# Decadal Wave Variability in the eastern North Atlantic associated with the NAO

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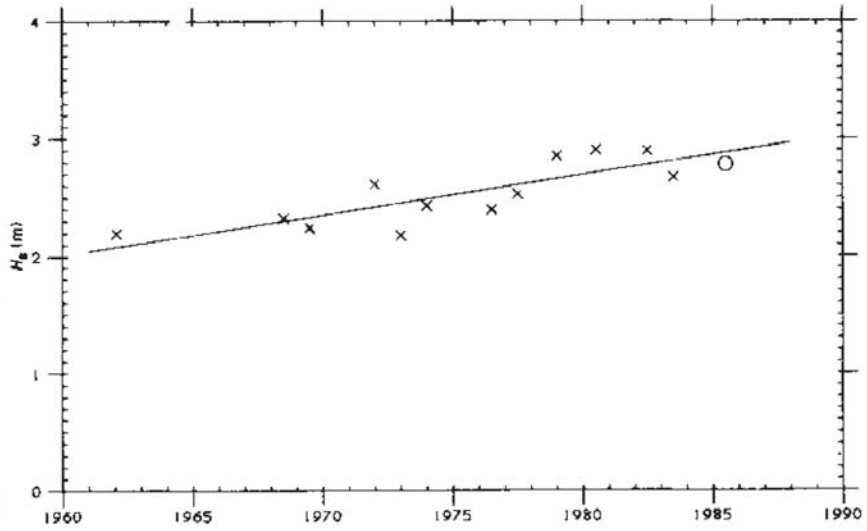
Richard Gibson

# Motivation

Published observations show North Atlantic was getting rougher over 1960s – 1990s.

- due to climate change?

? ?



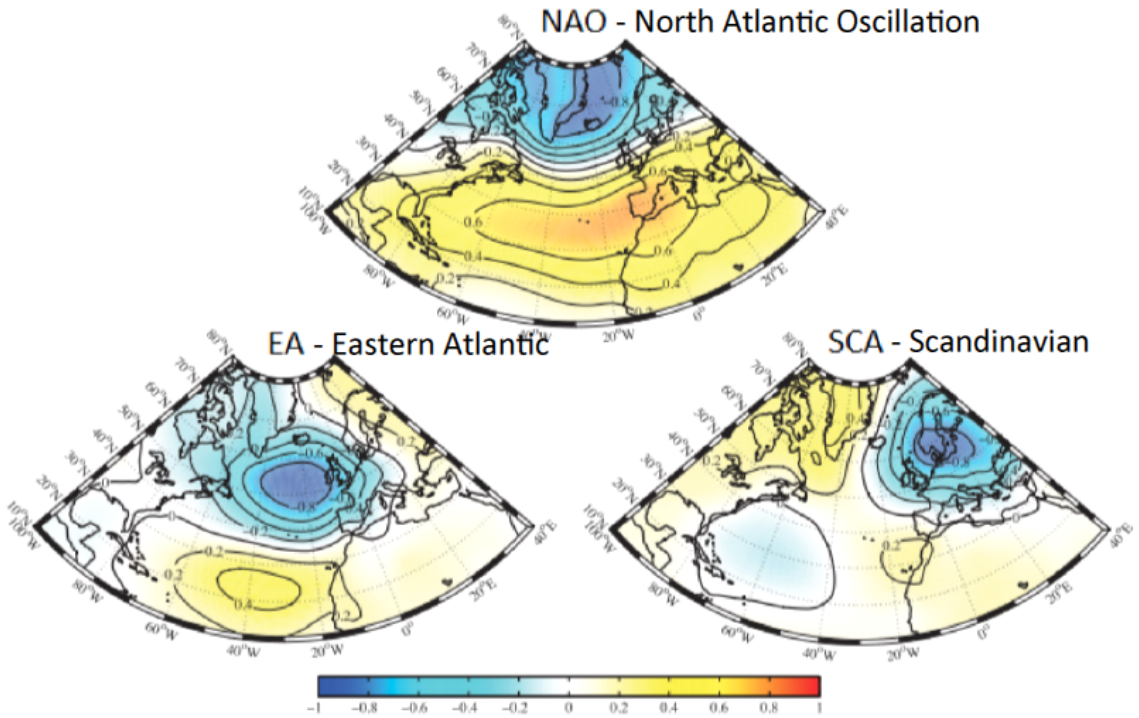

? ?

Ref: Carter, D., and L. Draper (1988), Has the north-east Atlantic become rougher?, Nature, 332, 494.

# Questions

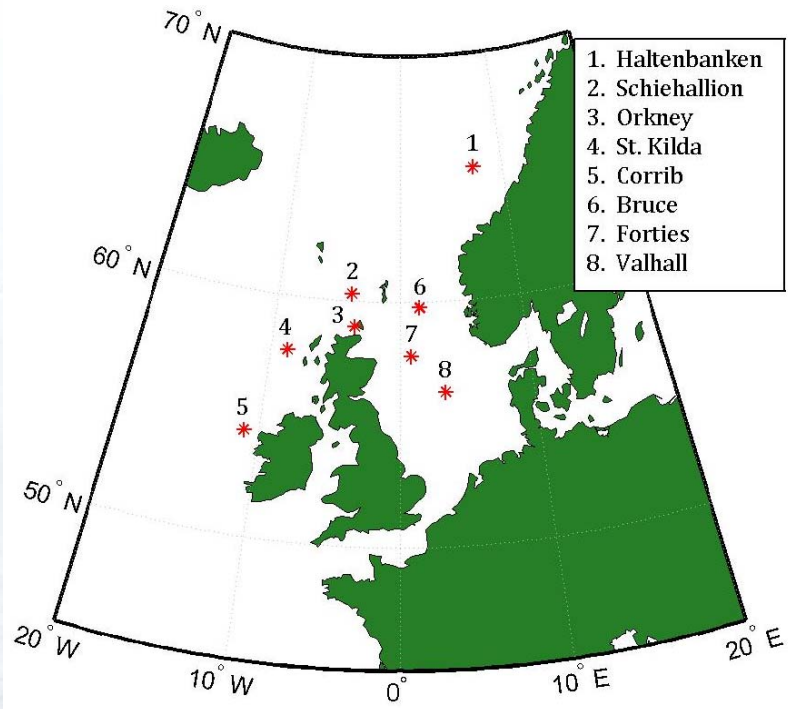
- Is there an average wave climate at a particular location?
- Are the waves over the last 25 – 50 years a reliable guide to the next 25 or 100 years?
- The available wave records are too short, is there a way to infer a longer time history for wave climate back to the past (over 400 years)?

