Reply to Referee #1

Dear Referee #1,

We would like to thank you for your time, valuable comments and for the interest shown in the topic. In our opinion you have helped a lot in improving the clarity of the paper. We have answered all your comments, following the same order that you used. Text in blue refers to text added/modified in the new version. Thanks again

The authors

What I am missing – this as a more general comment – is a further discussion of the forecast horizon in relation to the range of the lidar measurements. The authors explain why they only could use data with a reach of up to 6 km. But I would think that is rather a weak point of the specific experiment, and data with higher ranges (possibly up to 10 km or beyond) may be available for very near-future analyses. How would this impact the results of the study?

Thanks for the interesting point. We have now included a paragraph regarding this comment in the Concluding Remarks section, between the first and second original paragraphs.

In this paper the forecasting horizon is limited to 5 min due to the maximum range of the lidar measurements (6 km) and the high wind speeds experienced during the measurement campaign. A long-range lidar system with a maximum range of 10 km could forecast wind speeds up to 17 m/s, thus generating forecasts with a horizon of 10 min. Long-range lidar systems would be particularly interesting to detect ramp events, i.e., large variation in wind speed within a short period of time, especially when unexpected decreases in wind speed cause severe power drops. Since commercially available ultra-range lidars can now measure up to 30 km (Kameyama et al., 2012) the forecasting horizon for this application could be extended up to 30 min ahead.

Kameyama, S., Sakimura, T., Watanabe, Y., Ando, T., Asaka, K., Tanaka, H., Yanagisawa, T., Hirano, Y., and Inokuchi, H.: Wind sensing demonstration of more than 30km measurable range with a 1.5mu;m coherent Doppler lidar which has the laser amplifier using Er,Yb:glass planar waveguide, in: Proc.SPIE, vol. 8526, pp. 8526 – 8526 – 6, https://doi.org/10.1117/12.977330, 2012.

A further general comment relates to the structure of the manuscript, which I think should be overworked by the authors. The sections 'Wind data analysis', 'Wind conditions' and 'Modelling coastal effects' amount to a major part of the paper before the actual key part (the section on the forecasting itself) is reached – I do not think that the proportions are fair here, and I am also missing the central theme at some points. Furthermore, I think the partitioning of the individual sections may be revised – the description at the beginning of section 2 is e.g. followed by sub-section 2.1 (and two sub-subsections) but no further sub-section. Sections 4 and 5 then have another structure. Please check again carefully if the structure of the manuscript really supports the logical chain and development of the argumentation or if this can be improved.

This part has been improved by including the wind conditions section (previously 3) as a subsection into the wind data section (now 2.2). The section Modelling coastal effects (previously section 4 and now section 3) has a new title "Modelling coastal effects for wind speed forecasting correction" to clarify its purpose. We believe it is necessary to explain in detail how we modelled the coastal effects. Therefore, we consider this part a full section of the paper.

[p.1 l.10] A figure from 2015 is given here – but the manuscript is from end of 2017. Please try to find a more up-to-date figure.

This has been updated with the new data released from the year 2017. A new record set by Denmark of 43.4%. Thanks for the recommendation.

In 2017 Denmark produced a record 43.4% of the country's electricity with wind energy.

Reference:

The Danish Wind Industry Association (DWIA): Wind energy production as a percentage of total electricity consumtion 2005 - 2017, http://www.windpower.org/en/knowledge/statistics/the_danish_market.html, 2018.

[p.3 first paragraph] Readers who do not know about the RUNE experiment already may miss that RUNE is the name of a publicly funded project run by DTU and partners. Please add these details. Also the Hovsore test site may not be known by all readers.

The authors consider they have included enough references to the project. Besides they think that the information about the project should be included in the Acknowledgement part, as it is done.

Regarding the Hovsore test site, this part has been modified:

Our study is based on measurements performed during the Reducing Uncertainty of Near-shore wind resource Estimates (RUNE) campaign (Simon and Courtney, 2016; Floors et al., 2016). The experiment was conducted at the western coast of Denmark, north of the area of Høvsøre (see Fig. 1) and close to one of DTU's wind turbine test station. A comprehensive analysis of the wind conditions at Høvsøre during a ten years period from the test station's meteorological mast, located 1.7 km east of the North Sea (see Fig. 1, position 8) is presented in Peña et al. (2016).

[p.3 Figure 1] I would prefer to have the explanations of the numbers/positions (only type of measurement system maybe) in the caption.

