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Low-level jets representation in numerical models: insights from LiDAR observations

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Introduction

Low-level jets (LLJs) within the boundary layer are critical phenomena influencing wind energy generation.

However, the representation of LLJs in model datasets, such as reanalysis and hindcast data, may contain inaccuracies.

This study aims to validate the depiction of LLJs in the ERA5 and NORA5 datasets and conducts a climatological analysis of LLJs using a 50-year bias-corrected ERA5 dataset.

Model validation

The LLJ speed and fall-off ratio are underestimated in both NORA4 and ERA5, particularly for strong LLJs.

To achieve consistent LLJ detection in models, two approaches can be considered:

- Lowering the detection threshold.
- Correcting the wind profile bias through quantile mapping of the wind profile parameters.

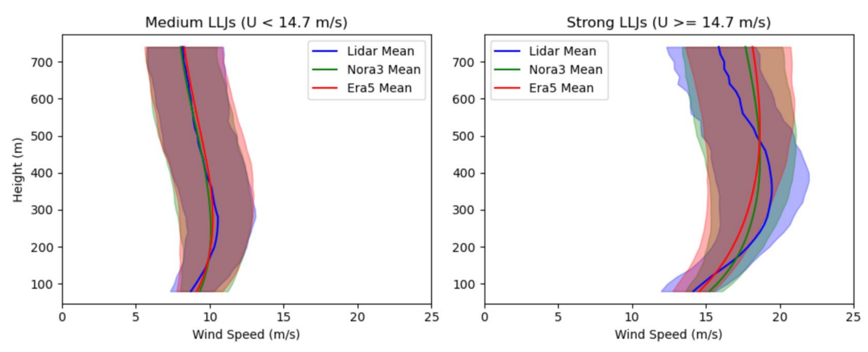

Figure 2. Composite of wind profiles for normal and strong LLJs for LiDAR, LiDAR, and ERA5 data. The inner quartile range is shaded.

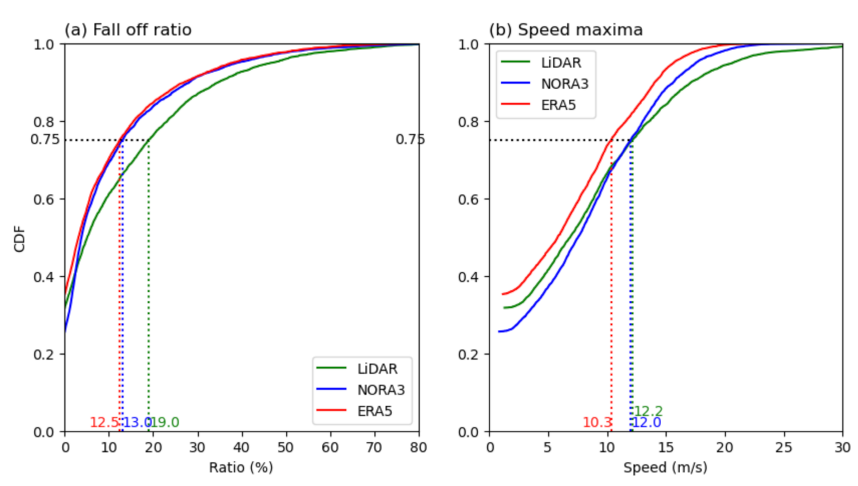

Figure 3. Cumulative distribution functions (CDFs) of Fall of Ratio (Vmax-Vmin/Vmax) for LiDAR, LiDAR, and ERA5 data .

Data

- Model validation: 1-hour wind profiles at the FINO1 met-mast from May 2015 to June 2016 (non-continuous) from LiDAR, NORA5, and ERA5 (interpolated every 20 m, from 80 m to 740 m).
- Climatology study: 1-hourly ERA5 data from 1969 to 2020 (continuous).