# NAO and other two modes




Ref: Moore, G., I. Renfrew, and R. S. Pickart (2013), Multidecadal mobility of the North Atlantic Oscillation, Journal of Climate, 26(8), 2453–2466.

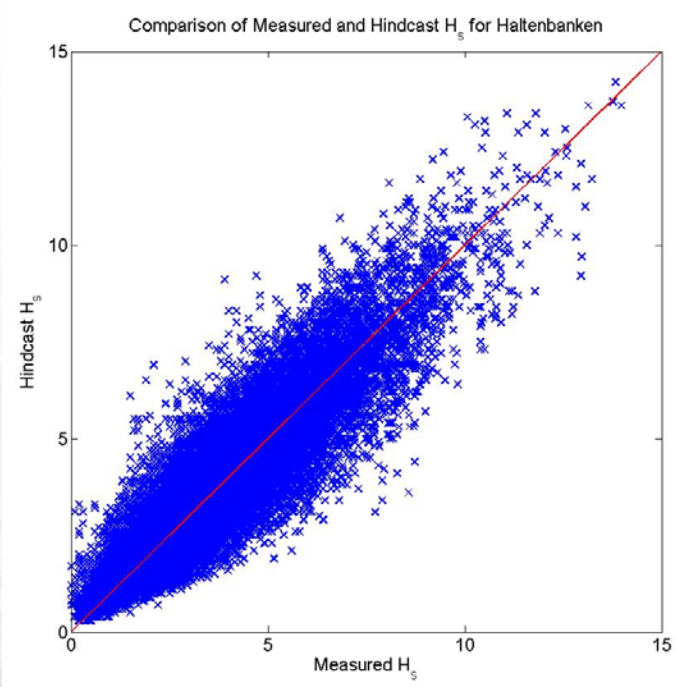
# Map of the locations

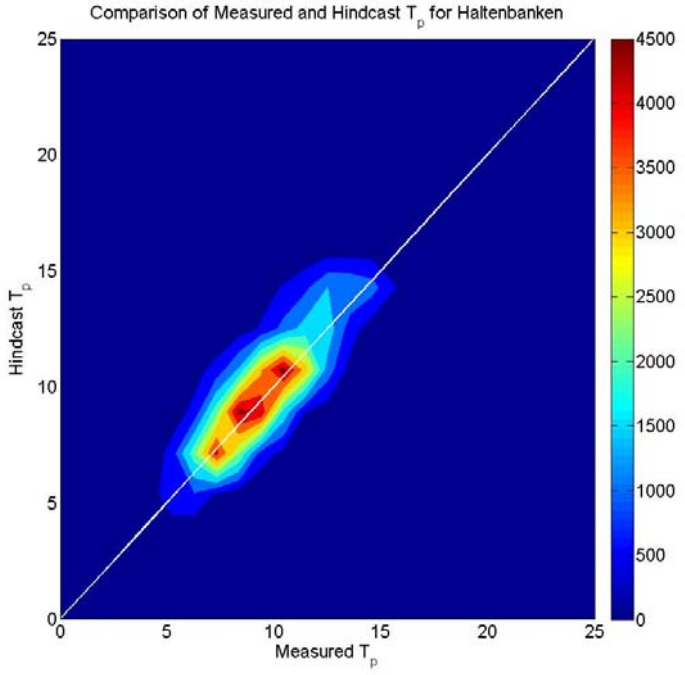



- Hindcast data: NORA10 for all from 1958 – 2011 (54 years)
- All data contain $H_s$, $T_p$, and $T_m$ sampled every 3 hours.
- Data also contain wave direction, wind speed and wind direction, and a split of total waves into swells and wind waves.
- Analysis is presented on total waves.

# Model/buoy comparisons

- Shown here for Haltenbanken



# Wave power estimate

- $P = \frac{\rho g^2}{64\pi} H_S^2 T_p$
- Note the use of $T_p$ rather than $T_e$ ($T_p \sim 1.2 T_e$).
- Winter weather is worst, summer rather benign.
- We look at total average power year by year (with year running from summer to summer, avoid splitting winters).
- In the near future, seasonal variation can be included for monthly wave power variability.

