EERA DeepWind conference, Trondheim 15-17 January 2025

Trends in Future of Offshore Wind Power Production: Wake and Climate Change Impacts: Sørlige Nordsjø-PyWake

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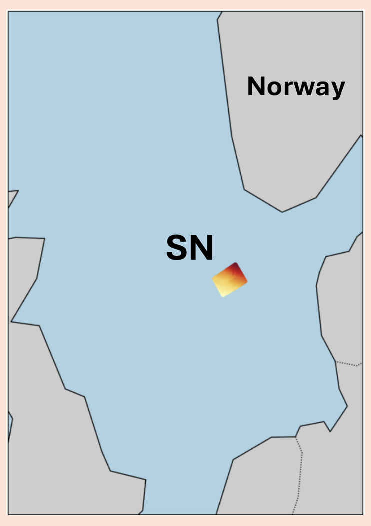
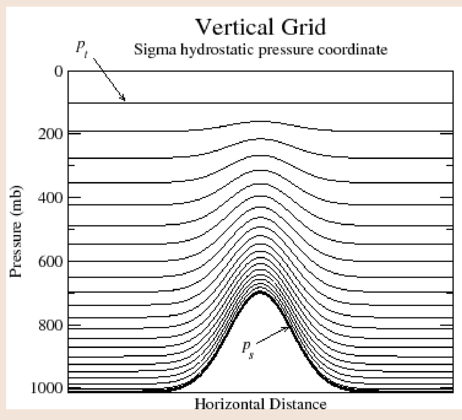
Introduction

This study aims to examine the long-term variability of wind resources and their associated power potential using mid-21st century CMIP6 simulations under the high-emission SSP5-85 scenario for the North Sea, with a specific focus on two Norwegian offshore wind sites, including Sørlige Nordsjø (SN). The impact of wake-induced power losses at this site is evaluated, and spatial correlations between the locations are analyzed (results not shown). Wake effects are incorporated into the climate projection data using an engineering wake model (PyWake). While the structural reliability of offshore wind turbines in relation to climate-induced changes in wind and wave conditions is also a key focus, it is deferred to a separate study to maintain a cohesive investigation centered on data processing and wake modeling.



Climate projections

This analysis examines wind speed at three heights (50m, 100m, and 200m), with surface wind data available every 3 hours and higher-altitude wind data provided at 6-hour intervals, covering both historical (1995-2014) and long-term periods. We utilize CMIP6 projections (for the simplicity here only HadGEM3-GC31 in pressure-sigma coordinate), with inherent systemic biases due to the simplifications of modeling Earth's complex systems and the coarse spatial resolution of climate models, which limits their effectiveness in studying localized behaviour.



Extracting 100 m wind speed time series from climate model simulations is a complex task. In this study, I use reference data that eliminates the need for extrapolation in pressure-sigma levels where pressure at model level k is calculated as.

$$p_k = a_k p_0 + b_k p_s$$

Here, p_0 is the reference pressure of the model, a_k and b_k are the sigma-level coefficients for level k, and p_s is the surface pressure.

The thickness between two model layers, z_{k+1} and z_k, can be derived using the hypsometric equation, based on the hydrostatic equation and the ideal gas law:

$$\Delta z = z_{k+1} - z_k = \frac{R_d T_v}{g} \ln \frac{p_k}{p_{k+1}},$$

where T_v is the mean virtual temperature between levels k and $k+1$. ϵ=0.622, R_d is the gas constant for dry air, g is Earth's gravitational constant, T is air temperature, and q is specific humidity

