A design-oriented fatigue Load Case selection method for floating offshore wind turbines

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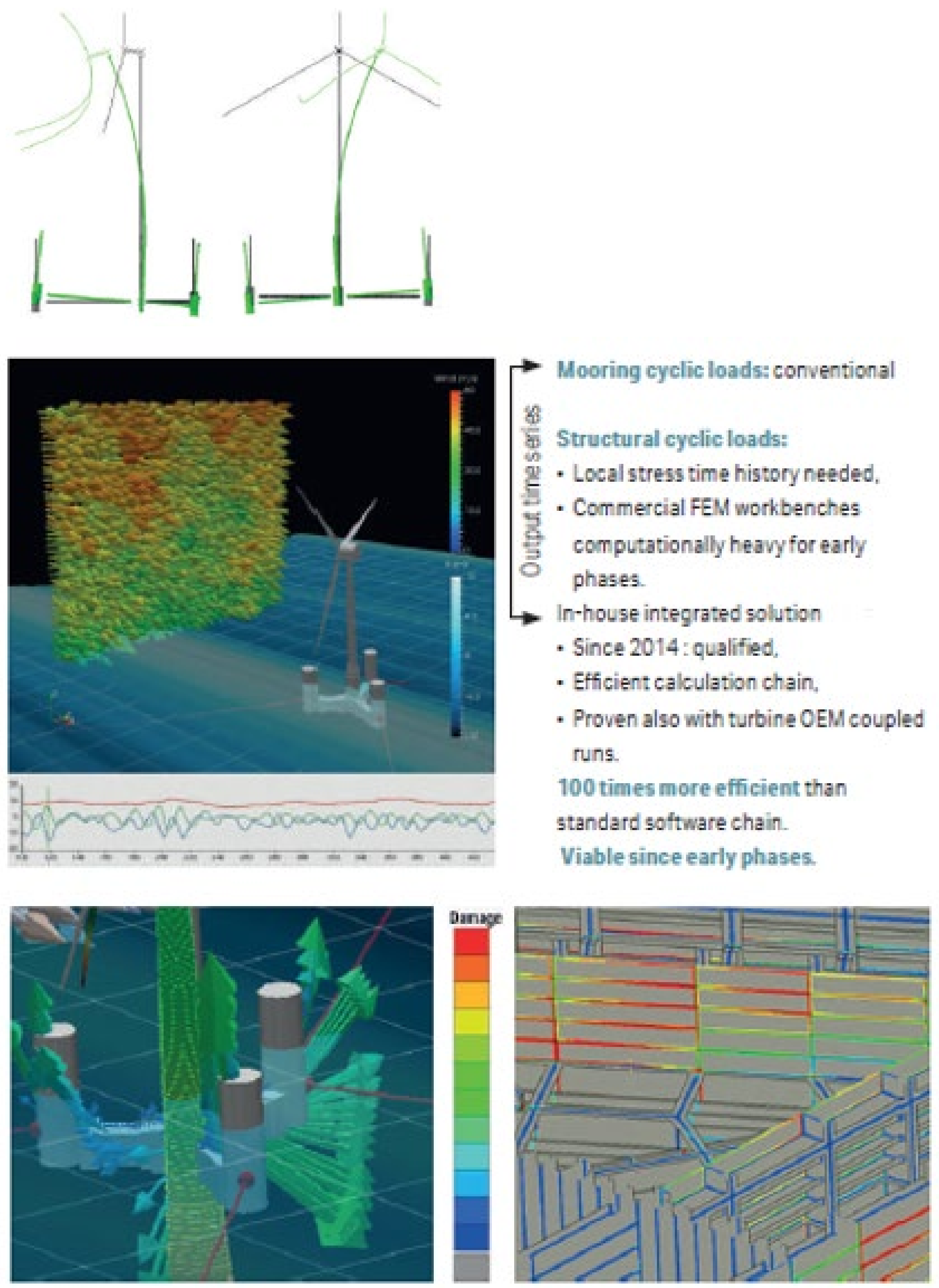
- Design Load Case (DLC) selection method: goals and process
- Results of the applied method:
  - ✓ Improvement of environmental representativity against typical practice
  - ✓ Response-based considerations
- Conclusions and perspectives

Floating Wind design expertise by Sofresid and France Energies Marines



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- ✓ France-based global engineering company, subsidiary of Ekium/SNEF group since October 2023
- ✓ **Floating wind substructure design** (>12 years expertise coming from Naval Energies team)
- ✓ Development of an integrated end-to-end industrialized and qualified **FOWT calculation chain**, from site conditions to structural details

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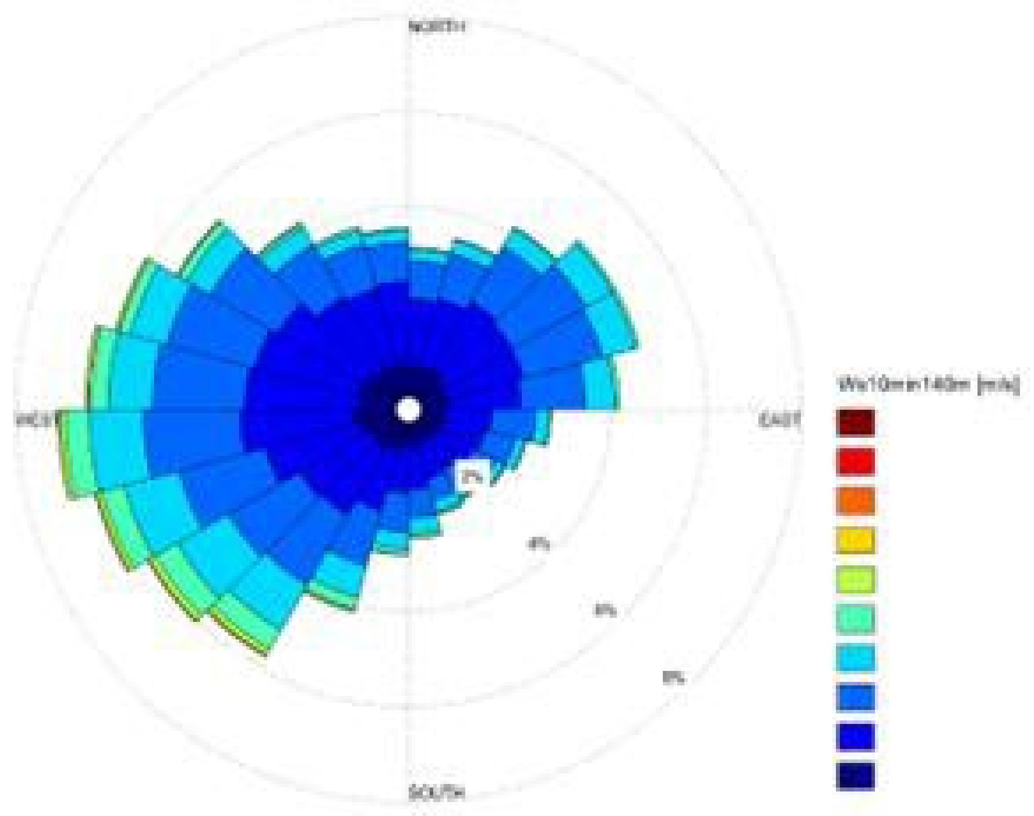
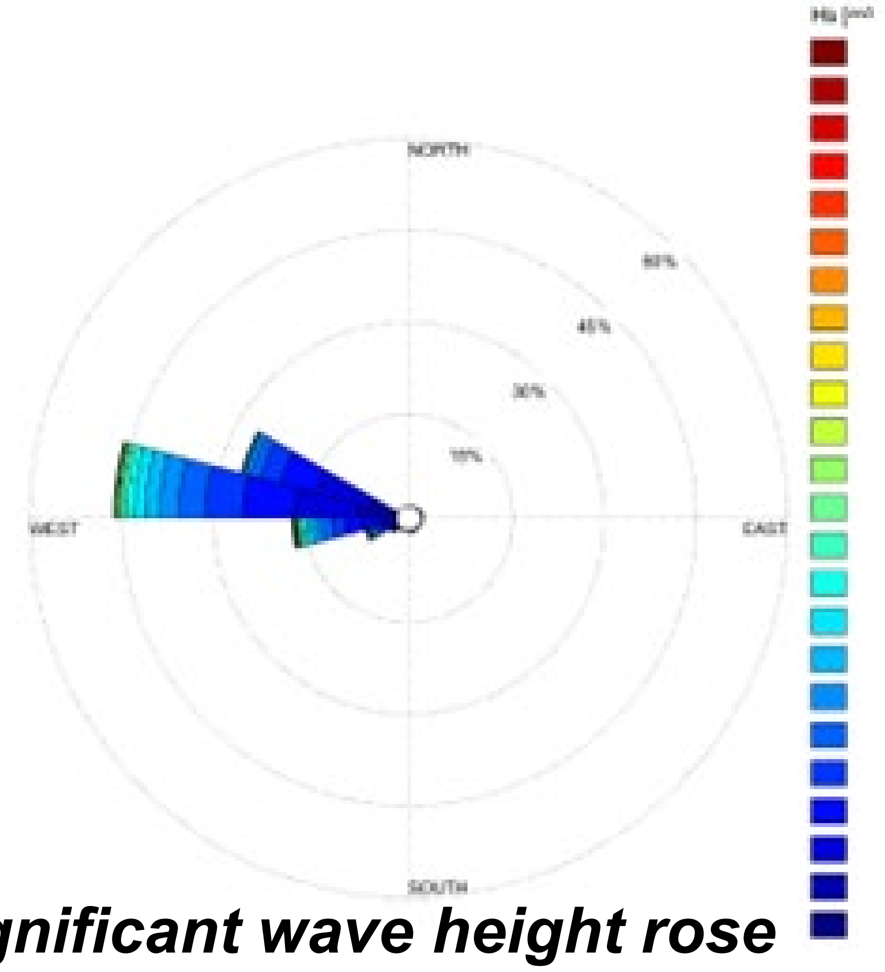
- ✓ France research center dedicated to offshore renewable energies
- ✓ Focus on public-private collaborative R&D programs