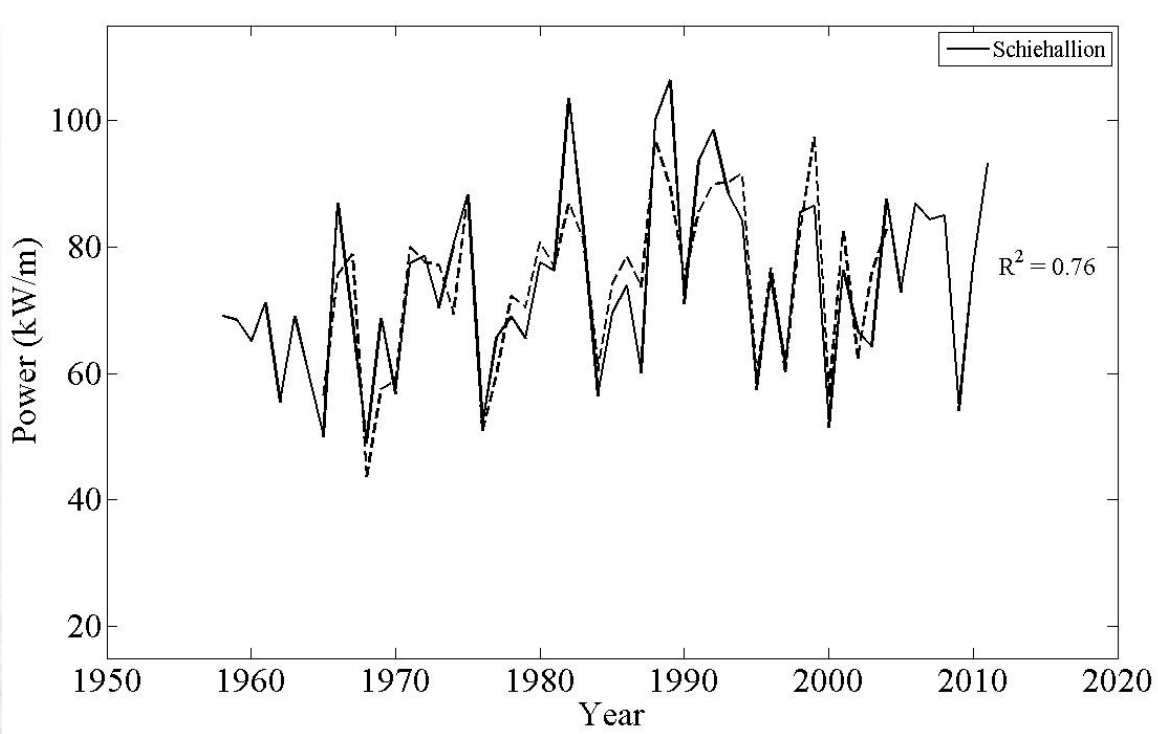
# Correlation with NAO and other modes

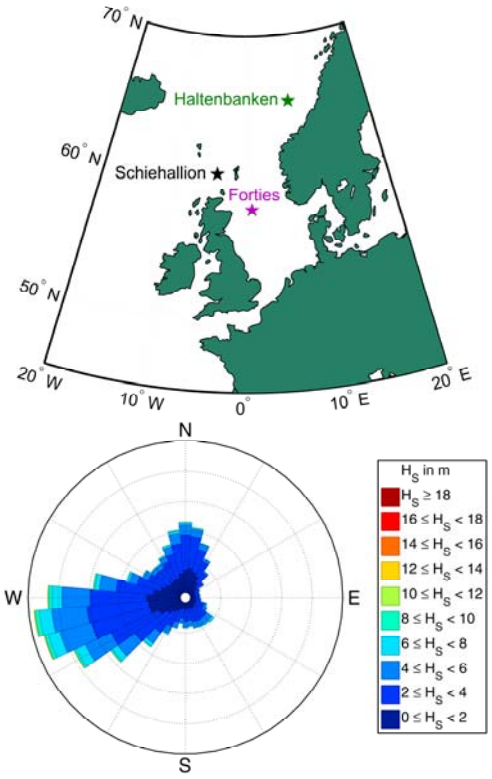
- Predictor model based on linear regression using climate indices.
- Indices obtained from Climate Prediction Center (NOAA, available from 1950 onwards).
- Model is trained over the period of hindcast data by minimising the variance.

$$f = \frac{1}{\sum(P(t) - \overline{P})^2} \times \sum[(P(t) - \overline{P}) - \tilde{b}(\mathrm{EA}_{hi}(t) - \overline{\mathrm{EA}}) - \tilde{c}(\mathrm{NAO}(t) - \overline{\mathrm{NAO}}) - \tilde{d}(\mathrm{SCA}_{\mathrm{hi}}(t) - \overline{\mathrm{SCA}})]^2$$

$$P_{\mathrm{predictor}} = \overline{P} \times [1 + b(\mathrm{EA}_{\mathrm{hi}}(t) - \overline{\mathrm{EA}}) + c(\mathrm{NAO}(t) - \overline{\mathrm{NAO}}) + d(\mathrm{SCA}_{\mathrm{hi}}(t) - \overline{\mathrm{SCA}})]$$

# Correlation with NAO and other modes



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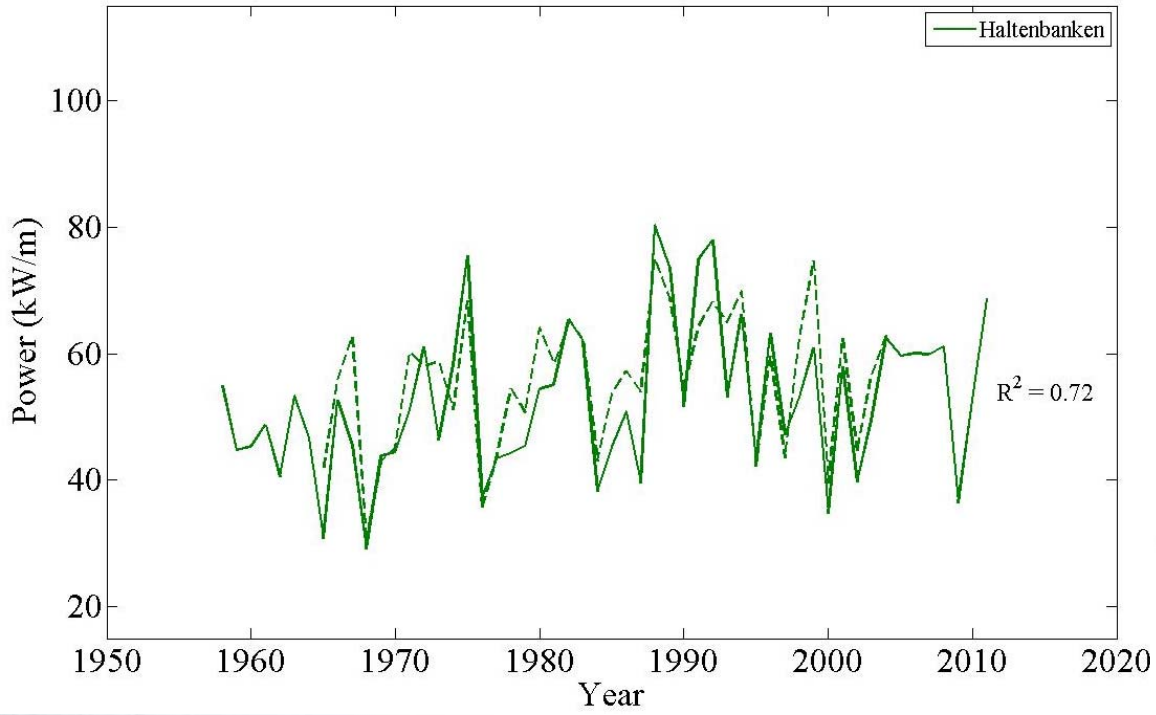


