

Wind Europe 2026

Session: Solutions for support structures to drive offshore wind beyond limits

More accurate support structure loads and lifetime reassessments by using site specific directional turbulence intensity

Jorge Garza¹, Christian Mørch¹

¹C2Wind

Date 2026-04-23
Author JOG
QC CBM
Doc no. 0-021-01
Revision 2

Table of Contents

- Introduction
- Typical approach
- Refined approach(es)
- Results

Take-aways:

Directional stability- and turbulence can be accounted for

Directional WFT can **yield lower interface loads**

Important for jackets **due to asymmetry & fatigue-driven design**

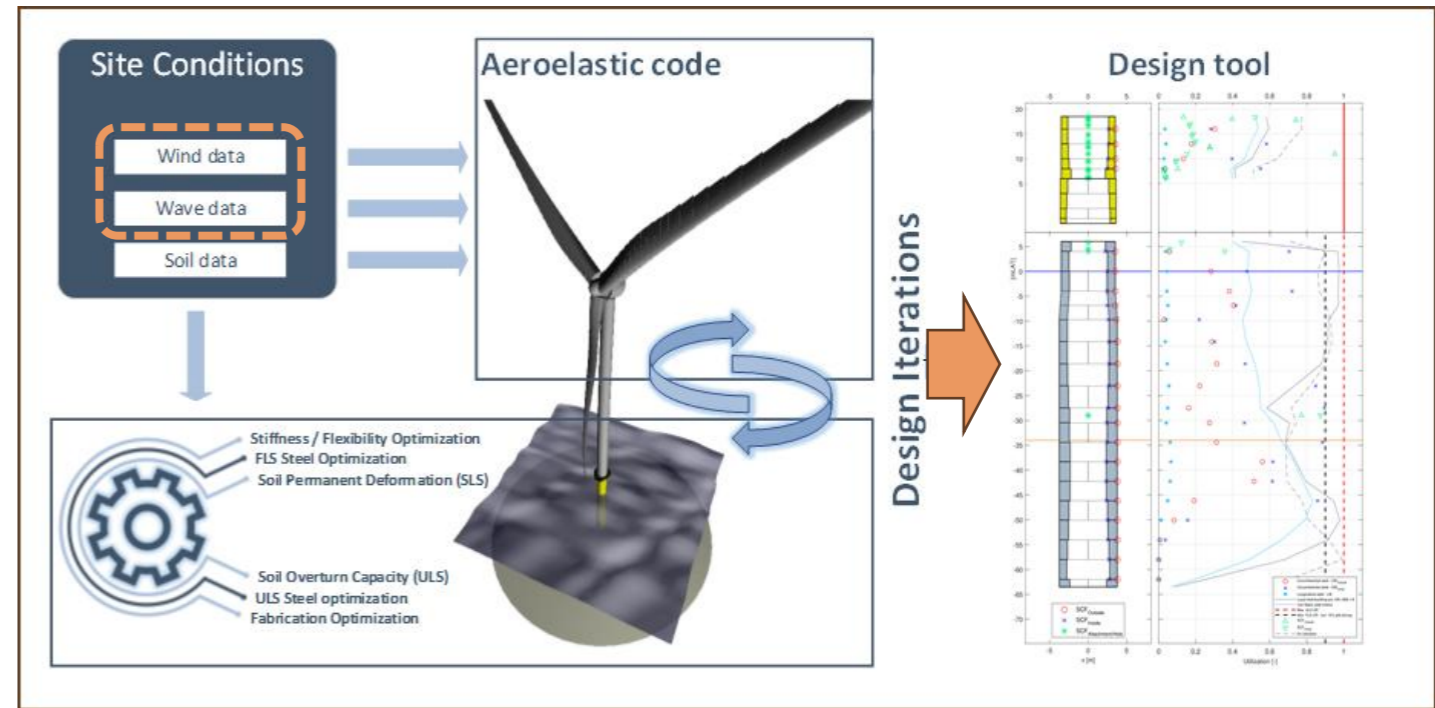
Introduction – Typical approach – Refined approach – Results

In principle

- Wave and wind inputs are directionally dependent and can be modelled as such.
- More complex dependencies could exist tied to site-specific physical drivers such as atmospheric stability and sea-state composition (ie. wind-sea & swell).