Introduction

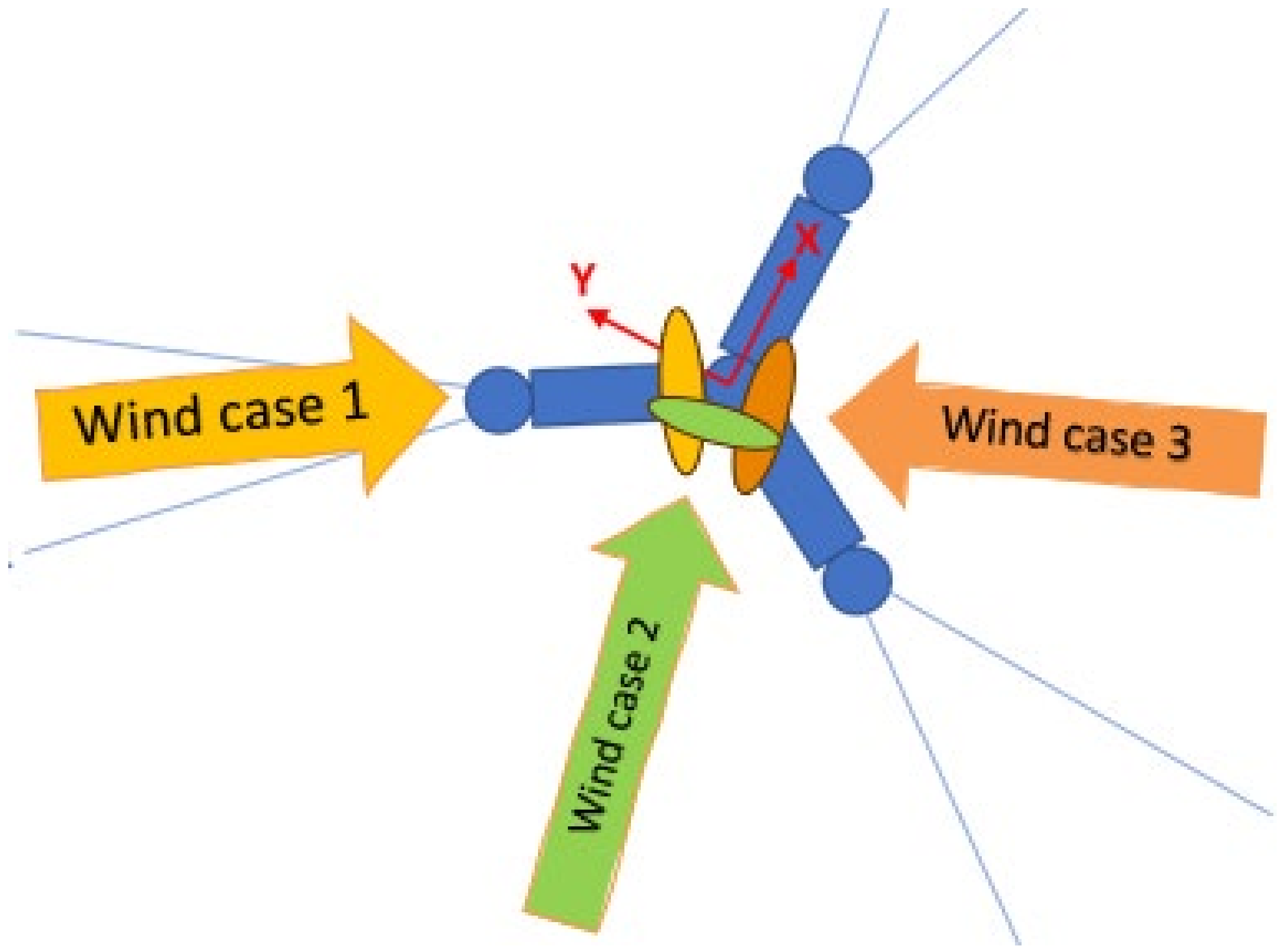
- Complex multidirectional wind / waves / currents



10-min @140m wind rose



Significant wave height rose



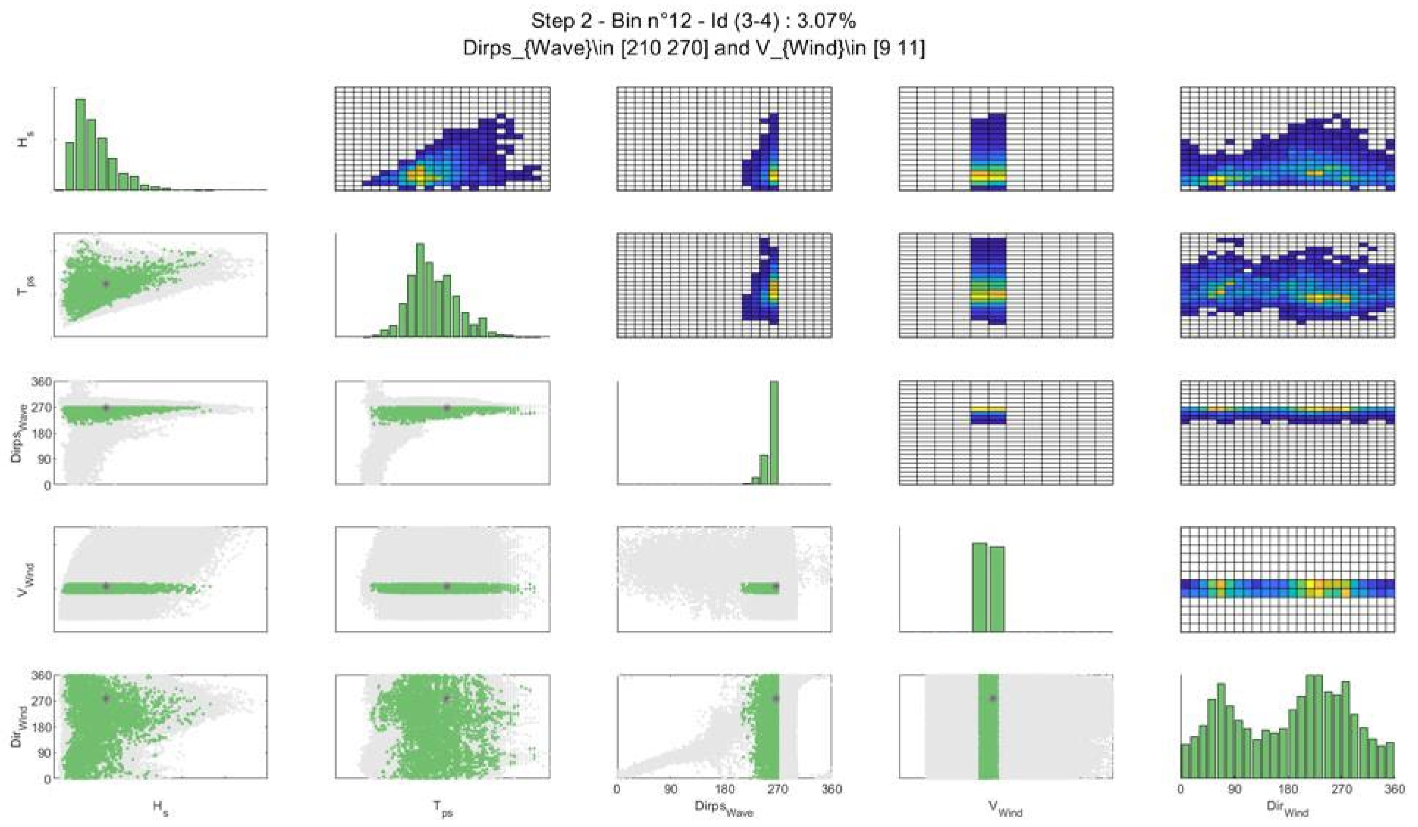
Floater and mooring lines schematic orientation

