Editorial Review

The authors greatly appreciate the fantastic and thoughtful feedback in this review and have worked to implement it into the manuscript in the following.

Abstract

TKE not defined on first use (always define acronyms on first use)

TKE has been defined before it is used:

Nocturnal LLJs are most frequently associated with stable stratification and low turbulent kinetic energy **(TKE)** and hence are more frequent during the winter months.

LLJ repeated a huge number of times – can this be reduced?

5 instances of "LLJ" have been removed, and the abstract now reads:

Output from six months of high-resolution simulations with the Weather Research and Forecasting (WRF) model are analyzed to characterize local low-level jets (LLJ) over Iowa for winter and spring in the contemporary climate. Analyses using a detection algorithm wherein the wind speed above and below the jet maximum must be below 80% of the jet wind speed within a vertical window of approximately 20 m – 530 m a.g.l. indicate the presence of a LLJ in at least one of the 14700 4 km by 4 km grid cells over Iowa on 98% of nights. Nocturnal LLJs are most frequently associated with stable stratification and low turbulent kinetic energy (TKE) and hence are more frequent during the winter months. The spatiotemporal mean LLJ maximum (jet core) wind speed is 9.55 ms^{-1} and the mean height is 182 m. Locations of high LLJ frequency and duration across the state are seasonally varying with a mean duration of 3.5 hours. Highest frequency occurs in the topographically complex northwest of the state in winter, and in the flatter northeast of the state in spring. Sensitivity of LLJ characteristics to the: i) LLJ definition and ii) vertical resolution at which the WRF output is sampled are examined. LLJ definitions commonly used in literature are considered in the first sensitivity analysis. These sensitivity analyses indicate that LLJ characteristics are highly variable with definition. Use of different definitions identifies both different frequencies of LLJs and different LLJ events. Further, when the model output is down-sampled to lower vertical resolution, the mean jet core wind speed height decrease, but spatial distributions of regions of high frequency and duration are conserved. Implementation of a polynomial interpolation to extrapolate down-sampled output to full-resolution results in reduced sensitivity of LLJ characteristics to down-sampling.

Can you speak to the importance of LLJ? Why do we care?

The following sentence has been added to the abstract:

Low-level jets affect rotor plane aerodynamic loading, turbine structural loading, and turbine performance, and thus accurate characterization and identification is pertinent.

Introduction

Lower-troposphoric doesn't mean much to many people, can you describe things in a bit more of a general way? WES is a domain journal not a discipline journal, so you want to make sure the article is accessible to a broader wind audience that may not be meteorologists

The following sentences have been improved for clarity and to improve general understanding of the phrases used:

The term low-level jet (LLJ) is applied to any lower-tropospheric (approximately 2 km or below) maximum of horizontal winds that exhibits confined vertical extent (Markowski and Richardson, 2011). LLJs are observed episodically in most regions of the world (Rife et al., 2010; Krishnamurthy et al., 2015). LLJ formation mechanisms and manifestations span a range of scales from synoptic (i.e. mid-latitude cyclones) down to meso- (i.e. weather fronts) and micro-scales (i.e. topographic complexity and day-night surface heating) (Blackadar, 1957; Chen and Kpaeyeh, 1993; Lackmann, 2002; Jiang et al., 2007; Tay, 2021).

Same comment goes to why do we care about LLJ for wind? Make sure this is described so that the reader has sufficient context

The following sentence has been added to enhance the description of previous LLJ studies to give more context:

LLJs at and below these altitudes have the potential to impact the wind speed, turbulence, and shear across typical wind turbine rotor planes (Gutierrez et al., 2014; Gutierrez et al., 2017; Nunalee and Basu, 2014; Wagner et al., 2019; Aird et al., 2020; Barthelmie et al., 2020). **Further, LLJs can increase wind farm performance through enhancing wake recovery (depending on atmospheric conditions and jet height), and may reduce wind turbine structural loading if the negative shear region of the jet interacts with the nacelle (Gadde and Stevens, 2021; Guttierez, 2017).** If LLJ speed maxima occur at or near the rotor plane, enhancements in turbulence and shear have implications for **aerodynamic blade** loading and longevity (Kelley et al., 2005).

