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Identification of Climatological Representative Days in the Mid-Atlantic for High-Fidelity Offshore Wind Energy Modeling

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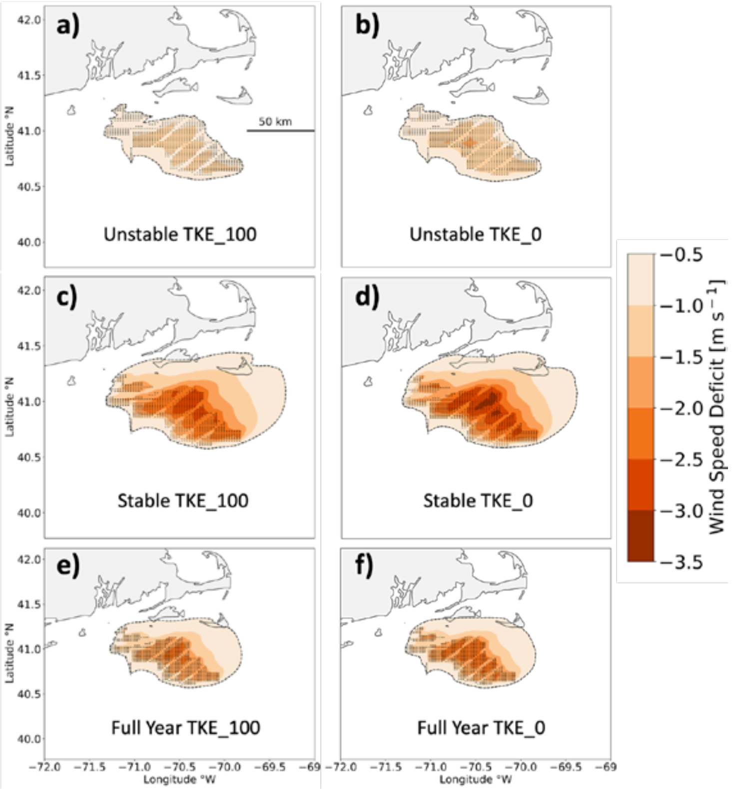
Overview

The Need to Quantify Cluster Wakes

- With the increase in wind energy areas in the Mid-Atlantic, the concern over wake-induced losses are valid (Shaw et al. 2022).
  - Wakes and cluster wakes can impact power production and the ability to forecast wind resource.
- Intra-array and inter-array wakes can impact power production and reduce the available wind resource to downstream wind farms (Rosencrans et al. 2023).
- Better site selection and array spacing can help mitigate these impacts, but this requires knowledge of the long-term climate in the region.
- Modeling the long-term climate for a large geographic region is computationally expensive, yet methods exist in the literature that can help address this issue.



Average wake wind speeds for different stability conditions

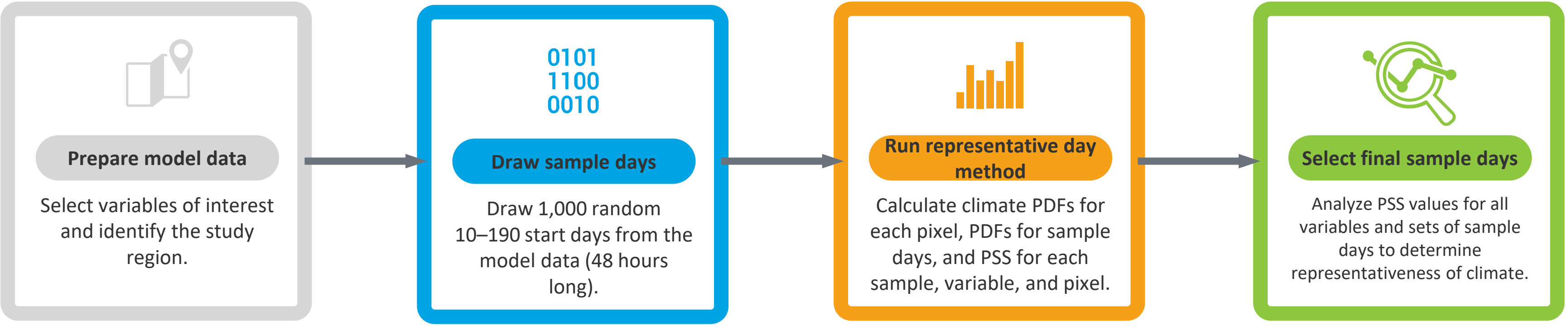
Source: Rosencrans et al. 2023, Figure 8

How to Quantify the Wind Climate in the Mid-Atlantic?