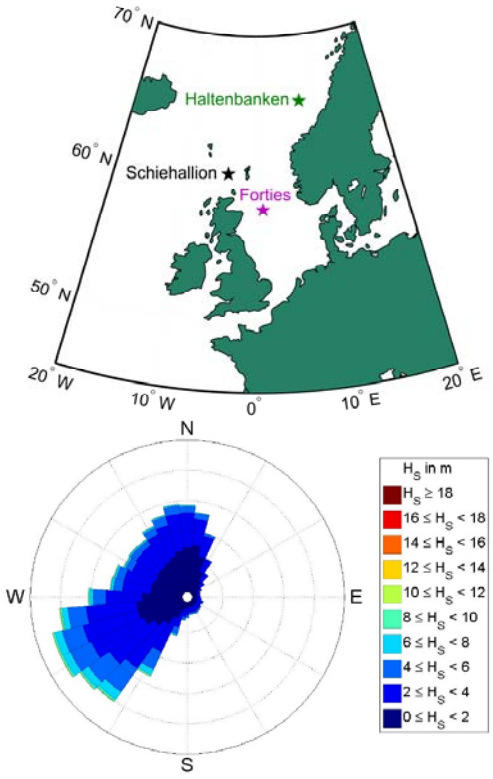

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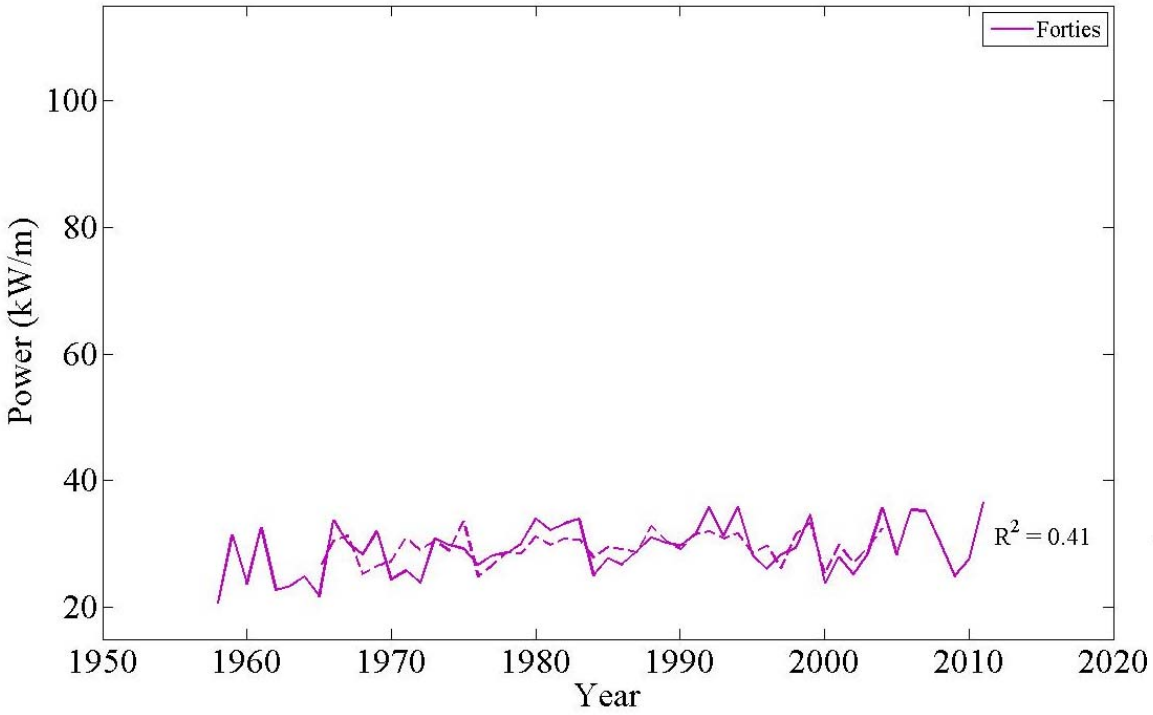
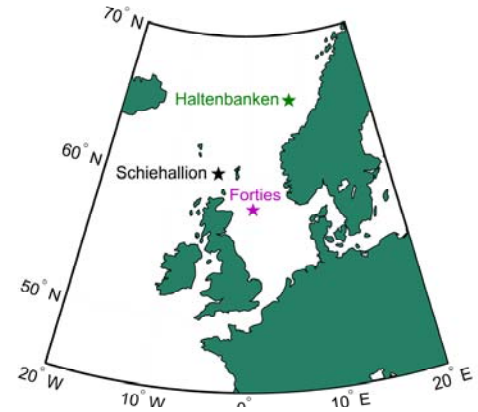
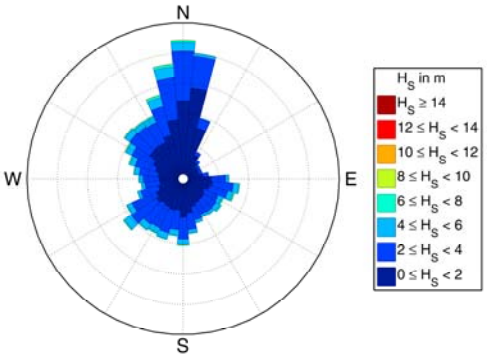
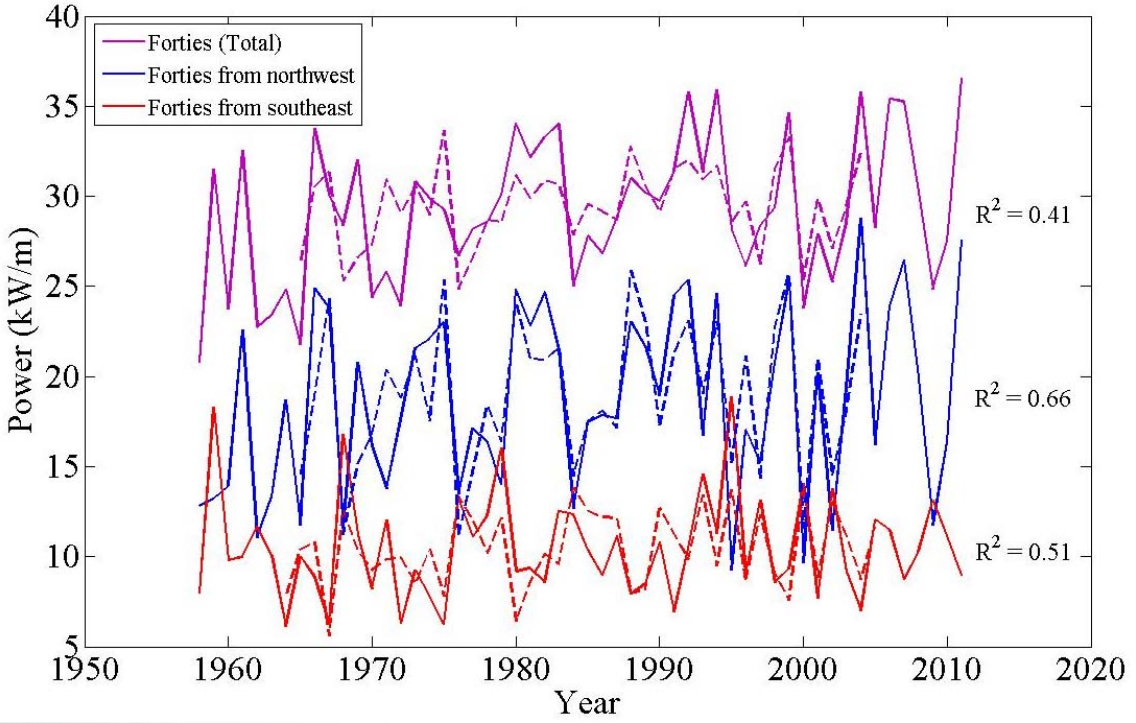
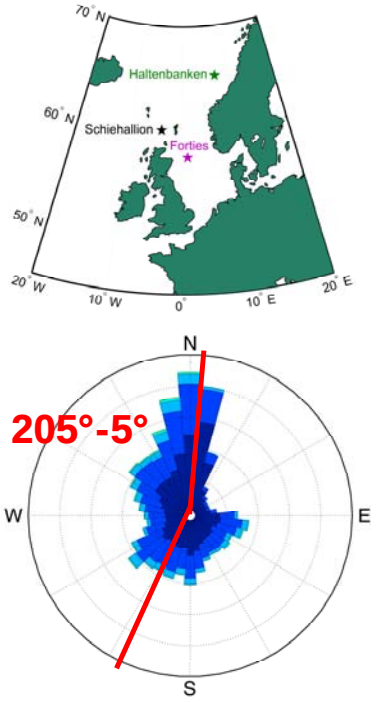