$$T_v = T\frac{(q+\epsilon)}{\epsilon(1+q)}.$$

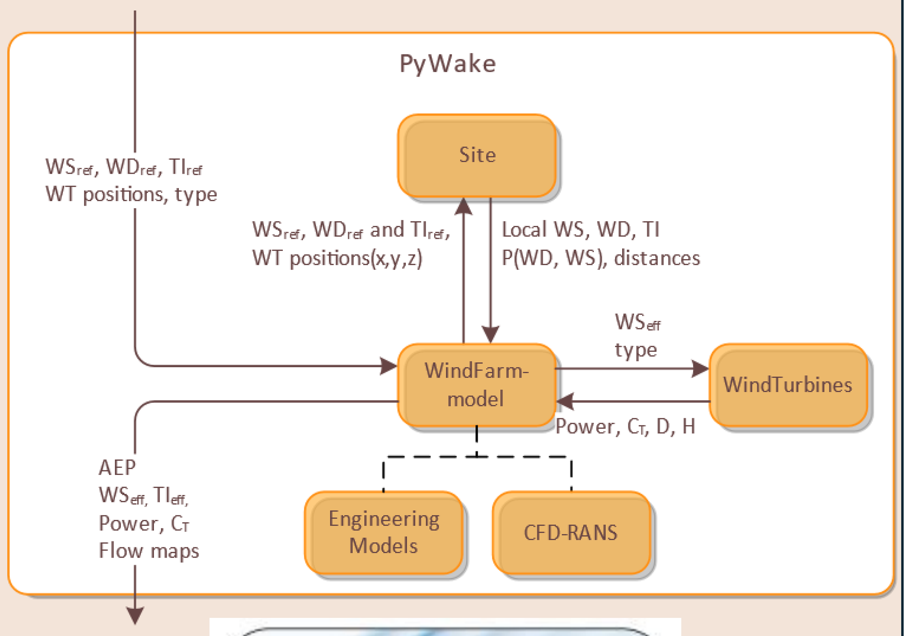
Much of the projection data is not readily available in this coordinate system, necessitating the estimation of wind speeds at higher altitudes. For example, the power law, which depends on the shear exponent, can be employed. However, the shear exponent varies over time and space, making it non-uniform. To address this, we can use ERA5 data corresponding to the CMIP6 projections. By estimating the shear exponent (αERA5αERA5) from the averaged ERA5 wind speeds at 10 m and 100 m, we can approximate the CMIP6 wind speed at 100 m using the 10 m wind speed as follows:

$$U_{100,\mathrm{CMIP6}} = U_{10,\mathrm{CMIP6}} \cdot 10^{\overline{\alpha_{\mathrm{ERA5}}}}.$$

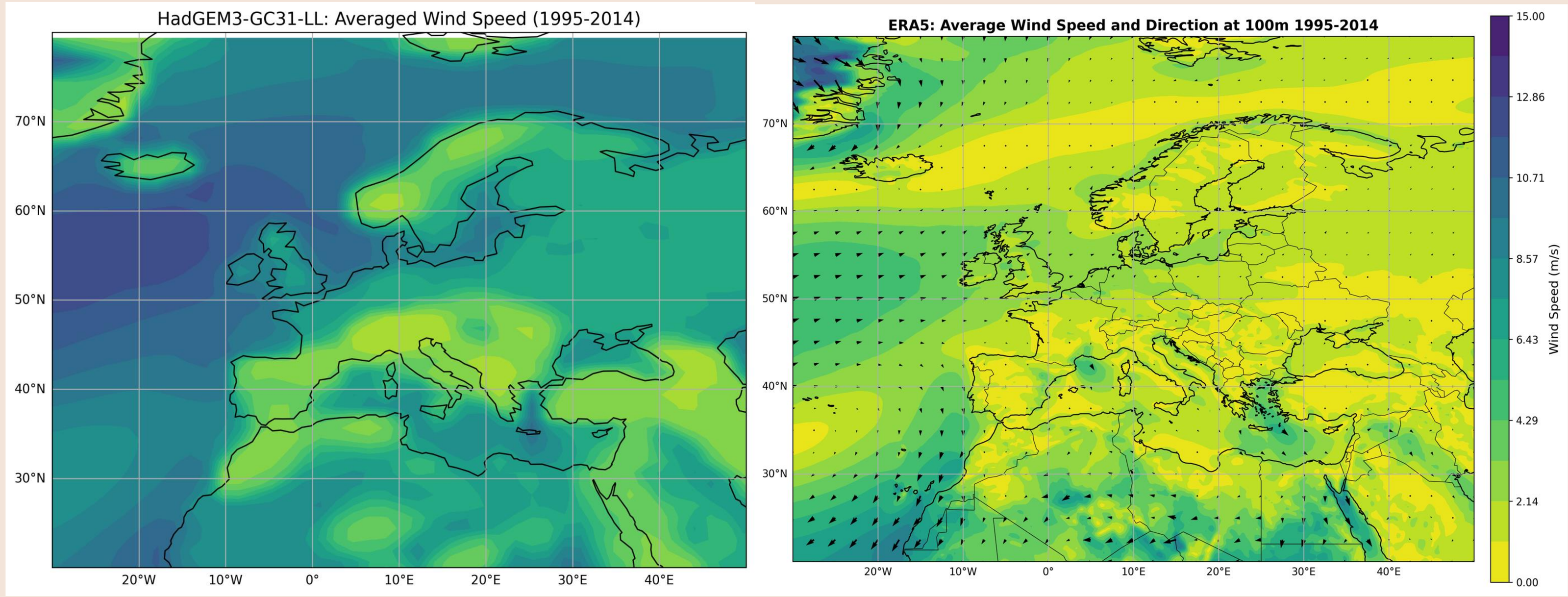
Bias correction (BC) and quantile mapping are proposed methods that eliminate the need for using a power law. These techniques can be implemented utilizing historical ERA5 data.