- To avoid expensive modeling of the actual climate, methods exist to find the number of representative days needed for a “good” or “near perfect” representation of the climate.
  - Fischereit, Larsén, and Hahmann (2022) leveraged the method of randomly selecting 48-hour periods in the climatic record, for a set number of days, for meteorological variables deemed important to the wind-wave climate in the German Bight.
  - The Perkins skill score (PSS) was used to compare the common areas between the probability density function (PDF) of the climate versus a random sample (Perkins et al. 2007).
  - They found that 180 days (90 day-pairs) were adequate for representing the wind-wave climate.
- We chose to adapt this method for wind energy areas in the Mid-Atlantic, selecting variables important for wind power production.

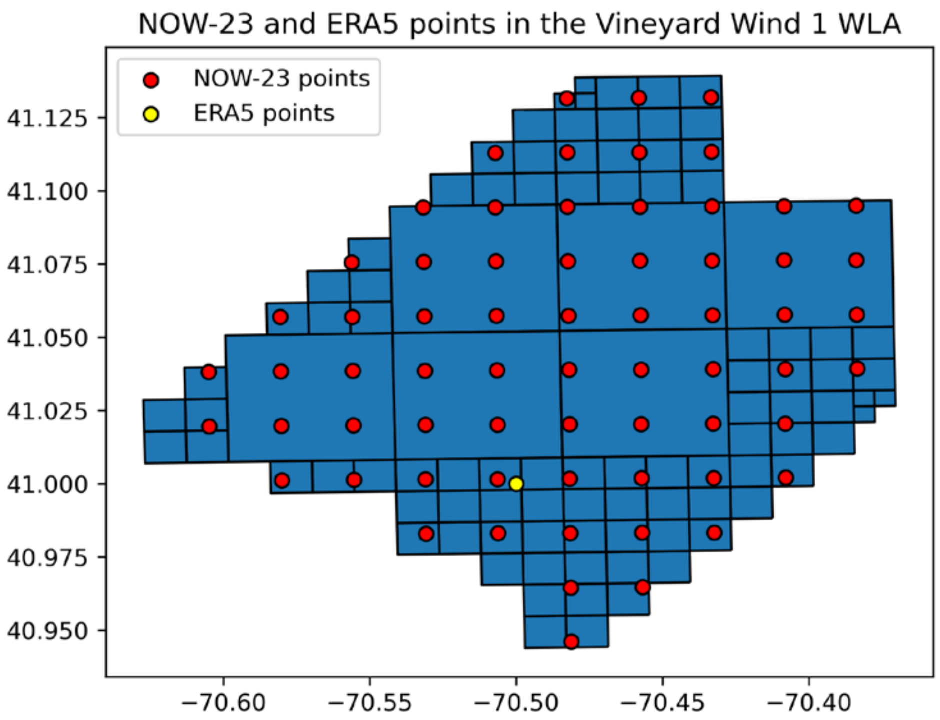
Overview of Representative Day Method

$$PSS(t,l) = \sum_{i=1}^{n} \min\left(Z^{c}(i,l), Z^{s}_{N(t)}(i,t,l)\right)$$



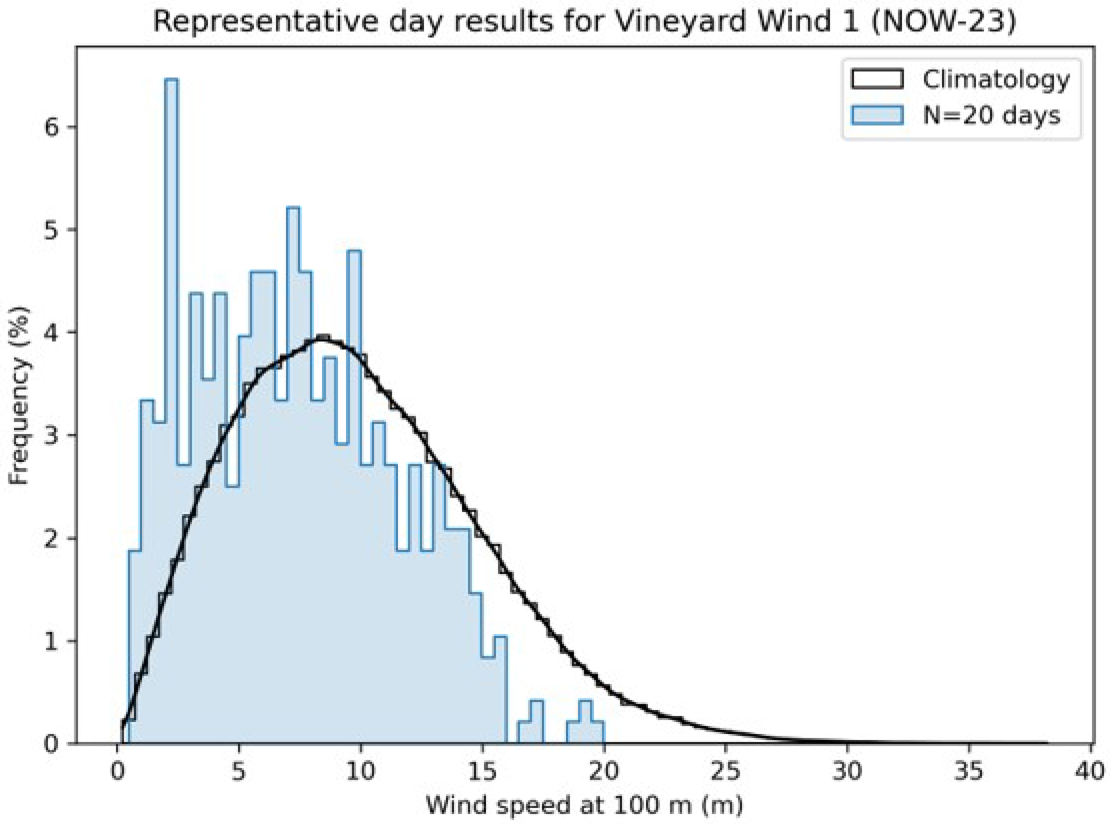
- PSS of 1 = perfect agreement with climate reference period
- PSS of 0.9 = “near perfect”
- PSS of 0.8 = “good”
- PSS of 0 = no overlap with climate reference period

