A 12000 year simulation of waves and winds in the North and Norwegian Seas

Offshore Consulting Group

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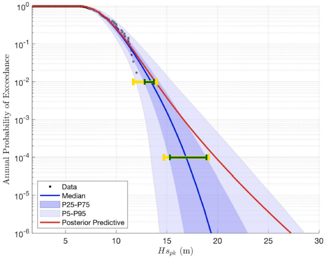
Background

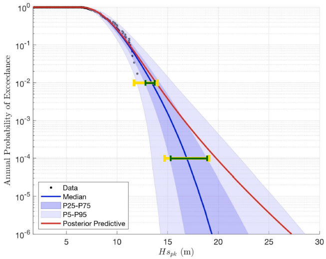
1. Motivation:
   - estimation of extreme, 10,000 year return period, metocean conditions;
   - significant wave height, maximum crest elevation, maximum wave height;
   - for the assessment of offshore platforms and critical infrastructure;
2. Approaches:
   - traditional methods require the extrapolation of a relatively short historical record $\rightarrow$ significant uncertainty in extreme values;
   - synthetic methods create more data $\rightarrow$ reduce the extrapolation uncertainty, but model uncertainty must be included.
3. NS1200 JIP:
   - very long simulations of the historical climate from climate model simulations;
   - estimates of extreme 10,000 year return period wave conditions across the North and Norwegian Seas;
   - 2015-Present, involving BP, UoR, AkerBP, Total, Equinor, MetNo and others.

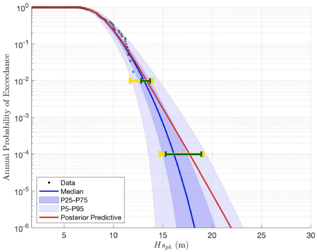
Historical Method



- The long-term distribution of significant wave height in the central North Sea using hindcast data.
- The blue fan shows the epistemic uncertainty in the extrapolation: the solid blue line is the median which is close to a ‘best-estimate’ or most probable value.
- The coloured bars are independent ‘best-estimates’ of 100 (top) and 10000 (bottom) year design conditions by different consultants (green, 2018) and different consultants and datasets (yellow, 2023).
- The red line is the posterior predictive estimate; the mean. It includes the effect of the uncertainty on the design conditions and is the ‘correct’ result if we’re interested in risk, probability of collapse, and when making decisions.
- We can reduce the uncertainty by: including more prior knowledge; or using more data.

Historical Method





- The epistemic uncertainty can be reduced by including more prior knowledge into the extrapolations.
- The long-term distribution of significant wave height: uninformative prior (left); and informative prior (right).
- Uninformative prior: there is an unknown finite limit to significant wave height.
- Informative prior: a limit on significant wave height based on a ratio to the water depth.

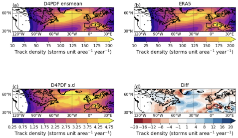
- Results are sensitive to the prior knowledge:
  - depth limits;
  - fetch limits;
  - possible limits on storm size, duration and intensity.

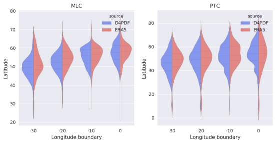
Synthetic Modelled Data

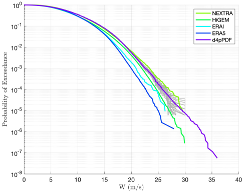
- Synthetic models span from purely statistical $\rightarrow$ hybrid statistical-dynamical $\rightarrow$ fully dynamical.
- North and Norwegian Seas dominated by extra-tropical storms: statistical models difficult $\rightarrow$ dynamical models.
- Climate model data: free running simulations of the historical climate.
- HiGEM, GFDL-ESM2M, and d4PDF, all provide extremely long data sets at a reasonable resolution for large scale synoptic systems.
- Reduce the statistical uncertainty in any extrapolations and allow for the direct dynamical modelling of design level storm events.
- Model uncertainty assessed using a multi-model ensemble.
- Effect of resolution also being quantified.