# Angular partitioning at Forties

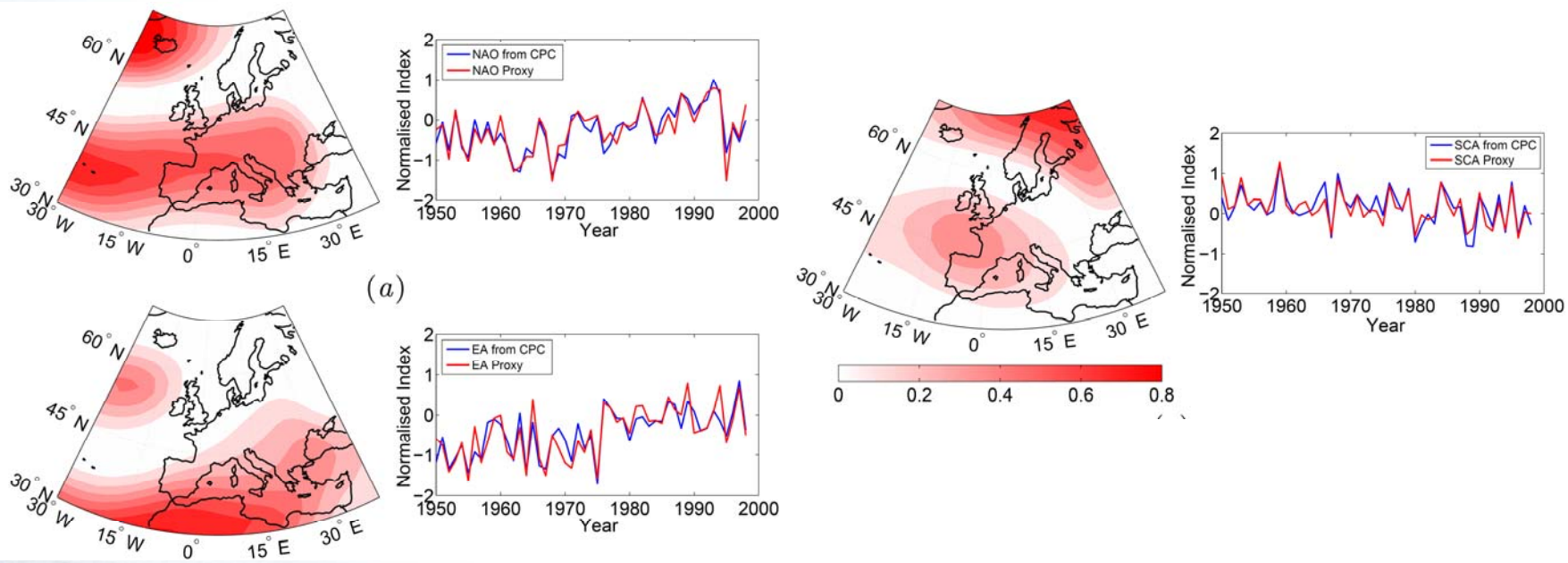



Nonlinear predictor model for better correlation for locations in North Sea.