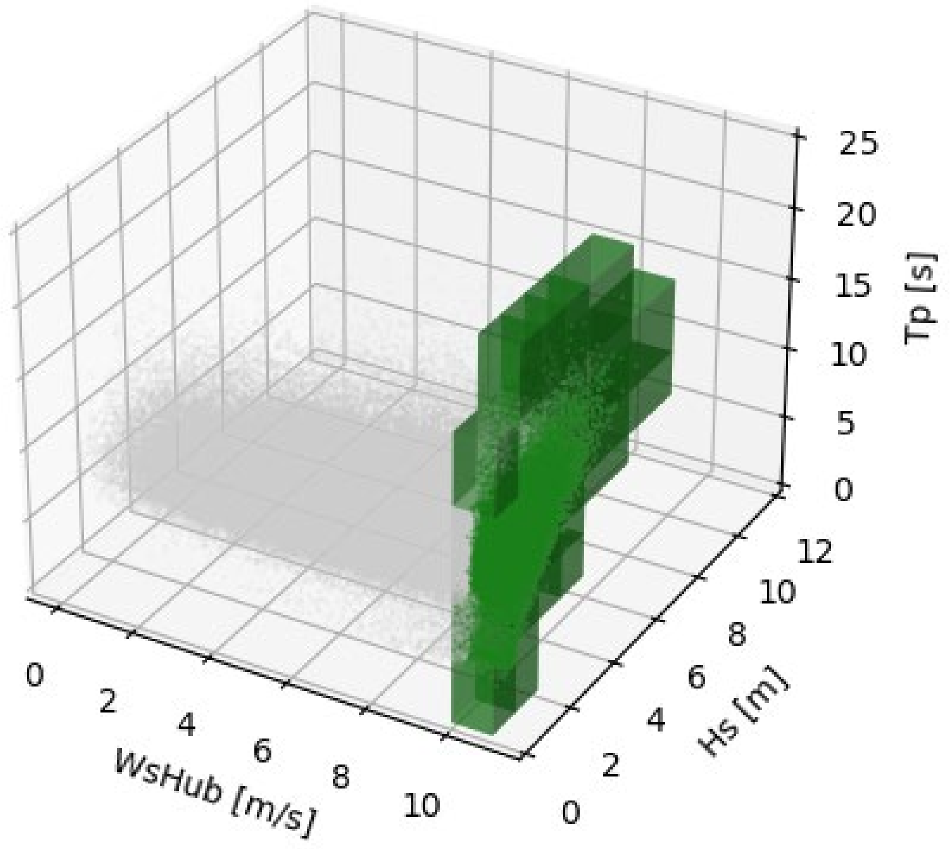
- Floating wind physics highly dependent on directions
  - ✓ **Joint conditions** of wind/wave/current parameters
  - ✓ Environmental component directions → fatigue loads distribution (e.g. over different pontoons, mooring lines…)
- High representativity requirements from normative guidelines such as DNV-RP-0286 (coupled analysis) [1] … with no methodology defined

Load Case selection: goals and proposed method

Goal: make the most of site data… within a limited DLC budget!

- Focus on fatigue DLCs (Normal Sea States)
- Typical industry practice: 2D distributions/relations→ **lossy**
- Presented method: full joint environmental conditions
  - ✓ **“hyperbox”** bins
  - ✓ timeseries = concomitance information
  - ✓ no “sacrificed” variable
- Flexible choices: options to ensure representativity of both environment and FOWT responses
  - ✓ exert control on DLC discretization
  - ✓ target number of DLCs (for computational cost)
  - ✓ appropriate choice of characteristic bin values

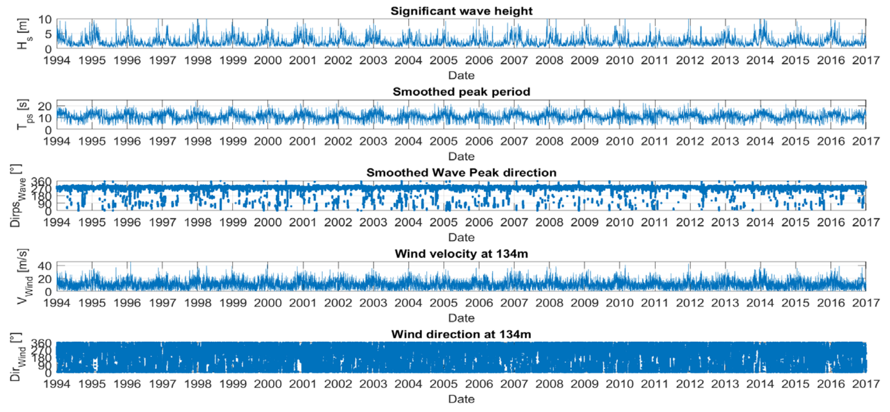




Load Case selection: goals and proposed method

Process: iterative discretization of *N* parameters into hyperboxes

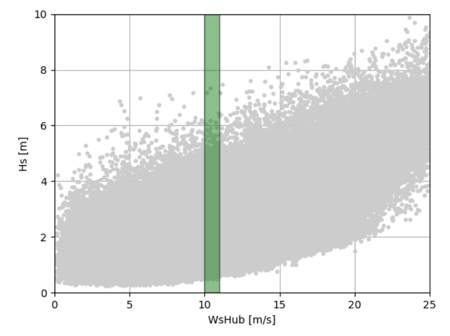
Quality controlled timeseries



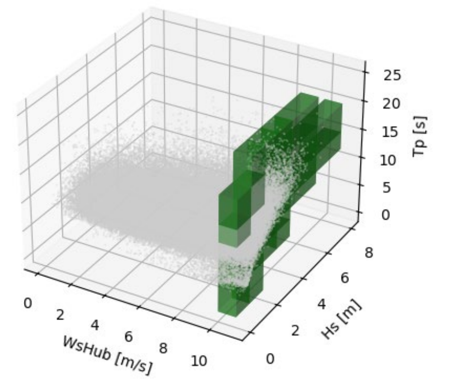
DLC Specification:
- Parameter order
- Bin discretization
- Box size
- Preliminary characteristic value

Hierarchical process:
- **Binning** in hyperboxes
- 1 box=1case, P(%)= nb points / total popul.
- Choose appropriate **characteristic value** (mean, mode, median,…)