Model Datasets Available Over the Mid-Atlantic



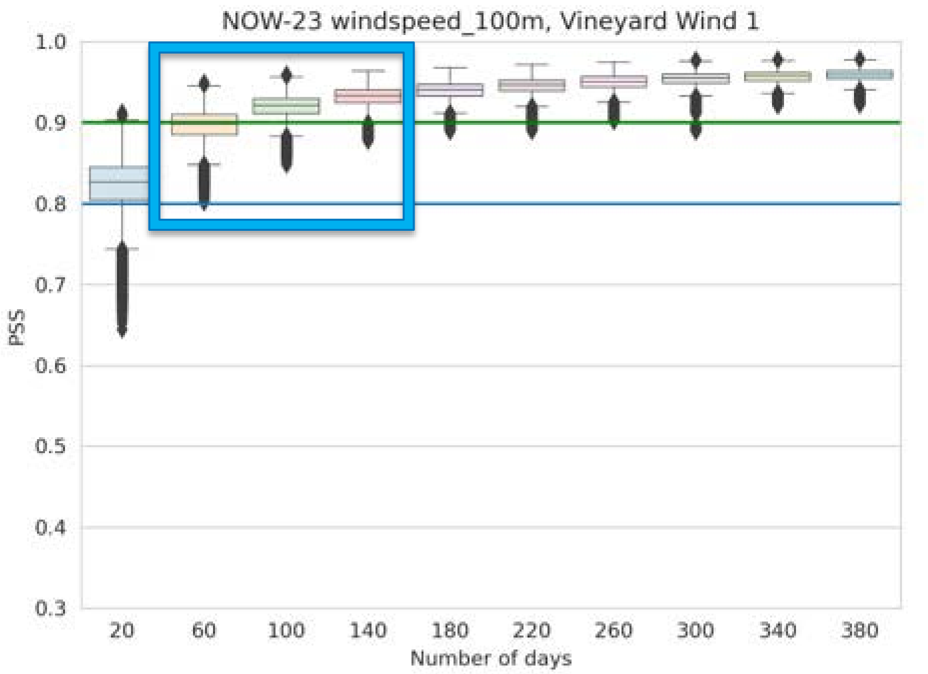
- Leveraged two datasets: NOW-23 and ERA5:
  - NOW-23 is 2-km spatial resolution, 5-min or hourly, model data for 2000–2020 (Bodini et al. 2020).
  - ERA5 is 0.25° (~31-km) spatial resolution, hourly, reanalysis data for 1940–present.
  - Initial variables considered:
    - Wind speed at 100 m, wind direction at 100 m, boundary layer height, turbulent kinetic energy at 100 m, and surface heat flux
    - These variables can have significant impacts on power production (Wharton and Lundquist 2012a, 2012b; St. Martin et al. 2016; Al Sam, Szasz, and Revstedt 2017).

Example of Sample Days Converging to Climate PDF



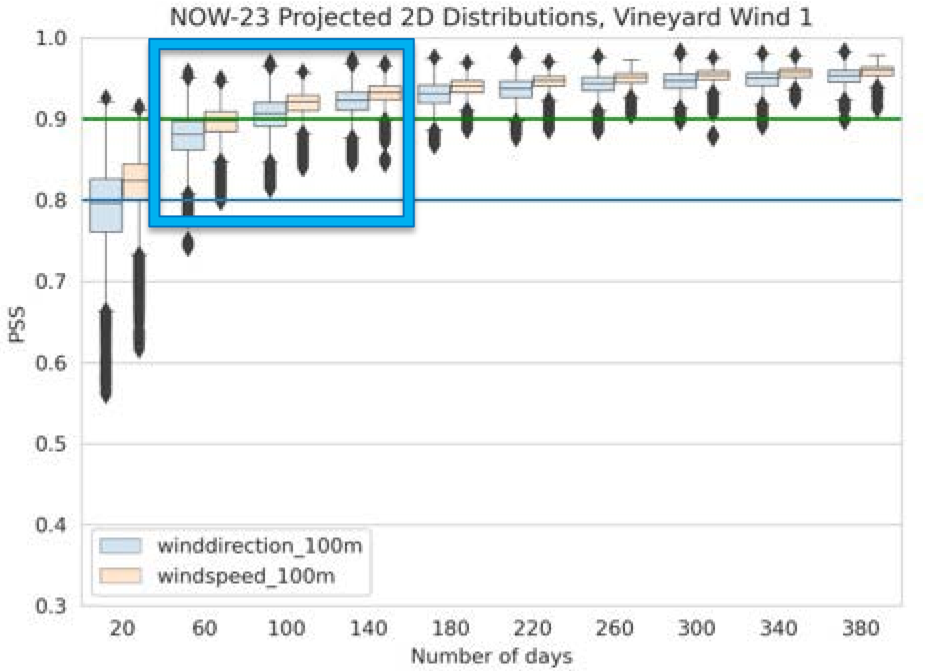
NOW-23 Vineyard Wind 1 Results—Individual Variables

- As expected, variability is higher with a smaller sample size and lower with a larger sample size.
- PSS values increase with increasing sample size.
- Median-wise:
  - Good results with 60 days
  - Near perfect results with 100 days.
- IQR-wise:
  - Good results with 60 days
  - Near perfect results with 140 days.

