# Using RSD data to validate mesoscale assessments of wind veer


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## Unlocking wind farm performance: why understanding wind veer is more critical than ever

Wind energy continues to be a cornerstone of our renewable future, but optimizing its potential requires an accurate assessment of complex atmospheric phenomena. One such phenomenon, wind veer, is increasingly recognized as an important factor impacting wind farm performance and, if not properly understood, can lead to significant underperformance and operational challenges. Natural Power's recent research, presented at the American Clean Power Research & Technology Conference recently, sheds light on how to gain insight into wind veer at sites where there is limited information from on-site measurements by instead using mesoscale reanalysis datasets which we have validated against on-site remote sensing devices (RSDs).

This research is particularly timely given the industry's shift towards larger turbine rotor diameters, which are more susceptible to variations in wind direction across the rotor plane. By understanding and quantifying veer at development sites, we can enable more accurate performance assessments and mitigate potential losses for wind projects, regardless of whether they have RSDs on-site.

## What exactly is wind veer and why does it matter?

At its core, wind veer is the change in wind direction with increasing height. While wind shear refers to the change in wind speed with height, veer specifically addresses directional shifts. These directional changes are commonly driven by factors such as nocturnal low-level jets, interactions between land and sea breezes, and complex terrain. Veer is increasingly being explored as a potential cause of regional wind project underperformance and operational challenges.

Turbine rotors today can span from 130 to 170 meters in diameter, which capture a much larger vertical slice of the atmosphere than ever before. If the wind direction at the bottom of the rotor is significantly different from the direction at the top, the turbine's blades will experience varying wind angles simultaneously. This can lead to:

➜ **Reduced energy capture:** Veer can decrease the energy flux that is normal to the rotor plane, meaning the turbine isn't optimally aligned with the wind across its entire rotor-swept area.

➜ **Non-optimal pitch/yaw angles**: Turbines attempt to adjust their blades (pitch) and orientation (yaw) to maximize energy capture. However, significant veer can make it difficult for the turbine's control system to find an optimal setting for the entire rotor, leading to inefficiencies.

➜ **Underperformance and operational issues:** Over time, these inefficiencies translate into reduced power production and potentially increased wear and tear on turbine components due to non-ideal off-axis loading.

The overarching goal of this research was to enable a generalized assessment of the impact of veer on project performance across the US, ensuring that even sites without expensive on-site RSDs can still be accurately evaluated for veer.

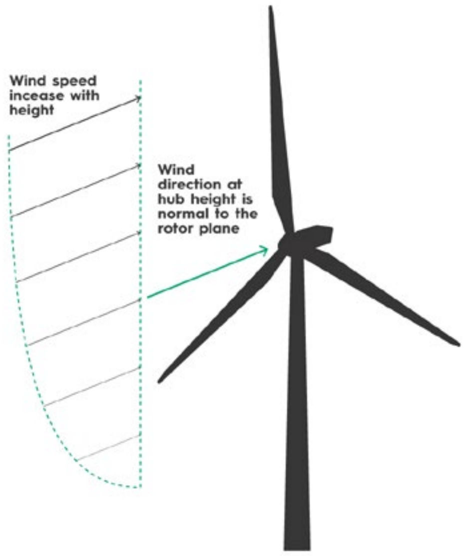


**Figure 1:** Wind sheer

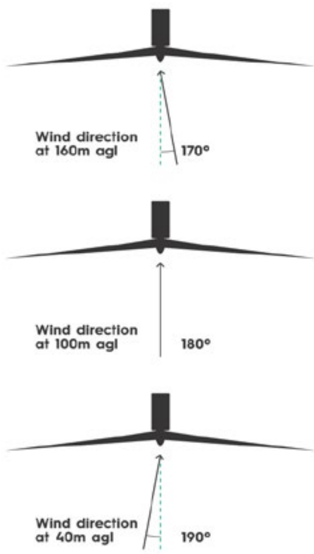


**Figure 2:** Wind veer, view from above turbine

## The methodology: comparing site RSD with mesoscale data

Natural Power collated a large dataset of around 120 years of RSD data from 104 deployments across 50 projects, spanning 21 states in the US and two Canadian provinces. Alongside this, long-term downscaled mesoscale time series data were extracted at multiple heights for each project site.