In practice

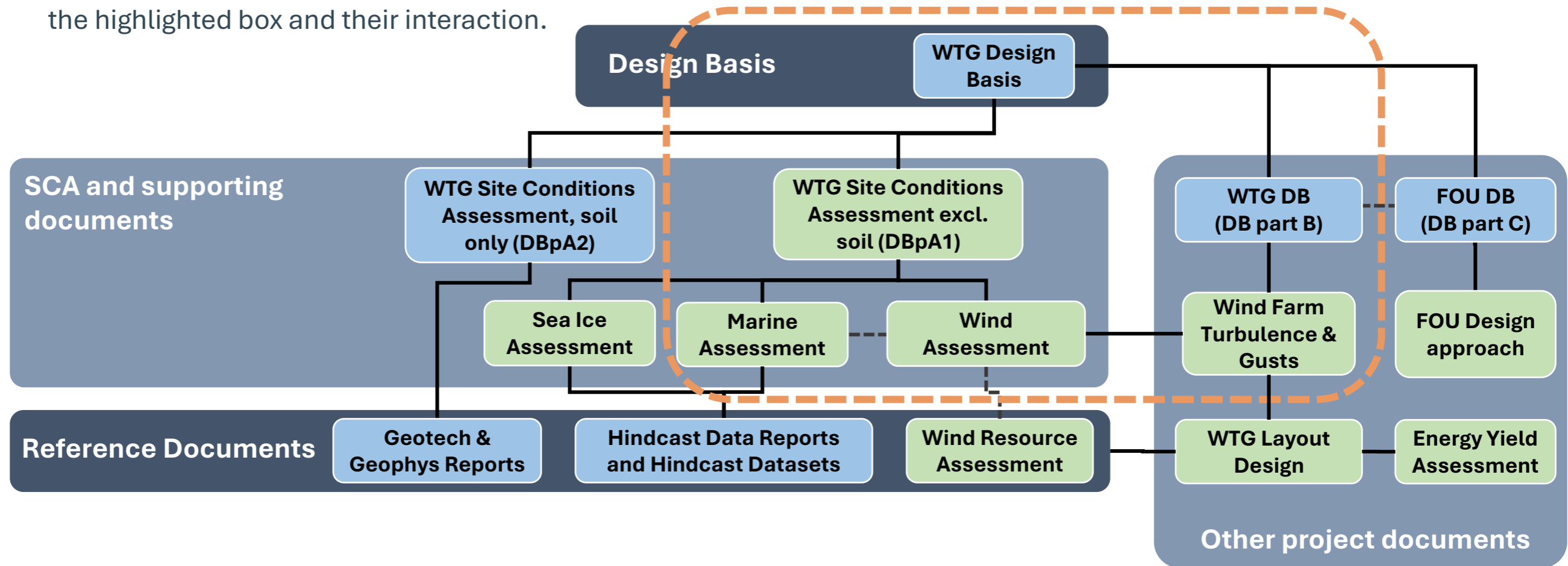
- Modelling wind and wave directional dependencies is state of the art.
- Modelling directional-, stability-, and sea-state dependencies all together is often challenging due to data limitations, simulation volume, certifiability, and the inertia of existing tools and methods.
- Ultimately, not all interdependencies are accounted for in ILA and conservative choices must be made.



Does it matter?

Introduction – Typical approach – Refined approach – Results

- The diagram shows an example Design Basis document ecosystem.
- The discussion will focus on the items within the highlighted box and their interaction.



Introduction – Typical approach – Refined approach – Results

Marine Assessment

- $H_{m0}(WS, WD)$ & $T_p(WS, WD)$
 - sometimes only (WS)
- (Ideally) wind-sea & swell separation – not always.

