covXtreme: open-source software for modelling extreme data sets

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Motivation

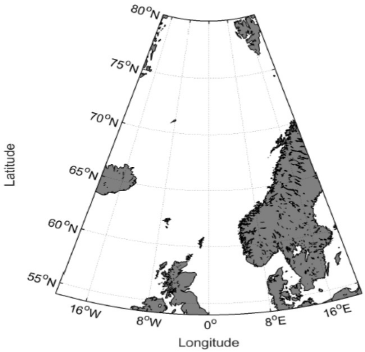
- In risk analysis, the **modelling of the extremes of natural phenomena** such as rainfall, temperature, winds and waves is needed
- Particularly interested in the largest events that we **might have seen or could possibly see**
- Statistical methods can be used to model these largest events and provide the basis for design criteria
- Want to be able to also **incorporate information about important covariates** e.g., direction or season that influence these natural phenomena
- Focus on oceanographic applications but covXtreme can be used more generally for **non-stationary multivariate extreme value analysis**

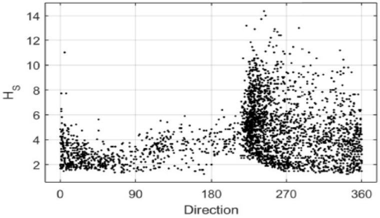
Motivation

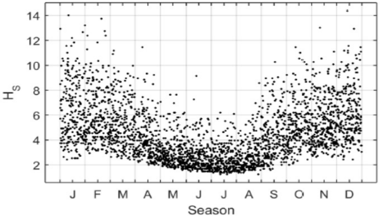
- Offshore operations **require the probability of failure** of manned structures and ships to be at the level of p=1e-4 per annum, corresponding to the so called **1 in 10 000 year criterion**
- This requires the understanding of the **extreme natural environment**:
  - Extreme behaviour of waves, winds and currents individually
  - Joint behaviour of waves, winds and currents
  - Impact of covariates such as direction and the time of year
- Want to be able to **propagate and quantify uncertainty** related to modelling extremes of oceanographic data

Motivation

Oceanographic data







Motivation

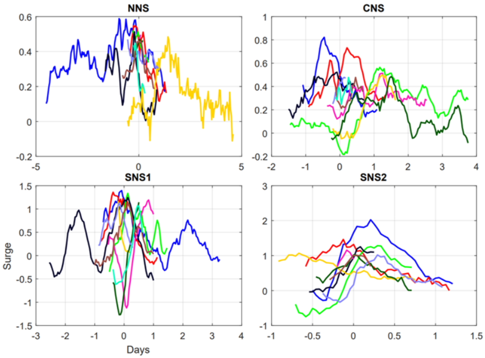
- Statistical tool should handle the following features:
  - Accurate estimation of the **tails of a data set**
  - Capture **covariate effects** such as direction and season
  - Account for the interaction between **multiple variables**
  - Careful handling of **uncertainty**

- As a result, we have developed covXtreme, a open source MATLAB software for the estimation of extreme conditions

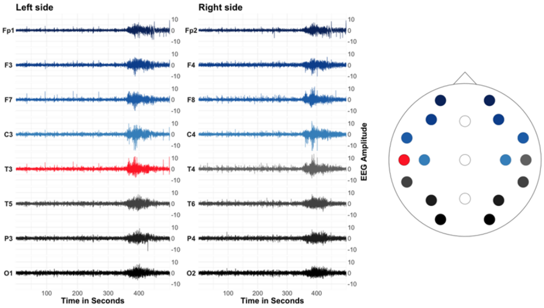
covXtreme

- covXtreme steps the user through a series of stages that result in the completion of a **full hazard risk analysis**
- MATLAB code is written in a **flexible modular way**
- Accompanied by an **user guide** that steps through two case studies
- A range of user settings can be specified - default settings are also provided
- Previous use of the code include Ross et al. [2018], Ross et al. [2020], Guerrero et al. [2021] and Barlow et al. [2023], example applications include surges, waves and neurology

Previous applications of covXtreme



Surge trajectories [Ross et al., 2018]



Brain signals [Guerrero et al., 2021]