The research team considered three different methods for calculating veer, ultimately selecting the “bulk veer” method for its analysis:

$$\beta_{bulk} = \frac{\theta_{top} - \theta_{bottom}}{z_{top} - z_{bottom}}$$

This method calculates a metric that represents the change in wind direction between the top and bottom rotor tip heights. The team then compared veer derived from RSDs against mesoscale data for heights between 40 and 140 meters and for wind speeds greater than 3 m/s. A key aspect of the methodology involved assessing any geospatial trends in veer across the US.

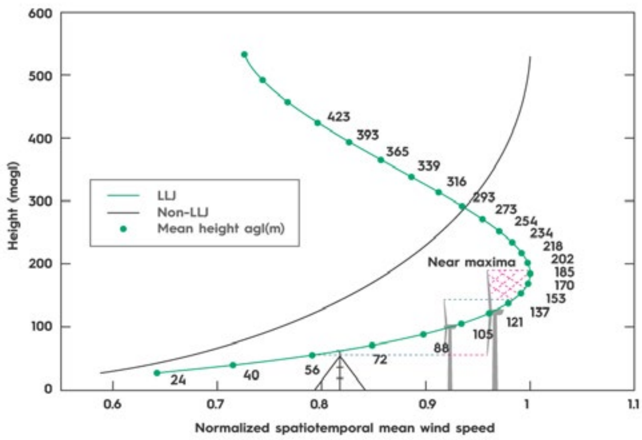


**Figure 3:** Typical altitudes that low-level jets occur

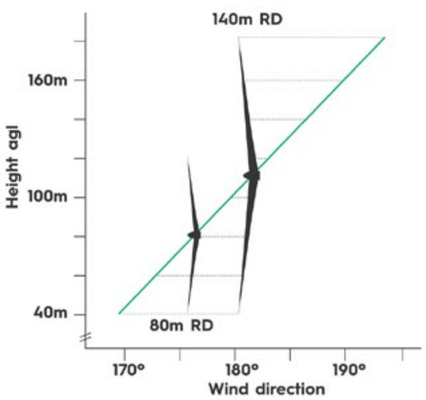


**Figure 4:** Difference in absolute veer for varying rotor diameters

## Key conclusions: What we learned about veer

The research yielded several significant conclusions that have direct implications for wind resource assessment and project optimization:

**Conclusion 1:** Mesoscale data provides a solid foundation for veer assessment, with regional nuances

A significant finding is that mesoscale data generally captures the shape of RSD veer histograms well.

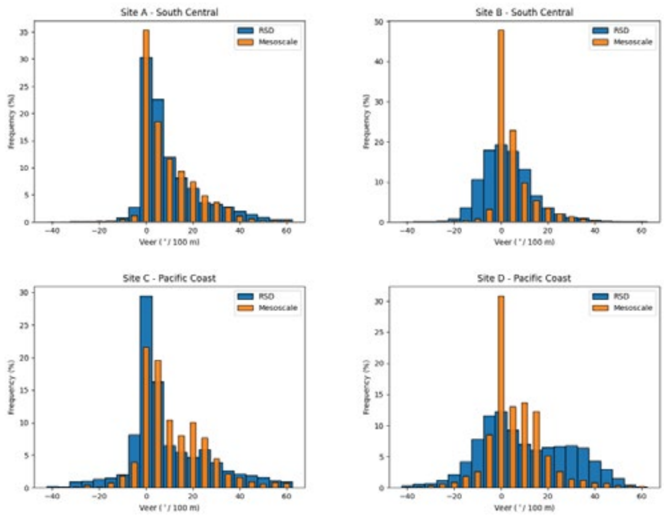


**Figure 5:** Regional variations in veer

This means that even without a costly on-site RSD, mesoscale models can provide a reasonably accurate representation of the frequency and distribution of different veer magnitudes in most regions.

The overall bias in mean veer between RSD and mesoscale data for concurrent timestamps showed reasonable agreement, with an approximately normally distributed error generally within +/- 2 degrees per 100 meters. Furthermore, the mean diurnal veer, when averaged across all 104 RSD deployments, demonstrates excellent agreement between RSD and mesoscale data. This suggests that mesoscale models are generally reliable for capturing daily patterns of veer.

However, the research also highlighted some important caveats:

➜ **Underestimation of minimal veer by RSDs:** Mesoscale data tends to predict more time with minimal veer than RSDs. This could imply that RSDs, due to their localized measurements, might pick up more micro-scale turbulence or subtle veer instances that mesoscale models, with their larger grid cells, might smooth over.