Wind Assessment

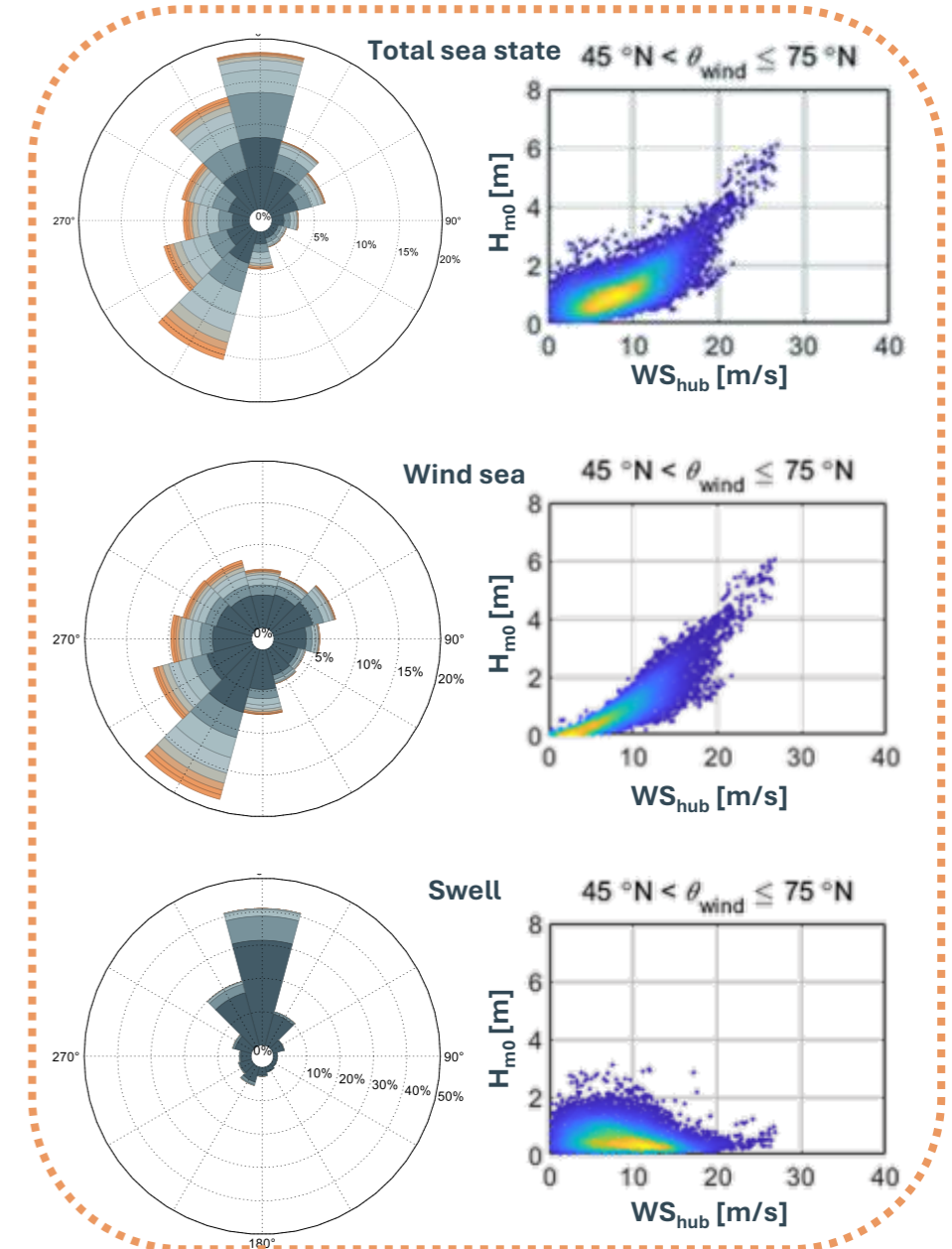
- $f(WS, WD); TI(WS, WD), \alpha(WD)$
 - often $TI(WS), \alpha$ omni.
- (Ideally & if relevant) stability-dependent.

WF Turbulence

- Ambient TI (omni- or directional) yields *omnidirectional* effective wind farm turbulence.

Integrated Load Analysis

- Aeroelastic simulations for all (WS, WD) relevant for FLS.
 - 720 simulations assuming no wind-wave misalignment
- *Omnidirectional* (envelope) wind farm turbulence



Introduction – Typical approach – Refined approach – Results

Marine Assessment

- $H_{m0}(WS, WD)$ & $T_p(WS, WD)$
 - sometimes only (WS)
- (Ideally) wind-sea & swell separation – not always.