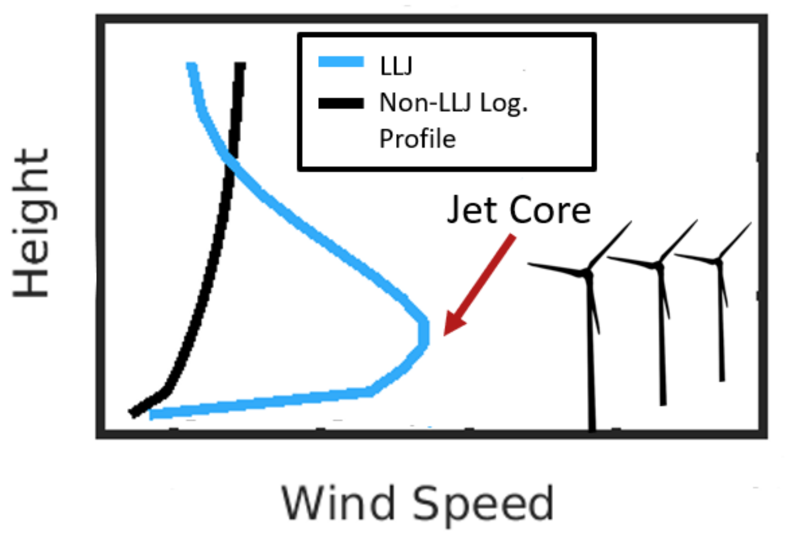
Generally the first paragraph has a lot of jargon that is very specific to the meteorological community and not the broader wind community – could be helpful to provide again more plain description, use "in other words, …" to give layman definitions of the key concepts

In addition to previous edits, the paragraph has been extended to give a more general description of the mechanisms and ideas being discussed:

The term low-level jet (LLJ) is applied to any lower-tropospheric (approximately 2 km or below) maximum of horizontal winds that exhibits confined vertical extent (Markowski and Richardson, 2011). LLJs are observed episodically in most regions of the world (Rife et al., 2010; Krishnamurthy et al., 2015). LLJ formation mechanisms and manifestations span a range of scales from synoptic (i.e. mid-latitude cyclones) down to meso- (i.e. weather fronts) and micro-scales (i.e. topographic complexity and day-night surface heating) (Blackadar, 1957; Chen and Kpaeyeh, 1993; Lackmann, 2002; Jiang et al., 2007; Tay, 2021). Mechanisms commonly invoked to describe the forcing mechanisms include diurnal (day-night) variations in baroclinicity over sloping terrain (referred to as the Holton mechanism, (Holton, 1967)) and diurnal variations in boundary layer friction (referred to as Blackadar mechanism (Blackadar, 1957)). Both mechanisms invoke decoupling of the planetary boundary layer from the surface. In the case of the Blackadar mechanism, this decoupling is due to changes in turbulent mixing associated with day-night stability differences. These stability differences begin at sunset as the boundary layer rapidly stabilizes as the land surface cools, resulting in an inertial oscillation that is conducive to LLJ formation. For the Holton mechanism, the decoupling can be attributed to pressure gradients arising from day-night heating of sloping terrain. Thus, both mechanisms result in a wind speed maximum and indicate LLJs are most frequent under stable conditions and hence at nighttime (Holton, 1967), and in areas with topographic and/or land cover variability (Parish, 1982). LLJ characteristics, such as frequency, intensity and duration also vary by seasonal and inter-annual timescales (Weaver et al., 2009; Liang et al., 2015).