	Resolution	Years
GFDL-ESM2M	100km	700
HiGEM	100km	1,200
d4PDF	60km	12,000

d4PDF Validation

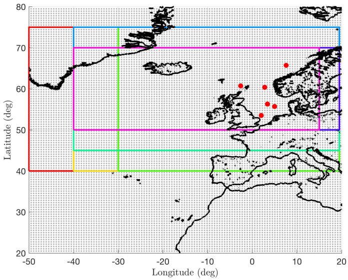


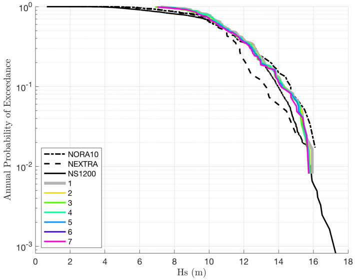




- Climate model data validated by comparing storm properties to historical events.
- Storms identified using UoR storm-tracking algorithm (Hodges, 1994).
- Wide range of storm properties considered: track density (left, UoR), track crossings (middle, UoR), translation speed, minimum MSL pressure, maximum vorticity, storm shape, seasonality, arrival rate, wind direction, wind speed (right), and many more.
- Overall, the models are largely unbiased and the storm properties and wind speeds lie within the spread of historical reanalyses.

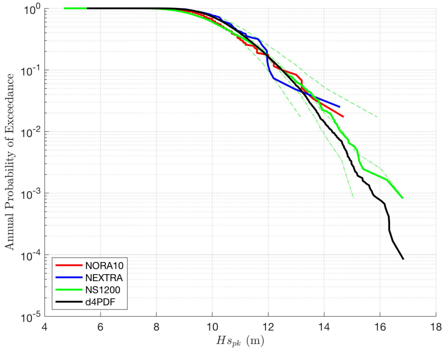
d4PDF Wave Modelling





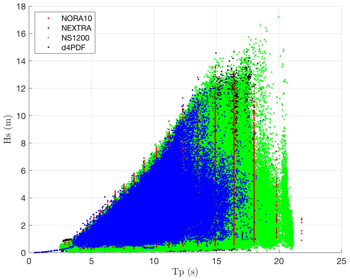
- Wave modelling completed for each model using WaveWatch3 (ST4) on a grid spanning the North Atlantic.
- Grid extent and source term calibration completed by comparing to reference hindcast data (NORA10) at six locations across the North and Norwegian Seas.

Results



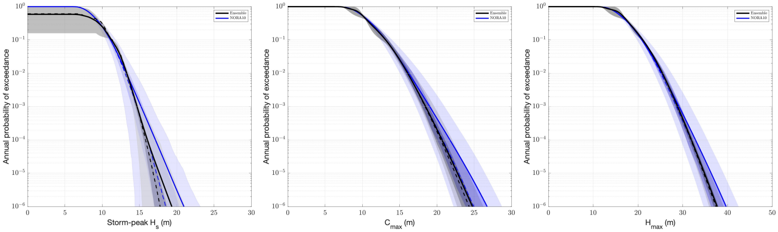
- Long-term distribution of significant wave height in the northern North Sea.

Results



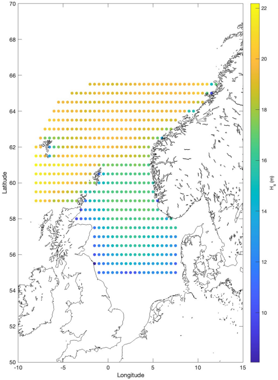
- Scatter plots of spectral peak period, wave direction, and significant wave height in the northern North Sea.

