Review of Sheridan et al. 2023: Offshore low-level jet observations and model representation using lidar buoy data off the California coast

First of all, I want to congratulate you on a very nice piece of work, that is really well written and is an important scientific contribution to the wind energy community. The figures are clear and easy to interpret and new creative ways of presenting the results are used, providing great insights in the data. It was a joy reading a manuscript that seems ready for publication as is.

The authors study observations of the wind profiles at two sites off the California coast, assessing them for low-level jets (LLJs). The seasonality and diurnal cycle of the appearance of the LLJs is investigated as well as key characteristics such as LLJ core height, core speed, and duration of LLJ events. Further, the authors validate three different models (the global ERA5 reanalysis and two regional models with different planetary boundary layer schemes) in terms of accurately resolving LLJs.

I only have some minor comments that I, humbly, think can enhance the manuscript further:

Thank you very much for the kind support of our work! We appreciated all of your suggestions for improvement and have incorporated them as follows.

L35: It would be helpful for the reader to add a map showing the exact locations of Humboldt and Morro Bay, including names of sites (such as Cape Mendocino and Point Sur that you mention in the text) on the map. Perhaps also photos of the buoys and a visual presentation of the data availability from Humboldt and Morro Bay could be included in this Figure.

Thank you for this helpful suggestion. The below map showing the locations of the lidar buoys, the wind energy lease areas, and the geographic features including Cape Mendocino and Point Sur has been added to the manuscript as Figure 1, along with a photo of the lidar buoys.

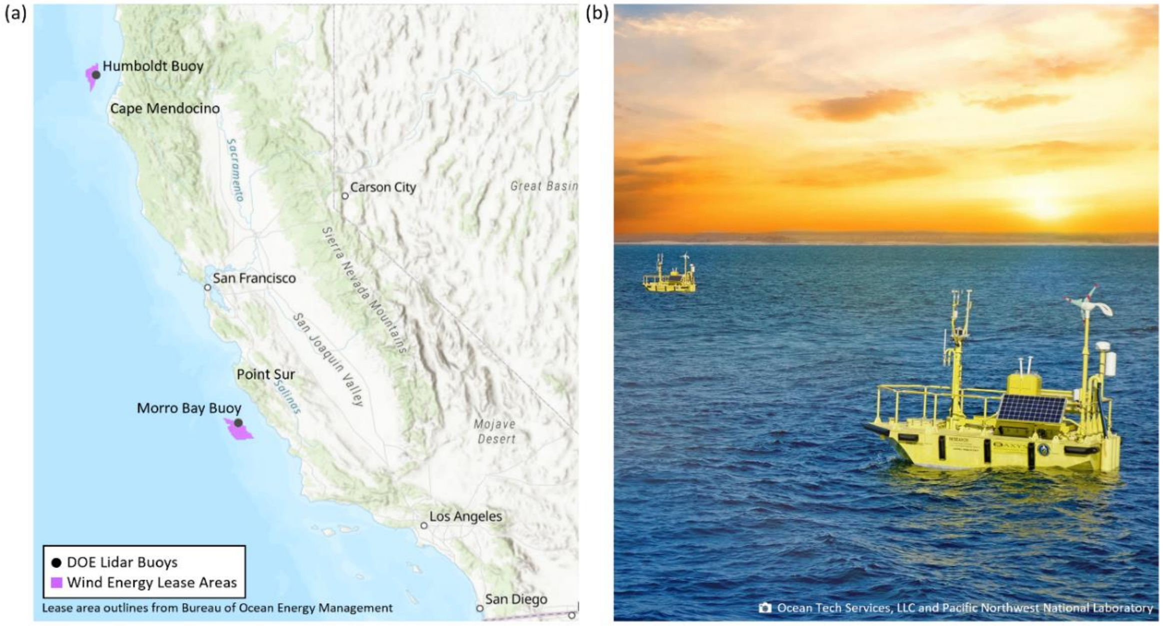

Figure 1. (a) Map of locations of the California DOE lidar buoy deployments and the California wind energy lease areas as of January 2024. (b) Photo of the DOE lidar buoys by Ocean Tech Services, LLC and Pacific Northwest National Laboratory.

