Adaption of multivariate extreme value modelling for extreme coastal events

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Overview

- Introduction
  - Coastal flooding
  - Motivation
  - Icelandic Road and Coastal Administration (IRCA)
  - England’s SoN Flood Risk Analysis
- Methodology and results
  - Study site
  - Data
  - Simulation of data
  - Wave overtopping discharge for coastal structures

Introduction – Coastal flooding

- Ocean wave travels inland
- Can be quite destructive
- Combination of:
  - Sea level
    - Astronomical factor
    - Swell
      - Wind
      - Wave
      - Barometric pressure
  - Wave height
    - Wave period
    - Wind speed
    - Barometric pressure
  - Wave direction

Introduction – IRCA Coastal Dept.

- Coastal defense/harbor design and construction
- Wind forecast (ECMWF)
- Wave forecast (ECMWF)
  - Offshore
  - Nearshore
- Wave measurements
- Flood risk analysis
- Evaluation of coastal flooding events
  - 24.dec 2003

Introduction – IRCA Coastal Dept.

- Occurred the morning of 24th of Dec. 2003

- Not a rare event for each variable

Variable	Measured	Return period
Significant wave height	9 m	< 1 year
Mean wave period	10,4 s	< 1 year
Maxium Sea level	+4,6 m	twice a year
Wind speed	20 m/s	>2% of the year
Atmospheric pressure	980 Mpa	>2% of the year

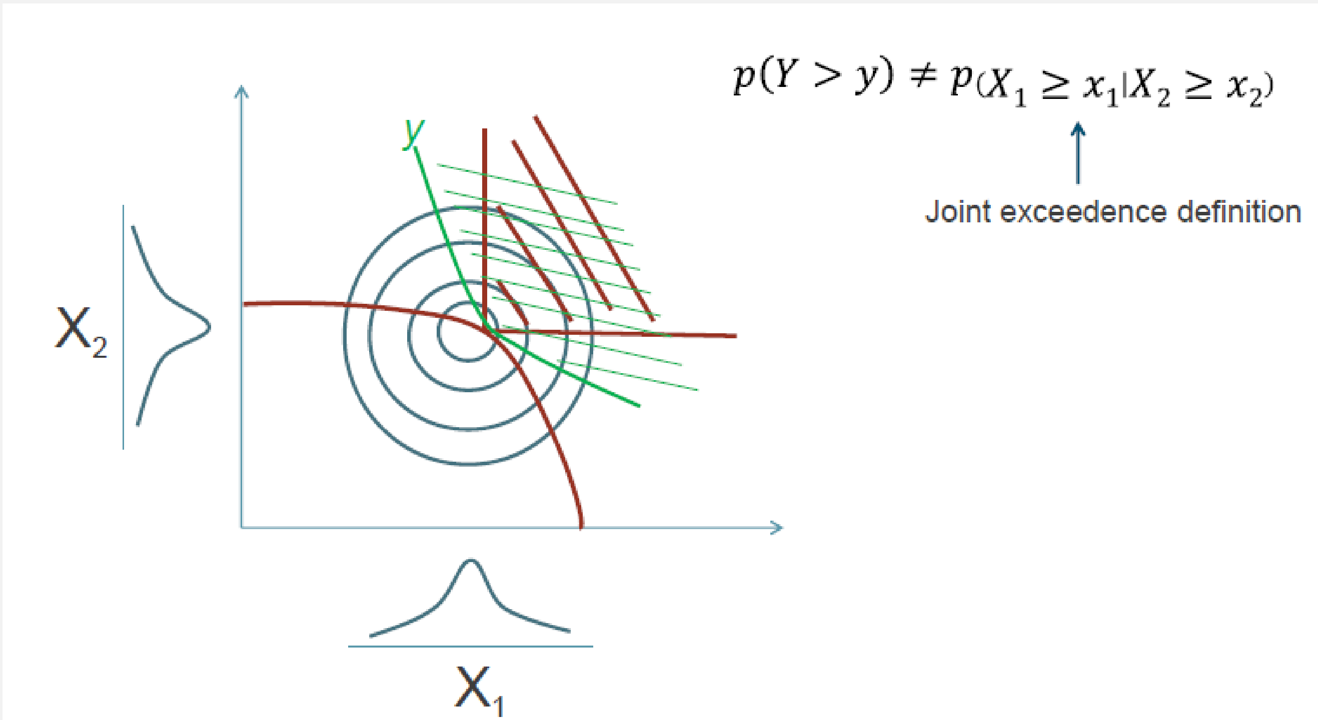
- Estimated return period based on historical data:

  Around 50-100 years

Introduction – Motivation

- Constant threat of coastal flooding
  - Increases with rising sea level
- More reliable way to evaluate return period of events

Introduction – Motivation



Introduction – SoN Flood Risk Analysis

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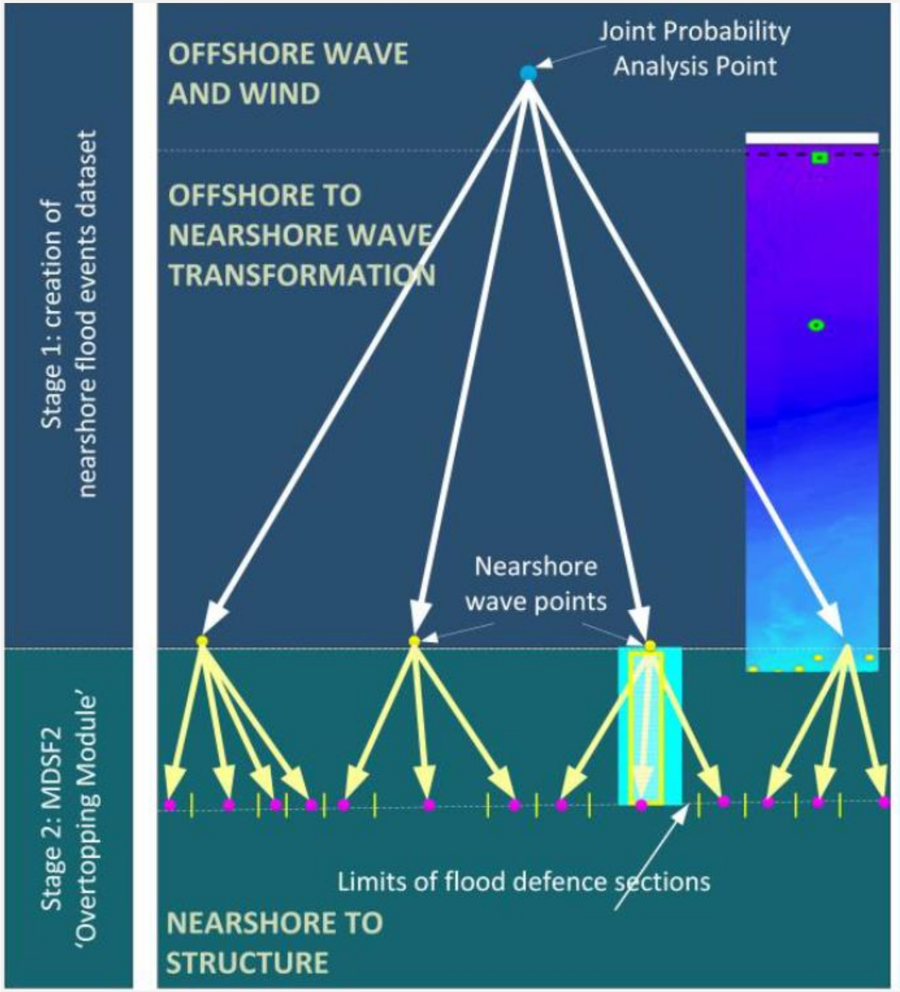
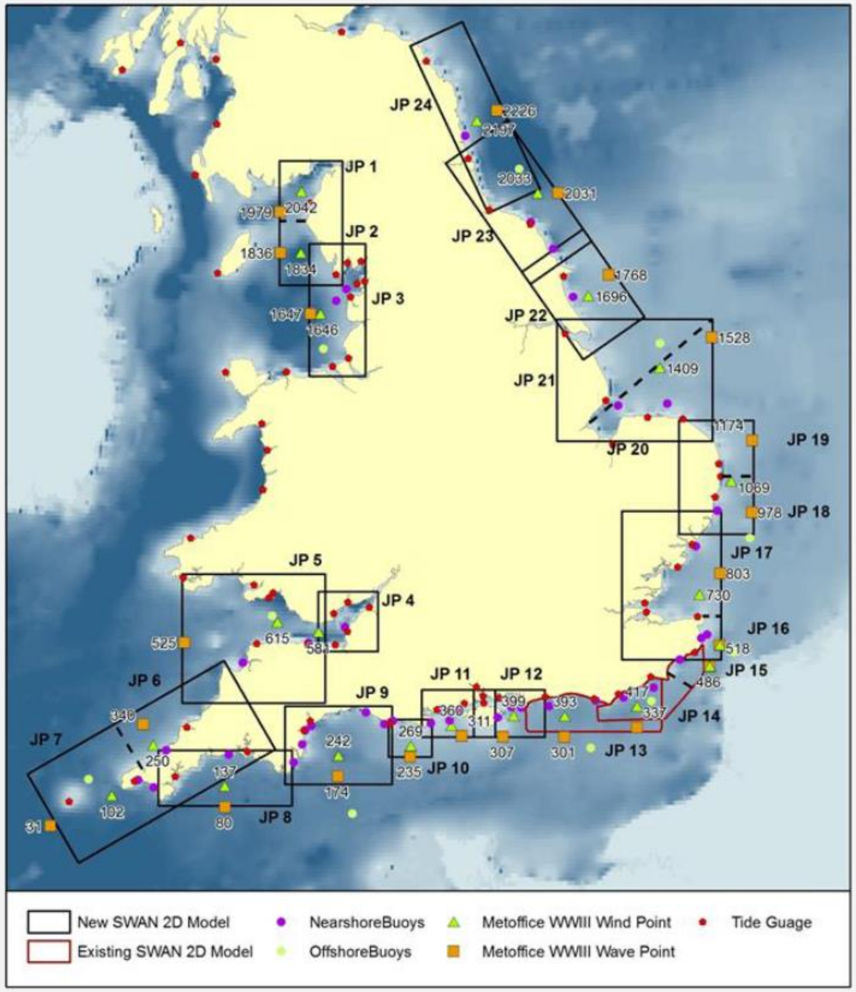
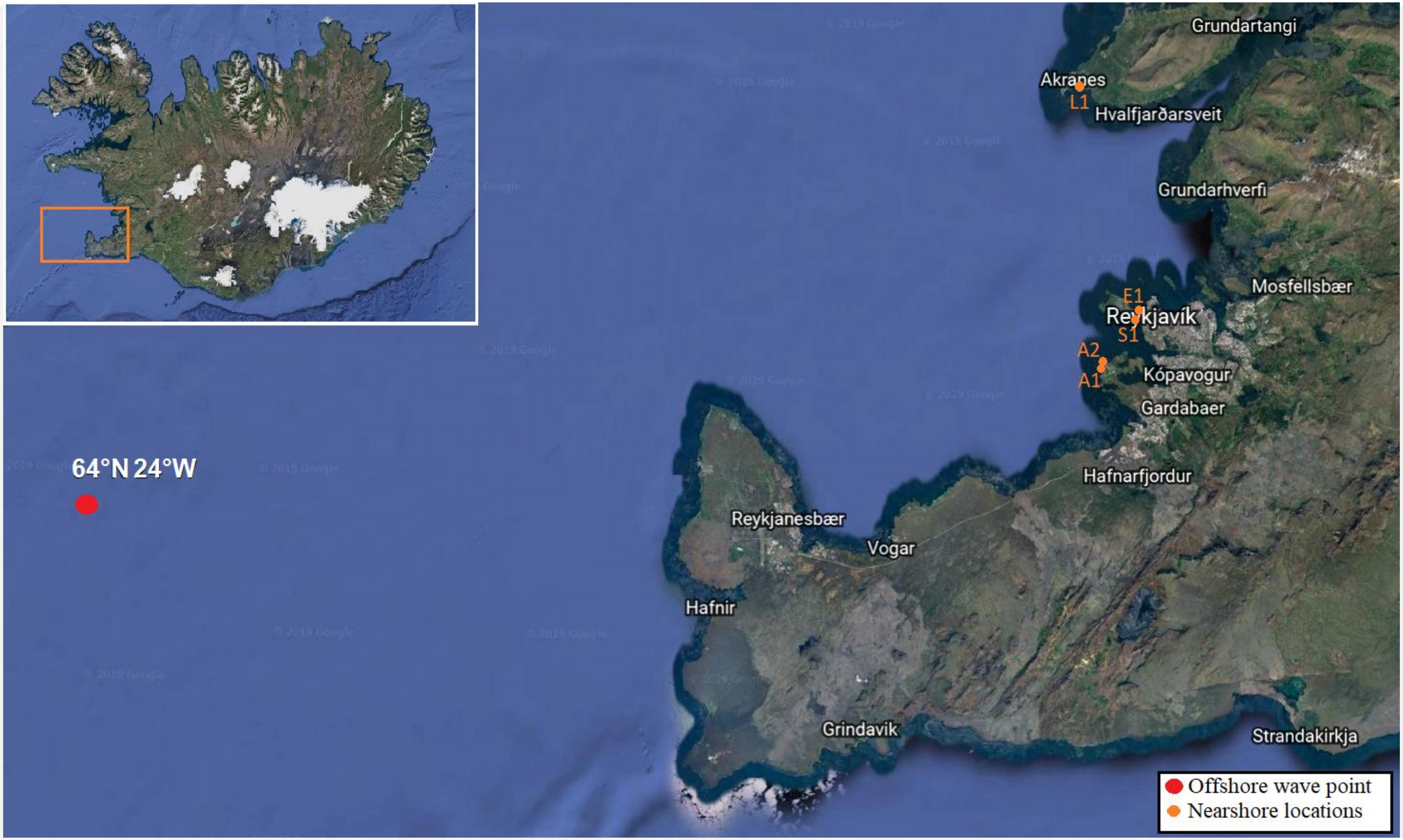
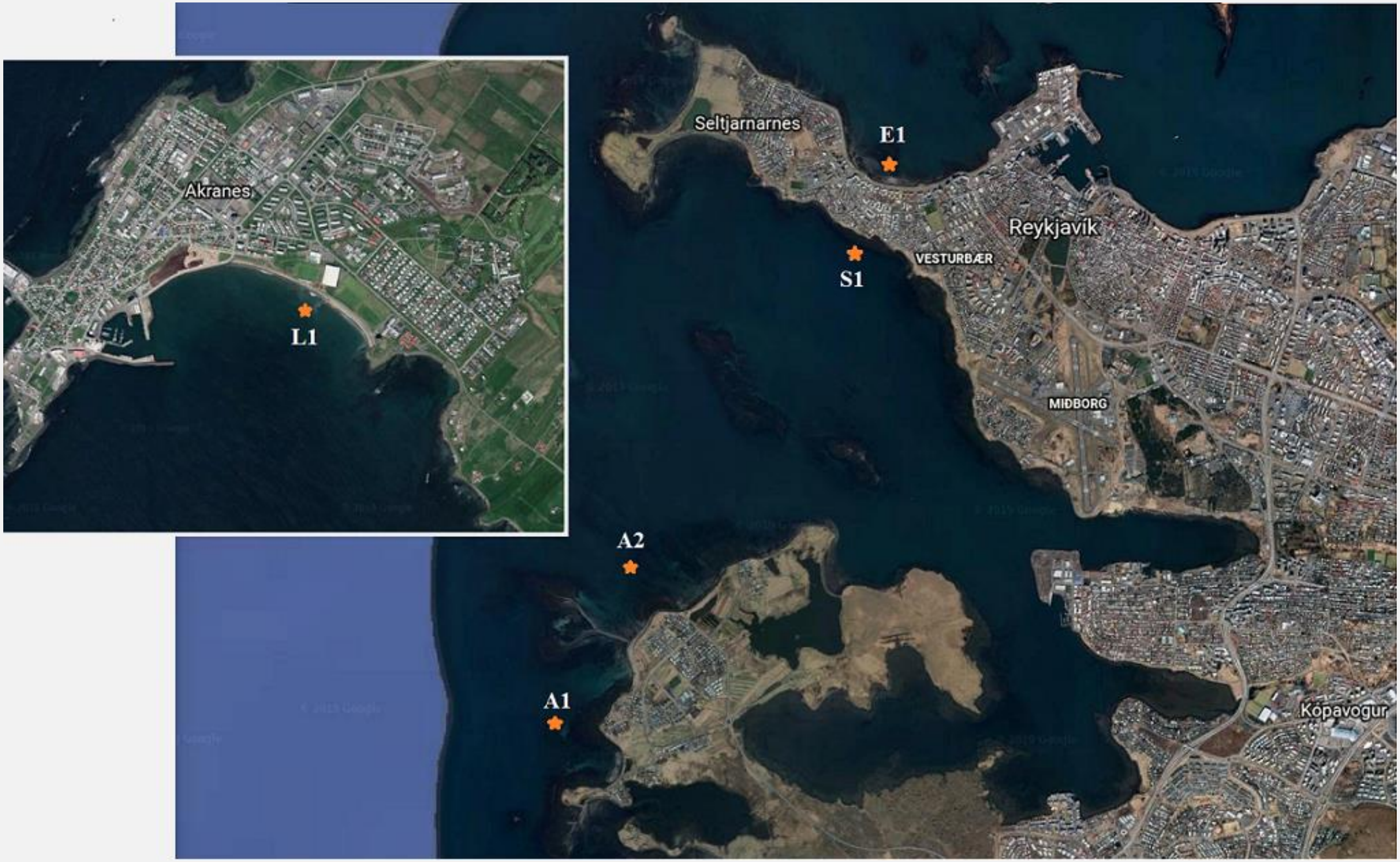