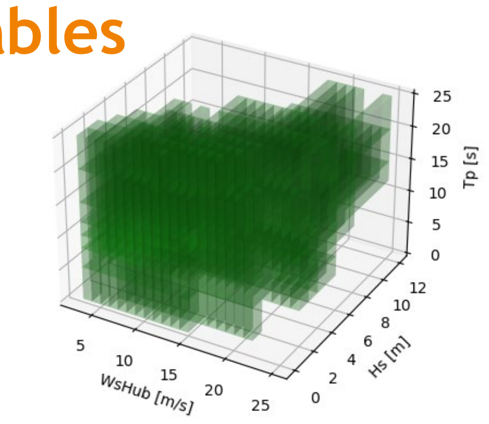
1st and 2nd variables discretization



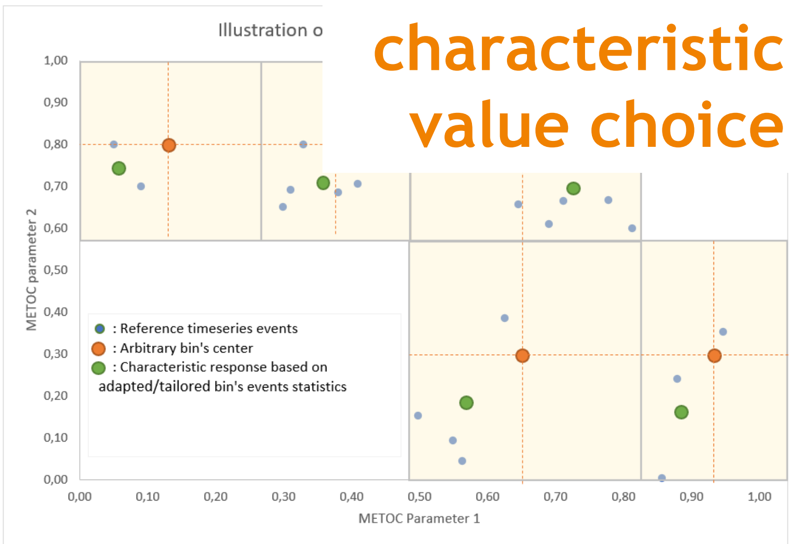
3rd variable discretization



result for 3 variables

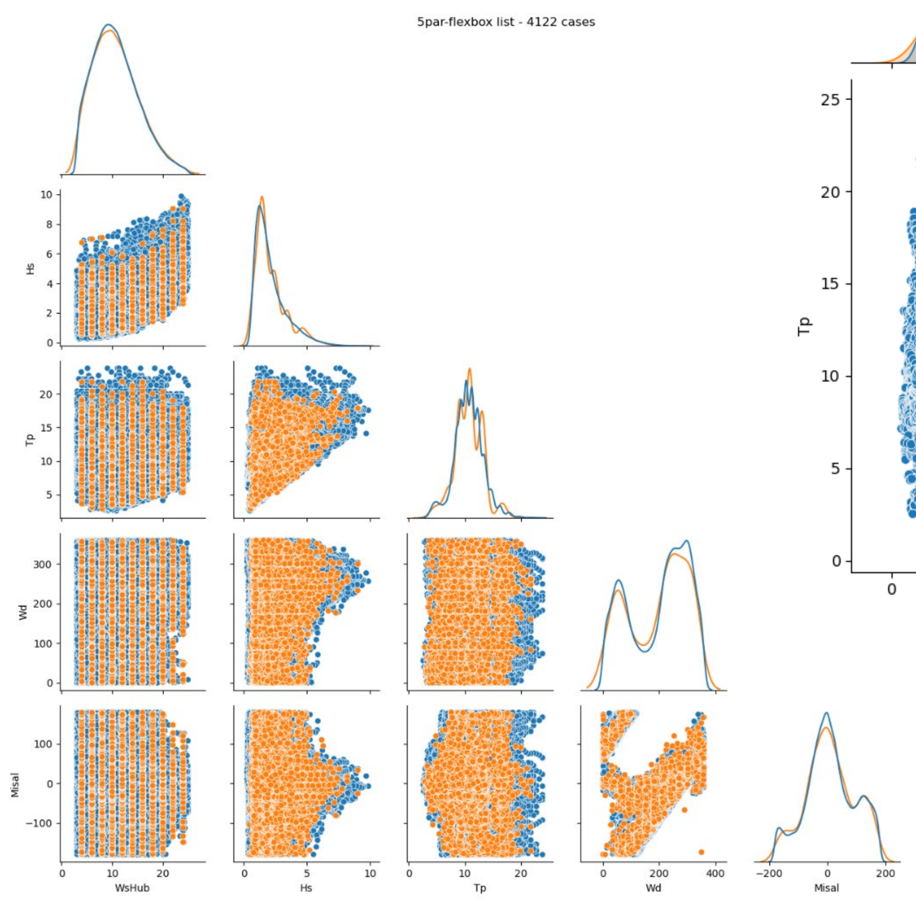


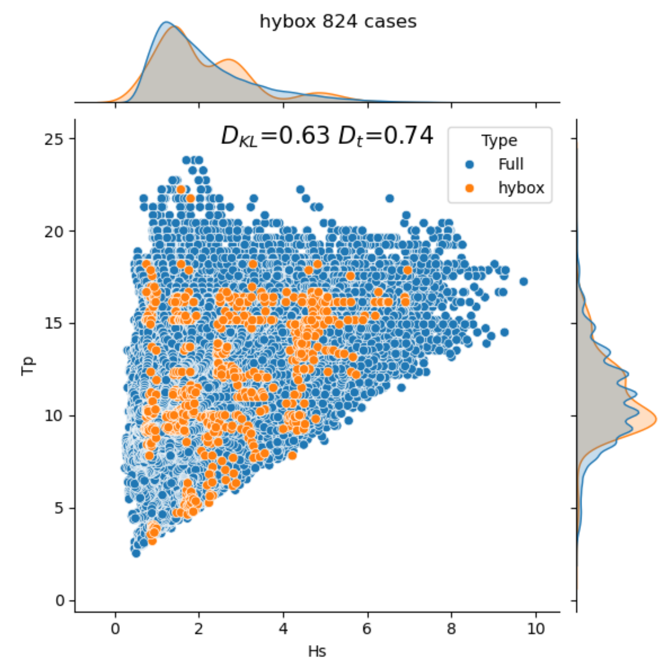
characteristic value choice



…continued with *N* variables incl. directions

Checks:
- Affordable number of DLCs
- Joint distribution inspection
- Distributions statistical distance

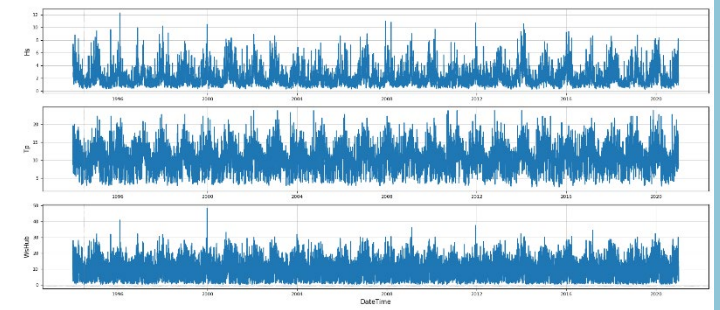




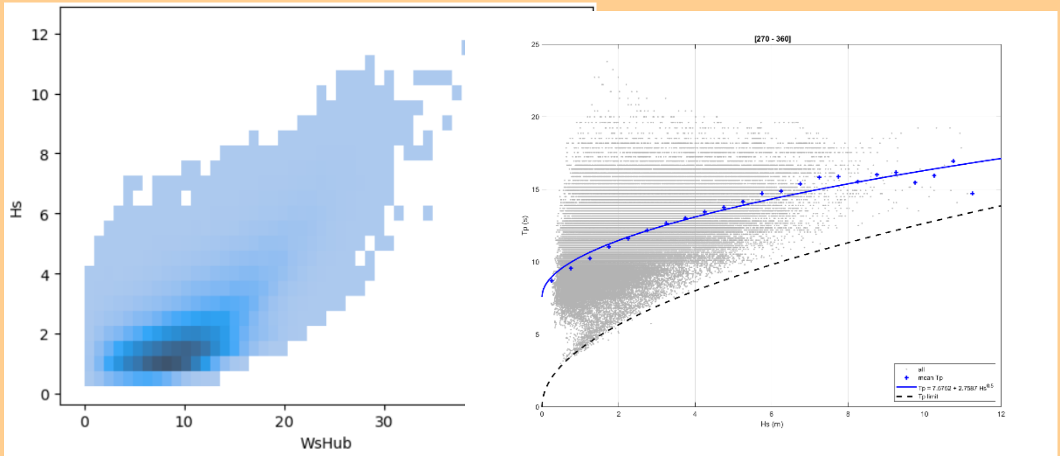
iterate until target number of DLCs and representativeness is reached

Hyperbox versus typical approach – application with 3 parameters

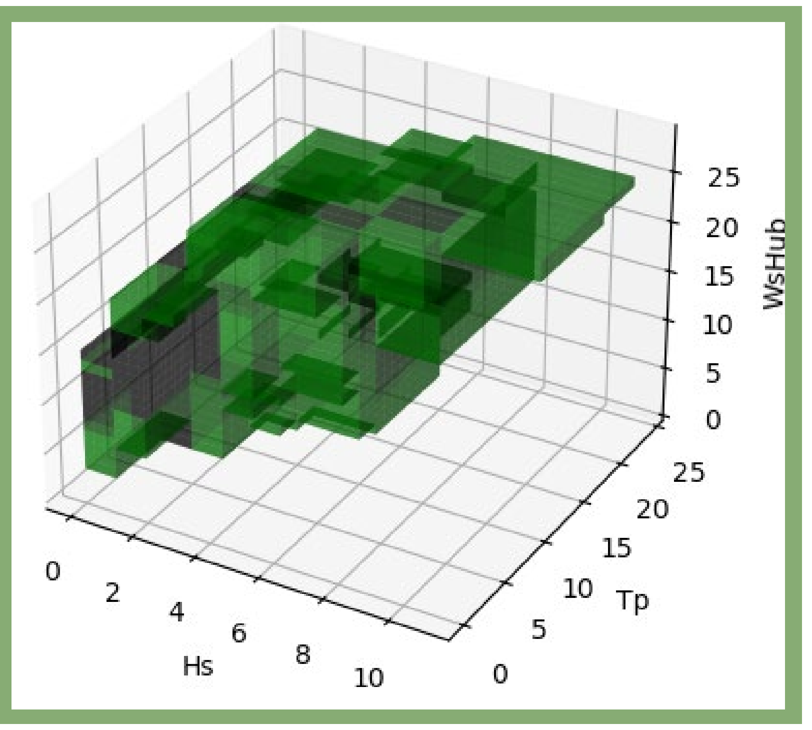
Full dataset:
- Ifremer ResourceCode wave hindcast NW Europe
- 27-year timeseries
~ 236688 time-stamps
- Ws140m10m, Hs, Tp

