Spatial Wind Energy Correlation and Intermittency: Wake Effects of 15MW Turbines in the North Sea

Viktor Dahl, Supervisor Mostafa Bakhoday Paskyabi and Co-Supervisor Asgeir Sorteberg

University of Bergen (UiB), Geophysical Institute (GFI) and Bergen Offshore Wind Center (BOW)

Wind Condition

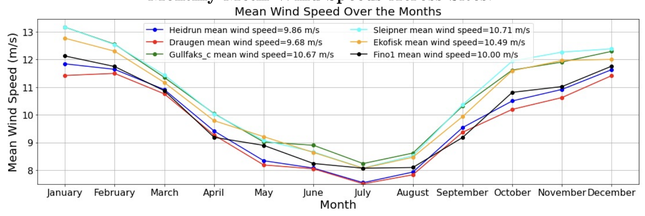
Wind Variables:

Wind Speed: Wind speeds vary significantly across sites, with Sleipner showing the highest speeds, while Fino1 exhibits more consistent wind conditions. Winter sees the strongest winds due to increased atmospheric pressure differences, ideal for energy production.

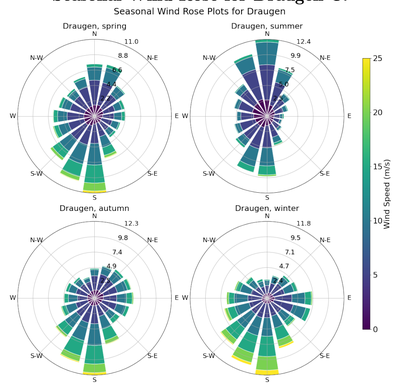
Wind Direction: Predominant wind directions are from the south, shaping turbine layout strategies. At Heidrun, a notable seasonal shift to northern winds during summer highlights the importance of adaptive planning to capture energy effectively.

Turbulence Intensity: Turbulence levels are highest at Heidrun, posing challenges for wake recovery but helping mitigate wake losses in winter. Higher turbulence in winter across sites promotes faster wake dissipation, making northern sites more favorable for reducing wake propagation.

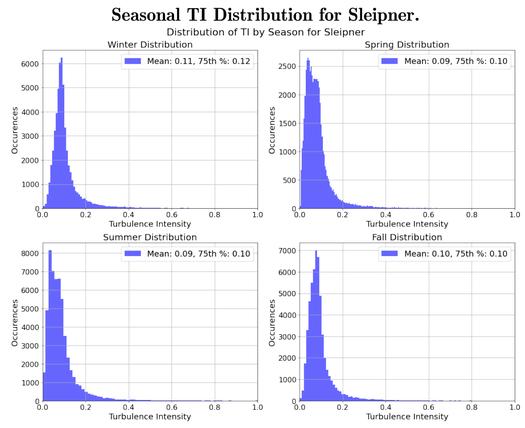
Monthly Mean Wind Speeds Across Sites.



Seasonal Wind Rose for Draugen C.



Seasonal TI Distribution for Sleipner.



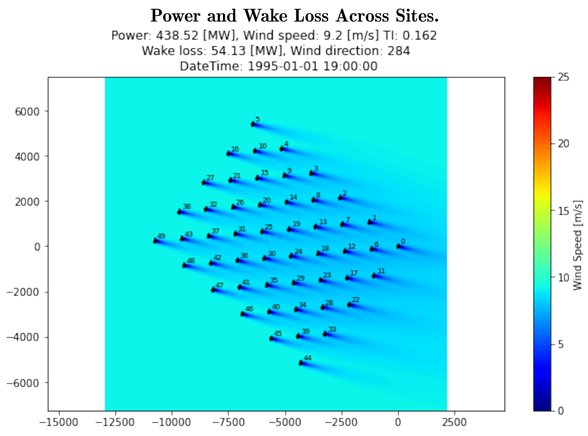
Power Production and Wake Loss

Power Production and Wake Loss:

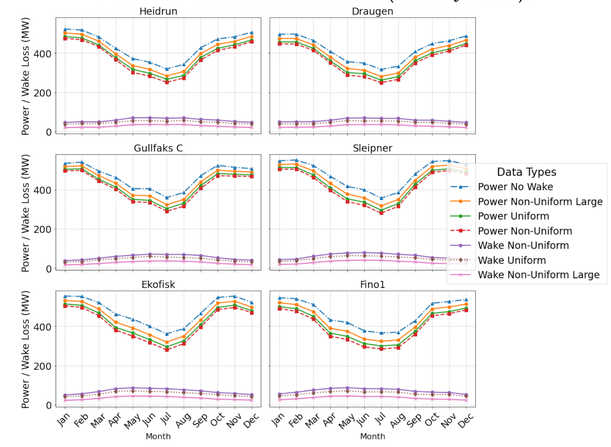
The Production: The atmospheric variables are modeled using the Niayiafar-Portè-Agel Wake Model in PyWake to assess wind speed and power production. Despite significant seasonal variation, Sleipner exhibits the highest average annual power production due to strong wind speeds. Summer sees increased wake losses, while winter's higher wind speeds and turbulence intensity mitigate wake effects, enhancing power output. Gullfaks C shows stable power production year-round, favoring continuous energy supply.

