Improvements in Sea and Swell Separation for Offshore Industry Applications

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Contents

Motivation

For the offshore wind industry, a good understanding of wave conditions is relevant for design, construction, maintenance and operation. For floating wind turbines, the swell waves are especially important as they have a significant influence on the structural motion.

It is therefore key to have a good representation of wave spectra and understanding of the sea and swell systems. Distinguishing between these simultaneous wave systems and accurately categorizing them as either sea or swell remains a challenging task.

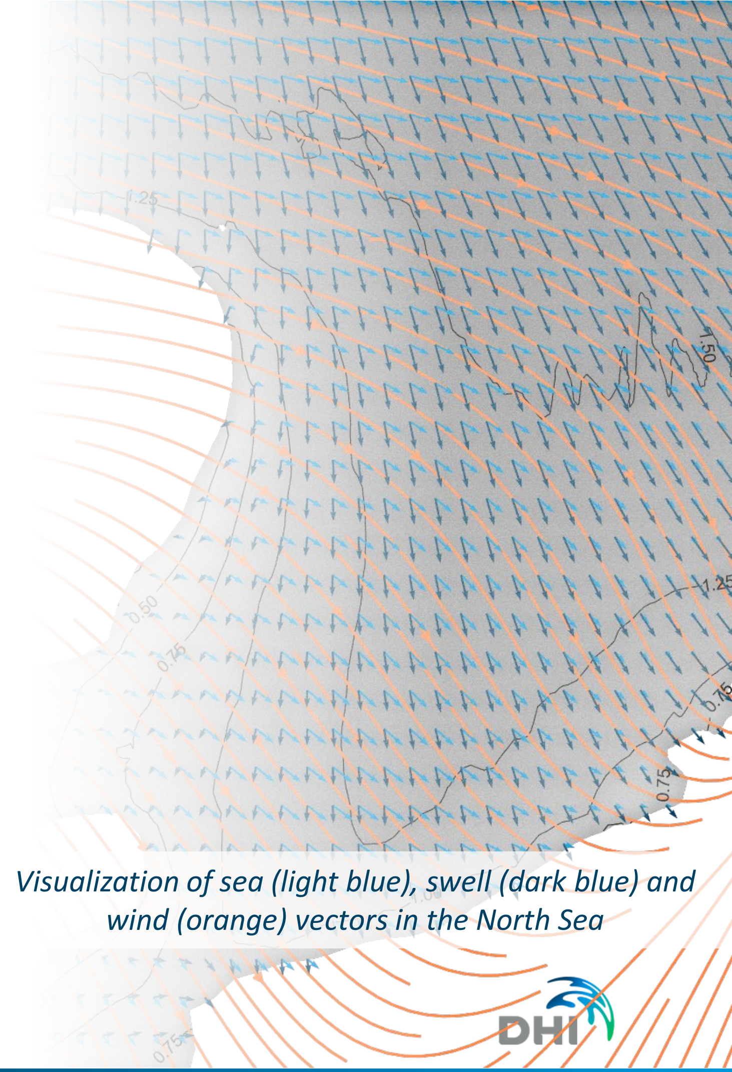
One of the common approaches is based on a **wave-age** criteria in which the wave direction and phase speed is correlated to the wind that generates them. The traditional parameters of the **wave-age** method typically assigns too much energy to swell (which in turn underestimates the energy assigned to wind-sea waves) and thus underestimate the wave energy that is aligned with the wind direction.

This approach has been revisited to improve the effectiveness of the sea-swell separation.

Methodology

Separation of wind sea and swell

- Many techniques have been developed to separate and categorize the different simultaneous wave systems in a sea state
- Geometric separation:
  - Iterative threshold-based partitioning algorithm by Gerling (1992)
  - Watershed: commonly used partitioning algorithm developed by Hasselmann et al. (1996), based on the hydrological concept of separating partitions analogous to inverted catchment area
- Wind sea–swell identification
  - Wave-age method: identification of wind sea and swell is based on the formulation of Komen et al. (1984) using 2D spectral wave and wind information
  - Wave Energy Statistical Method by Chen et al. (2002): defines the percentage split between wind sea and swell for a total sea state.
  - Overshoot Phenomenon: by Chen et al (2015) – compares spectral peaks of actual and theoretical spectra to identify the developing wind sea



Visualization of sea (light blue), swell (dark blue) and wind (orange) vectors in the North Sea