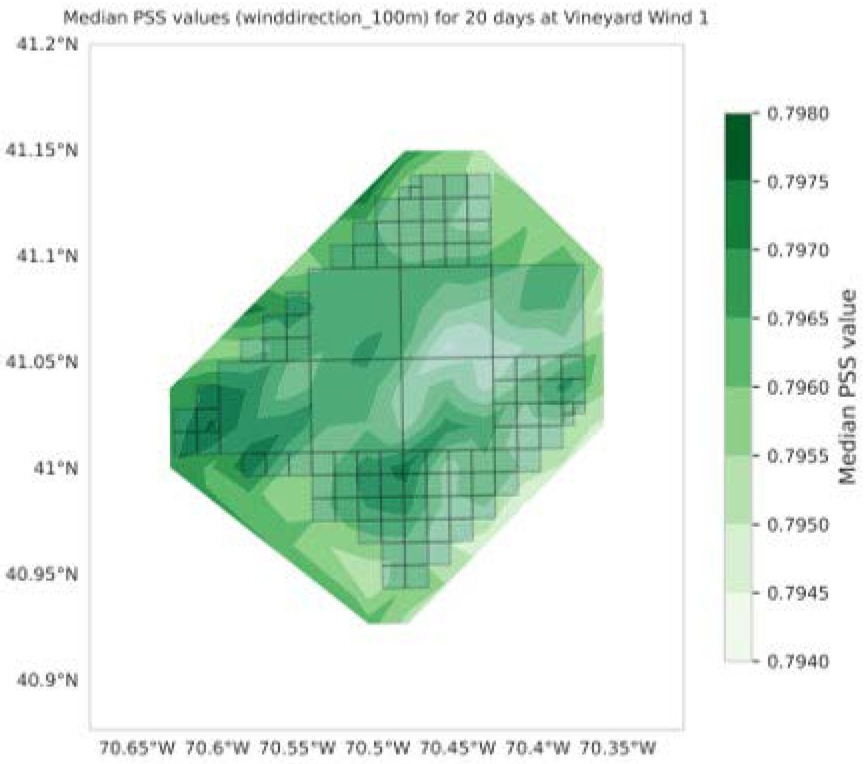


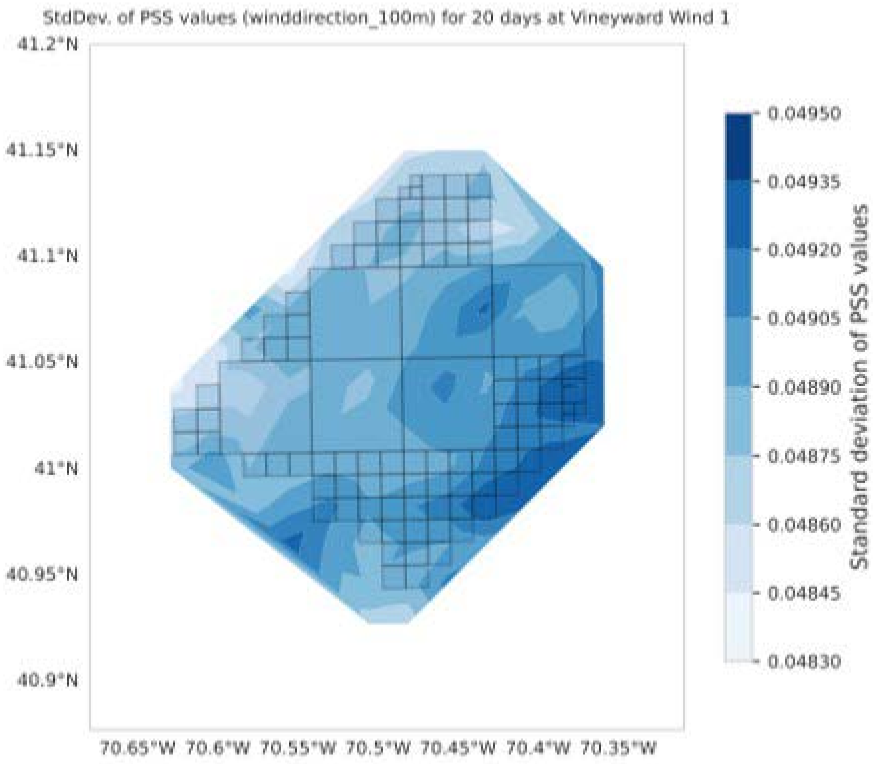
NOW-23 Vineyard Wind 1 Results—Joint Variables

