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WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on "Improving mid-altitude mesoscale wind speed forecasts using LiDAR-based observation nudging for AirborneWind Energy Systems" *by* Markus Sommerfeld et al.

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Dear Dr. Floors,

Thank you very much for your helpful review of our manuscript, “Improving mid-altitude mesoscale wind speed forecasts using LiDAR-based observation nudging for Airborne Wind Energy Systems”, wes-2019-7. We have modified the manuscript accordingly, removed or consolidated several figures and adapted the text.

Please find our response to individual comments below.

Changes are highlighted in the “Supplementary Material” pdf. Text and figures marked in red were removed from the original submission and replaced by text and figures marked in blue. Following are our replies to your comments and a description of modification to the manuscript.

Sincerely,
Markus Sommerfeld

Comments by the Referee

0.1 General comments

The paper is a useful contribution to a better understanding of the winds at larger heights, which is not only relevant for the AWES applications for which the paper is written, but also in general for large wind turbines. Nudging with wind observations within the boundary layer has not been done a lot, so it is interesting to see how the WRF model behaves. I have two major issues with the paper:

1. *In the abstract it is stated that: "Observation nudging improves the overall accuracy of WRF". This cannot be concluded based on this study, because the observations are assimilated and then also used for evaluation. This will obviously result in the model being closer to the measurements, but this has nothing to do with WRF being more accurate 'overall'. If you want to draw this conclusion you would have to compare with measurements that are not assimilated in the model, preferably at some distance away from the point where the observations are nudged. Otherwise it should be more clearly written that the nudging is only valid at the lidar point: as it can be seen from Fig. 6 the modelled wind speed is just bias-corrected with approx. 1 m/s over a 180 km area, but it might well be that this detoriates wind speed comparison at other locations. For example, it could be that the bias at this point is caused by a wrong surface roughness or other local flow properties, which means the bias does not exists in other places. Also the nudging is likely only valid over land, because over sea the physical processes that determine the wind profile at a given time are different. All this should be written more clearly throughout the abstract/results/discussion/conclusion. Figures 2-6 all show the same message: nudging brings the model closer to the observations, so they can be combined into one or perhaps two figures. Figure 11 and 12 also show the same thing and can be combined.*

- The sentence in the abstract has been changed to a more precise formulation: 'Observation nudging improves the WRF accuracy at the measurement location.'
- Wind conditions and WRF simulation offshore are not subject of this manuscript and no investigation of observation nudging offshore have been performed. While we assume that the non-physical nature of observation nudging impacts the flow offshore as well, we can not draw this conclusion at. We therefore would prefer not mentioning offshore conditions in this paper.
- While figure 2-6 all show the impact of observation nudging, they present different aspects. Figure 2 visualizes the correlation between measurements and absolute occurrence of certain wind conditions, figure 3 shows the overall altitude dependent impact of nudging, figure 4 shows a representative day and figure 5 and 6 shows the spatial impact of observation nudging. We see that figure 5 and 6 show similar results and chose to remove figure 6.
- Figure 11 shows the mean wind speed profiles categorized based on Obukhov length whereas figure 12 shows the purely mathematical k-means clustered wind speed profile probability distribution. This mathematical approach was chosen due to the lack of heat flux and temperature measurements and to be consistent with "LiDAR-based characterization of mid-altitude wind conditions for airborne wind energy systems" doi: 10.1002/we.2343. Since the WRF simulations provide all this information we decided to represent the Obukhov length categorized data in the same way as the k-means clustered data previously.

2. *The definition of the Obukhov length in Eq. 4 is not clear or wrong: to classify stability one should take into account the effect of the *virtual* kinematic sensible heat flux and not the dynamic sensible heat flux directly from WRF (W/m2), which seems to be implied in Eq. 4 (although Hsfc is not defined anywhere). In the WRF model surface layer fluxes are split up in a sensible and latent heat flux. Sensible*

and latent heat flux are equally important in a fairly moist areas as Germany (see for example Stull (2017) or Floors et al. (2013)), so they should both be used when computing the Obukhov length.