We also appreciate the idea of visual representation of data availability and have added Figure 2 to the manuscript to address this recommendation.

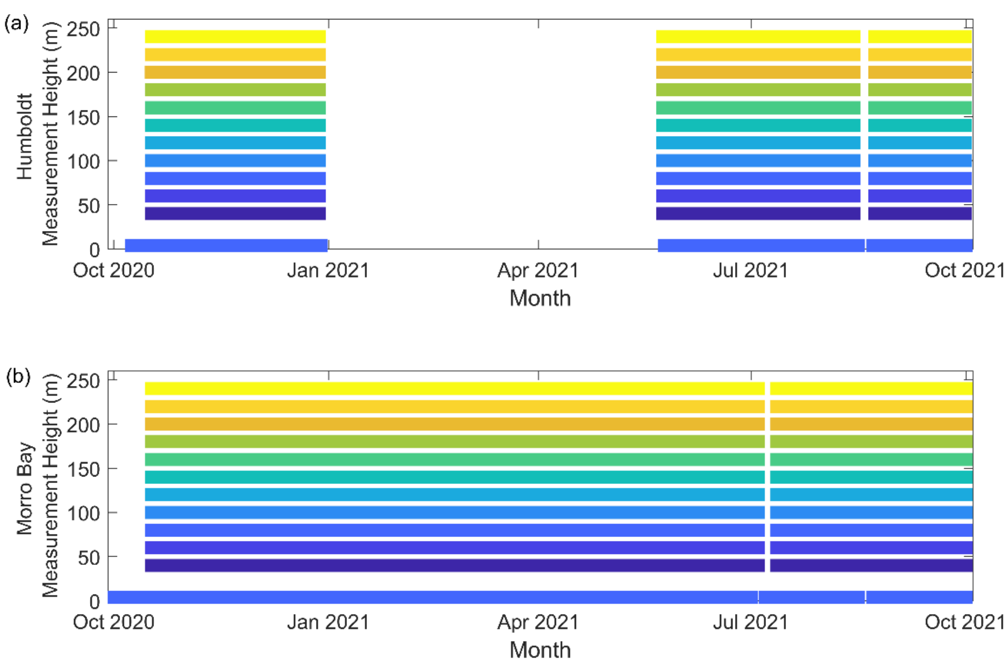

Figure 2. Availability of the near surface and lidar wind data at (a) Humboldt and (b) Morro Bay during the study period.

L47-48: 300 – 400 m is still in a layer above the top of the rotor of an offshore wind turbine. It would be good to give an example of the size (hub height and rotor diameter) of a modern offshore wind turbine, such as the NREL 15 MW turbine you refer to later on.

Great idea! We have used the Offshore Wind Market Report: 2023 Edition to provide real-world comparisons of offshore wind turbine dimensions with the summertime LLJ core heights as follows:

"The jet occurs at the top of the marine boundary layer with frequent core heights of 300 m – 400 m (Parish 2000), which are above the 2022 average offshore wind turbine hub height (116.6 m) and rotor diameter (174.6 m) (Musial et al., 2023). However, Musial et al. (2023) reported significantly larger hub heights (near 160 m) and rotor diameters (near 250 m) from future project announcements, leading to prospective rotor-swept upper limits approaching summertime LLJ core heights." (Lines 52-56)

Musial, W., Spitsen, P., Beiter, P., Duffy, P., Mulas Hernando, D., Hammond, R., Shields, M., and Marquis, M.: Offshore Wind Market Report: 2023 Edition, Tech. Rep., U.S. Department of Energy Office of Energy Efficiency Renewable Energy, https://doi.org/10.2172/1997466, 2023.

L54-55: The New European Wind Atlas (e.g., Dörenkämper et al. 2020) would also be a nice reference here

The reference to the New European Wind Atlas has been added to the discussion of wind resource products that use ERA5 as an input boundary condition per your suggestion. (Line 63)

L66: To add more information on the offshore wind profile and LLJs and how they are affected by the selection of the PBL scheme, I would suggest adding a couple of sentences summarizing the results from Svensson et al. (2016)

Thank you for recommending this important paper for the literature review. We have added the following to the manuscript, along with the reference you provided: "Svensson et al. (2016) found that no single PBL scheme among six evaluated in WRF outperformed the others in representing the wind speed and temperature profiles, the jet core height and wind speed, and the maximum wind shear during three LLJ case studies over the Baltic Sea." (Lines 75-77)

L94: Here it could just be clarified that: 17 October 2020 to 30 September 2021 *(i.e., almost a year)* for Morro Bay and 17 October 2020 to 27 December 2020 and 24 May 2021 to 30 September 2021 *(i.e., six months in total)* for Humboldt.