On. This same point, it might even be nice to have a few simple graphics illustrating a LLJ or a situation where one is / is not present to contrast

The following graphic has been added to help describe a LLJ profile as compared to non-LLJ profiles and describe their interaction with the rotor plane, as well as defining the location of maximum wind speed, the jet core:



Lines 49 to 54 speak to the importance of the work – this should be elevated and extended

In addition to the previous edits clarifying the impact of the LLJ on wind turbines, the following sentence has been added to emphasize that LLJs are going to be even more pertinent with increasing wind turbine dimensions:

If LLJ speed maxima occur at or near the rotor plane, enhancements in turbulence and shear have implications for aerodynamic blade loading and longevity (Kelley et al., 2005). **As wind turbine heights, rotor diameters, and capacities increase, it is likely that LLJs will interact more profoundly and frequently with the rotor plane, with increasing turbine dimensions resulting in more interaction with the jet core (Barthelmie et al., 2020).**

After line 72, the paper jumps right to a description of the approach in the paper, but will the paper remedy the limitations around standard characterization that was highlighted in lines 55 to 72? I think it can be strengthened how this paper will address the shortcomings in the earlier work – its in the actual results but doesn't come through super strong

The following paragraph has been added to discuss insights the paper provides for issues highlighted in 55-72:

Thus, due to frequent variation of LLJ definitions, it is pertinent to examine the types of LLJs (characteristics) that each definition extracts and the agreement between definitions. As LLJs occur due to atmospheric forcing on multiple scales (synoptic, meso, micro), it is possible that their wind speed profiles are a consequence of atmospheric conditions during the time of their generation, and jet profiles might be more likely to be extracted by certain definitions depending on atmospheric conditions or topography. A greater understanding of jets extracted through definitions used throughout literature can thus reduce uncertainty in future studies and inform choice of definition.

It may also be helpful to have a paper roadmap as a last paragraph (its sort of there but not really)

The authors appreciate the suggestion but for now the paragraph remains unchanged in this way, to avoid potentially becoming overly repetitive.

Methodology

Maybe provide a brief description of WRF for the general wind community

The following sentence has been added to explain the uses of WRF and what it is:

The Weather Research and Forecasting Model (WRF) is a mesoscale numerical weather prediction model that is widely used in wind energy assessment and forecasting applications, such as predicting the impact of climate change on wind power generation and creating wind energy production estimates offshore and onshore (Pryor et al, 2020; Salvação and Soares, 2018, Prósper et al., 2019).

Figure 2 would actually make a nice graphic for the introduction similar to what I mentioned above

Figure 2 was used as inspiration for the graphic in the introduction.

Results

I like figure 7 but I think it would be easier to see actually if it were two separate figures side-by-side so the y-axis could provide an exact description of the content (rather than having it in the caption)

The authors like this suggestion but think it might be easier to compare the proportions of LLJs extracted with each definition given how the figure is currently set up.

Figure 8 is a bit hard to digest – there is a lot of information being shared here but the flow is a bit hard to follow in this section moving from the discussion of figure 7 to discussion of figure 8

You may consider even sub-sectioning section 3.2 - It would be good (since there isn't a separate discussion section) to add a paragraph after figure 9 to summarize the key insights from the analysis in section 3.2 –

3.2 has now been sub-sectioned and reads more easily, and sentences are added to describe the purpose and reasoning behind each sub-section:

i) Initial demonstration of sensitivity to LLJ definition

Any LLJ analysis is naturally dependent on the detection algorithm applied. Thus, a sensitivity analysis is performed using differing LLJ detection thresholds (see Table 2). The impact of selecting different thresholds (five different fixed thresholds ranging from 1 to 5 ms^{-1} in increments of 1 ms^{-1} and five different variable thresholds ranging from 10 to 50% in increments of 10%) is illustrated in Figure 7 for the WRF grid cell that exhibited the highest LLJ frequency in the seasonal analysis (grid cell location indicated in Figure 2). Sensitivity is firstly demonstrated for a single grid cell to concisely prove sensitivity without confounding factors related to terrain elevation. Domain-wide frequencies are presented in Figure 9 for the most frequently used LLJ definitions and indicate that there is terrain-related sensitivity to the LLJ criteria employed.

ii) Sensitivity of LLJ definition across entire domain (ensemble sensitivity)

Ensemble characteristics for LLJs extracted with each definition are analyzed to better understand LLJs extracted with each definition. Domain-wide LLJ frequencies are analyzed for the two most common definitions used in LLJ literature (criteria group 2) and indicate where, in a domain with complex terrain, each type of LLJ (as extracted by the definitions) is likeliest to be extracted.

