Suppression of precipitation bias on wind velocity from continuous-wave Doppler lidars

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Iteration: First review round.

REVIEW COMMENTS

OVERALL SUMMARY

The authors address a timely subject in wind-lidar remote sensing, which is the removal of the bias caused by precipitation in the measurement of wind velocity. This topic is of interest aligned with different research programmes in the EU and US (e.g., NASA Clouds, Aerosol and Precipitation programme).

The authors successfully demonstrate the proposed bias-removal method by conducting a field experiment at the Risø of the Technical University of Denmark that uses three wind-scanner lidars staring at same point and reference sonic anemometer measurements. The experiment discusses the impact of different rain rates (although limited to a maximum of 4 mm/h) and –up to a point- the effect of different lidar focusing lengths. The paper is well written and easy to read. The experimental part was carefully planned and executed.

Sect. 4.1 addressing the signal processing method – a core part of the manuscript - could be improved a bit along the lines suggested by the General Comments below. Sect. 5 figures could be streamlined and summarised considering that the manuscript already contains as much as fifteen figures, many of them multi-panel.

All considered, I recommend minor revision along the lines suggested by the general comments below.

GENERAL COMMENTS

My first comment essentially addresses the processing methodology of Sect. 4.1 in light of making –an already good manuscript- into a better structured and self-contained manuscript to read. Please consider these comments:

- The signal processing part is a bit weak. Please include a processing diagram block describing: (i) the standard and (ii) the new signal processing method proposed. This is a core part of the paper. Please connect the contents of Sect. 4.1 with the block diagram.
- Structure: I suggest dividing Sect. 4.1 in three parts:

1) Standard signal processing of the 3 kHz Doppler spectra: (L152-L159) + L161-L167. I'd say L160 talking about the 50 Hz spectrum is orphan and should be moved somewhere close to L179 when you start talking about the down sampling of the spectrum. Clearly separate between 3-kHz and 50-kHz processing. Clearly enunciate the down-sampling block.
2) Comparison between aerosol and rain Doppler spectra (L168-176).
3) The "proposed" method of the paper (L177-187).

The support of literature references included in this section is weak.

Second, I think the amount of Figure panels in Sect. 5 could substantially be reduced or moved to a Supplementary Materials Section considering that the manuscript already contains as much as fifteen figures, many of them multi-panel. For example, Fig. 12 could be skipped and Fig. 13 retained along with summary comments given in the text or with the help of a supporting Table. Most of the scatter plots can substituted by a Table describing the determination coefficients obtained plus a link to the Appendix /

Supplementary Materials for the interested reader. Similarly, Fig. 14 could be streamlined by including only panels b-d-f (WindScanner #3) and a comment or Table with descriptive PDF statistics.

> But I leave the final selection of Figures/panels to the authors, or alternatively, to choose a better art arrangement.

SPECIFIC COMMENTS

L5 “the noise-flattened Doppler spectra.” Consider: “the noise-flattened 3-kHz-sampled Doppler spectra”.

L9 Consider: “at 50-Hz (20 ms) temporal resolution”

L10 Please clarify “conventional”

L25-30 In Sect. Introduction please comment a bit on the probe-length turbulence averaging effects in comparison to e.g., cup anemometers since this is an important drawback of focusing lidars (e.g, averaging of spatial turbulence scales).

L26 Change “that” into “which”

L54 Not sure acronym “CW” (continuous wave) has previously been defined. Preferably, use “CW” in caps.

L84 “can be approximated as [REF needed],”

Tab. 4. Please check if “angle to the North” is computed correctly. In a Cartesian coordinate system, angles are defined positive CCW. And angles between vectors (or between e.g., vector “1” and vector North) are computed by using equipollent vectors so that their origin coincides with the Cartesian origin (i.e., point 5 = projection of point 4 in the XY plane). From the geometrical angles given in Fig.3b and assuming North is 0 deg then I’d say ”Angle to North” should be: (WindScanner 1) -42.6 deg; (WindScanner 2) 180 + 7.1.deg = 187.1 deg; (WindScanner 3), 60.7 deg. Please clarify if other Math/Physics conventions are used.