We appreciate the helpful suggestion and have modified the sentence per your recommendation: "The final periods of record employed in this study are 17 October 2020 to 30 September 2021 (i.e., almost a year) for Morro Bay and 17 October 2020 to 27

December 2020 and 24 May 2021 to 30 September 2021 (i.e., almost seven months) for Humboldt…" (Lines 105-107)

L106: Clarification: intervals of 20 m between 40 m and 240 m a.s.l. *(i.e., 11 height levels)*

"(i.e., 11 height levels)" has been added to this line per your helpful suggestion. (Line 124)

L108: Here the information that data was collected as 10 min averages should be added. Also, a few words on the quality control of the data would be nice.

The following sentences concerning the observations have been added to Section 2.1 per your recommendation: "The temporal resolutions of the lidar and near-surface measurements utilised in this analysis are 10-minute averages. Quality control of the measurements, discussed in detail in Krishnamurthy et al. (2023) included making sure sensors were not reporting beyond the manufacturer limits, comparisons with nearby sensors, removal of abnormal spikes in the data, physics-based analyses, motion correction, and filtering based on the signal-to-noise ratio for the lidars." (Lines 120-123)

Krishnamurthy, R., García Medina, G., Gaudet, B., Gustafson Jr, W. I., Kassianov, E., Liu, J., Newsom, R. K., Sheridan, L., and Mahon, A.: Year-long Buoy-Based Observations of the Air-Sea Transition Zone off the U.S. West Coast, Earth System Science Data, 15(12), 5667-5699, https://doi.org/10.5194/essd-15-5667-2023, 2023.

L159 and throughout the manuscript: Using comma signs as thousand separators could increase the readability of the large numbers (such as 24,878 observations on L159)

Commas have been added to large numbers throughout the text.

L170-171: As the distributions of LLJ event duration is highly skewed (as also shown in Figure 8), the median duration should also be presented, accompanying the mean value.

Good idea. We have updated the sentences accordingly:

"The average (median) LLJ duration at Humboldt was 1.6 hours (0.8 hours)." (Line 202)

"The average (median) LLJ duration at Morro Bay was 2.2 hours (1.0 hour)." (Line 203)

L183-184: You refer to Figure 3a and Figure 3b, but there are no panels in Figure 3.

Thank you for pointing out this typo! We have changed the references of Figure 3a and 3b to simply Figure 5 (based on the updated figure numbering from new figures suggested by the reviewers).

L185: Commenting on the diurnal cycle presented in Figure 3, I think you should also mention that the comparison between the two sites is possibly biased because of the data outage at Humboldt. It would be great if you could add confidence intervals around the lines in Figure 3 to motivate how certain you can be if there actually is a diurnal cycle in LLJ occurrence.

Per your helpful suggestion, we have reworded the discussion on the diurnal cycle of LLJs as follows: “At Morro Bay, a dependency on the time of day is noted for LLJ presence, with more LLJs occurring in the hours before local midnight and fewer LLJs occurring during the morning, afternoon, and early evening (Figure 5). At Humboldt, however, LLJs occurred across the diurnal cycle with little variation in frequency (Figure 5), though the comparison may be biased due to the data outage during the Humboldt deployment.” (Lines 216-219)

Additionally, we have added the 95% confidence intervals to the figure:

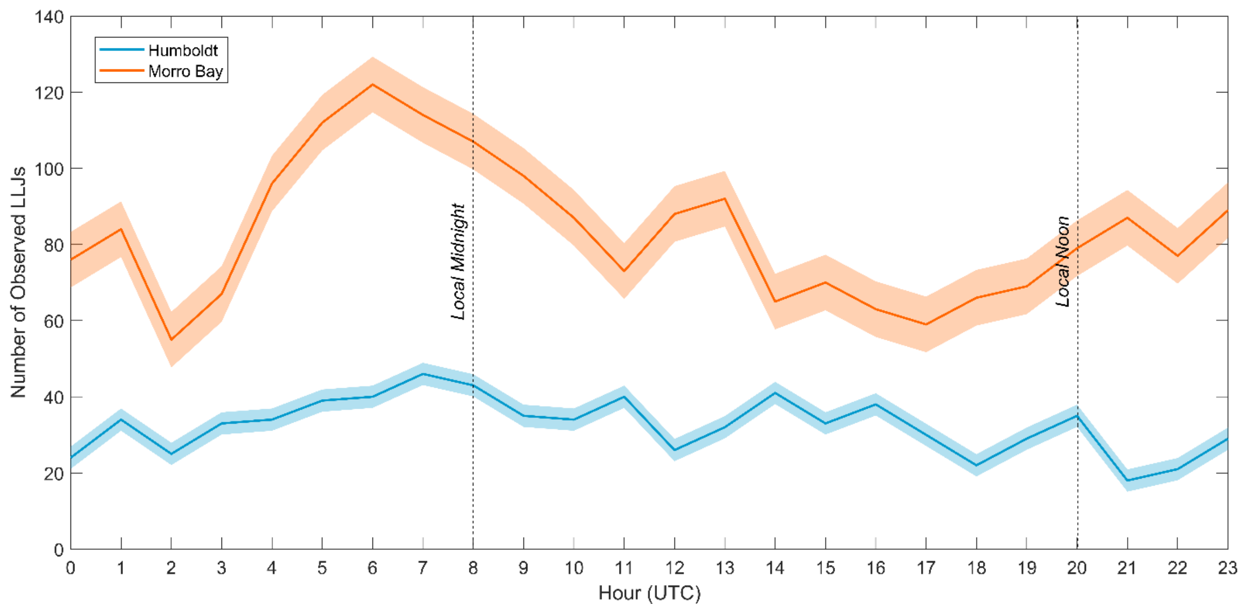

Figure 5. Diurnal trends in LLJ occurrences during the Humboldt and Morro Bay lidar buoy deployments with 95% confidence intervals.

Figure 6: In the caption, if you could write “bulk wind shear below the jet core”, that would remind the reader and help interpreting the plot.

“bulk wind shear below the jet core” has been added to the caption of the new Figure 8 per your nice suggestion.

L242: Is it the closest grid points that have been used? Please specify the distance between the grid points used and Humboldt and Morro Bay, respectively.

The closest grid points were used and the following text has been added to provide clarification: “Horizontally, the nearest model grid point to each buoy is selected for evaluation. The Humboldt buoy location is 8.3 km from the nearest ERA5 grid point and 1.1 km from the nearest CA20-Ext and NOW-23 grid points. The Morro Bay buoy location is 10.7 km from the nearest ERA5 grid point and 0.7 km from the nearest CA20-Ext and NOW-23 grid points." (Lines 284-286)

L247: Also, Kalverla et al. (2020) should be cited here (see Figure 6 in that paper)

The citation has been added as follows, thank you. "To evaluate the performance of models for LLJ representation off the California coast, we utilize the following methodology from Hallgren et al. (2020) and Kalverla et al. (2020) to categorize whether each model captures, misses, or incorrectly reports an LLJ at a given timestamp." (Lines 288-290)

L252-256: In addition to the success rates, the frequency bias should be included.

Thank you for this helpful suggestion to add a new helpful metric for model performance. We have provided the following text concerning frequency bias:

"While CA20-Ext produced the most LLJ hits for the California deployment, it also produced the most false alarms across the models (150 and 193 at Humboldt and Morro Bay, respectively). The false alarms contribute significantly to the CA23-Ext frequency bias, the ratio of the total number of predicted LLJs to the total number of observed LLJs (Hallgren et al., 2020). A frequency bias of one is a perfect score, while a frequency bias above (below) one indicates model overestimation (underestimation) of the number of observed LLJs. The CA20-Ext frequency biases of 2.5 (Humboldt) and 1.4 (Morro Bay) represent significant model overestimation of observed LLJs, particularly at Humboldt. NOW-23 produced 41 and 70 false alarms at Humboldt and Morro Bay which, combined with the hits, results in frequency biases indicative of model underestimation (0.8 and 0.5, respectively). ERA5 produced 2 and 6 false alarms at Humboldt and Morro Bay, generating frequency biases emblematic of significant model underestimation (<0.1 at both sites)." (Lines 302-310)