Wind Assessment

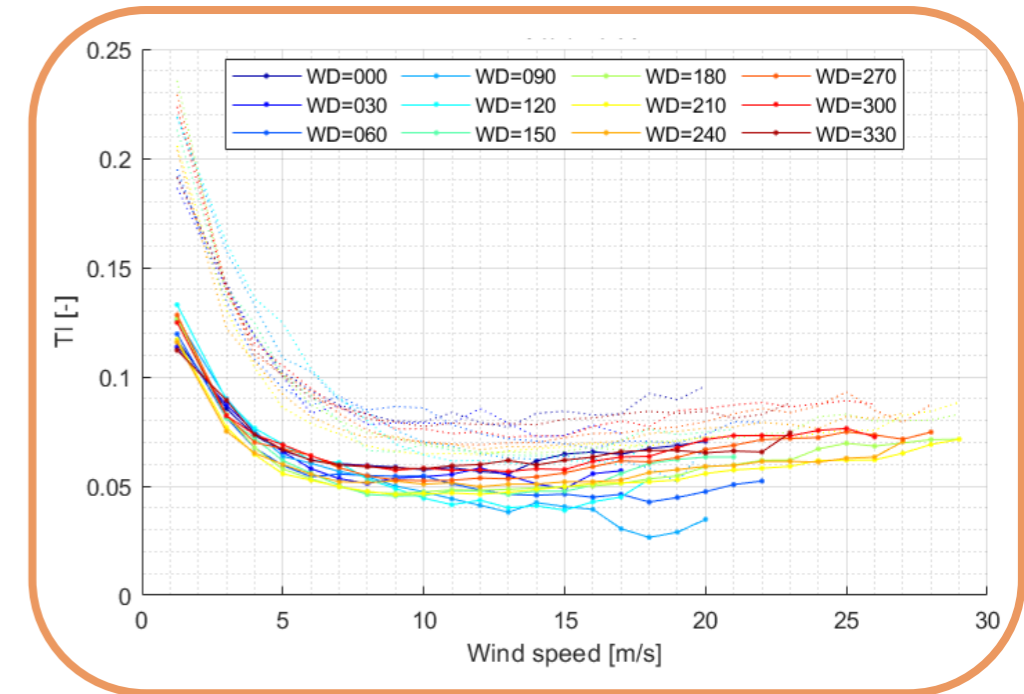
- $f(WS, WD); TI(WS, WD), \alpha(WD)$
 - often $TI(WS), \alpha$ omni.
- (Ideally & if relevant) stability-dependent.

WF Turbulence

- Ambient TI (omni- or directional) yields *omnidirectional* effective wind farm turbulence.

Integrated Load Analysis

- Aeroelastic simulations for all (WS, WD) relevant for FLS.
 - 720 simulations assuming no wind-wave misalignment
- *Omnidirectional* (envelope) wind farm turbulence