Wake model: PyWake

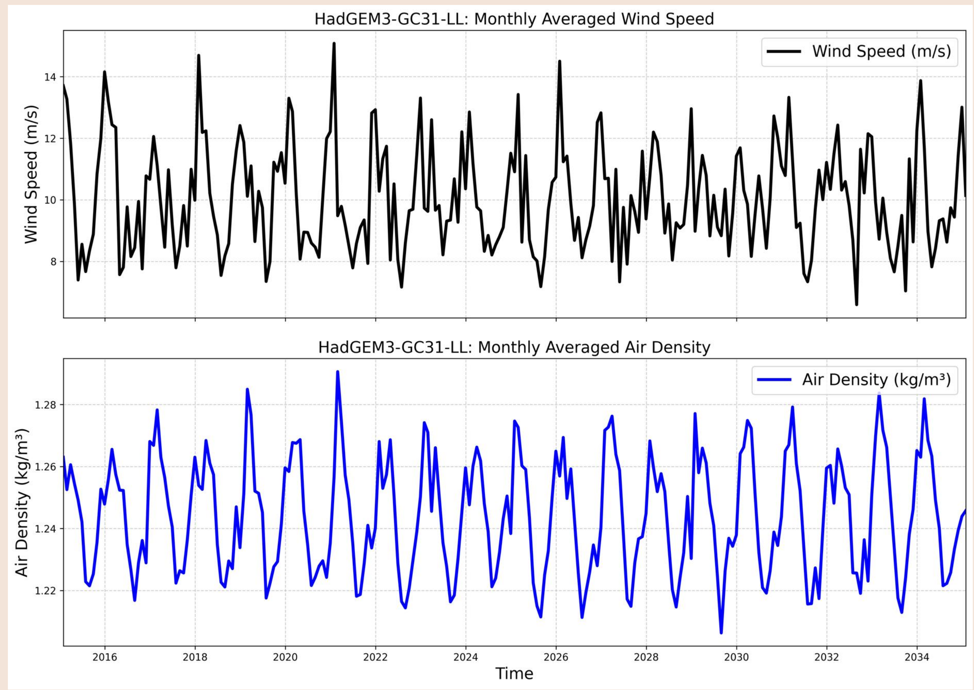
The wake model computations utilize the open-source wind farm simulation tool PyWake (Pedersen et al., 2019). Key meteorological inputs include the mean hub-height wind speed (for the NREL 15MW turbine), wind shear exponent (derived from reanalysis data), ambient streamwise turbulence intensity (TI) at hub height, and wind direction. Turbine-specific inputs encompass rotor diameter, hub height, turbine coordinates, and the thrust and power coefficients across varying wind speeds for the 15MW turbine.