- Simply put, we project the values of one variable onto the axis of another.
  - This gives an idea of how these variables change together.
- Aggregated across Vineyard Wind 1, the projected 2D distributions do not appear to differ much from single variable distributions.
- Similar results are obtained via ERA5 (not shown).



Spatially, Variability Is Small Across Vineyard Wind



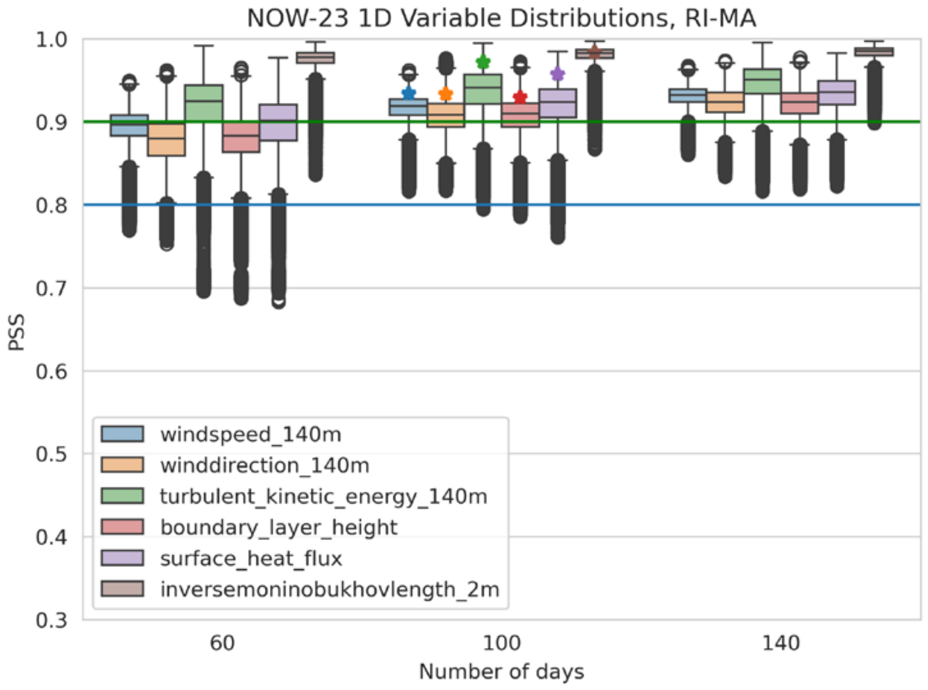


Initial Interpretation of the Results

- The total number of days required to represent (>0.9) the long-term climate for the variables considered is less than that of Fischereit, Larsén, and Hahmann (2022):
  - They considered 180 days, whereas we think 100–140 days suffices, depending on the resources.
- The results seem reasonable because the Weather Research and Forecasting (WRF) model is self-contained, whereas the Fischereit, Larsén, and Hahmann (2022) results were based on observations.
- Joint distributions do not indicate that additional simulation days will be needed, but the spread of the distributions does increase (extremes).

Next Steps–Expand Spatial and Variable Space

- Ultimately, we will study two separate regions in the Mid-Atlantic:
  - Rhode Island and Massachusetts wind energy areas
  - New York-New Jersey-Delaware-Maryland.
- We will investigate variables closer to hub height.
- The initial results indicate a similar pattern with Vineyard Wind:
  - Near perfect with 100 days.



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