We have changed the caption of the figure as suggested:

Figure 1: Map of the area of the RUNE campaign indicating the positions of the dual-setup lidars (1 and 3), the PPI lidar (2), the profiling lidars (2, 4, 5, 6 (7)) the met-mast (8) and the wave buoy (9) located 150 m away from position 6.

[p.3 l.10] Here it says that position 6 and 7 are for a short-range lidar – which is actually a floating lidar – but in the remainder of the text it is only referred to the data from a wave buoy. This needs to be clarified. Was the wave buoy deployed at the same position (twice) as the floating lidar?

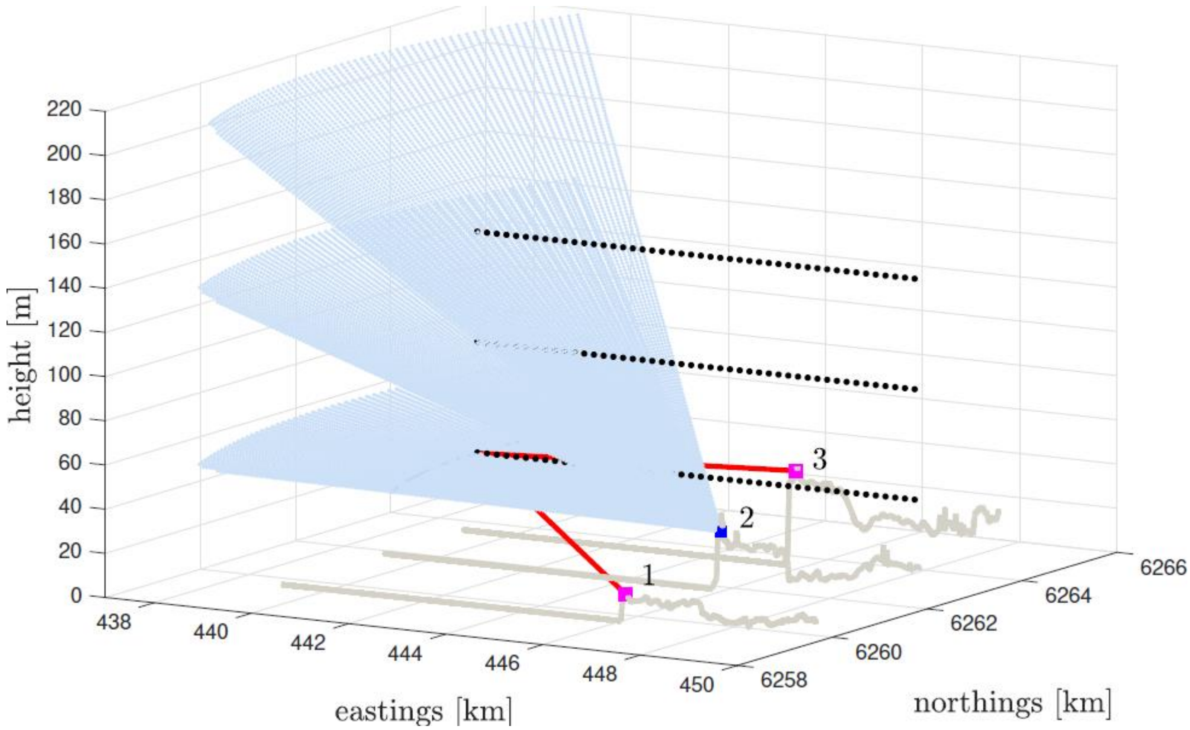
The wave buoy was located at a different position (position 9). This has been updated in the table and corrected throughout the document. Two references for the wave buoy have also been added.

Sanchez, R. and Rørbæk, K.: Metocean Buoy Deployment, Tech. rep., DHI, 2016.

Floors, R., Lea, G., Pena Diaz, A., Karagali, I., and Ahsbahs, T.: Report on RUNE's coastal experiment and first inter-comparisons between measurements systems, Tech. rep., DTU Wind Energy E-0115(EN), DTU Wind Energy: Roskilde, Denmark, 2016a.

[p.4 Figure 2] Figure needs to be reworked. For instance, I can see only one black line – and also details are not easy to be depicted.

Figure 2 has been reworked for clarity purposes.



[p.4 l.10] Here it says that 'Observations close to the lidar systems were also discarded some more detail (why this is bad), and the beams' geometry may be shown to define a certain threshold.

The angle between the beams should be large enough to allow measuring a difference in radial speed, but if it gets close to 180° this could lead to an error in the reconstruction of the wind speed when the wind is perpendicular to the beam direction.