L95a Please state and clarify to the reader the “key” numbers of the processing. Don’t let the reader guess them. Specifically:

1) Fast Fourier Transform (FFT) frequency_resolution: 120 MHz / 512 samples = 234.4 kHz/samples → speed resolution = (lamdda/2)*freq_resolution = 0.183 m/s
2) Spectrum_estimation period = sampling rate (1/120 MHz) x 512 (samples/spectrum) x 78 spectrum/average = 332.8e-6 [s] → spectrum_estimation rate = 1/spectrum_estimation_period = 3 kHz

L95b Please briefly summarise which power spectral density (PSD) and which peak spectral estimation method is used to retrieve the Doppler shift. I think this should also be remembered to the reader and shortly discussed later on, in L153-155.

L93 I recommend to repeat “all times are UTC+1” in all figure captions involving time series to help the reader.

L100 “less than the beam transit time of a typical rain drop”. Please add literature REFERENCE.

L101 Please briefly clarify how the 0.35 ms transit time was estimated. E.g., at 9 m/s fall velocity we get, 9 m/s x 3.14 mm = 28 ms (in the near field “waist” of the laser beam).

L109 Consider to give manufacturer/model for the wind vane and temp sensors.

L118 I recommend drawing X, Y and Z labels on Fig. 3a to help the reader identify the given unit vectors ([−0.36, −0.39, −0.85], [−0.10, +0.82, −0.57] and [+0.84, −0.47, −0.26]).

Tab. 2 What does symbol “/ ≥” means in “$0.1875/\geq 8$? Is that a typo?

Fig.7-8. Font size. The “10-min” text in X and Y labels of panels (b) can barely be seen. Please enlarge font and include in the captions “Comparison of 10-min wind speed”.

Fig. 9 CAPTIONS (comment to be extended to all manuscript figure captions) I recommend setting label letters at the beginning of each sentence and not at the end or in the middle of the sentence, for better clarity. I recommend to begin each figure caption with a sentence giving an overview of what the figure is about. Then use follow-up labels (a), (b) addressing each panels. E.g., "Rain event September 27th, 2022, 15:00-19:30 measured by the Thies (…)**. (a)** Rain Intensity. **(b)** Distribution of the number of measurements … (color coded)."

I also recommend including in the caption the temporal resolution of the data (although this may seem repetitive), e.g., 1 minute, in this case.

L155 Please introduce acronym "power spectral density (PSD)" See also comment L95b for discussion.

L157-160 Different issues. Unclear. I would suggest expanding the spectral estimation part. In detail:

a) "However, if the wind velocity is around zero, this procedure does not work." Why, taking into account that the noise PSD is not zero? Please clarify.

b) L158-160 "where the line-of-sight velocity fluctuates around zero". At this point in text, mention to the reader that vertical line at approx. bin 255 (please clarify bin no.) corresponds to the zero-Doppler shift.

c) Why such a negative red peak at bin 255 occurs for the background noise (red trace) in Fig. 10a?

L178 "down sample". Please clarify how the "down-sampling" procedure is carried out. Is it that given the normalised spectra, which make evident the rain returns as very high and narrow peaks, these spectra are screened out for "very large" peaks, therefore, removed from the spectra average? This is known as histogrammed filtering but no quantitative criterion is given. Please give a quantitative criterion for screening out the "rain returns" in Fig. 10d. For example, is that percentile 90 of the cumulative distribution? Please consider to include this histogrammed filtering block in the proposed processing diagram above.

Fig. 10. Please vertically align panels (a) and (c). Please use the same X-axis range to ease comparison.

Fig. 10 caption. Please add: "The solid black line stands for the zero frequency bin" (as in Fig. 11).

Fig. 10. Which method is used to compute the PSD? E.g. Periodogram or others. Please include literature reference.

Fig. 11 Caption, L4. "represent the median frequency bin" or "stand for the median frequency bin"

Fig. 11 (b)(d) Please use the same frequency-range (X-axis) in both panels.

L209 Change "that occurred" into "which occurred"

L222 "more" missing → it rains more heavily than lightly

Tabs. 4-5 Please repeat in caption key information on "rain intensity" and "probe length".

Tab. 4. Please stick to two decimal digits everywhere. Please check for errors/typos on column "light-rain minute"

Figs. 12-13. Legends: The logical order should be "sonic-raw-norm" instead of "raw-sonic-norm".

Fig. 16 caption. Please repeat in caption "probe length" values to help the reader.

CONCLUSIONS Please give conclusions on your findings about the performance of the methods for different probe lengths (short/large probe length, which is an important point –although more risky- or your research) as well as future lines. Part of the conclusions given in L183-185, L221-224, L244 should be rewritten / summarised in Sect. Conclusions.