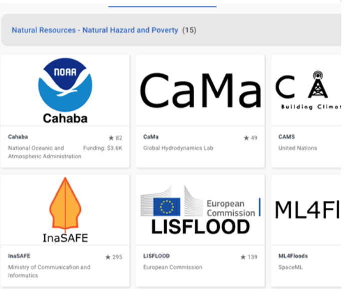
covXtreme

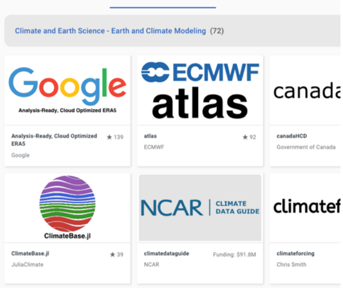
- **Stage 1:** selection of extreme events from an environmental data set or simulation of a data set: selection of independent events
- **Stage 2:** selection of covariate bins, for example wave height as a function of direction: capture covariates for upcoming marginal modelling
- **Stage 3:** estimation of marginal models with respect to covariates: non-stationary modelling as a function of covariate bin
- **Stage 4:** joint estimation of oceanographic variables, for example the behaviour of wind speed when wave height is large: account for interaction between multiple variables
- **Stage 5:** estimation of environmental contours for risk assessment: interpretable summary for design engineers

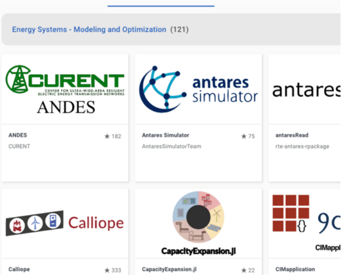
How covXtreme has been useful in Shell?

- Development of code bases such as covXtreme maintains **Shell's reputation as a leader in the sector**
- Application of covXtreme has yielded **cost savings and improved safety offshore**
- covXtreme is used for testing and scoping of improvements to Shell's proprietary risk analysis software
- **Established track record** of covXtreme through extensive testing using relevant case studies
- Ability to do an **efficient system analysis of offshore risk**
- Use in **upskilling and training** of new staff and working with academic and industry partners

How does covXtreme fit in LF Energy’s landscape?







How could this code be useful more generally?

- **Educational** tool for the offshore sector: users can be data scientists, statisticians and practitioners
- covXtreme **motivates and explains** how natural hazard analysis problems are solved
- **First openly available tool** that brings together important elements of an risk analysis:
  - modelling a single variable
  - modelling multiple variables
  - incorporating the effect of covariates
  - system based response estimates
- covXtreme has the **key functionality to solve a typical risk analysis problem in a pragmatic manner**

Public enagagement and future development

- covXtreme is **openly available through GitHub**: `https://github.com/sede-open/covXtreme`
- Journal article detailing methodology behind covXtreme is under review
- Presentations at statistics conferences e.g., RSS Conference (2023)
- Being **actively used by existing collaborators**
- External partners can build additional functionality into the code
- Opportunity to publicise with existing community and potentially interested communities, for example the flood risk sector

Potential future applications of covXtreme

- Pluvial and fluvial flooding
- Coastal risk of flooding
- Accounting for regime shifts in data sets e.g., financial or temperature data
- Operational maintenance of platforms, ships and wind turbines

BBC

Summary

- covXtreme enables **quick analysis of extreme data sets**
- **Computationally efficient and pragmatic** software for hazard risk analysis
- Non stationary **marginal and dependence modelling** with comprehensive uncertainty quantification
- **Improved quantification and communication** of risks associated with extreme events

References

A M Barlow, E Mackay, E Eastoe, and P Jonathan. A penalised piecewise-linear model for non-stationary extreme value analysis of peaks over threshold. *Ocean Eng.*, 2023.

Matheus B. Guerrero, Raphaël Huser, and Hernando Ombao. Conex-connect: Learning patterns in extremal brain connectivity from multi-channel eeg data, 2021. URL `https://arxiv.org/abs/2101.09352`.

J. E. Heffernan and J. A. Tawn. A conditional approach for multivariate extreme values. *J. R. Statist. Soc. B*, 66:497–546, 2004.