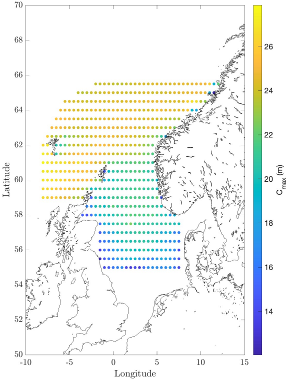
Results



- Ensemble and NORA10 estimates of significant wave height, maximum crest elevation and maximum wave height in the central NorthSea.
- Climate model ensemble includes extrapolation and model uncertainty.
- Significant wave height: consistent with our ‘best-estimate’ from historical analysis.
- Crest elevations: LOADS crest height distribution includes nonlinearities beyond second-order and wave breaking.
- Wave heights: LOWISH-Boccotti distribution includes effects of bandwidth and wave breaking.

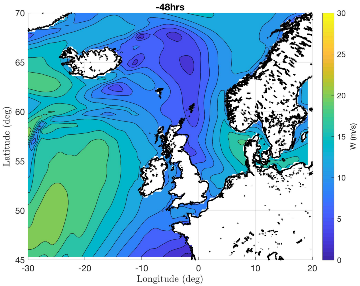
Results

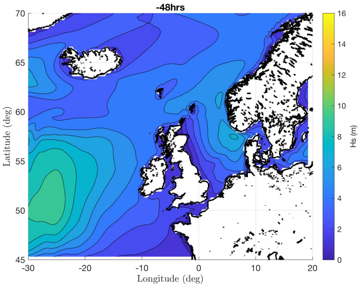




- Left: multi-model estimate of 10,000 year significant wave height across the North and Norwegian Seas.
- Right: multi-model estimate of 10,000 year maximum crest elevation across the North and Norwegian Seas.

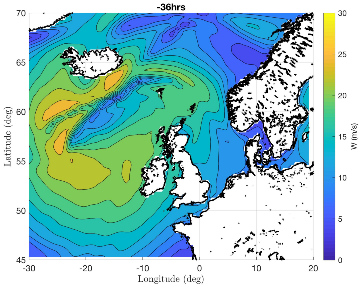
d4PDF 10k storm

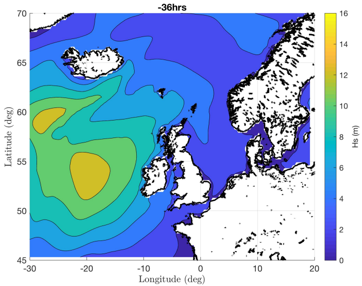




- Wind speed (left) and significant wave height (right).

d4PDF 10k storm





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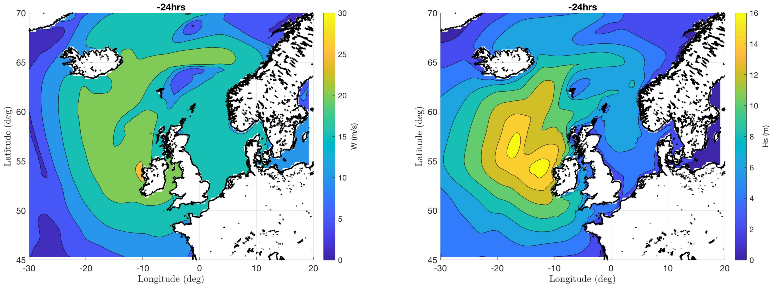

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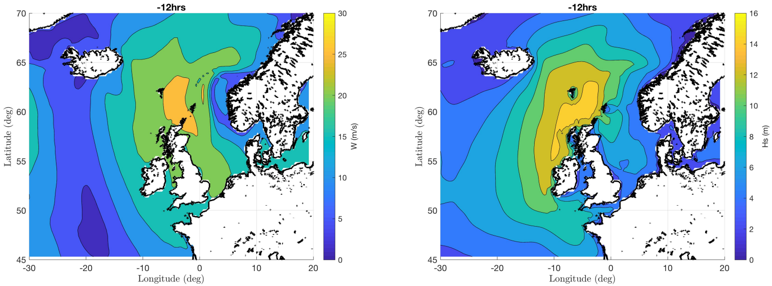