Hallgren, C., Arnqvist, J., Ivanell, S., Körnich, H., Vakkari, V., and Sahlée, E.: Looking for an Offshore Low-Level Jet Champion among Recent Reanalyses: A Tight Race over the Baltic Sea, Energies, 13(14), 3670, https://doi.org/10.3390/en13143670, 2020.

Figure 13: As you are commenting on the prior LLJ event in the text, I would love to see the time series starting already at 07:00 UTC to also include this event in the plot. Perhaps you could also mark the LLJ core for each time step where an LLJ is present in the panels?

Per your helpful idea, the figure now begins at 7:00 UTC and the LLJ core heights have been indicated.

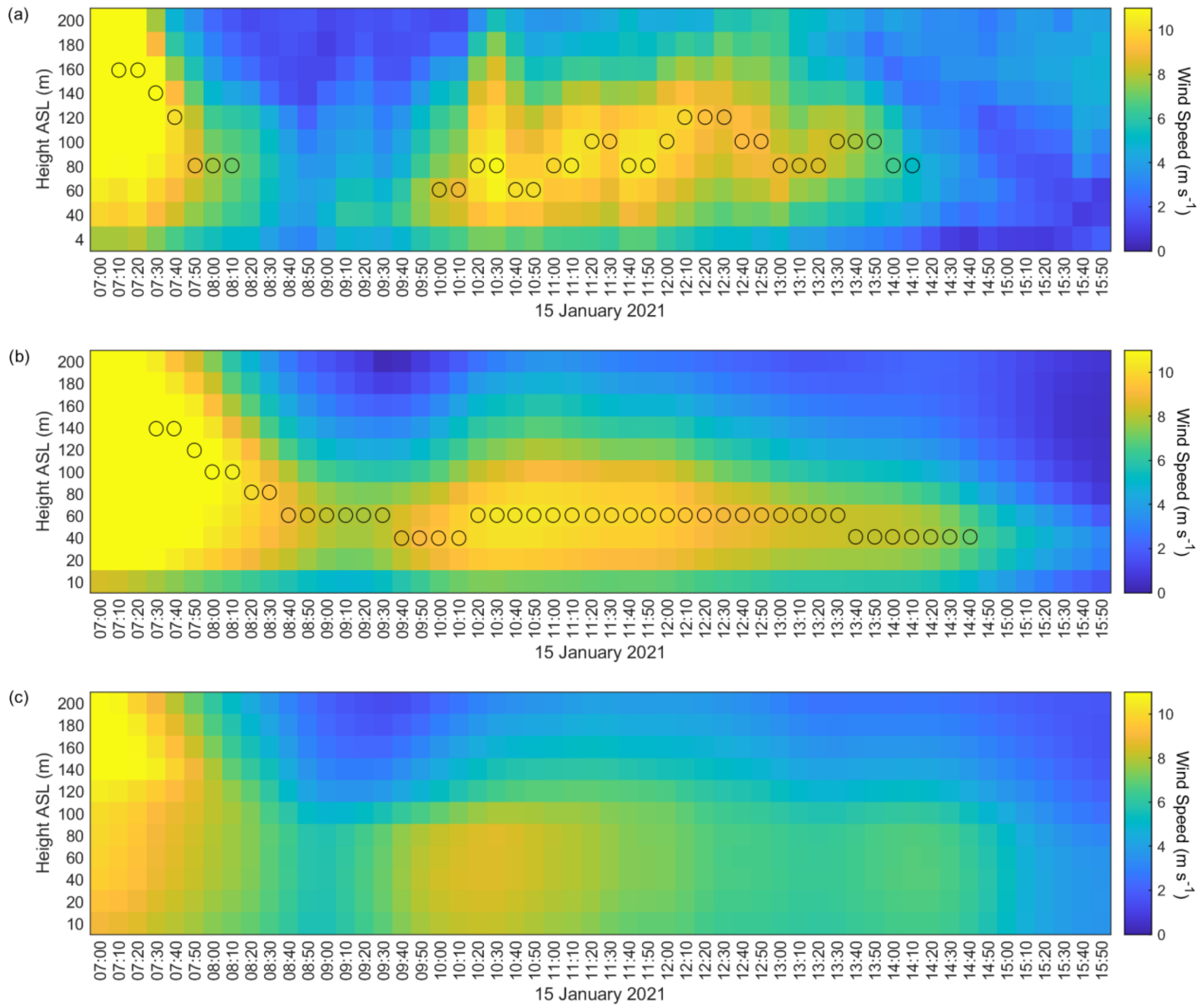

Figure 15. (a) Observed, (b) CA20-Ext-simulated, and (c) NOW-23-simulated wind speeds during an observed low-level jet on 15 January 2021 at Morro Bay. Reported timestamps are in UTC. Markers indicate the (a) observed and (b), (c) modelled jet core heights.

L375: Using the rotor equivalent wind speed (REWS) instead of only the hub height wind speed to calculate the estimated power production would really strengthen the work. For reference see e.g., St. Pé et al. (2018) and Murphy et al. (2020).

Excellent suggestion! We have reworked all of the analysis in the Discussion to utilise the REWS instead of just the hub height wind speed.

L409: Finally, adding a paragraph discussing general similarities and differences when comparing your results with LLJ studies from e.g., the US Atlantic coast, the North Sea, and the Baltic Sea, would put your work into a broader context and would be very valuable for future reference.

We agree, and combined your idea with another reviewer's suggestion for the final paragraph as follows: "Coastal and offshore measurement campaigns, while challenging to execute, provide valuable data collections to support the evaluation of potential wind energy generation in an offshore setting. The increasing number of such deployments is advantageous for understanding the characteristics of meteorological influences, such as LLJs, on the wind profile in unique locations. For example, recent measurement campaigns yielded