We have added the following sentence after "since here the angle between the beams approaches 180°" and reference to the text:

"and, consequently, the uncertainty of the reconstructed speed becomes very high (Stawiarski et al., 2013)."

Stawiarski, C., Träumner, K., Knigge, C., and Calhoun, R.: Scopes and Challenges of Dual-Doppler Lidar Wind Measurements—An Error Analysis, Journal of Atmospheric and Oceanic Technology, 30, 2044-2062, https://doi.org/10.1175/JTECH-D-12-00244.1, 2013

We also included in page 6, line 4, after "the measurement ranges are longer than in the PPI"

"and, consequently, the uncertainty in the sensing height will be higher."

[p.8 l.1] ... 'shows the [averaged] reconstructed 10-min-mean wind speeds', I guess – this should be explained/specified in some more detail.

This has been clarified in the new version:

Figure 7 shows the ensemble average wind speed of all 10-min mean wind speeds reconstructed from the dual-setup observations…

[p.10 Figure 8] 'top' and 'bottom' in the caption should be left and right I guess – please correct, and/or add identifications (a) and (b) or similar. Beyond, it is rather difficult to read and understand the figures – please add some more explanation and also make the scales better comparable.

This has been modified in the new version. For better comparison only the orography corrections for 50 and 150 m AMSL are shown. The same scale is used for both plots. The caption now says:

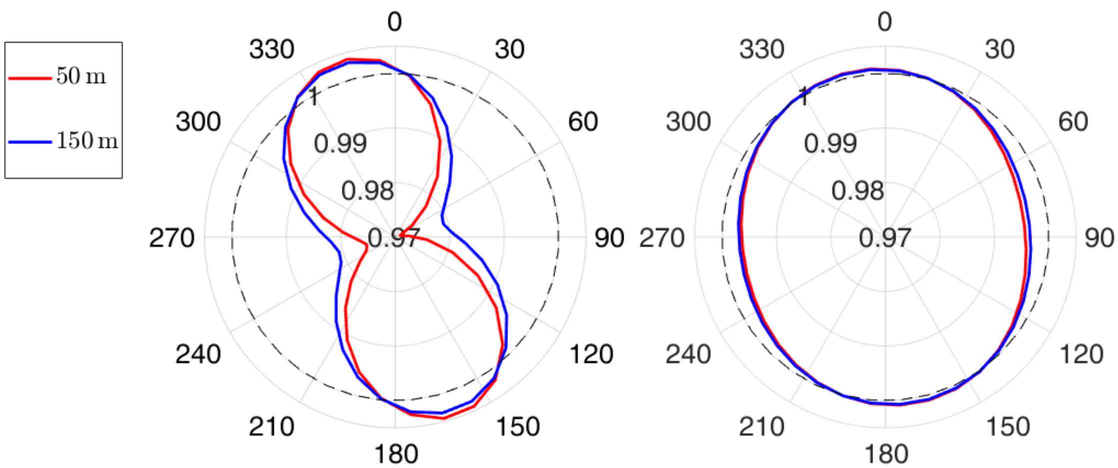


Figure 8: Directional orography effects O(x,z,dd) at x=500 m (left) and x=2950 m (right) from the coast at two heights AMSL.

We have also modified Eq. (2) on page 9, since the orography correction also depends on the wind direction.

$$\mathrm{U_{obs}(x, z, dd) = U(z_0(x), z)O(x, z, dd)}$$

, where O is an orography correction that depends on the height, the distance to the coast x and the wind direction dd. Note that we assume that z0 varies with the distance to the coast.

Also in page 13 we have modified the following text:

The orography corrections at the downstream position are applied using the measured wind direction at (1), i.e.

$$\mathrm{U^o_{2,z2} = U_{2,z2}(t)O(x_2, z_2, dd_1)}$$

[p.11 eq.(4)] This needs to be explained/specified further – I guess the bold letters refer to vector quantities (?)

The bold quantities refer to vector quantities. This section has been reformulated in the paper.