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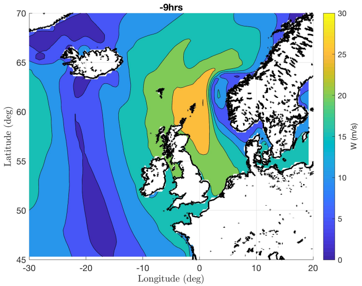

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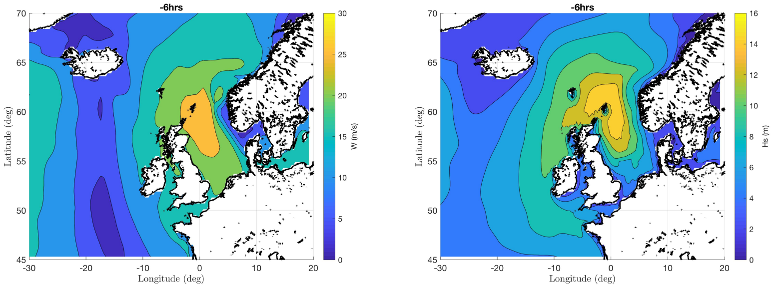

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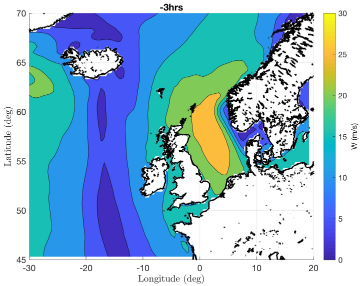

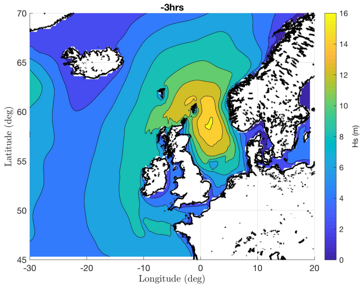

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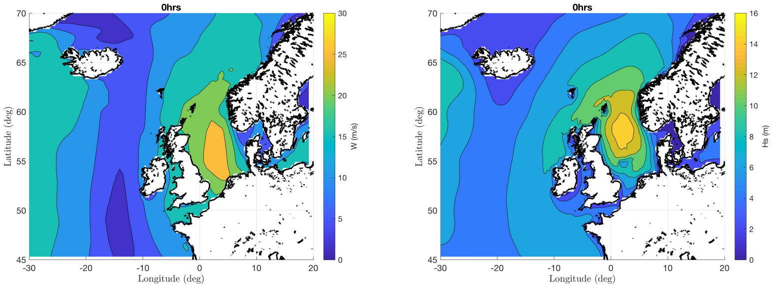

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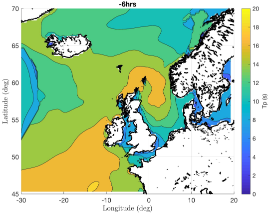

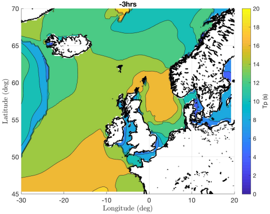

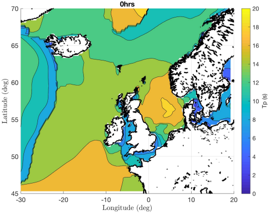

Summary

1. Multi-model ensemble of extremely long simulations of the present climate: GFDL, HiGEM, d4PDF.
2. Estimates of extreme wave conditions modelled using WaveWatch3.
3. Estimates of significant wave height, maximum crest elevation, and maximum wave height across the North and Norwegian Seas.
4. Simulations of extreme design level events.
5. Other work within NS1200 JIP and other related projects:
   - 5.1 Multi-model ensemble has been applied within structural reliability calculations.
   - 5.2 Multi-model ensemble approach has been applied to climate change.
   - 5.3 The approach can also be applied in other regions where extra-tropical cyclones dominate the extremes.

Bibliography

K.I. Hodges. A general method for tracking analysis and its application to meteorological data. *Monthly Weather Review*, 1994.