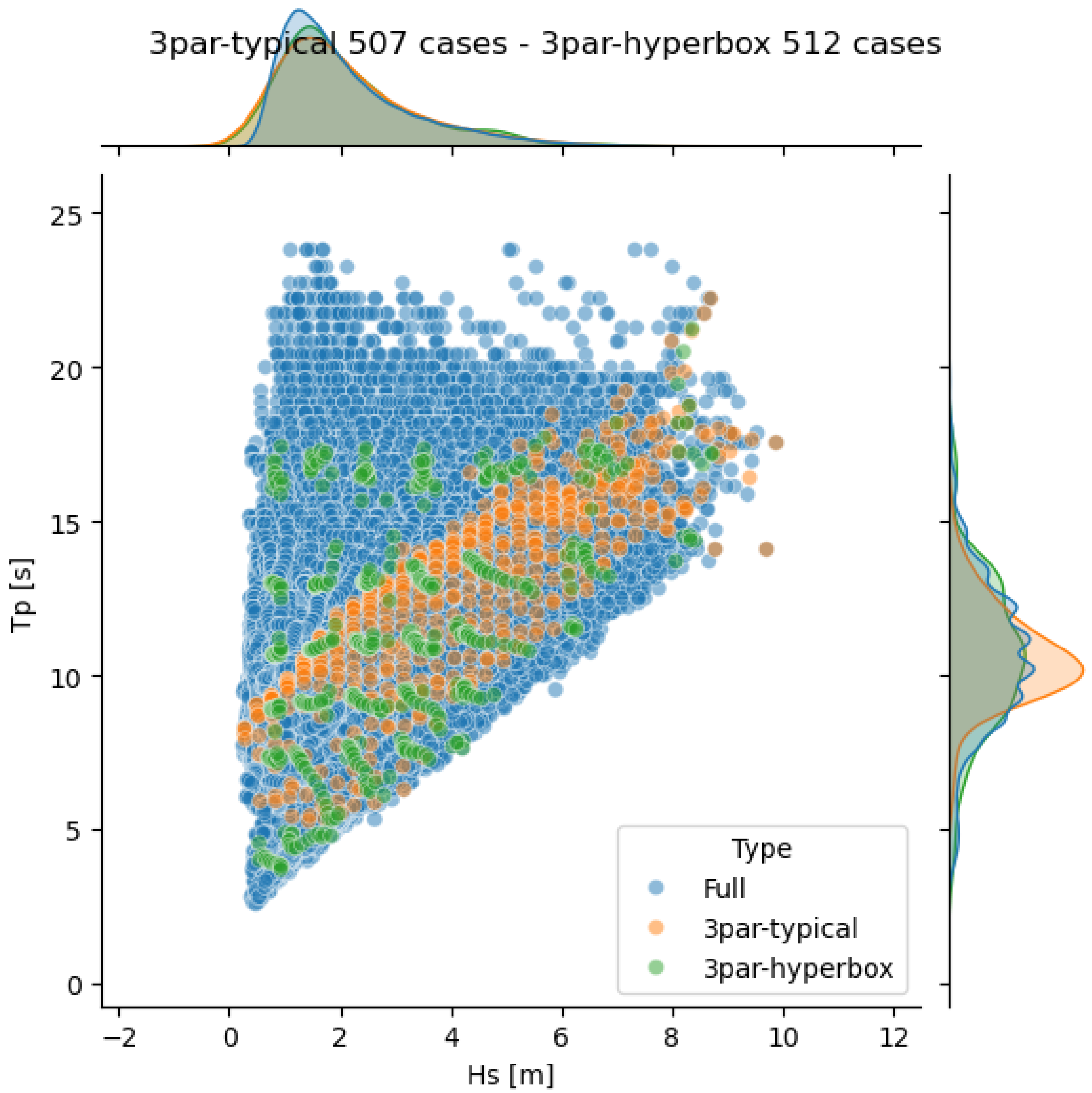


Typical approach:
- Joint distribution Ws-Hs
- Relation Tp|Hs
~ Target ~500 cases



Hyperbox approach:
- 3D joint distribution Ws-Hs-Tp
- Stats using original dataset
~Target ~500 cases





Hs-Tp joint scatter plots

RESULTS
Better distribution agreement using hyperboxes instead of scatter diagrams.
No "sacrificed" variable.

Parameter(s)	Resolution	Typical method (507 DLCs)	Hyperbox method (512 DLCs)
Ws dist	2 m/s	0%	0%
Hs dist	1 m	17%	2%
Tp dist	2 s	19%	7%
Ws-Hs dist	2 m/s – 1m	9%	1%
Hs-Tp dist	1m – 2s	29%	8%

Statistical distance to full data distribution

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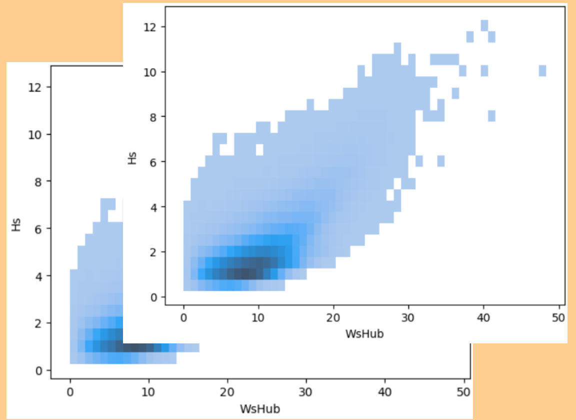
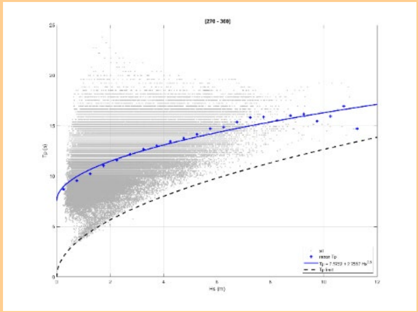
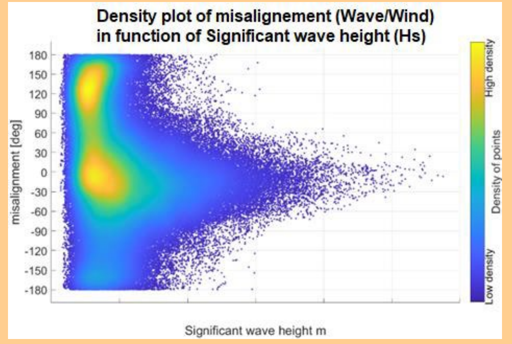
Hyperbox versus typical approach – 5 parameters

Full dataset:
- Ifremer ResourceCode wave hindcast
- WsHub, Hs, Tp, Wd, Dirp, Wd

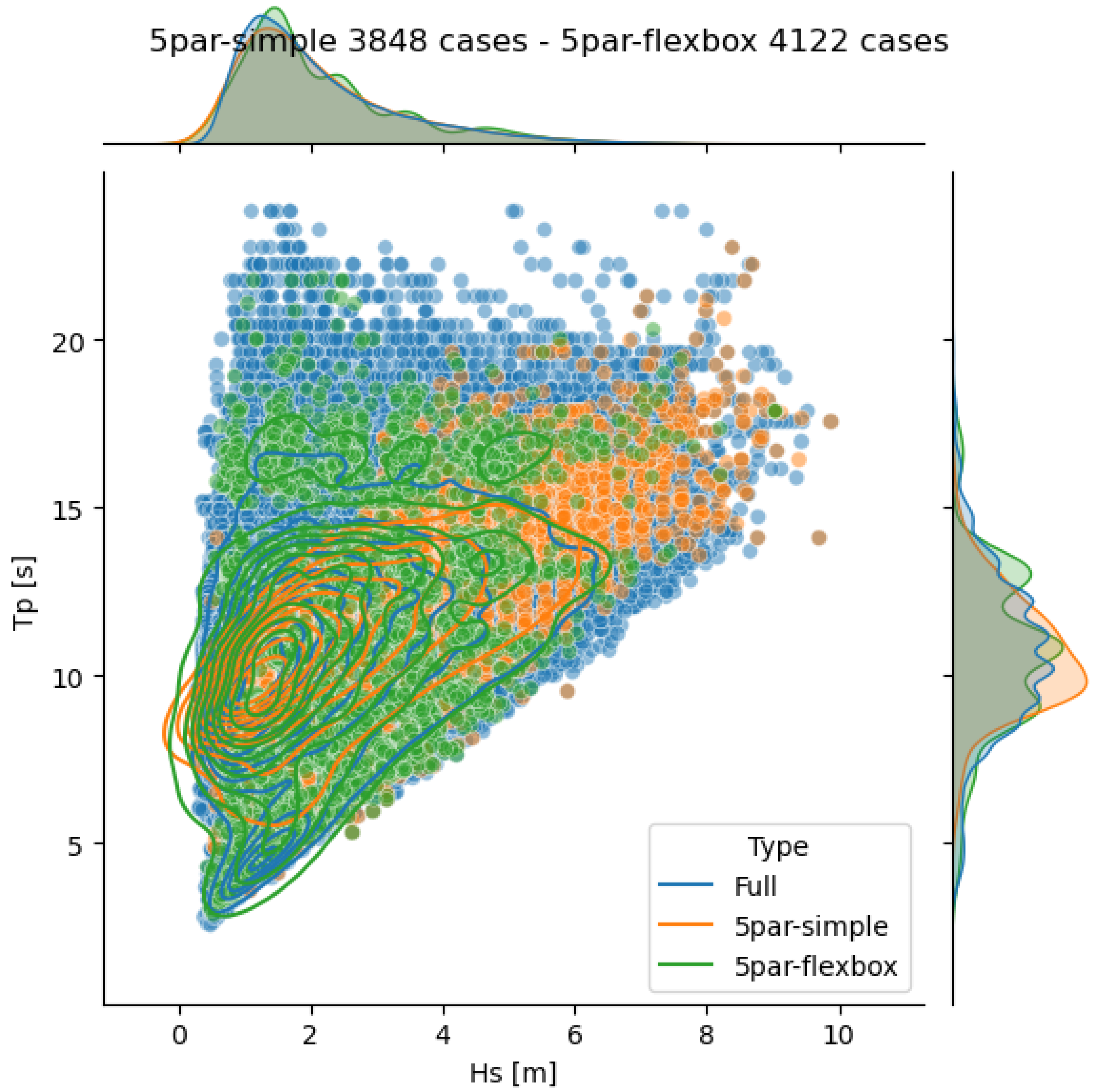
Typical approach:
- WsHub-Hs joint distribution per wind sector
- Relation Tp|Hs
- Wind-wave average misalignment per WsHub/Wd/Hs