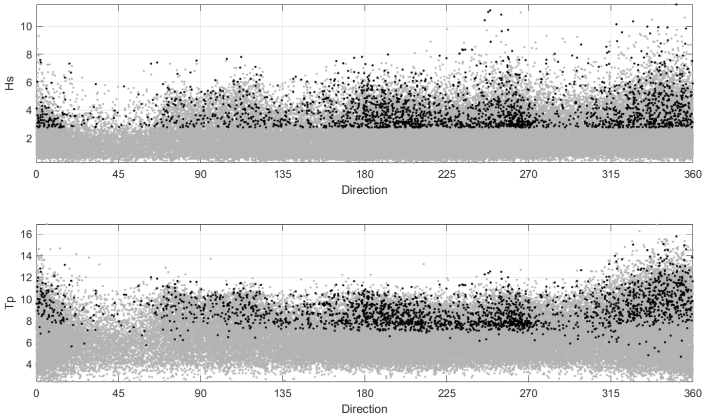
E Ross, S Sam, D Randell, G Feld, and P Jonathan. Estimating surge in extreme North Sea storms. *Ocean Eng.*, 154:430–444, 2018.

E. Ross, O. C. Astrup, E. Bitner-Gregersen, N. Bunn, G. Feld, B. Gouldby, A. Huseby, Y. Liu, D. Randell, E. Vanem, and P. Jonathan. On environmental contours for marine and coastal design. *Ocean Eng.*, 195:106194, 2020.

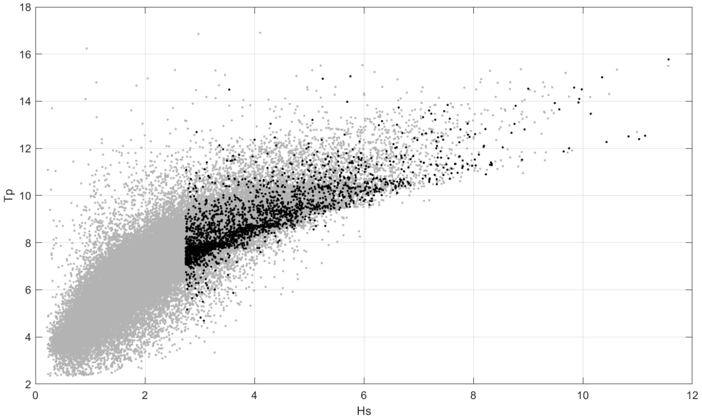
Case Study: Hs and Tp

Example application of covXtreme: modelling the relationship between significant wave height (Hs) and peak period (Tp)