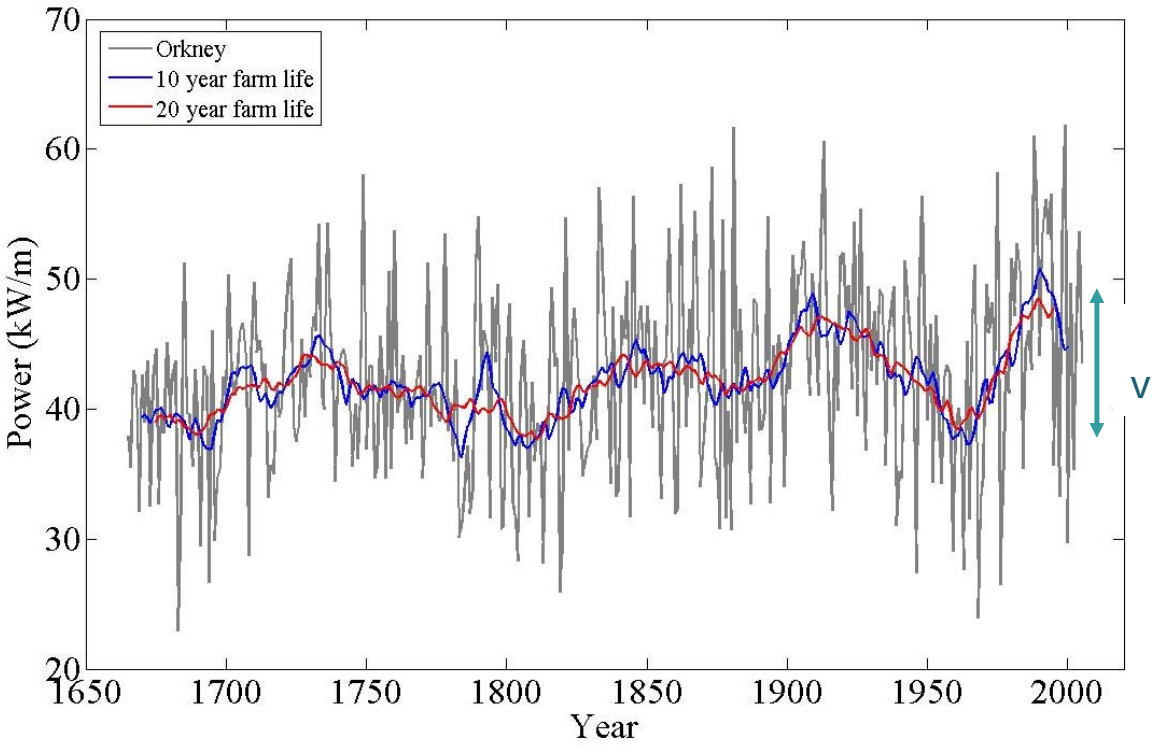
# Proxy index based on pressure fields for reconstruction prior to 1950

- Using reconstructed winter pressure fields from Luterbacher (2002).

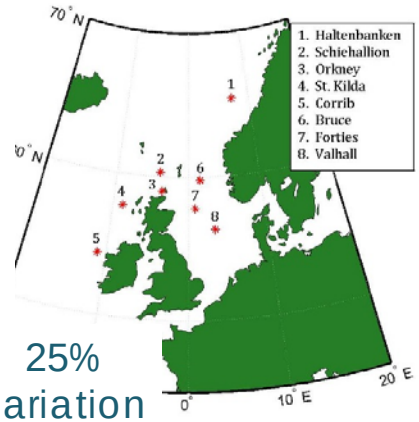



Ref: Luterbacher, J., E. Xoplaki, D. Dietrich, R. Rickli, J. Jacobeit, C. Beck, D. Gyalistras, C. Schmutz, and H. Wanner (2002), Reconstruction of sea level pressure fields over the Eastern North Atlantic and Europe back to 1500, Climate Dynamics, 18 (7), 545–561.

# Reconstructed ocean wave power at Orkney




25% variation

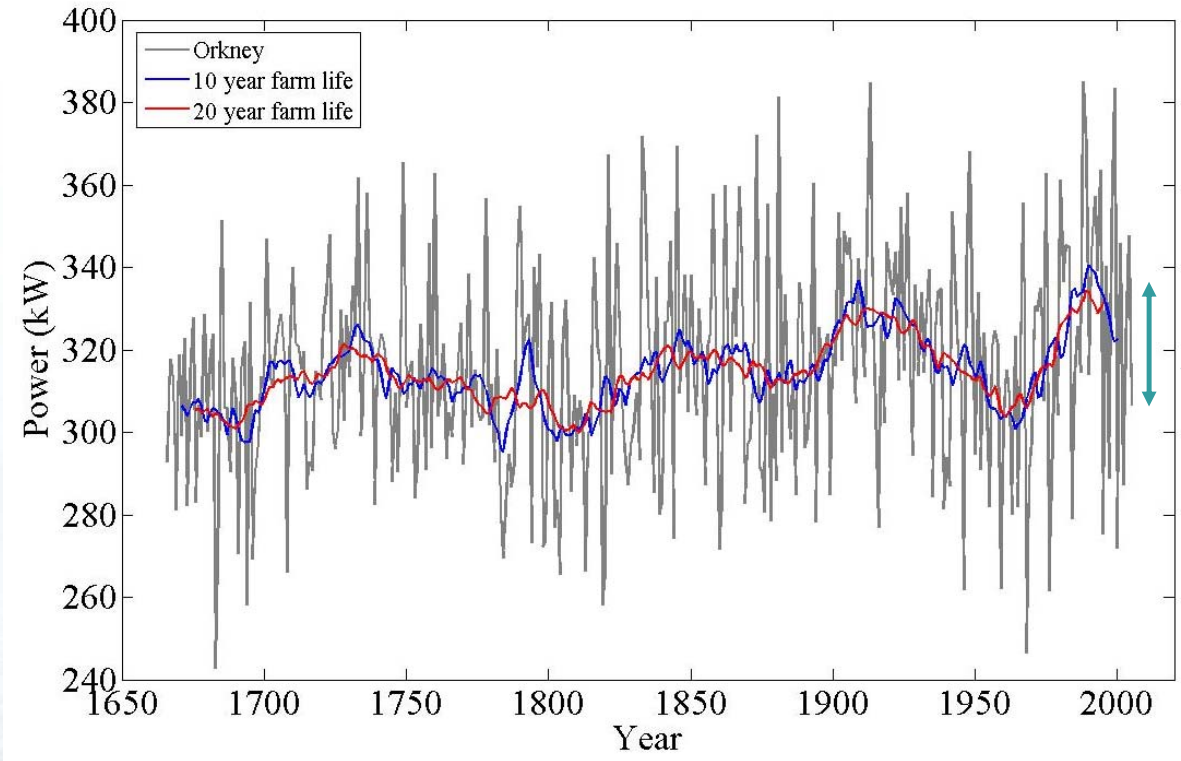


# The M4 wave power machine – Prof. Peter Stansby

MANCHESTER 1824
The University of Manchester

- Three-float system separated by half a wave length.
- Broadband frequency response in irregular waves.