Hyperbox approach:
- 5D joint distribution
- Statistics using original dataset



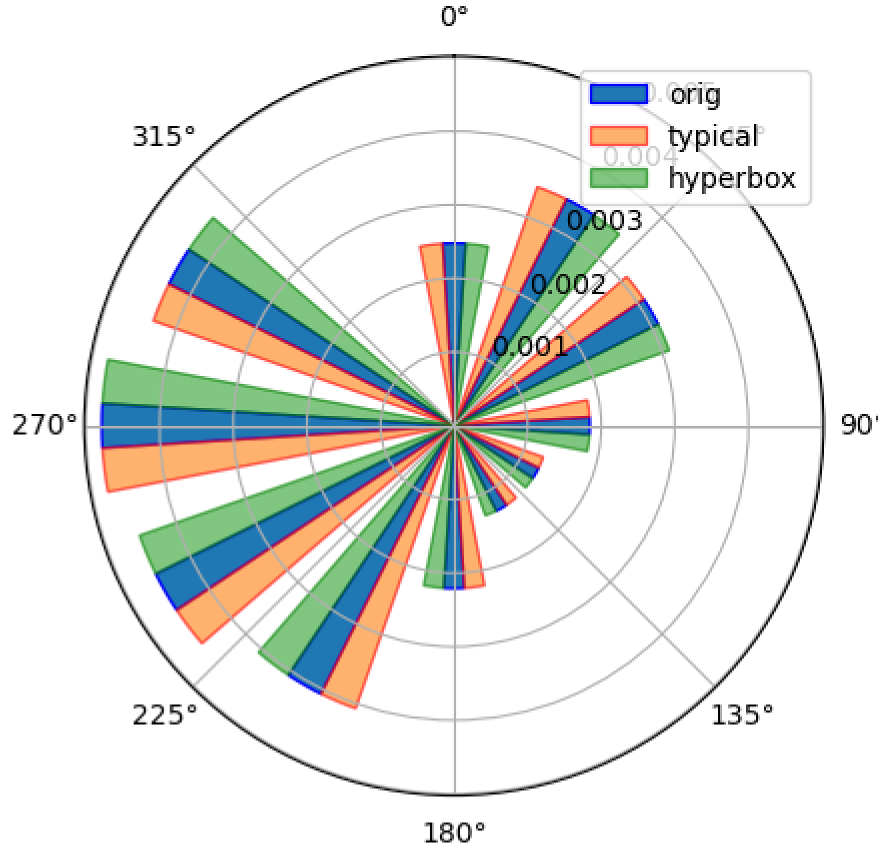
Hs-Tp joint scatter plots

RESULTS

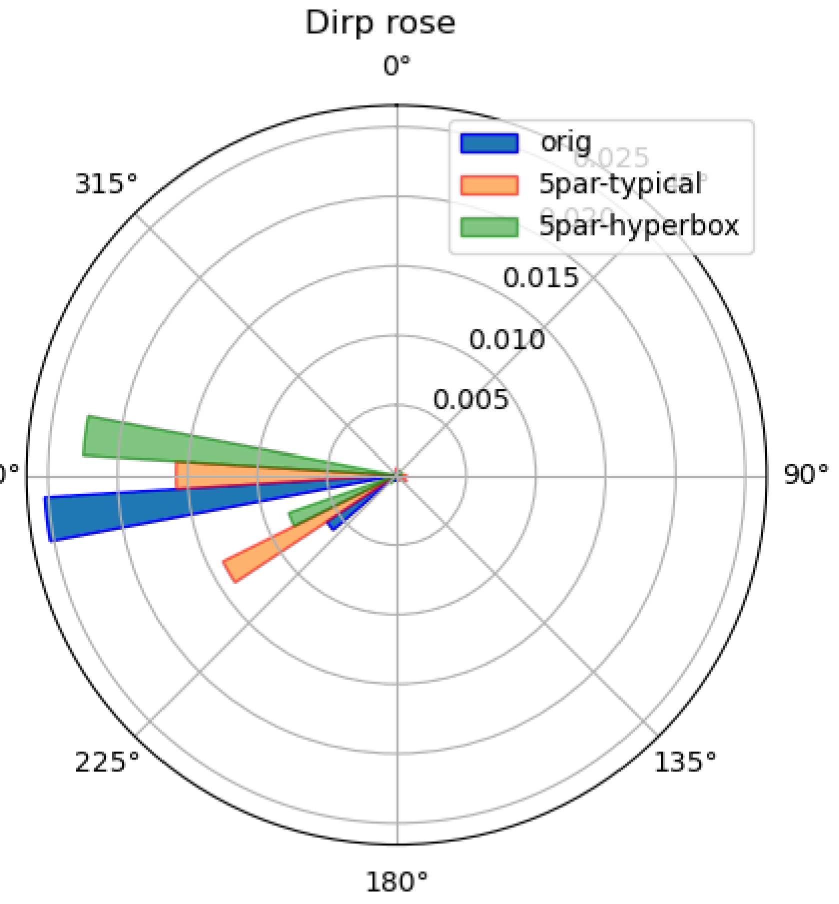
Better repartition across directional components

Parameters	Resolution	Typical method (3848 DLCs)	Hyperbox method (4122 DLCs)
Ws dist	2 m/s	0%	0%
Hs dist	1 m	17%	<1%
Tp dist	2 s	16%	<1%
Ws-Hs dist	2 m/s – 1m	8%	12%
Hs-Tp dist	1m - 2s	24%	6%
Dirp	30 deg	59%	17%
Wind-wave misal	45 deg	21 %	7 %
Misal-Hs	1m-45deg	67%	17%

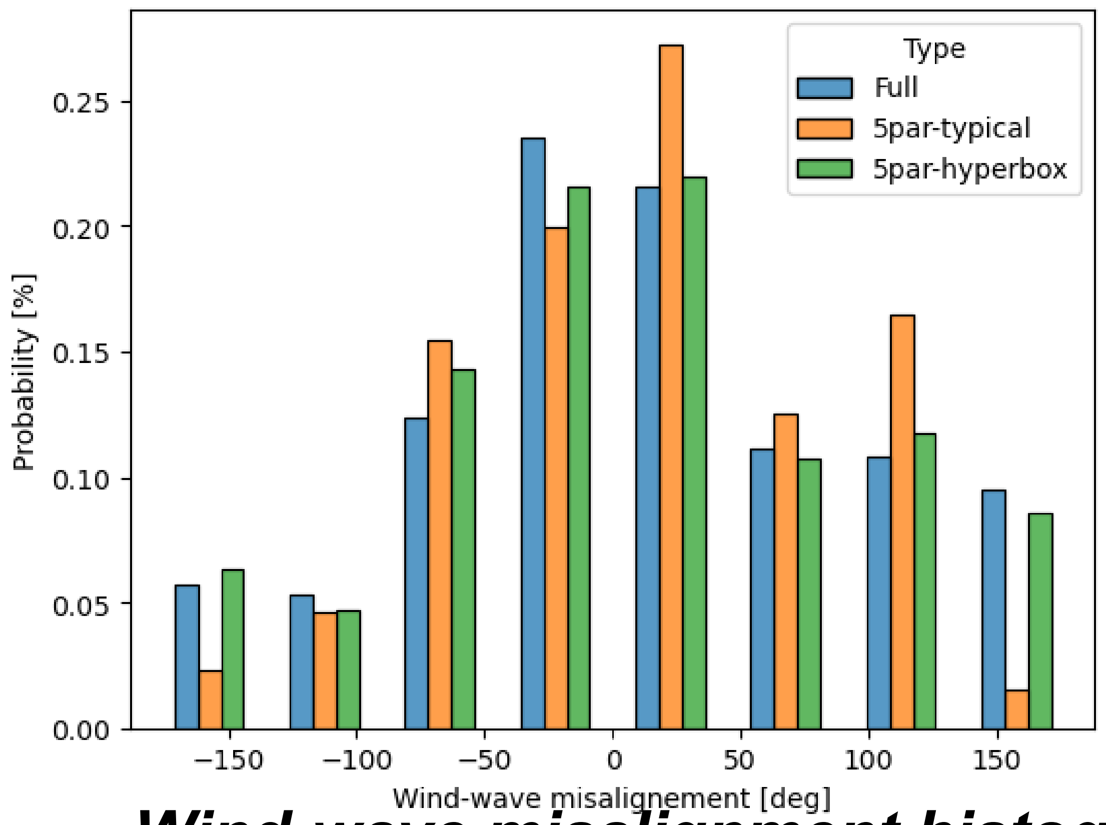
Statistical distance to full data distribution