Wave age method

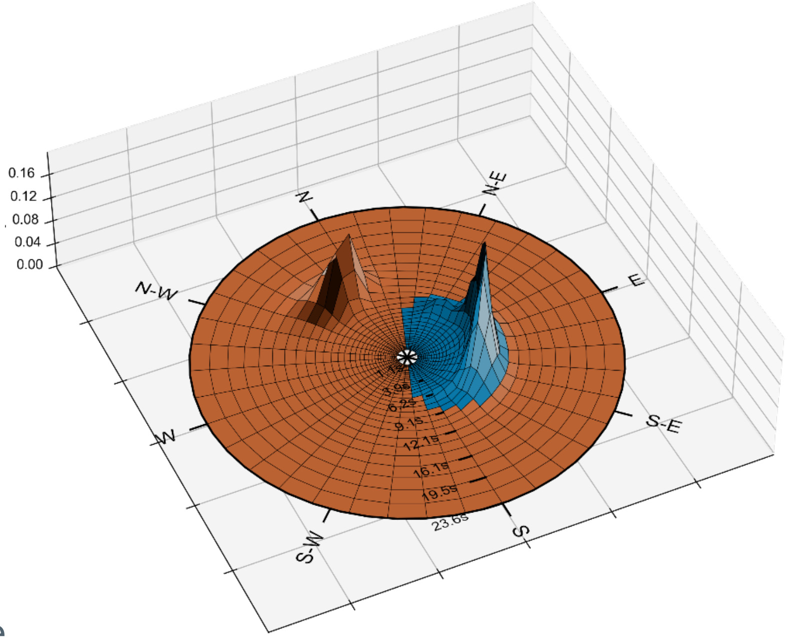
The wave age method was originally defined by Komen et al. as an equation that defines the region in the 2D wave spectrum as wind-sea if it satisfies the following relation:

$$\frac{U_{10}}{c}\cos(\theta_{waves} - \theta_{wind}) > \beta$$

Where

- U_{10} is the wind velocity at 10 m above the water surface
- c is the wave-phase speed
- θ_{waves} and θ_{wind} are the wave propagation and wind directions
- β is a calibration factor, with values that range in between 0.5 and 0.83

The selection of the factor β directly affects the extent of the wind-sea area in the spectrum



2D Spectrum showing wind partition in blue and remaining energy (swells) in orange

Proposed modification

- In the third-generation spectral wave model MIKE 21 SW, the wave age method is utilized for separation of sea states into wind-sea and swell.
- Standard parameters were not providing a good cutoff of sea/swell, thus the following modification has recently been implemented:

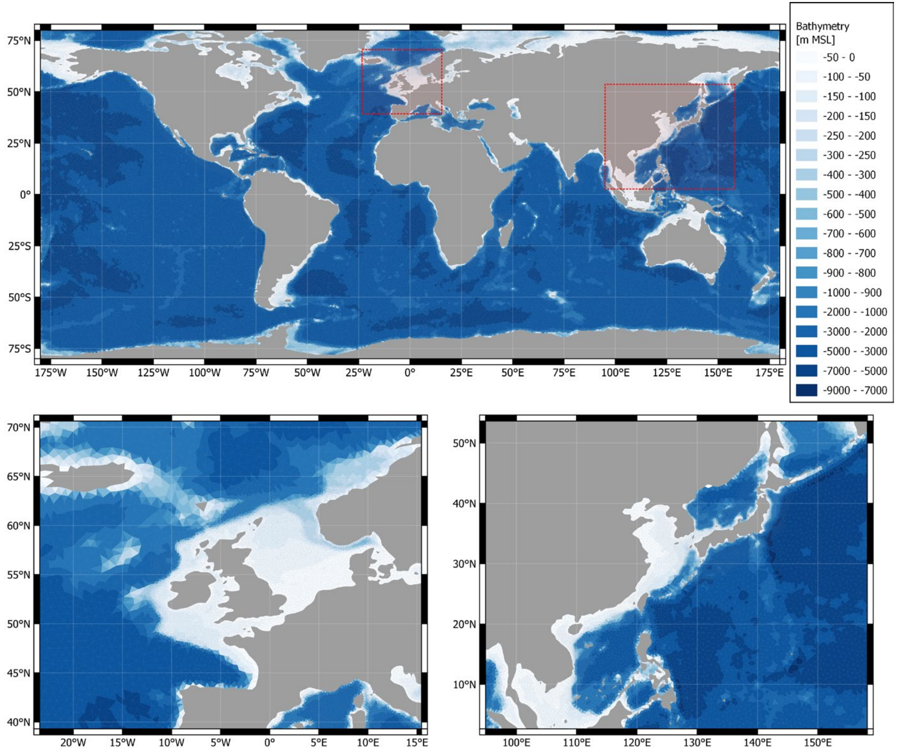
$$\frac{U_{10}}{c}\cos(\theta_{waves} - \theta_{wind})^{\alpha} > \beta$$