locationally-driven diversity in the time of year for most frequent LLJ occurrence, namely May in the Baltic Sea (Hallgren et al., 2020), April – November in the New York Bight (McCabe and Freedman, 2023), and January at Morro Bay. Offshore observations are also needed for highlighting research areas for wind modelling improvement, such as the studies of Hallgren et al. (2020) and this work in noting the limitations of ERA5 representation of LLJs in distinct environments. The breadth of wind profile characteristics revealed by such measurement campaigns encourages similar analyses in new areas of offshore wind development interest. Subsequent DOE lidar buoy deployments include the waters off Hawaii and the U.S. Atlantic coast. Additionally, we look forward to expansion in the understanding of offshore LLJ occurrence and features, particularly in vertical extent, as floating lidar technology continues to advance. We hope this work encourages increased offshore wind observational campaigns to support validation and improvements for modelling of atmospheric phenomena like LLJs." (Lines 459-471)

References:

Dörenkämper , Martin, et al. "The Making of the New European Wind Atlas – Part 2: Production and Evaluation." Geoscientific Model Development 13.10 (2020): 5079-5102, doi: 10.5194/gmd-13-5079-2020)

Kalverla, Peter C., et al. "Quality of wind characteristics in recent wind atlases over the North Sea." Quarterly Journal of the Royal Meteorological Society 146.728 (2020): 1498-1515, doi: 10.1002/qj.3748

Murphy, Patrick, Julie K. Lundquist, and Paul Fleming. "How wind speed shear and directional veer affect the power production of a megawatt-scale operational wind turbine." Wind Energy Science 5.3 (2020): 1169-1190, doi: 10.5194/wes-5-1169-2020

St. Pé, Alexandra, et al. "Classifying rotor-layer wind to reduce offshore available power uncertainty." Wind Energy 21.7 (2018): 461-473, doi: 10.1002/we.2159

Svensson, Nina, et al. "Stable atmospheric conditions over the Baltic Sea: model evaluation and climatology." Boreal Environment Research, ISSN 1239-6095, E-ISSN 1797-2469, Vol. 21, s. 387-404 (2016)