Can you explain better why you chose the variable threshold of 20% for section 3.3 work? Maybe link it back to the discussion in prior 3.2? It goes back to the usefulness of a transition paragraph between sections 3.2 and 3.3

The following lines written for the first round of reviews have been added into the manuscript to clarify:

Results from this sensitivity study inform choice of criterion for the initial study; both criteria types are biased toward certain maximum LLJ speeds and choosing a criterion in the least strict group could result in LLJ wind speed profiles that are hardly differentiable from non-LLJ (as indicated by the lower shear displayed in jets extracted in criteria group 1). Further, criteria group 2 features definitions most relevant to previous studies, and the variable criterion chosen allows for analysis of LLJs that might have been previously undefined through usage of only a fixed criterion (as is common in previous literature).

Do you think you would expect the same or similar results in section 3.3 if you used different criteria?

This is an interesting question; it seems that this would depend on the consistency of the LLJ profiles themselves, which would be dependent on shear. The following has been added to the manuscript to answer this question in a thought experiment:

Though a 20% variable criterion is utilized for this sensitivity study, it is possible that usage of a different criterion might affect the results and increase the efficacy of the polynomial fit in resolving lower-resolution LLJ profiles. For example, for higher wind speed LLJs (wind speed maximum > 17 ms^{-1}) that are extracted by the fixed criterion, shear across the rotor plane remains relatively constant (Aird et al., 2020). In contrast, LLJs exhibiting lower wind speed maxima as are more commonly extracted by the variable criterion (wind speed maximum between 5 and 11 ms^{-1}) exhibit a nearly linear decrease in rotor plane shear with an increase in height A.G.L. These differences are attributed to lower jet core maximum heights for LLJs extracted with variable criteria (Figure 9). Thus, it is possible that extrapolating the LLJ profile from lower-resolution wind speed profiles as extracted from a fixed criterion would prove to be more effective due to more constant shear and higher wind speed maxima.

Again, consider a summary / key point / transition paragraph after figure 11 for end of section 3.3

The following has been added to summarize the results of the second sensitivity study and relate the two sensitivity studies, as in the previous comment:

Ensemble LLJ characteristics display sensitivity to the resolution of wind speed profiles, but this can be mitigated through extrapolating the wind speed profile to higher resolution through a polynomial fit. This sensitivity appears to be consistent across the domain and irrespective of terrain complexity, as regions of highest LLJ frequency and duration are preserved when LLJs are extracted from full resolution wind speed profiles and manually down-sampled wind speed profiles. Though a 20% variable criterion is utilized for this sensitivity study,….

Conclusions

Conclusions are largely descriptive and repetitive of paper content – can they be more succinct and speak more clearly to the key findings and contribution of the work?

The following sentences have been added to concisely describe and summarize findings:

LLJs as extracted by fixed criteria are predominantly characterized by higher speeds and shorter durations. LLJs extracted by a variable criterion exhibit a higher duration and lower wind speed maxima. In the context of previous work, lower LLJ wind speed maxima as extracted by variable criteria correspond to more stable conditions and decreased TKE, further explaining the increase in LLJ duration. The difference in LLJ types as extracted by each definition correspond to terrain complexity; in the region of the state with less complex and sloping terrain, a higher frequency of LLJs are extracted with the variable criterion. Previous literature implements either a fixed criterion (most common) or a fixed and variable criterion in tandem. Thus, it is possible that for regions with less complex terrain, a variable criterion must be implemented to adequately capture all wind speed profiles with LLJ behavior. The converse is true for employing a fixed criterion: to adequately capture higher speed, shorter duration LLJs such as those that occur more frequently over complex and sloping terrain, it is pertinent to employ a fixed criterion. Thus, the usage of both a variable and fixed criterion to extract LLJs is recommended.

What recommendations would you make based on the work in terms of LLJ characterization and identification?

See previous, and the following has been added:

Based on findings, employing a polynomial interpolation to enrich the number of datapoints in the wind speed profile may prove beneficial in resolving ensemble LLJ characteristics.

What future work remains to be done / where would you go from here?