Wind rose



Wave rose



Wind-wave misalignment histograms

A design-oriented fatigue Load Case selection method for floating offshore wind turbines – DeepWind, Trondheim, 2024

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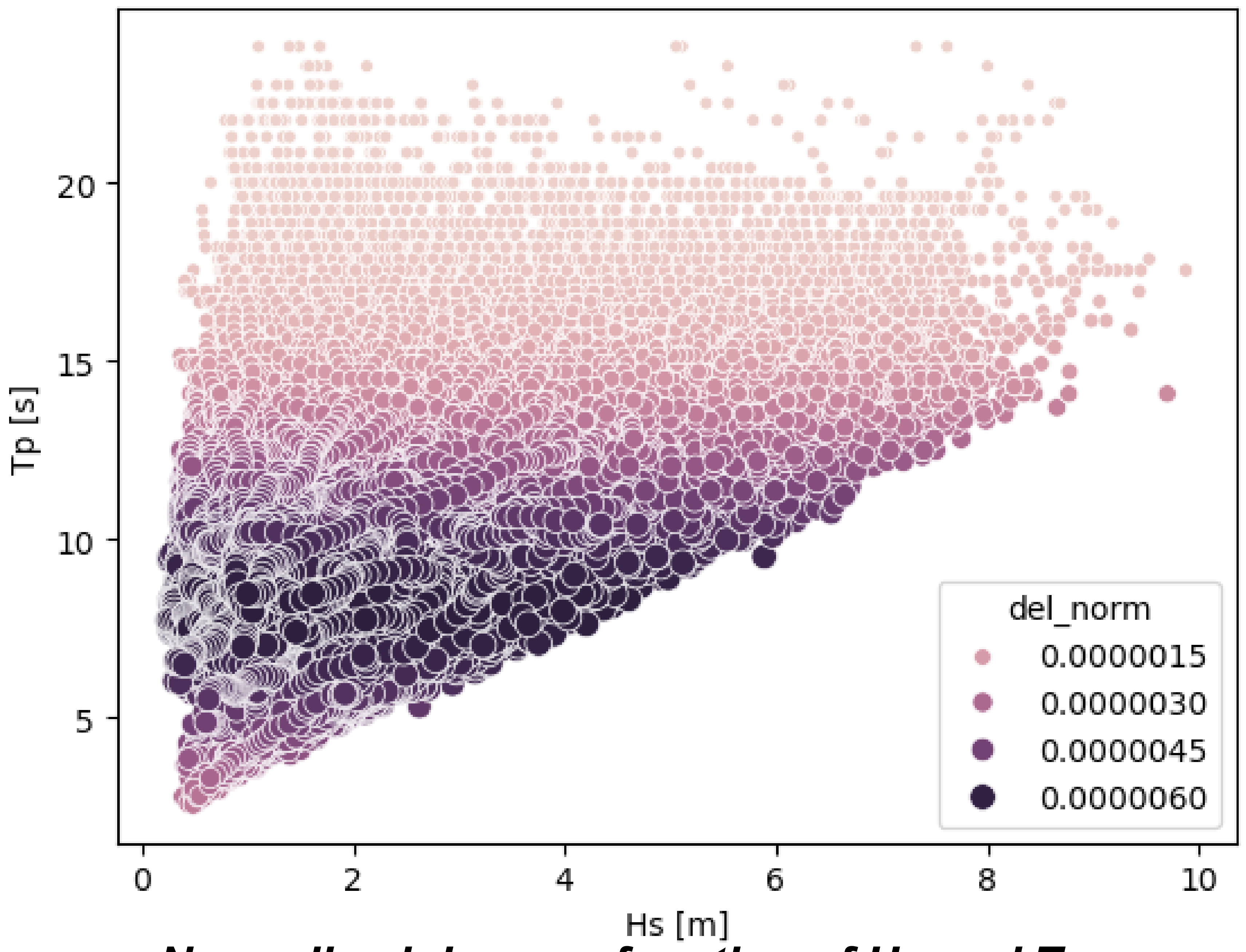
Recommendations for response-based choices

- Increase the **resolution** where it matters for the design.
  E.g. refine the discretization around peak periods where the RAO shows most damage

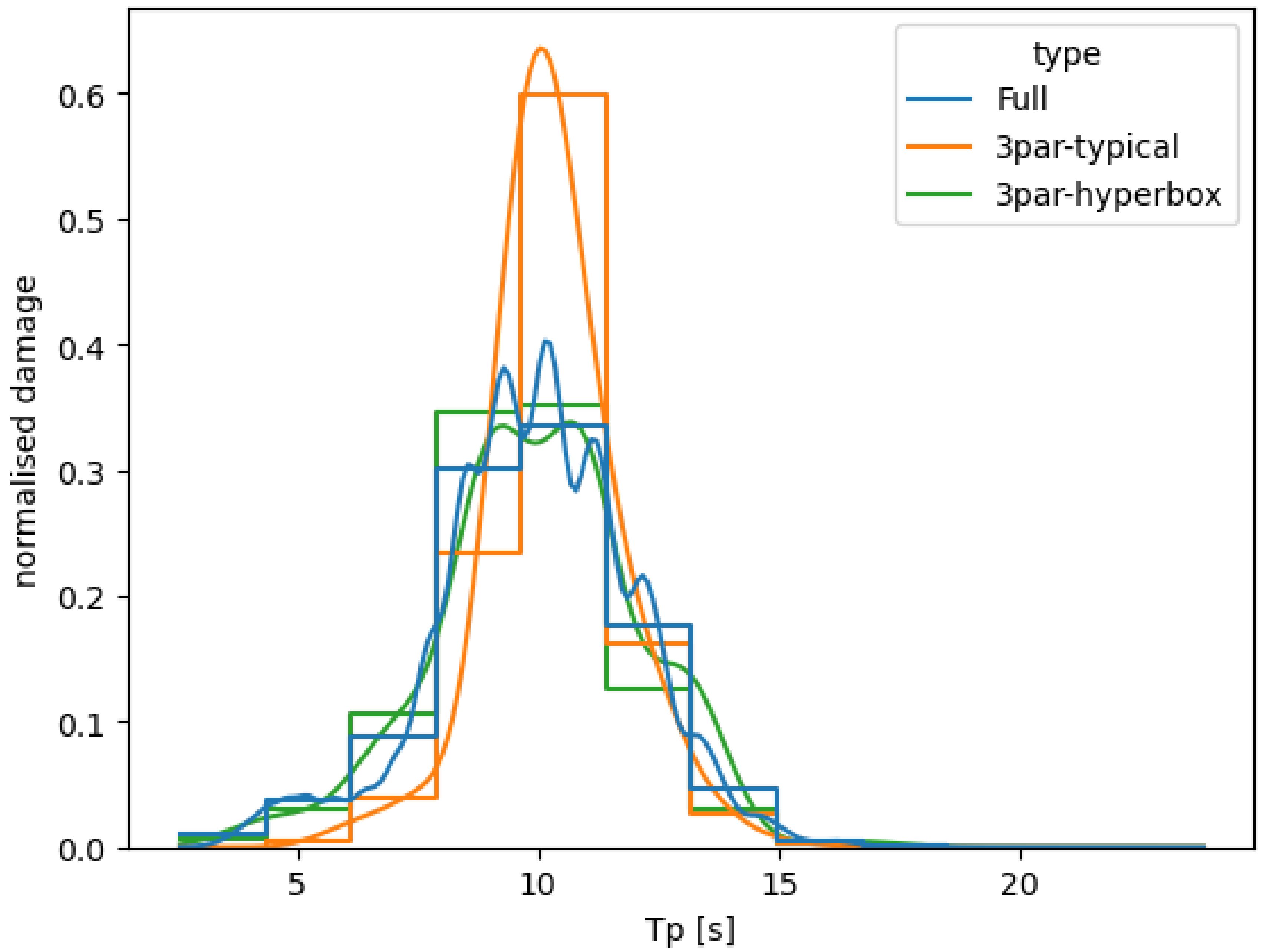
  Let's consider a damage sensitive to Tp in 6-10s interval in the 3-parameter case