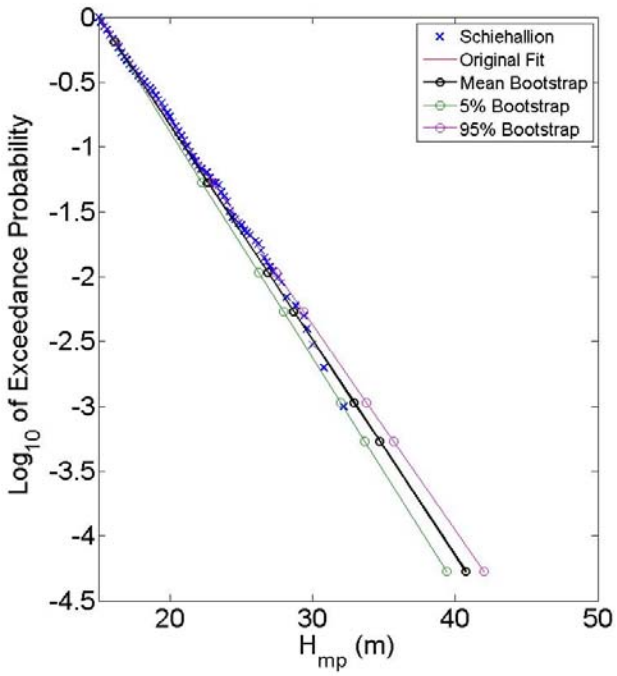
# Reconstructed practical wave power extracted by the M4 machine at Orkney




10% variation

# Estimating 100-year storm severity

- Via the most probably maximum individual wave height in a storm, $H_{mp}$ (see Tromans and Vanderschuren 1995).
- Peaks-over-threshold, threshold value = 1000 largest storms for 54 years of data, which corresponds to about 20 storms per winter, roughly 1-2 per week.
- Maximum likelihood method as estimator for exponential-type tail.
- Five-year sliding window analysis to obtain temporal variability of $H_{mp}$.

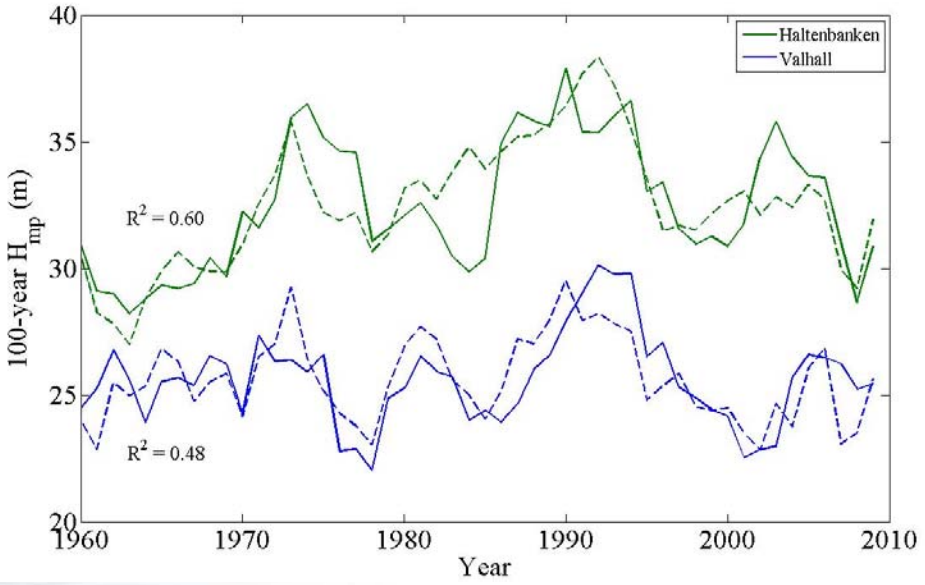


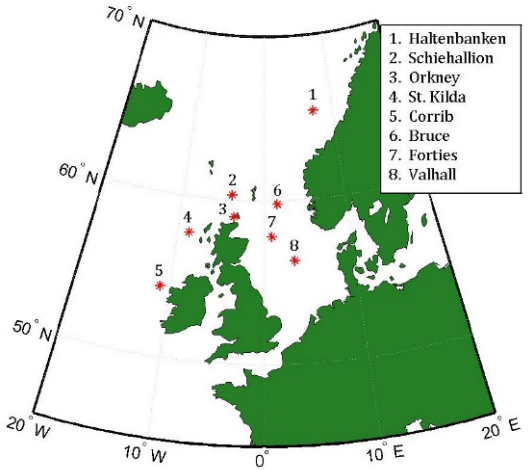

Ref: Tromans and Vanderschuren (1995), Response based design method in the North Sea: Application of a new method, in Offshore Technology Conference, OTC 7683, Houston.

# Correlation with the teleconnections

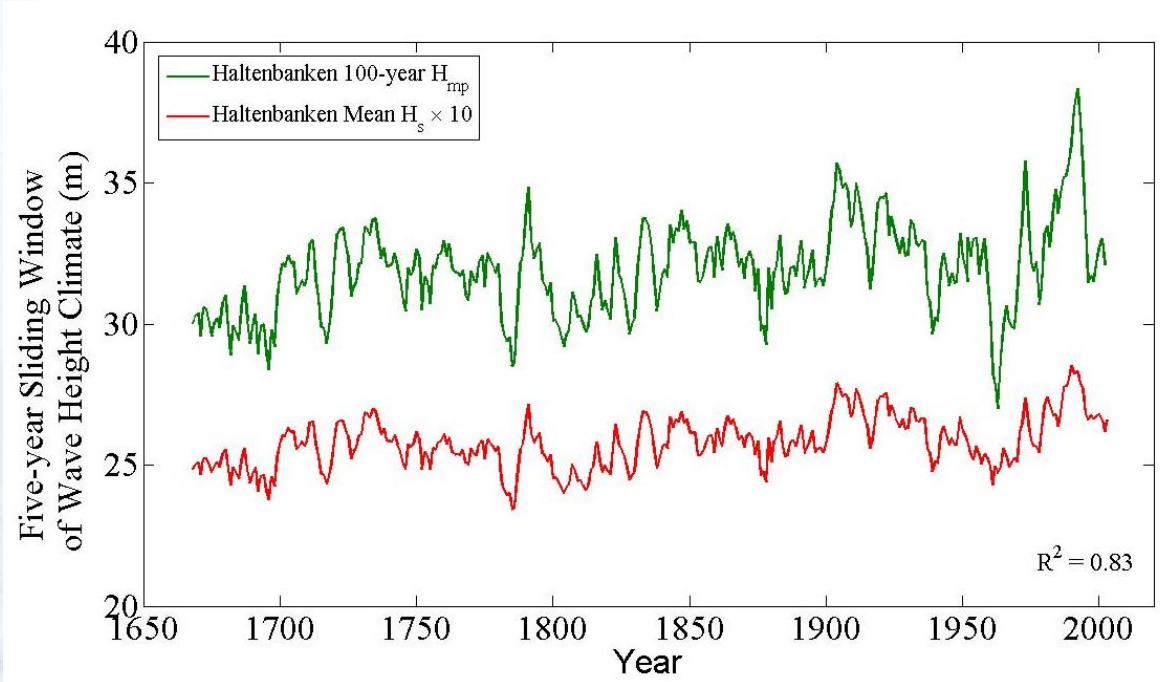
- Same predictor model as the mean wave climate correlation, except all NAO, EA and SCA indices are low pass filtered (moving average) of 5 years.