Layout Performance: The uniform layout consistently minimizes wake losses and stabilizes power production, outperforming the non-uniform layout for restricted size configurations. Larger non-uniform layouts generate higher power but suffer from the need for a greater area, hence higher cable cost. Power distribution analysis reveals production is prone to either max or zero production.

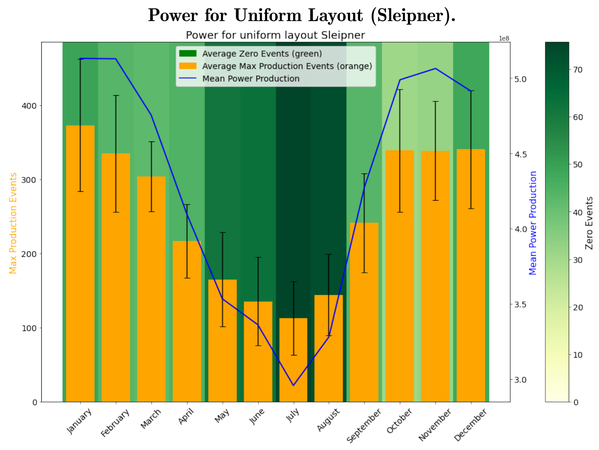
Power and Wake Loss Across Sites.



Power and Wake Loss Across Sites (Monthly Series).



Power for Uniform Layout (Sleipner).



Intermittency

Correlation:

Interconnection of distant sites with low correlations, such as Heidrun with Ekofisk or Fino1, is suggested to help reduce simultaneous low-production events, improving stability. Seasonal trends show lower correlations in winter, enhancing interconnection benefits compared to summer.

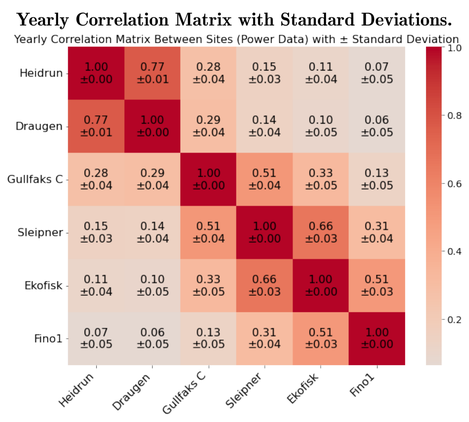
Coherence:

Mesoscale patterns are localized, favoring site dispersion to reduce wind similarity, while planetary-scale patterns exhibit high coherence across distant sites. Pairing sites like Heidrun and Fino1 minimize simultaneous wind events. Draugen and Heidrun face coherent wind events but experience little of the same weather events as distant sites like Fino1.

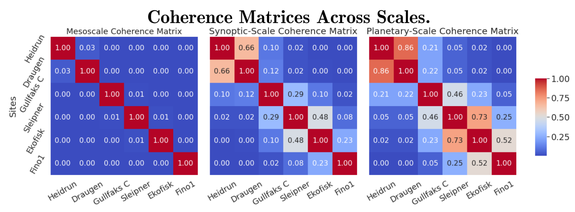
Reducing simultaneous zero-power production events:

The analysis highlights distance as a critical factor in achieving low correlations. Coherence analysis further supports this, showing that while mesoscale coherence favors localized variability, planetary-scale patterns synchronize conditions across regions. The zero-power production matrices validate these findings, demonstrating that distant sites with low correlation and coherence, like Heidrun and Fino1, experience fewer overlapping zero-power production events. This makes such pairings highly effective for ensuring reliable and continuous energy output.

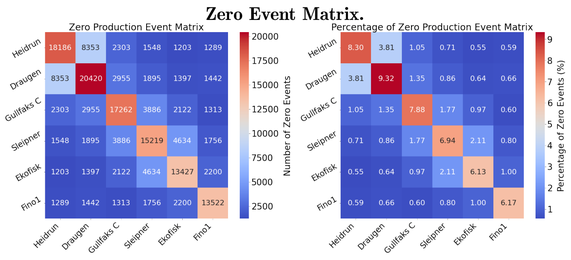
Yearly Correlation Matrix with Standard Deviations.



Coherence Matrices Across Scales.



Zero Event Matrix.



