ZP firmware. In general, within the specified accuracy of the manufacturer no significant difference where observed in the output of the two wind lidars, considering the 10-minute averaged data of the horizontal wind speed and wind direction. The ZX973 instrument shows a smaller bias at high wind speed above 20 m/s. The ZX973 shows larger data availability at the lower height (more than 99%), but lower at the heights (down to 94% at 300 m). The ZX973 has much less wrongly assigned wind direction measurements (by 180°) than the ZP738. The filesizes in the ZX firmware are significantly larger. This can be solved for the .csv files by removing the "checksum" column; this is not possible for the .zph files. For the MODBUS application one should note that part of the registers in the configuration data are shifted in the ZX firmware.

We would recommended to accept the ZX firmware, as the data quality compared to the ZP firmware is equally good or even better, with additional benefits regarding the unaveraged data (quality controlled, possibility of retrieving the individual time stamps).

Acknowledgment

We acknowledge Rijkswaterstaat Maritiem Informatievoorziening Service Punt (RWS-MIVSP) for supporting this measurement campaign and providing the two ZephIR 300M instruments. We also acknowledge Alfons Driever (KNMI) for technical support.

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