➜ **Challenges in complex terrain:** The study revealed that terrain and veer complexity in Pacific Coast sites were not fully captured by mesoscale data. This underscores the importance of exercising caution when relying solely on mesoscale data in highly complex geographical areas where localized atmospheric effects can be pronounced.

➜ **Regional differences in nocturnal veer:** While the overall diurnal agreement is strong, the variance in diurnal veer by region is largely driven by nocturnal differences. This suggests that regional modeling and analysis might need to pay particular attention to night-time conditions to accurately capture veer behavior.

This conclusion is of significance for the industry, as it supports the feasibility of using readily available mesoscale data for initial veer assessments at all sites, thereby avoiding an inconsistent pre-construction analysis penalty for sites with RSDs.

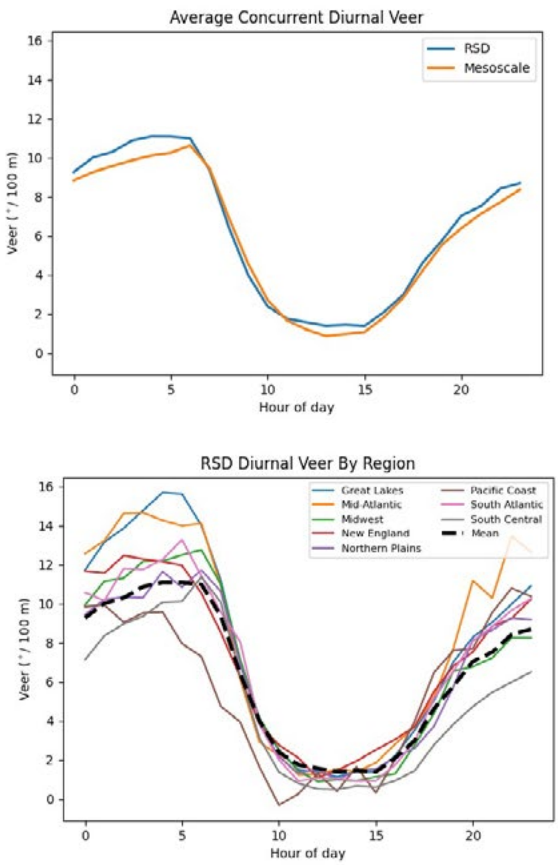


**Figure 6:** Diurnal variations in veer

**Conclusion 2:** Veer becomes increasingly critical with larger turbine rotor diameters

As the wind industry continues to deploy larger turbines with ever-increasing rotor diameters, the impact of veer is expected to become even more significant and impactful. Modern turbines are designed to capture more energy by sweeping a larger area, but this also means they are exposed to a wider range of atmospheric conditions, including more pronounced veer.

The increased susceptibility of larger rotors to differences across the rotor plane means that a given amount of veer will likely have a more substantial effect on energy capture and turbine loads than it would on smaller, older turbines. This reinforces the urgency for the industry to better understand, model, and account for veer in all stages of wind project development and operation.

**Conclusion 3**: A geospatial model of veer across the US reveals regional patterns and opportunities

The development of a geospatial model of ERA5 veer across the US provides a powerful tool for understanding regional patterns of veer. This model can help identify areas where veer is more prevalent, both generally and during specific times of the day (e.g., hours 0-6).

The regional comparison of median RSD and mesoscale veer rates reveals interesting insights:

➜ Regions like the Great Lakes and Mid-Atlantic generally exhibit higher median veer rates than South Central or Midwest in the US.

➜ While mesoscale data generally aligns well, some biases exist. For instance, mesoscale data tends to slightly underestimate veer in Alberta/Saskatchewan, Canada, and the Mid-Atlantic, while slightly overestimating it in the South-Central US.

This geospatial understanding is crucial for:

➜ Targeted resource assessment: Identifying "high veer" regions allows developers to incorporate veer considerations early in the site selection and resource assessment phases, potentially adjusting turbine layouts or selecting turbine technologies more resilient to veer.

➜ Informed project operation: For existing projects, understanding regional veer patterns can help diagnose underperformance issues and inform operational adjustments or retrofits.

➜ Strategic RSD deployment: While the goal is to reduce reliance on RSDs, the geospatial model can help prioritize where future RSD deployments might yield the most valuable data to refine regional models, especially in complex areas.