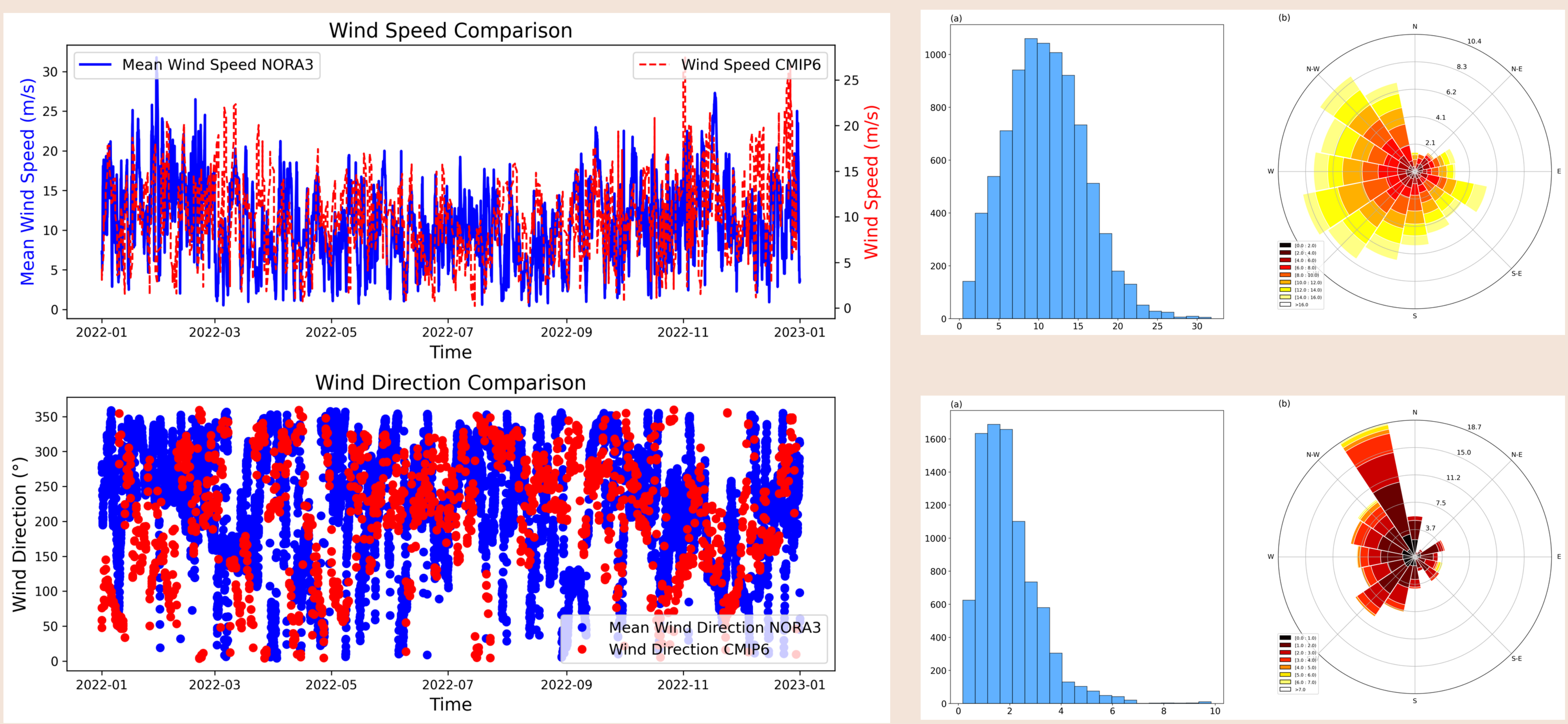
Results



Comparing the averaged wind at 100 m extracted from the pressure-sigma coordinates with the ERA5 averaged wind (and NORA3 below) for the period 1995-2014 in both plots. Various methods, such as power law with constant or variable shear, or quantile correction (not shown), can be applied. Using a constant shear exponent may be unrealistic and could lead to wind field overestimation. Bias correction may exaggerate extreme winds, while quantile correction, based on historical wind data, assumes that the future period's distribution will mirror the historical period.



Comparing NORA3 wind and wave versus CMIP6



I estimate the spatial and temporal variation of wake and internal wake losses using PyWake, employing techniques such as TurboPark. For the Sørlige Nordsjø II offshore wind farm, which consists of 753 15MW turbines, the internal wake losses are estimated to be more than approximately 20% in some wind cases.

References

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