Introduction – Typical approach – Refined approach – Results

Limitations

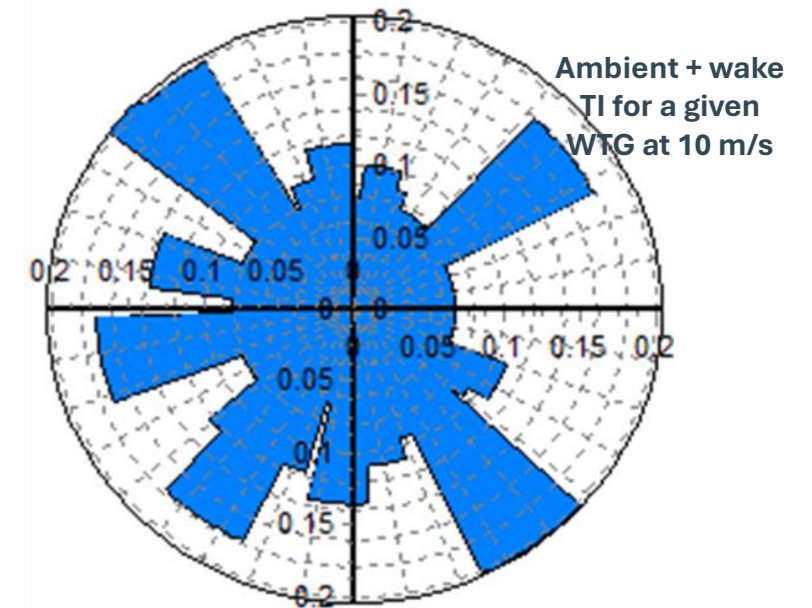
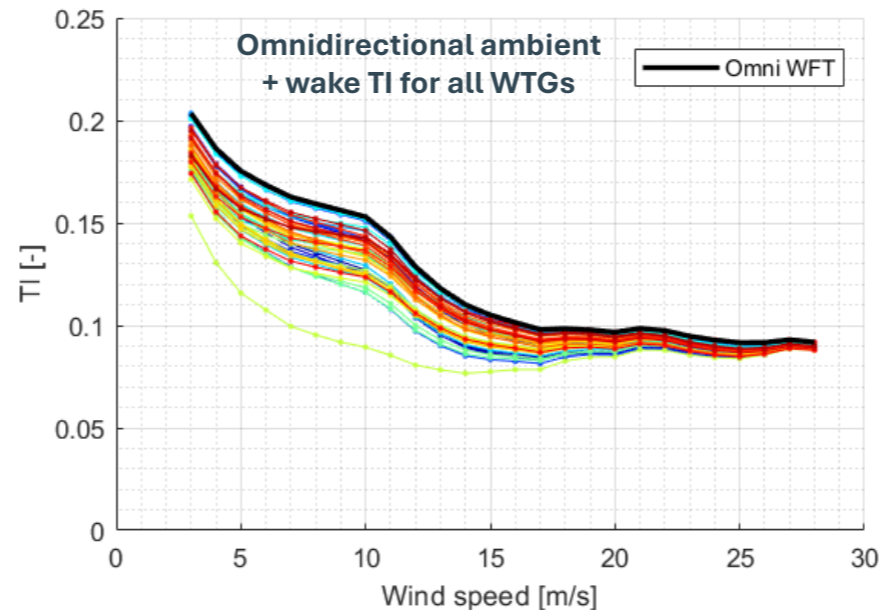
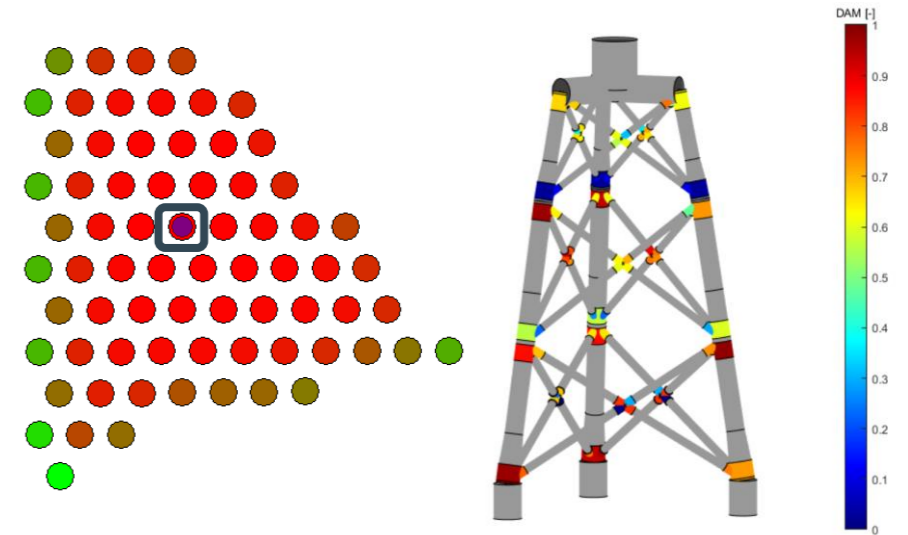
- Can we really get $TI(WS, WD)$?
 - If we get it, can we trust it? Certify it?
- Why do we use only omni WFT?
 - IEC 61400-1, Annex E.

How does WFT look?

- Ambient + wake turbulence for all WTGs, WS & WD.
- Most exposed WTG drives the envelope.
- Integrated over WD with wind distribution.

Why is WFT important?

- Sites with complex interdependencies (nearshore, stability, tight & asymmetric layouts).
- Structures like jackets are typically fatigue-driven and sensitive to directional loads in their design.



Introduction – Typical approach – Refined approach #1 – Results

Marine Assessment

- $H_{m0}(WS, WD)$ & $T_p(WS, WD)$
 - sometimes only (WS)
- (Ideally) wind-sea & swell separation – not always.