- We adjusted our calculation of the Obukhov length in equation 4. The equation, which was taken from Sempreviva and Gryning, 1996 “Humidity fluctuations in the marine boundary layer measured at a coastal site with an infrared humidity sensor”, now takes latent and sensible surface heat flux into account.
- $OL = \left(\frac{-u_*^3\theta_v}{kg}\right)\left(\frac{1}{Q_S} + \frac{0.61}{Q_L\theta}\right)$
- Equation 18.16 just uses the kinematic surface heat flux in Stull,2017: Practical Meteorology An Algebra-based Survey of Atmospheric Science

0.2 Specific comments

- *p3l8: It would be useful to give the opening angle of the lidar.*
  - Added the opening angle in brackets: 62 degree or 28 degree to the horizon.
- *p4l2: What CNR threshold is used for filtering the data? What is the definition of an ’available’ measurement?*
  - We used a self-defined filter described in the “LiDAR-based characterization of mid-altitude wind conditions for airborne wind energy systems” doi: 10.1002/we.2343. We added a short description in this manuscript and refer to the previously mentioned paper for detailed information. Data availability is defined as the time when useful data (not filtered out) is available divided by the total time of the measurement period (6 months).

- *p4l6-9: I would remove this, because it has nothing to with the measurements, which is what the section is about. It is also discussing some of the results which have not yet been presented.*
  - Agreed and removed.
- *p4l13-17: All brackets make this section difficult to read. Please rewrite.*
  - Removing these brackets is difficult as some of them are due to the bibliography style, reference to figures and the definition of new abbreviations.Rewrote the definition of NoOBS and OBS in a sub-clause and removed the brackets around the WRF version.
- *p4: Please mention the land-surface, radiation and surface-layer scheme that were used in the WRF model.*
  - land-surface option: sf_surface_physics: 4, Noah-MP land-surface model (see additional &noah_mp namelist)
  - long wave: ra_lw_physics: 1, rrtm scheme
  - short wave: ra_sw_physics: 1, Dudhia scheme
  - radt: 18,6,2 min between physics calls
  - surface-layer option: sf_sfclay_physics: 5, MYNN surface layer
  - reference: https://esrl.noaa.gov/gsd/wrfportal/namelist_input_options.html
- *p6l2: 180 km is a very large distance. See major comment 1.*
  - The radius of 180 km is chosen so that the entire inner domain is affected by obs nudging and the spatial impact can be quantified.
  - changed subsentence to:"... thereby affecting the whole inner domain."

- *p7l2: I assume the wind direction is not calculated like this because it would lead to discontinuities when crossing 360 degrees. Please add more details.*
  - Angular difference is calculated by using *angdiff* in Matlab. The results are wrapped on the interval $[-\pi,\pi]$. Added a sub-clause to this point.
- *Section 4.1-4.3: see major comment 1;*
  - See response to comment 1.
- *p14l10-12: I think this is an important conclusion from this work and I agree that this is a potential application of using nudged WRF simulations. Perhaps it is useful to relate this to the discussion in Gryning et al. (2019) regarding the wind speed bias from lidars as a function of CNR threshold and data availability, to show that this issue is not specific for the site studied in your paper.*
  - Added this reference. We agree that it is good to point out that this is not a site specific issue.
  - Added to conclusion:
    * The bias between real and LiDAR measured wind speed, which depends on the applied CNR threshold and data availability, can result in a misrepresentation of the actual wind conditions especially at higher altitudes. Mesoscale models, particularly with observation nudging, can be used to account for this error.
- *p16l9-11: The wind speed in summer is mostly lower due to the lower synoptic pressure gradients in that time of the year, not so much due to the stratification (particularly at greater heights).*
  - Changed this sentence to reflect this fact.
- *p19 table 2: Maybe better to also express this as percentage instead of number of obs.*

- Adapted the table.

- *p19l7: It is not clear to me how the lidar measurements are normalized: with the friction velocity from the OBS run?*
  - Clarified formulation. Simulated friction velocity and heat flux is used to categorize and normalize LiDAR data.

- *p26: Remove Appendix A, it is not discussed anywhere.*
  - removed figures in appendix A1.

0.3 Technical corrections

- *p5l20: "(see equation: 2)" –> "(see Eq. 2)"*
- *p9 Fig 4 label: Abbreviation HWS is not defined*
- *p14l2: 100m –> 100 m (and m not in italics).*
- *p17l2: to (Sommerfeld et al.) –> to Sommerfeld et al. Also I don't know the journal policy but usually you can only include references that are 'accepted' and not those that are 'in review'.*
- *p17l4: ? –> ref*
- *p20l3-4: These two lines repeat the same thing.*
- *p20l5: ?? –> ref*
- *p21l7: Please split equation and units.*
- *p21l10: drag coefficient and drag coefficient? Also equal sign is not enclosed in '$'.*

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Discussion paper

- *p22 Fig. 13 caption: there is mention of a),b),c) here but they are not in the figure.*
- *p23l14: decreases –> decreases.*

- All technical corrections above have been addressed.

Please also note the supplement to this comment:
https://www.wind-energ-sci-discuss.net/wes-2019-7/wes-2019-7-AC1-supplement.pdf

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