- DHI has developed a series of numerical model tests to improve sea/swell separation using both α and β:
  - Tested range: $\alpha = 0.15$ to 1.00 and $\beta = 0.70$ to 0.83
  - Improved parameters: $\alpha = 0.2$ and $\beta = 0.78$
- Comparison of original and improved parameters follows in next section

Application

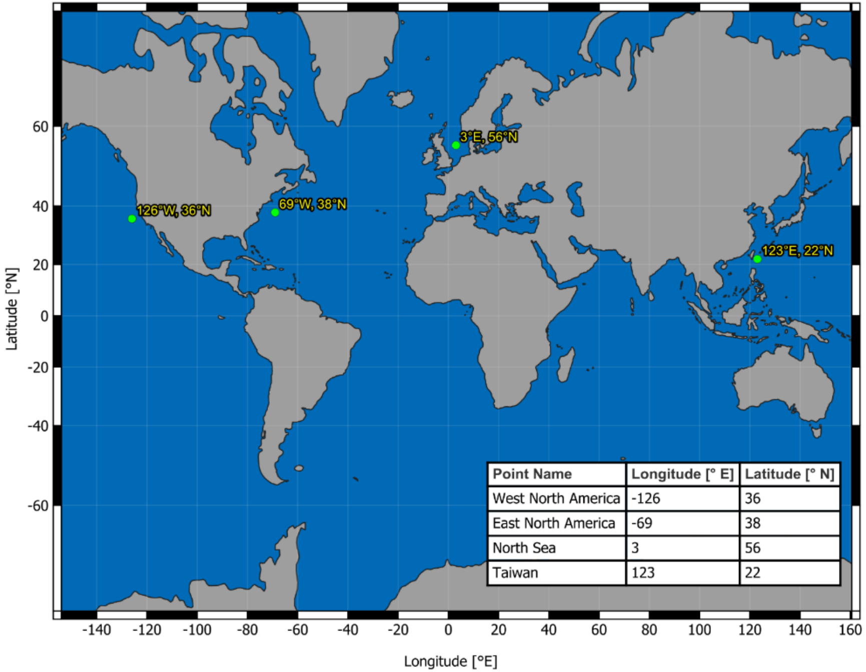
Spectral Wave Model: Setup

- DHI's Global Wave Model (GWM), using the MIKE 21 Spectral Model was used to evaluate the proposed modification.
- Key setup parameters:
  - Unstructured (triangular) numerical mesh, with a resolution that varies between 50 km in offshore regions down to 15 km near the coastline (cell center-to-center distance)
  - Fully spectral, instationary formulation, with source terms by Arduin et al.
  - Wind field forcing (varying both in space and time) from the ERA5 dataset (with some modifications to improve the extreme wave height results)
  - Wind speed stability correction by means of the COARE algorithm