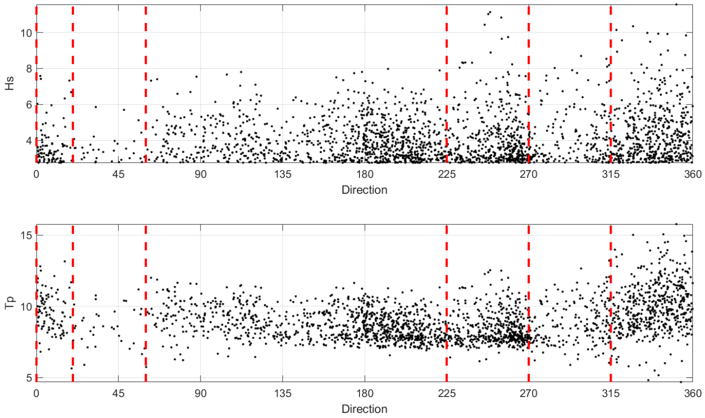
Stage 1: extraction of storm peaks



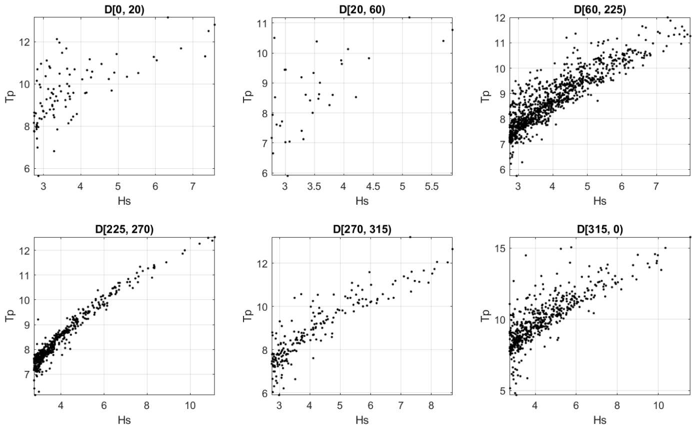
Stage 1: extraction of storm peaks



Stage 2: selection of bins



Stage 2: joint behaviour of Hs and Tp



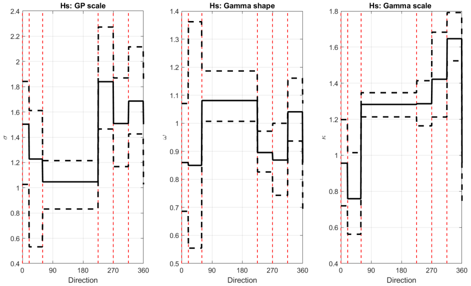
Stage 3: marginal model

- Set a bin dependent threshold ψ_b to define extreme events
- For data below the threshold fit a **Gamma distribution**
- For data above the threshold fit a **generalised Pareto (GP) distribution**:
  - Threshold ψ_b with scale ν_b and shape parameter ξ
- Likelihood above the threshold:

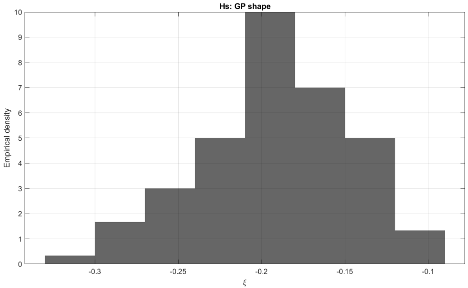
$$\ell(\dot{x}_i \mid \xi, \boldsymbol{\nu}, \boldsymbol{\psi}, \lambda) = \log \prod_{b=1}^{B} \prod_{\substack{i; A(i)=b; \\ \dot{x}_i > \psi_b}} f_{GP}(\dot{x}_i \mid \xi, \nu_b, \psi_b) + \lambda \left(\frac{1}{B} \sum_{b=1}^{B} \nu_b^2 - \left[\frac{1}{B} \sum_{b=1}^{B} \nu_b \right]^2 \right)$$

Stage 3: marginal model (Hs)

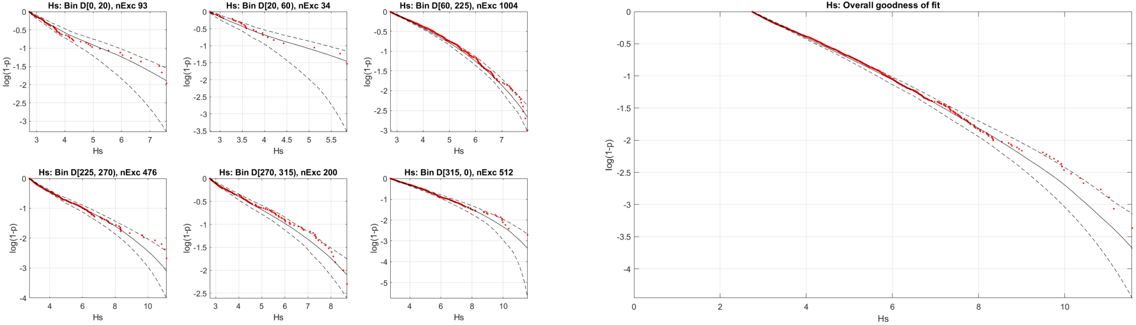
GP scale and Gamma parameters



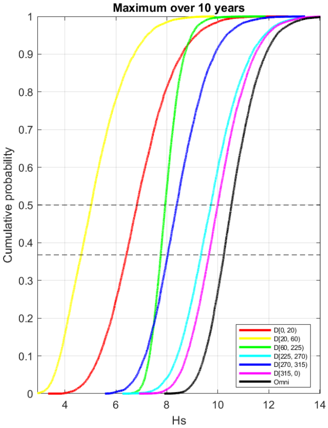
GP shape parameter

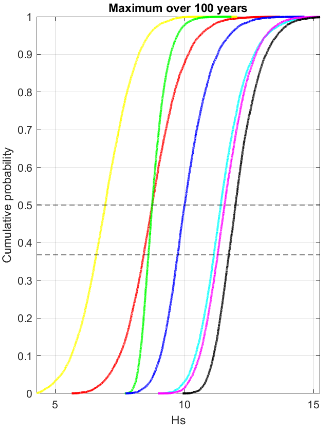


Stage 3: marginal model assessment (Hs)



Stage 3: marginal return values (Hs)