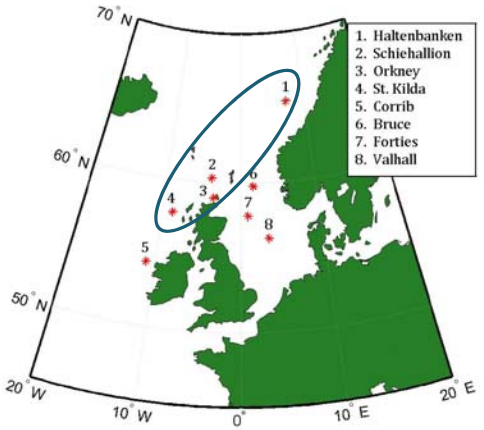
  Five-year sliding window:



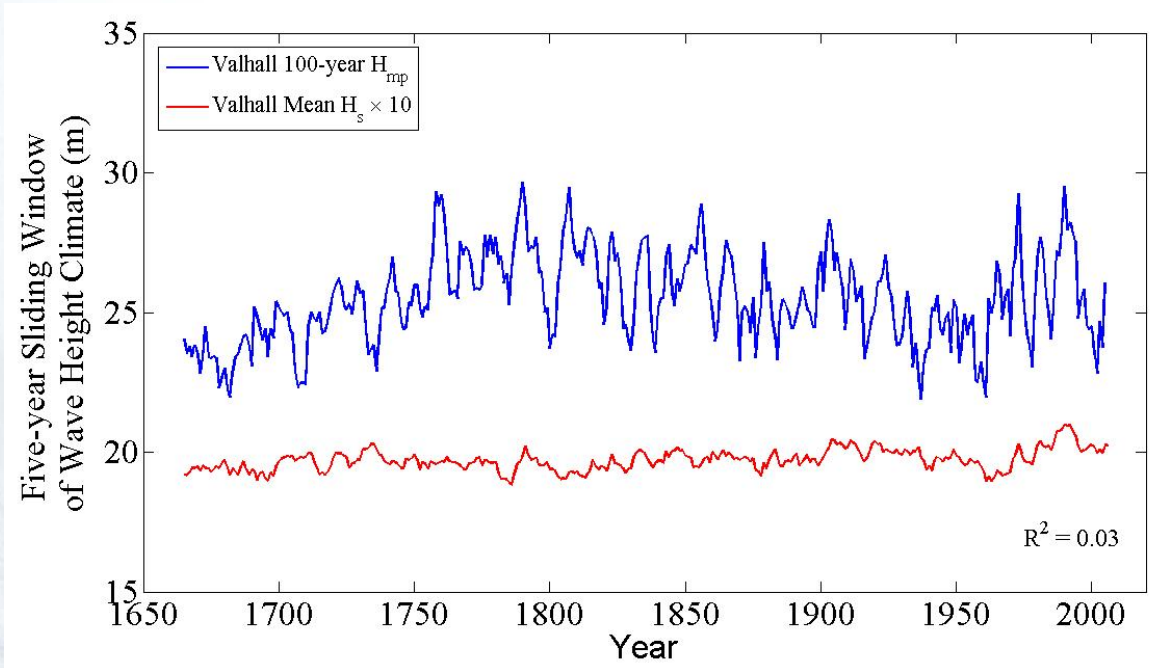
# Reconstruction of extreme and mean wave climate

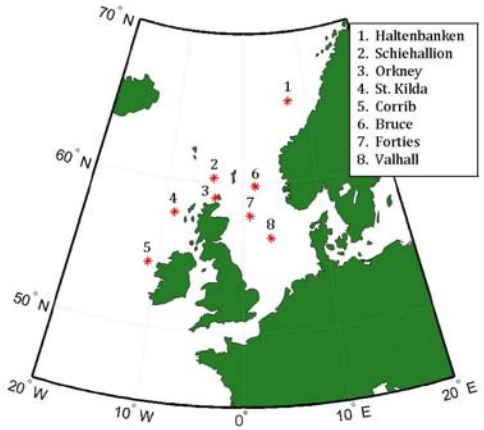



For open North-Atlantic locations: variations of mean and extreme wave climate are comparable.

# Reconstruction of extreme and mean wave climate




For North Sea locations: variations of mean and extreme wave climate are different.

# In conclusion:

- Is there an average wave climate at a particular location?
  **Yes, but the average has to be over several decades as there is a lot of decadal variability (in general).**

- Are the waves over the last 25 – 50 years a reliable guide to the next 25 or 100 years?
  **Maybe? Depending on what the NAO is doing.**

- The available wave records are too short, is there a way to infer a longer time history for wave climate back to the past (over 400 years)?
  **Yes, by establishing a strong link with the NAO.**

# Acknowledgement

We thank BP Sunbury for providing the wave data and acknowledge support from UK EPSRC through project SMARTY.

For more information:


- Santo, H., Taylor, P. H., Woollings, T., & Poulson, S. (2015). Decadal wave power variability in the North-East Atlantic and North Sea. *Geophysical Research Letters*, *42*(12), 4956-4963.

- Santo, H., Taylor, P. H., Woollings, T., & Gibson, R. (2015). Decadal variability of extreme wave height as a measure of storm severity in the North-East Atlantic and North Sea. *Geophysical Research Letters (submitted)*.

- Santo, H., Taylor, P. H., Eatock Taylor, R. and Stansby, P. (2015). Decadal Variability of Wave Power Production in the North-East Atlantic and North Sea for the M4 Machine. *Renewable Energy (submitted)*.