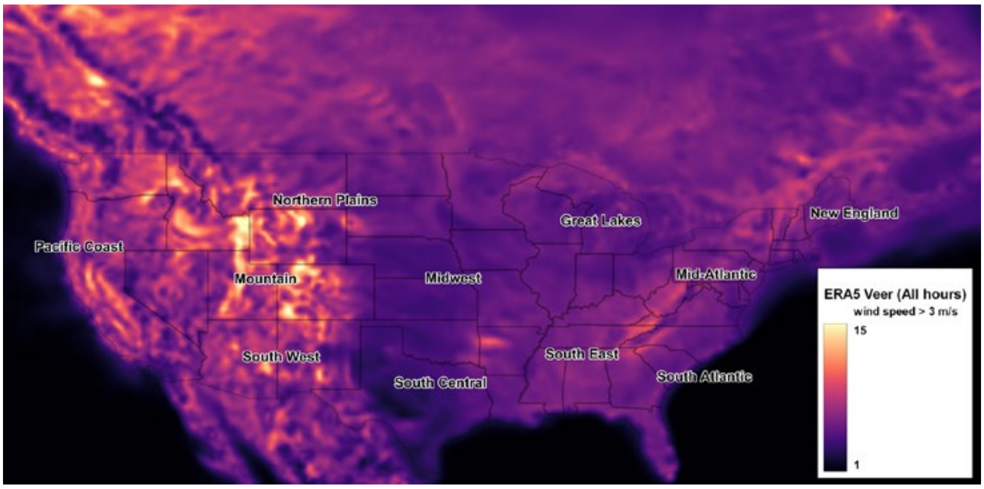


**Figure 7:** Veer derived from ERA5 (all hours)

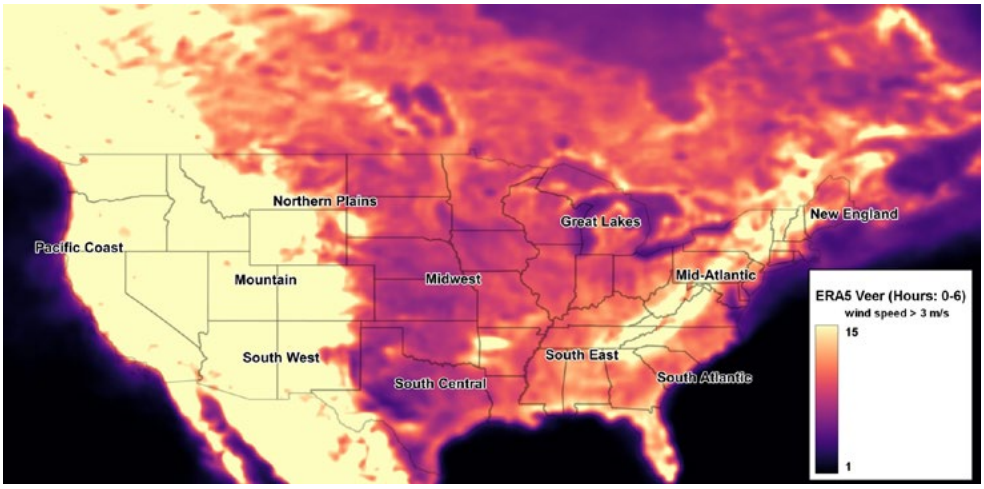


**Figure 8:** Veer derived from ERA5 (0-6 hours)

## Looking ahead: integrating veer into wind energy practices

The research by Natural Power marks a significant step forward in our understanding and ability to quantify wind veer. The next critical steps involve:

→ **Supplementing regional datasets:** Integrating more regional RSD data, especially as RSDs become more common in pre-construction projects, will further refine and validate the geospatial models.

→ **Quantifying performance impact:** The ultimate goal is to precisely determine the impact of veer on project performance regionally and refine time-series modeling related to veer-induced losses or underperformance.

→ **Validation with SCADA data:** Validating these models against actual SCADA (Supervisory Control and Data Acquisition) data from operational wind farms will be crucial to ensure their real-world applicability.

→ **Integrating into assessment tools:** Finally, the aim is to capture the effects of veer directly within wind resource assessment methodologies.

By proactively addressing wind veer, the wind energy industry can enhance the accuracy of energy yield predictions, improve operational efficiency, and ultimately unlock the full potential of wind power generation. This research provides invaluable insights for wind farm owners, operators, developers, and consultants seeking to optimize their assets and contribute to a more reliable and efficient renewable energy grid.

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If you have any queries related to the content of this paper, please contact:

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