Wind profile fitting

$$U(z) = U_{log}(z) + U_{jet}(z)$$

$$U_{log}(z) = \frac{u_*}{\kappa}\log\left(\frac{z}{z_0}\right), \qquad U_{jet}(z) = U_m \frac{z}{z_m} e^{\frac{1}{s}\left(1-\frac{z}{z_m}\right)^s}$$

Advantages:

- Mitigate small variations/errors
- Fill missing data
- Bias correction (quantile mapping)

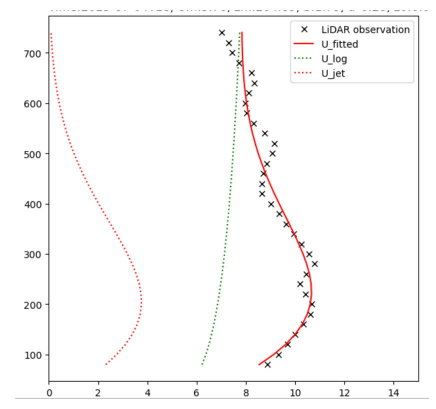

Figure 1. An example of wind profile fitting for ERA5 data

LLJ climatology at FINO1 using bias correct ERA5 wind profile

In contrast to the predominant winds, which originate from the South-West, the LLJs are predominantly from the South-East.

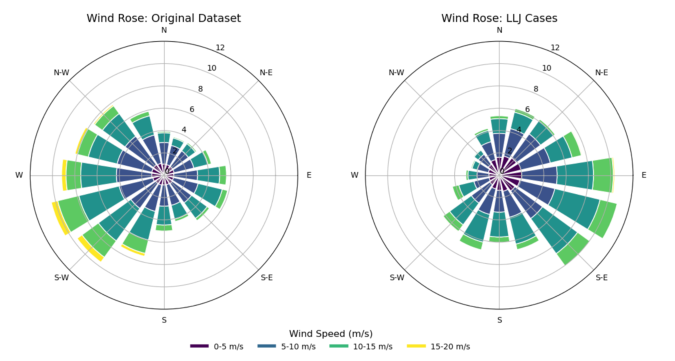

Figure 4. Wind roses derived from 50-year bias-corrected ERA5 data at 200 m, showing wind patterns for the entire dataset (a) and for detected low-level jets (LLJs).

Using the K-means method applied to the wind profile components (U and V), the LLJs can be classified into three distinct groups (Cluster 1, Cluster 2, and Cluster 3), corresponding to directions from the SW, NE, and SE, respectively.

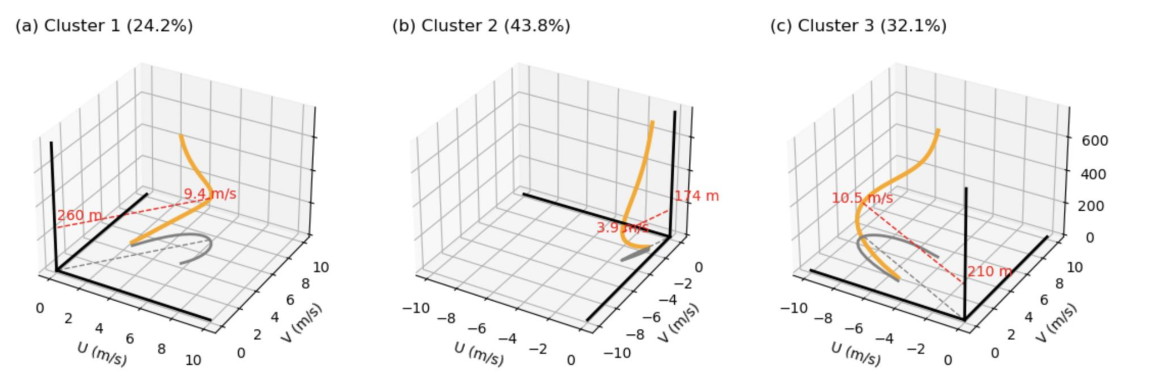

Figure 5. 3D wind profile of 3 clusters from the K-means analysis of (U, V)

Each group can be further divided into two subgroups based on the vertical gradient profile of potential temperature, which reflects atmospheric stability.

The analysis shows that LLJs are associated with either an upper (a) or a lower (b) stable layer. The former, characterized by an upper stable layer, tends to have weaker stability but is the most frequently observed.