Global Wave Model (GWM) bathymetry

Spectral Wave Model: Analysis Points

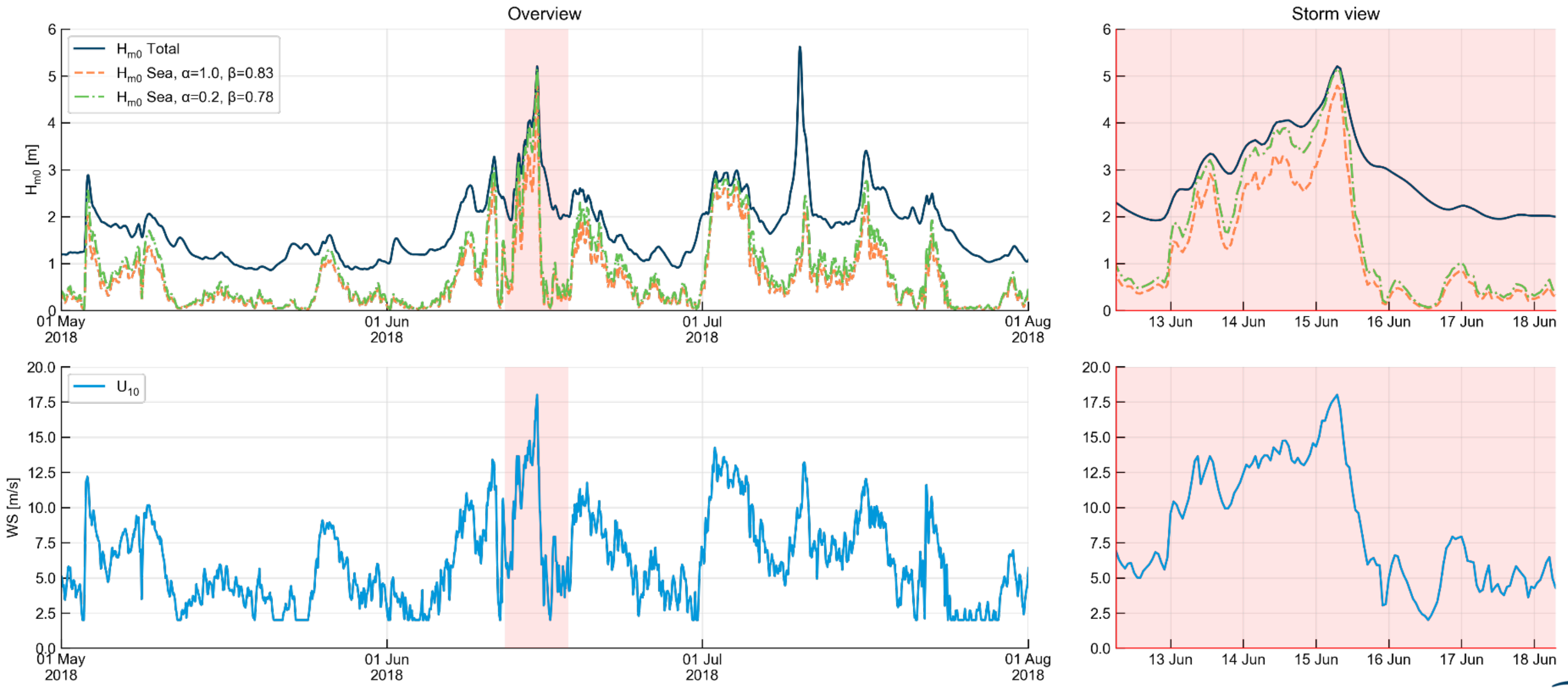


Point Name	Longitude [° E]	Latitude [° N]
West North America	-126	36
East North America	-69	38
North Sea	3	56
Taiwan	123	22

- A qualitative analysis was undertaken based on offshore spectral energy data from 4 different geographical locations
- The 2D directional spectra was split into wind-sea and swell components
  - $\alpha = 1$ and $\beta = 0.83$ (original)
  - $\alpha = 0.2$ and $\beta = 0.78$ (improved coefficients)

Model results: Philippine Sea (Taiwan)

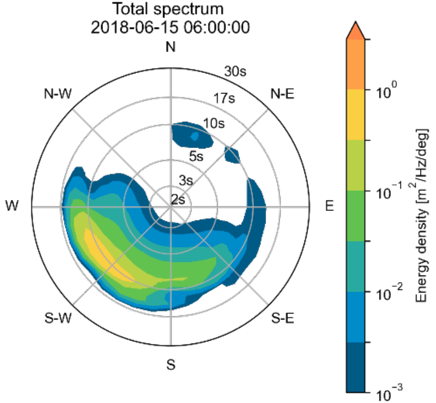
Time series comparison



Model results: Philippine Sea (Taiwan)

Example 2D spectra for single time step

Total spectrum



Wave Age separation

Default:

$\alpha = 1$

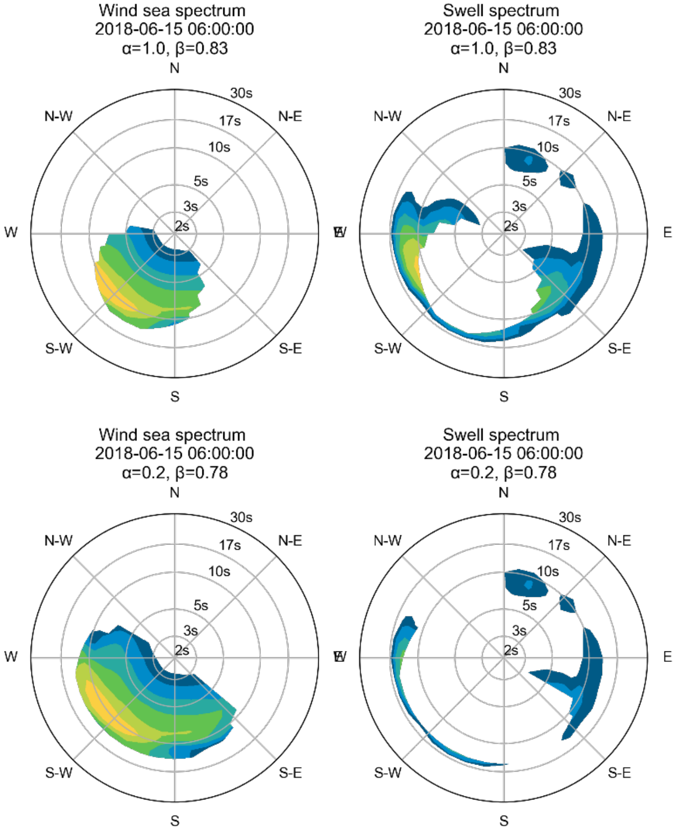
$\beta = 0.83$

Improved coefficients:

$\alpha = 0.2$

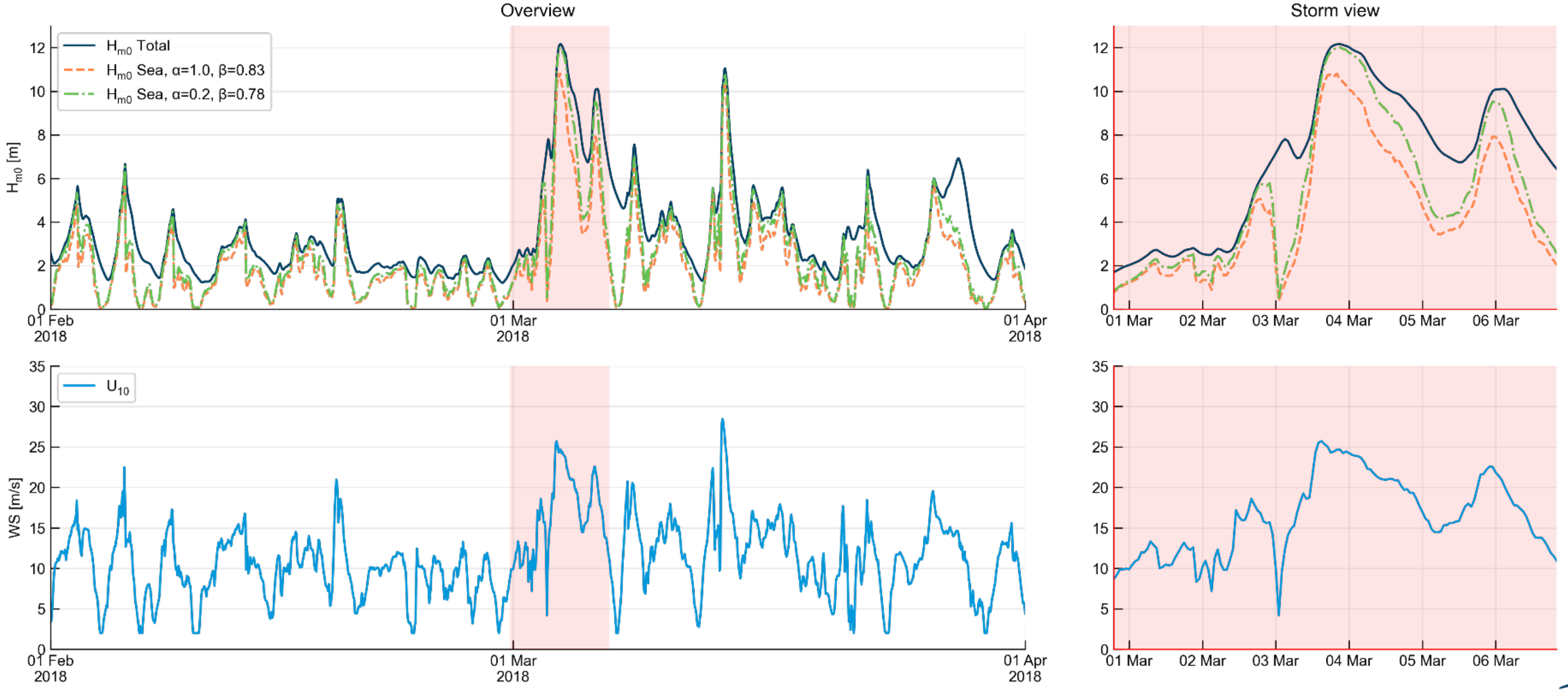
$\beta = 0.78$

Wind sea ***Swell***



Model results: Atlantic Ocean (US East Coast)