Uncertainty in Maintenance

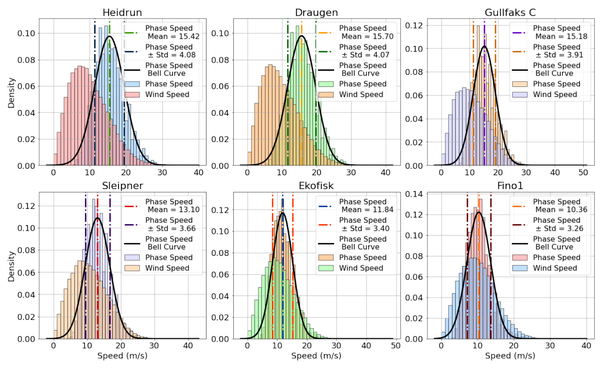
Description:

Northern Sites: Heidrun and Draugen face challenges due to wind-wave misalignment, higher phase speeds, and extreme wind conditions, limiting maintenance opportunities. The mature sea state, indicating well-developed wave systems at these sites, reflected in higher wave age, adds complexity to operations.

Southern Sites: Sleipner, Ekofisk, and Fino1 offer more predictable conditions due to narrower distributions of wind and wave phase speeds and lower wave ages, which result in closer wind-wave alignment. Fino1 stands out for having the lowest wave age and standard deviation, facilitating smoother maintenance scheduling.

Weather Windows: Wind-wave correlation reveals that calm seas align with low winds, while extreme winds coincide with high waves, complicating operations. Seasonal variations show fewer maintenance windows in winter at northern sites due to taller waves and high wave ages. Southern sites, such as Fino1, provide a more balanced distribution of weather windows, simplifying planning. Draugen offers frequent opportunities but faces wave height challenges, while Fino1 benefits from balanced weather windows and lower variability.

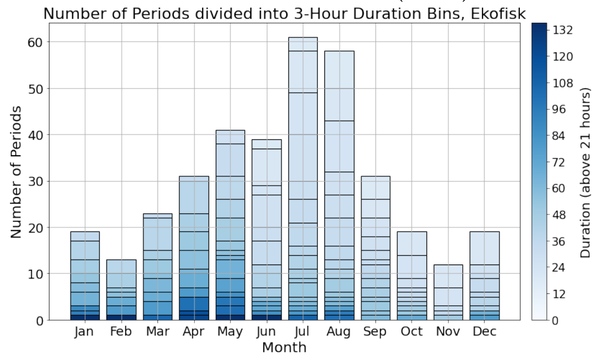
Phase and Wind Speed Distributions.



Site	Mean Wave Age±std [-]	Wind-Wave Directional Correlation
Heidrun	2.24 ± 1.43	0.446
Draugen	2.33 ± 1.49	0.424
Gullfaks C	2.14 ± 1.40	0.429
Sleipner	1.87 ± 1.30	0.075
Ekofisk	1.71 ± 1.20	0.119
Fino1	1.55 ± 1.19	0.162

Table: Mean wave age (1995–2020) and wind-wave correlation.

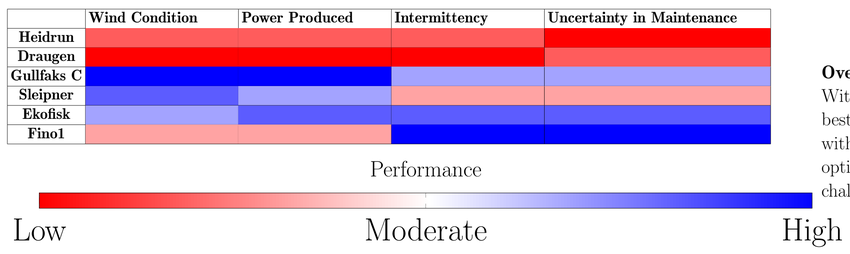
Maintenance Weather Windows (Ekofisk).



Conclusion

Analysis Summary:

Based on the conclusion to the objectives listed above, the table reveals the performance of the four topics: *Wind Conditions*, *Power Produced*, *Intermittency*, and *Uncertainty in Maintenance*. Observably, out of the six sites investigated, Heidrun and Draugen perform worst in all topics, ranking last and second to last, respectively. Gullfaks C performs best in *Wind Conditions* and *Power Produced* but ranks third in *Intermittency* and *Uncertainty in Maintenance*. Sleipner excels in *Wind Conditions*, performs well in *Power Produced*, but scores lower in the other topics. Ekofisk shows a consistent improvement across all topics, while Fino1 starts low but ranks highest in *Intermittency* and *Uncertainty in Maintenance*.



Overall Performance:

Without differentiating between the topics, and considering equal weighting, Gullfaks C emerges as the best performer, followed by Ekofisk, Fino1, and Sleipner. Draugen has the lowest overall performance, with Heidrun slightly above it. This ranking underscores the importance of site-specific strategies for optimizing wind farm operations and balancing power production, intermittency, and maintenance challenges.

LaTeX TikZposter