A brief sentence about future work has been added to the second to last paragraph in the conclusions:

Future work to explore the impact of LLJ definitions in offshore conditions is warranted.

Second Round – Review #1

The authors greatly appreciate that the reviewer has read and reviewed the revised work, and have worked to implement the comments as follows. The authors are grateful for two rounds of very helpful and thoughtful feedback.

102-105: The performance of the MYNN scheme with respect to resolution and low-level jets is also discussed in Floors et al. (2013). This could be a good reference to add here as well.

The authors have added the following sentences clarifying results found in previous studies regarding the MYNN scheme:

Key physics settings in the simulation presented here parallel those used in a similar study of the Orinoco LLJ over South America (Jiménez-Sanchéz et al., 2019); i.e. the Mellor-Yamada-Nakanishi-Niino **(MYNN)** 2.5 (Nakanishi and Niino, 2006) PBL scheme is used, along with the MM5 surface layer scheme (Beljaars, 1995), and the Noah land surface model (Tewari et al., 2004). The MYNN scheme is selected as it has been validated previously for WRF simulations in the Great Plains and **shown to adequately model the PBL height when compared to observations (Zhang et al., 2020)**. Further, **studies of LLJs in the Great Plains** indicate that nocturnal LLJ characteristics may be less sensitive to the scheme employed than vertical resolution; **the MYNN scheme has been shown to have minimal mean absolute error when simulating key jet core conditions, particularly with fine vertical grid spacing and a high model top pressure level such as that utilized in this simulation (50 hPa)** (Smith et al., 2018, Jahn and Gallus, 2018). Note that in all analyses presented herein only wind speeds within the lowest 530 m of the atmosphere are considered. This implicitly limits the detection of LLJs to levels below that height.

l113: it is fine that the authors do not want to run more simulations and have changed the word 'climatology' to 'seasonal analysis', but I think this aspect should still be made more clear in the abstract and conclusions. When somenone would read the abstract one could easily think all data shown in the paper are general, but in fact they only concern spring and winter.

The following information has been added to the abstract to clarify that six months of output are considered.

Abstract: Output from **six months of** high-resolution simulations with the Weather Research and Forecasting (WRF) model are analyzed to characterize local low-level jets (LLJ) over Iowa **for winter and spring in the contemporary climate.**

l132: You could also consider using the greek letter alpha for wind shear.

The Greek letter alpha has been added instead of "shear":

(d) Mean shear (α) across the nominal rotor plane (Eq. 2).

$$\alpha = \left(\frac{U_{Z_2} - U_{Z_1}}{Z_2 - Z_1}\right) \quad (2)$$

l300: Shorten caption to something like "As Table 3..."

The following has been added to the figure caption in place of the previous sentence:

Temporal mean wind speed profiles per group are calculated from LLJ events in Tables 3 and 4.

Table 5: Please include also half and quarter resolution in the table. The number of levels are already visible in the figure and in the discussion you refer to the 'half', 'quarter' etc.

	Mean Jet Core Wind Speed (ms^{-1})	Mean Height of Jet Core (m a.g.l.)	Mean LLJ Duration (hours)	% LLJ with Jet Cores within the Rotor Plane	Spatiotemporal LLJ Frequency

Sensitivity Analysis B: Down-sampling of output					
Full Resolution: 25 Vertical Levels	9.55	182.64	3.52	39.15	17.32%
13 Vertical Levels **(½ Resolution)**	9.18	172.89	3.35	41.83	15.12%
7 Vertical Levels **(¼ Resolution)**	8.53	156.43	2.98	46.95	10.75%

Both resolutions have been specified in the table as shown above.

l411: I assume you fit the polynomial to the quarter resolution so maybe replace 'these' with 'quarter resolution' or something otherwise it is a bit ambigious what 'these' refers to.

The following sentences have been revised for clarity:

These profiles (**extrapolated to full resolution from quarter resolution**) are then input into the LLJ detection algorithm (20% variable) and resulting ensemble characteristics are compared **to LLJ characteristics from full resolution profiles and the original down-sampled quarter resolution profiles**.