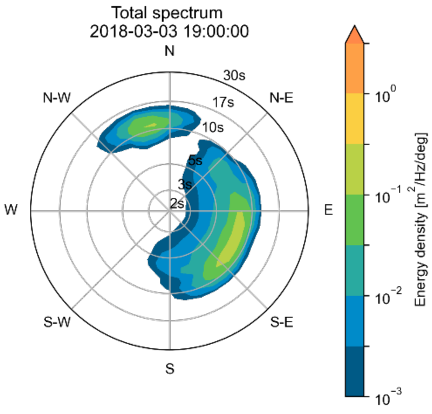
Time series comparison



Model results: Atlantic Ocean (US East Coast)

Example 2D spectra for single time step

Total spectrum



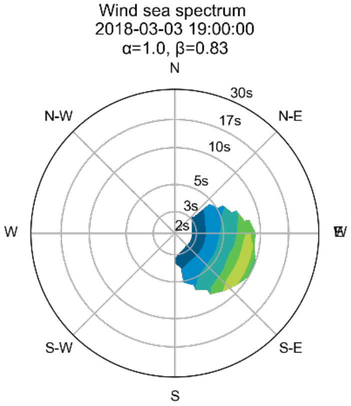
Wave Age separation

Default:

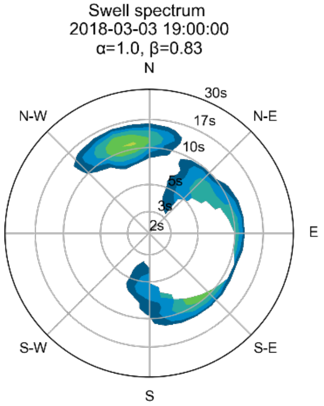
$\alpha = 1$

$\beta = 0.83$

Wind sea



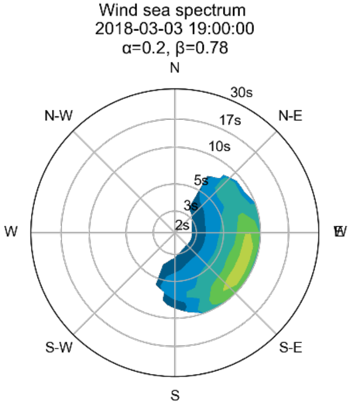
Swell

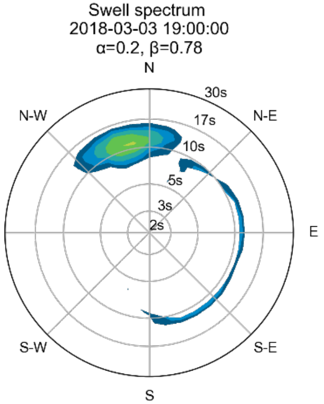


Improved coefficients:

$\alpha = 0.2$

$\beta = 0.78$





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Conclusion

Summary

A qualitative analysis was undertaken based on offshore spectral energy data from four different geographical locations. The analysis compared wind-sea and swell partitions separated with the original and modified wave age methodology.

In all cases, the modified wave-age methodology showed an improvement in the sea/swell separation, generally assigning more energy to the wind-sea partition compared to the default coefficients − especially in cases of strong wind speeds and/or wind-sea dominant partitions.

The modified methodology has been applied by DHI in recent commercial projects related to offshore wind farms.

Limitations

- The Wave Age equation alone cannot identify several wave systems, as it only distinguishes between wind-sea and swell.
- Rapid changes in wind direction and/or strong refraction and diffraction can lead to inaccuracies in wind-sea and swell separation.
- The wind-sea and swell separation is a hard cutoff – no ‘blending’ of systems.

Future research

- Quantitative metrics for validation
- Application to measurements
- Widen geographical and temporal validation

Acknowledgements

- C2WIND for original suggestion for the modified wave-age criterion

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