If at a time t a considerable change in wind speed occurs at position (1), this event will appear at the position (2) after some time Δt. In other words, this event can be foreseen at position (2) with a time ahead Δt. In our analysis, the downstream position is set to 500 m from the PPI lidar (position 2) in the westerly direction at z2= 33.76 m, which corresponds to the height of the intermediate PPI elevation scan. Lidar measurements are performed at multiple upstream positions (range gates) from which the forecast can be originated. This can be understood as having multiple virtual met-masts over several distances west of the downstream position. To keep a fixed forecast horizon, the upstream position (1) and height z1, from which the wind is advected, are determined dynamically at each time stamp using the 5-min moving average wind speed v2 (t) and direction at the downstream position. But because the vector v2(t) might not be parallel to the line of virtual met-masts, we use the vector projection of the advected distance on the wind direction $|r12|=|\Delta t v2(t)|\cdot\cos(\theta)$, with θ defined as the angle between the wind direction and 270 °. Because high wind speeds were observed during the measurement campaign, and the limit for high quality PPI measurements is≈ 6 km, we establish a forecast horizon of 5 min. We assume that a change in wind speed, observed 5 min ahead at the position (1) will propagate with a wind speed v1(t) and travel the distance r12 in the time Δt= 5 min.

[p.12 l.4] Here it says that only 'periods with wind speeds below 17 m/s' were selected, but this is not the case for period 3. Please comment on this or correct statement, respectively.

We have corrected this in the new version.

...with mean wind speeds below 18 m/s.

[p.19 l.4] ... 'were able to predict the wind speeds better than the benchmarks'. Please quantify this better (for your conclusions). Can you estimate the corresponding impact on a possible application?

We have calculated the improvement over persistence and ARIMA for all advection models and included a table with the results. Table 4.

We also included the following paragraphs in the results section:

Page 14. L25. After "in bold".

The improvement of the advection models over the benchmarks persistence and ARIMA are shown in Table 4. Values corresponding to best performance are indicated in bold.

Page 14. L26. After "statistical forecasting models":
The improvement over persistence using the best calibrated advection model for each period, ranges from 21-38%. Compared to the benchmark ARIMA the improvement ranges from 4-28%.

Page 18. L2. After "less turbulent".
For stable cases, disregarding the periods of high wind speed (1 and 9), the best calibrated advection models give improvements over persistence of 21-26 % and over ARIMA of 24-28 %

Table 4. Improvement of all advection models over the benchmarks persistence (Imp_P) and ARIMA (Imp_A).

		A		AH		AHR		AHRO	
Period	stability	Imp_P (%)	Imp_A (%)	Imp_P (%)	Imp_A (%)	Imp_P (%)	Imp_A (%)	Imp_P (%)	Imp_A (%)
1	stable	-448.98	-511.36	-275.51	-318.18	-157.14	-186.36	-102.04	-125.00
2	neutral	-158.42	-180.65	-27.72	-38.71	25.74	19.35	**29.70**	**23.66**
3	neutral	-96.36	-137.36	**20.91**	**4.40**	17.27	0.01	4.55	-15.38
4	neutral	-86.42	-106.85	16.05	6.85	**27.16**	**19.18**	8.64	-1.37
5	neutral	-60.18	-86.60	17.70	4.12	**38.05**	**27.84**	32.74	21.65
6	stable	-11.43	-8.33	24.29	26.39	**25.71**	**27.78**	22.86	25.01
7	neutral	-94.17	-100.86	4.17	0.86	**25.02**	**22.41**	19.17	16.38
8	neutral	-156.86	-172.92	-12.75	-19.79	**22.55**	**17.71**	14.71	9.37
9	stable	-600.02	-584.09	-416.28	-404.55	-276.74	-268.18	216.28	-209.09
10	stable	-2.33	2.22	**20.93**	**24.44**	2.33	6.67	-11.63	-6.67

In the Concluding remarks section we have also included the following paragraphs.

At the beginning:
This paper evaluated the use of wind lidar observations for very short-term forecast of near-coastal winds. From our analysis on periods with neutral atmospheric conditions, the best fitted advection-based model with corrections showed an improvement over the benchmarks persistence and ARIMA of 21-38% and 4-28%, respectively.

After "original line 23":
Our analysis is a first input component to a decision-making model that may include spot market prices, scheduled supply and demand and balancing costs. Thus, here it is not intended to quantify the economic impact of using a lidar-based wind speed forecast. However, as the balancing costs are proportional to the root mean square error, it can be assumed that they will decrease. In particular, as in most of the periods analysed the maximum absolute error is lower than that of the benchmarks, using a lidar-based wind speed forecast might have a positive impact on integrating offshore wind power into the grid.

[p.22 ll.20-21] The reference seems not to be complete, please add details. Is this an article?
This reference (technical report) is now completed.

Thanks again for this very interesting and informative manuscript – I am looking forward to seeing a revised version.

Thank you again for your interest.