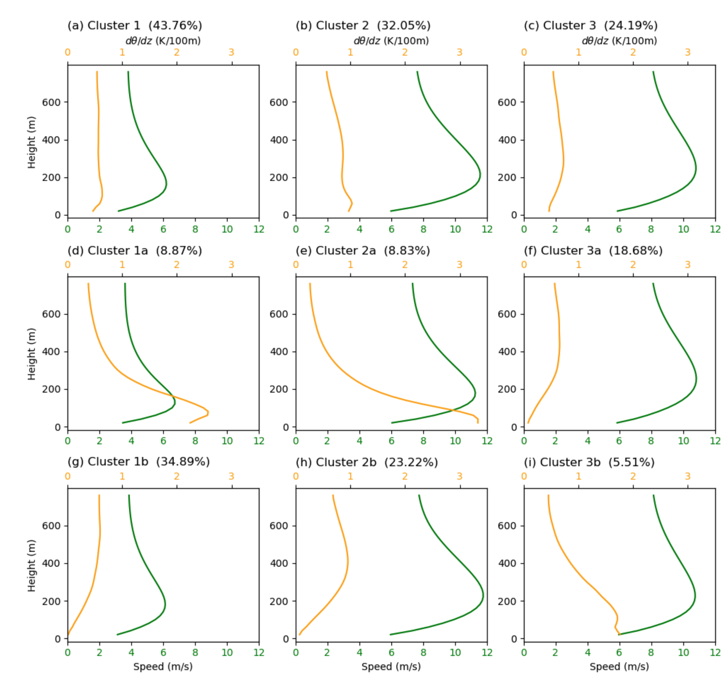

Figure 6. Profile of wind speed and vertical gradient potential temperature for 3 LLJs clusters (a-c) and 6 subclusters (d-i)

The SW LLJs occur primarily in winter, the NE LLJs are most common in summer, while the SE LLJs predominantly occur during spring and autumn.

LLJs with lower stable layers are typically associated with a single peak in March or May, occurring in the early morning (SW), late afternoon (NE), or midnight (SE).

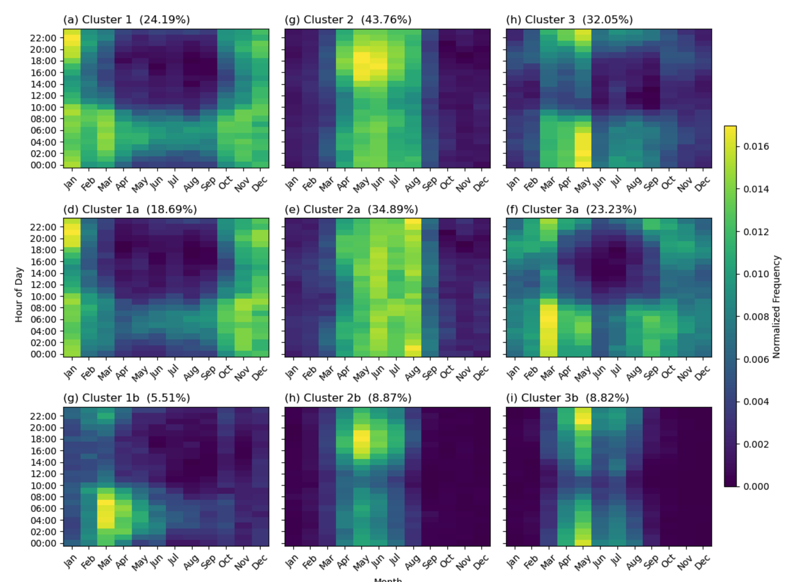

Figure 7. Occurrence of LLJs over months and hour of day for LLJs clusters and subclusters.

Summary

- We developed a parametric wind profile fitting method to enable LLJ detection and bias correction.
- Compared to LiDAR observations at FINO1, both ERA5 and NORA3 underestimate strong LLJs.
- Cluster analysis using 50-year bias-corrected ERA5 data identified three main LLJ groups originating from the SE, SW, and NW, each associated with a stable layer either above or below the jet.
- Further analysis is needed to investigate the mechanisms driving these LLJs.

Acknowledgment

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