Wind Assessment

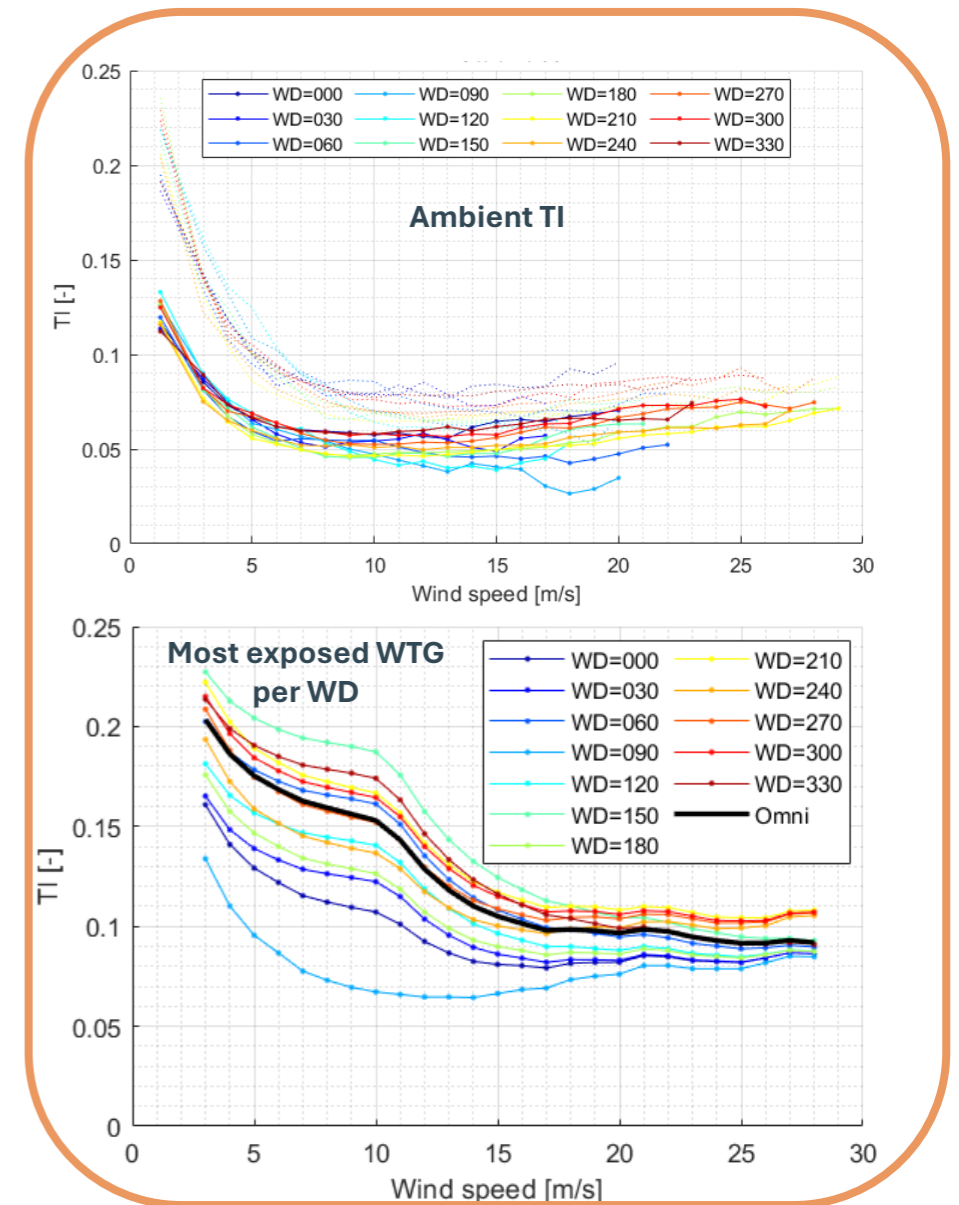
- $f(WS, WD); TI(WS, WD), \alpha(WD)$
 - often $TI(WS), \alpha$ omni.
- (Ideally & if relevant) stability-dependent.

WF Turbulence

- Ambient TI (omni- or directional) yields **directional** effective wind farm turbulence.

Integrated Load Analysis

- Aeroelastic simulations for all (WS, WD) relevant for FLS.
 - 720 simulations assuming no wind-wave misalignment
- **Directional** wind farm turbulence



Introduction – Typical approach – Refined approach #2 – Results

Marine Assessment

- $H_{m0}(WS, WD)$ & $T_p(WS, WD)$
 - sometimes only (WS)
- (Ideally) wind-sea & swell separation – not always.