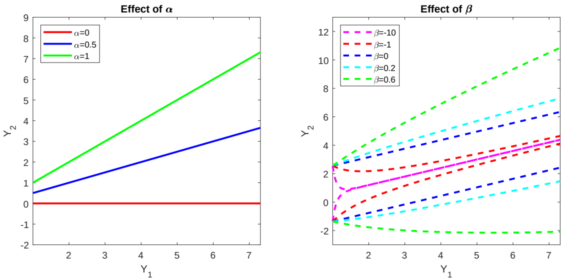


Stage 4: dependence model

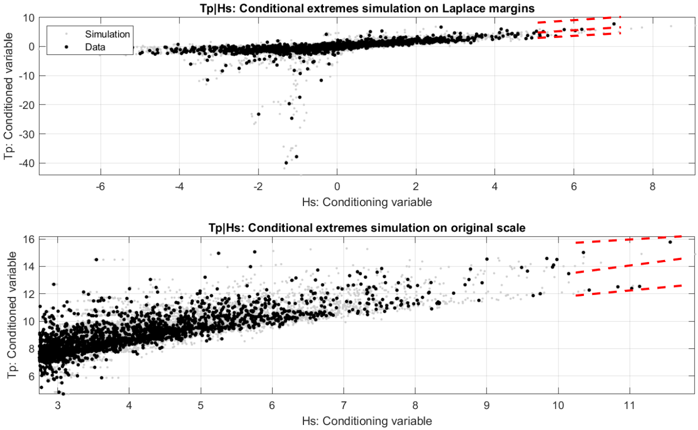
Conditional dependence model of Heffernan and Tawn [2004]:

$$(Y_2|Y_1 = y) = \alpha_b y + y^{\beta_b} W_b$$

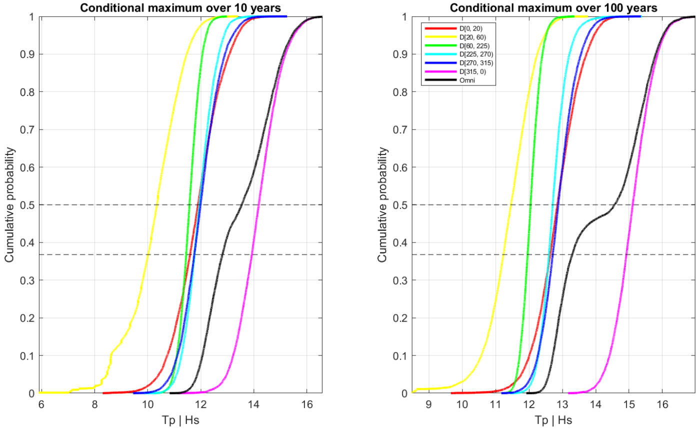
- $Y_2 = \text{Tp}$, $Y_1 = \text{Hs}$ *on Laplace scale*
- for $y >$ sufficiently large threshold ϕ
- $\alpha_b \in [-1, 1]$, $\beta_b \in (-\infty, 1]$
- $W_b \sim \text{DeltaLaplace}(\mu_b, \sigma_b, \delta)$



Stage 4 - simulations from the dependence model



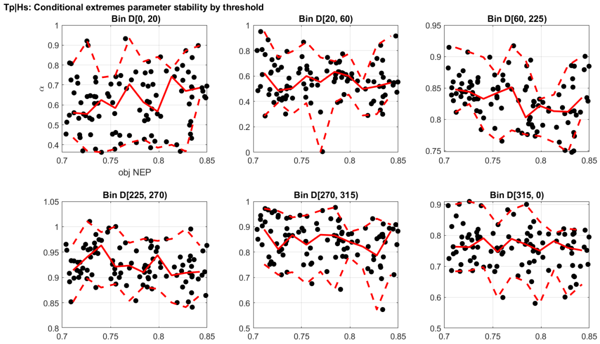
Stages 3 and 4: conditional return values (Tp|Hs)



Stages 3 and 4: dealing with uncertainty

Two sources of uncertainty:

- Bootstrap resampling
- Non exceedance probability threshold:
  $\phi \sim \text{Uniform}(\phi_{LB}, \phi_{UB})$



Dependence model threshold assessment

Stage 5: contour estimation

- Estimation of risk profiles
- Three different contour methods:
  - Exceedance (Exc)
  - Heffernan and Tawn (HTDns)
  - Huseby (Hus)
- Number of control factors