  - Typical method: 7% error
  - Hyperboxes: <1% error

  compared to full dataset total damage



Normalized damage function of Hs and Tp



Normalized damage per Tp

RESULTS
Reduction of fatigue conservatism

Recommendations for response-based choices

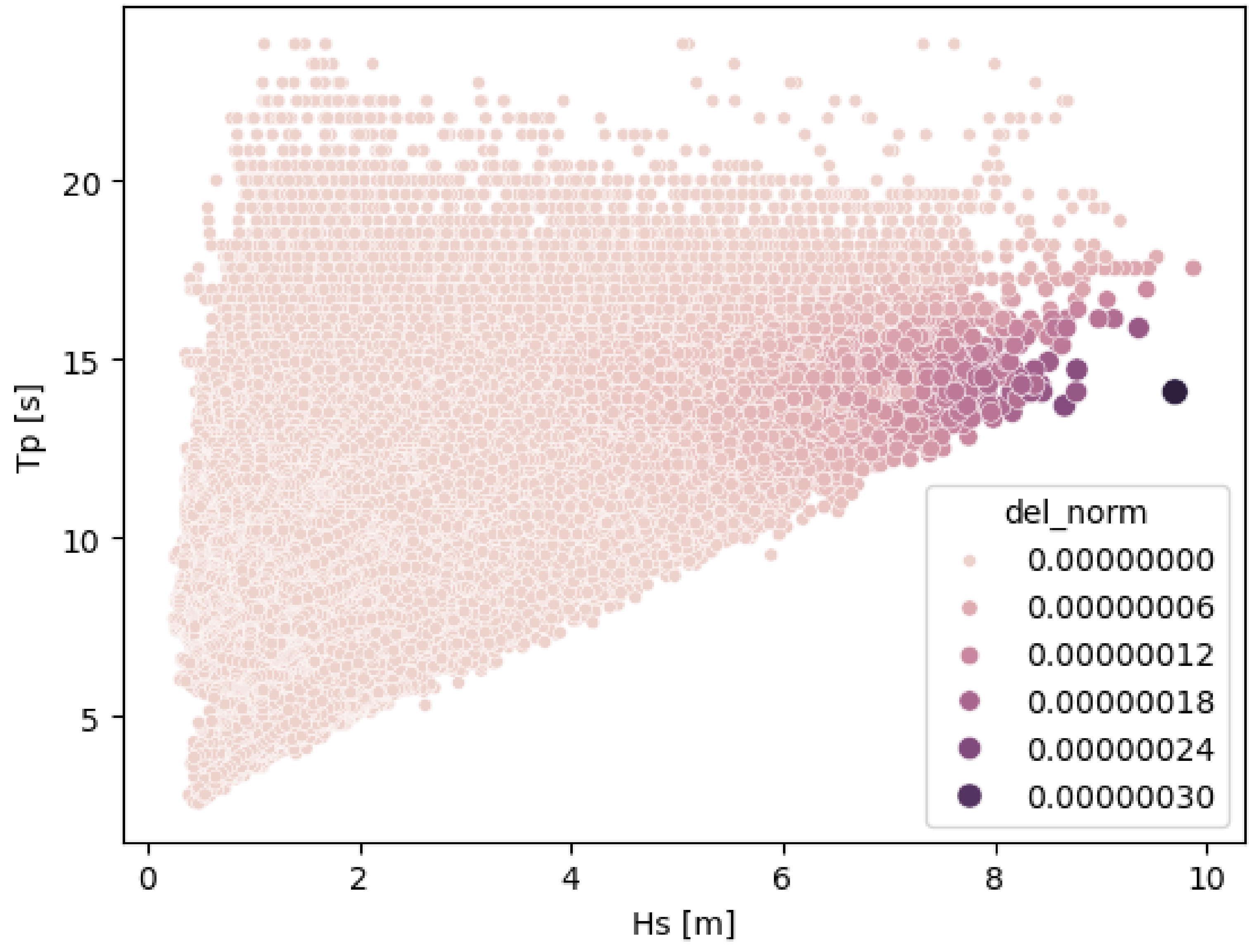
- **Characteristic values in agreement with the expected response**

  E.g.: for Hs, power-mean Hs^m with m the inverse slope of the fatigue S-N curve

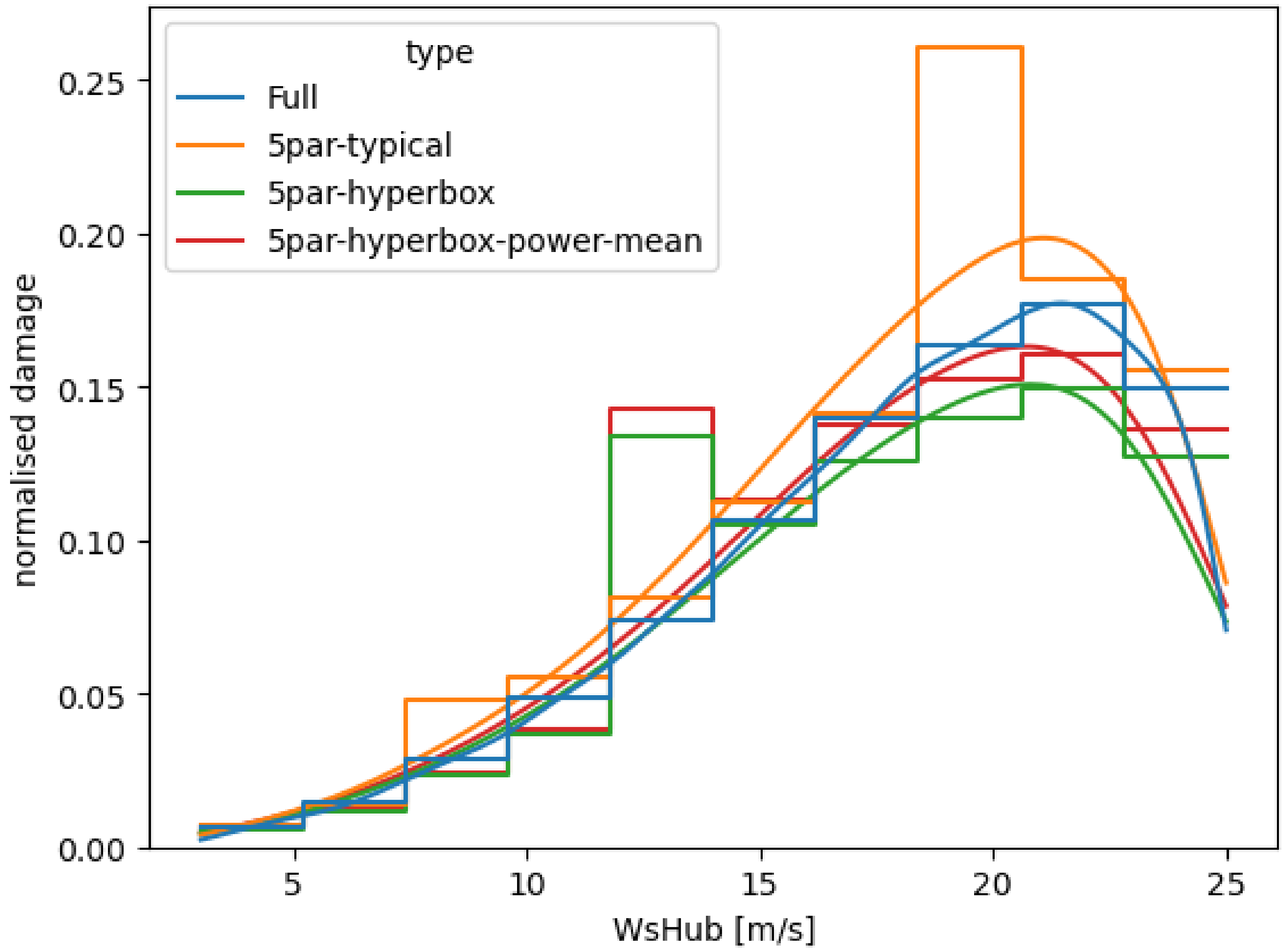
  Let's consider a damage proportional to Hs^4

  - Typical method with mean Hs: 16.6% error
  - Hyperboxes with mean Hs: -5.5% error
  - Hyperboxes with power 4 mean Hs: 1.6% error

  compared to full dataset total damage



Normalised damage function of Hs and Tp



Normalised damage per wind speed @hub height

RESULTS

Improvement of damage assessment accuracy using response-based choice of characteristic values

Conclusions and perspectives

- Efficient and accurate method for fatigue DLC selection, based on site environmental time-series, adaptable to project stages and FOWT properties
- Further work:
  - ✓ Assessment of the method in conjunction with the load and response computations (ILA)
  - ✓ Possible definition of statistical model of damage as function of metocean parameters (machine learning), e.g. for product mastery of a FOWT substructure

More information: Helene.Pineau@sofresid.com

References

- [1] DNV-RP-0286 Coupled analysis of floating wind turbines, Recommended practice, Edition 2019-05 - Amended 2021-10
- [2] Accensi, M., Alday, M., Maisondieu, C., Raillard, N., Darbynian, D., Old, C., Sellar, B., et al. (2021). ResourceCODE framework: A high-resolution wave parameter dataset for the European Shelf and analysis toolbox. In D. M. Greaves (Ed.), *Proceedings of the Fourteenth European Wave and Tidal Energy Conference* (pp. 2182-1-2182-9). University of Plymouth, UK: EWTEC.