Wind Assessment

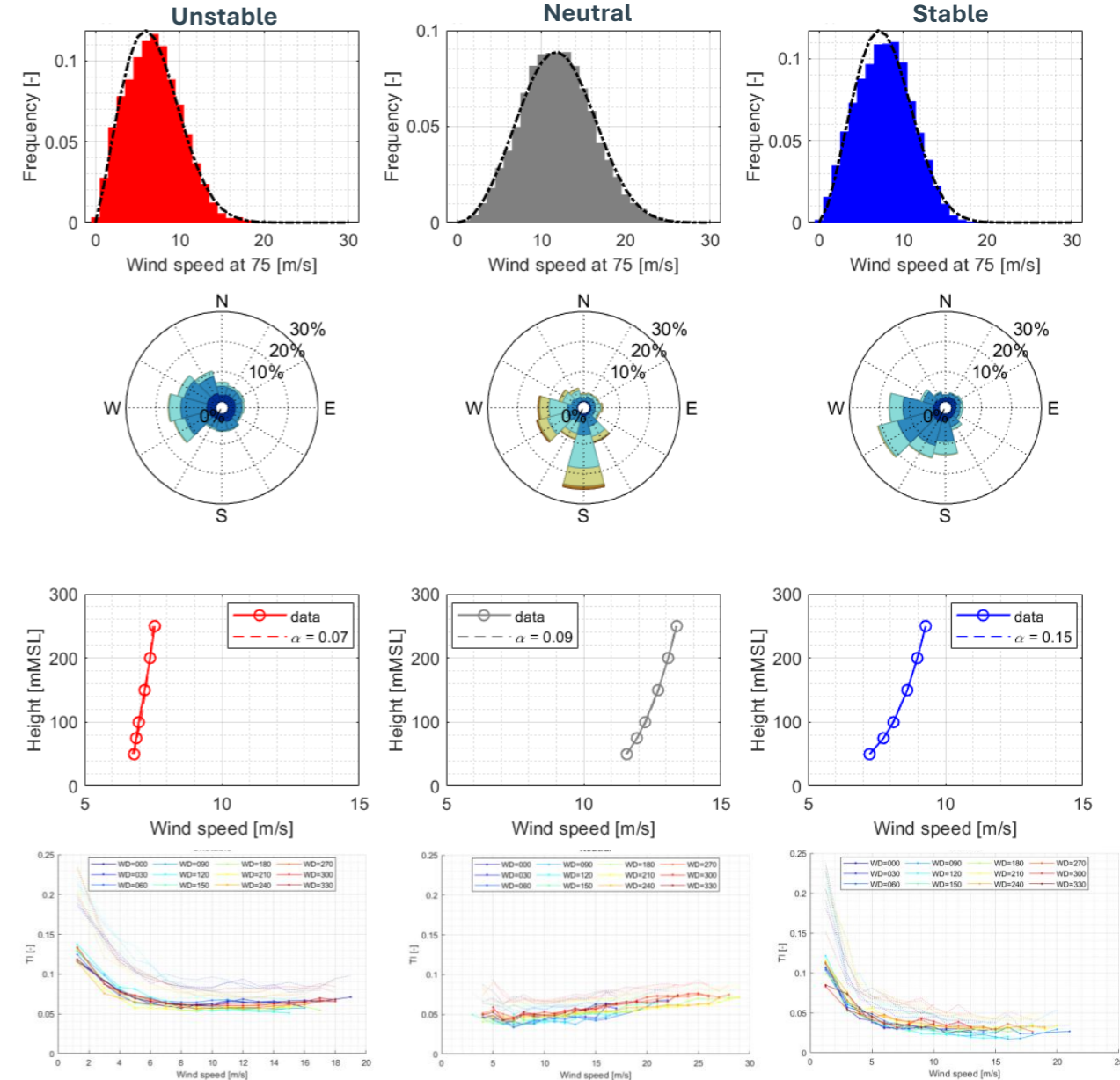
- $f(WS, WD, z/L)$; $TI(WS, WD, z/L)$, $\alpha(WD, z/L)$
 - More details on the derivation in our ePoster.

WF Turbulence

- $TI(WS, WD, z/L)$ yields **directional** effective wind farm turbulence.

Integrated Load Analysis

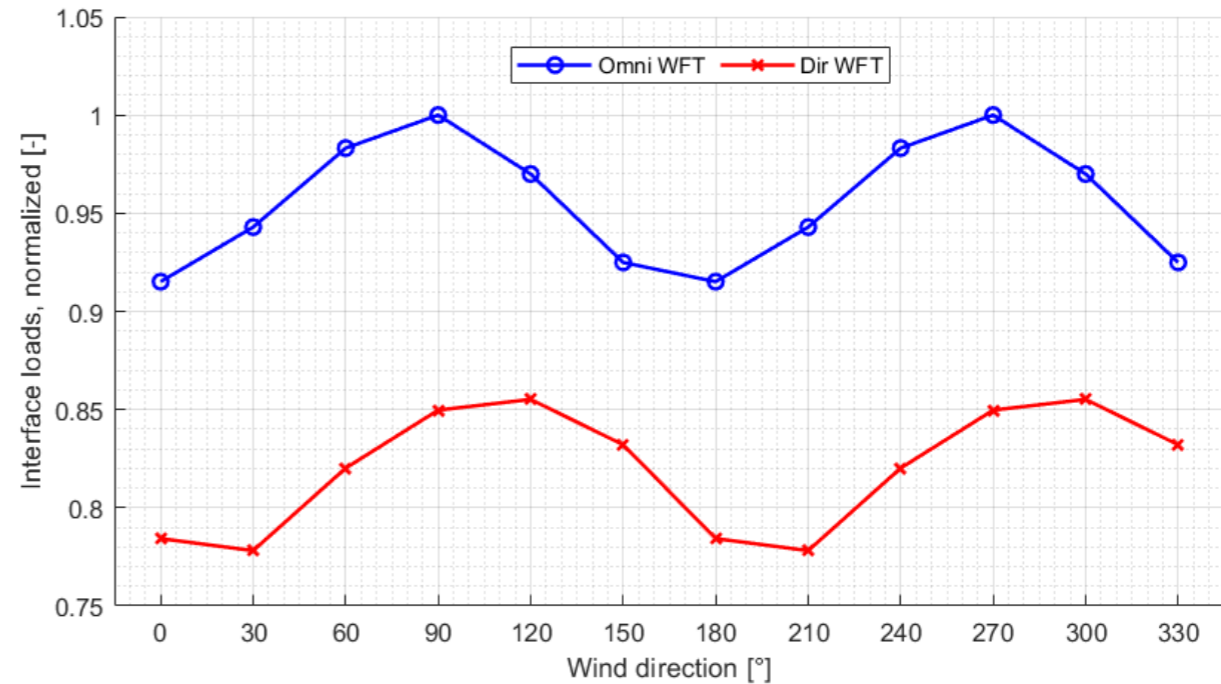
- Aeroelastic simulations for all (WS, WD, z/L) relevant for FLS.
 - 3 x 720 simulations assuming no wind-wave misalignment
- **Directional** wind farm turbulence



Introduction – Typical approach – Refined approach – Results

Test Case #1

- OWF in the Irish Sea.
- >40 WTGs, ~15MW type
- Min. WTG spacing [4.0; 7.2] D
- Jacket foundations.
- Directional ambient TI
- Omnidirectional wind shear exponent
- No wave loads – isolating wind-only effects
- Run aeroelastic simulations with $m=5$, select interface loads for most severe wind direction sector as design interface loads.



Use of **directional wind farm turbulences**, all other things being equal, results in a **15%** reduction in fatigue loads

Introduction – Typical approach – Refined approach – Results

Test Case #2

- Nearshore OWF in the Irish Sea.
- >40 WTGs, ~15MW type
- Min. WTG spacing [4.0; 7.2] D
- Jacket foundations.
- Directional- and stability dependent ambient TI with land effects.
- Directional- and stability dependent wind shear.
- No wave loads – isolating wind-only effects
- Run aeroelastic simulations with $m=5$, select interface loads for most severe wind direction sector as design interface loads.



The reduction in design loads due to using **directional- rather than omnidirectional wind farm turbulences** is also present when accounting for stability, with a reduction of up to **6%**

Introduction – Typical approach – Refined approach – Results

Using directional WFT:

- Consistently yields lower interface loads.

Using stability:

- Allows for more accurate physics that can be relevant for complex sites.

Relevance:

- This degree of detail is especially important for jackets, typically fatigue-driven and directionally sensitive.
- Getting more accurate loads can be vital in lifetime reassessments.

Further refinements:

- Combining with sea state separation (*see our ePoster*)
- Advanced methods for ambient TI characterization even without measurements, (*see our ePoster*)

Up to 15% fatigue reduction with no additional effort and no additional costs

Can be applied to any site, and any support structure

A clearly more accurate representation of site-specific physics reduces risk

Let's discuss: JOG@C2Wind.com