Methodology – Study site



Methodology – Data



Methodology – Data

- 35-year timeseries at an offshore location (1980-2015)
  - Wave hindcast from ECMWF*
    - Wave height, H_s
    - Wave period, T_m
    - Wave direction, θ_{Hs}
  - Wind hindcast from ECMWF*
    - Wind speed, U
    - Wind direction θ_U
  - Sea level measurements from M&T ehf.
    - Astronomical component, A
    - Surge, S

At offshore point 64°N24°V

From the Old harbour in Reykjavík

*European Centre for Medium-range Weather Forecasts

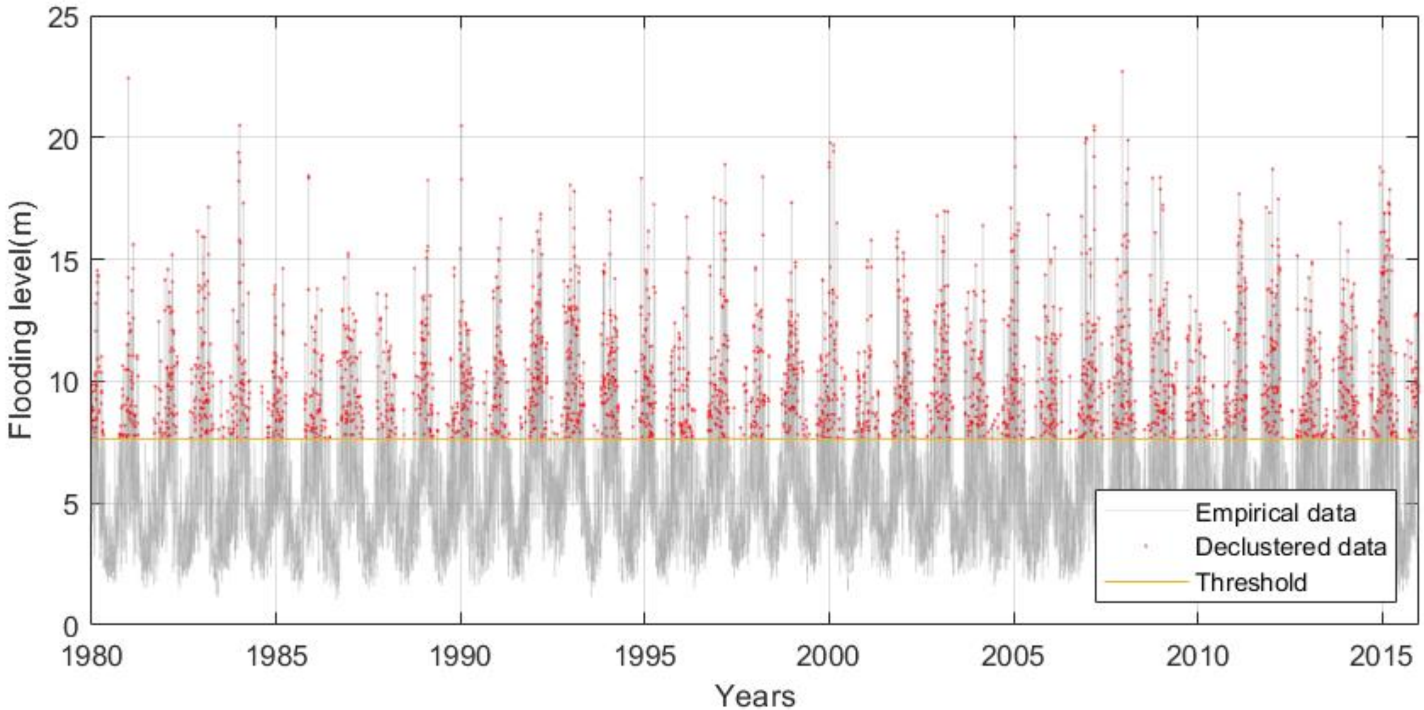
Methodology

1. Simulation of large offshore wind and wave dataset
    1. De-cluster data
    2. Fit a General Pareto Distribution to de-clustered variables, H_s, U and S
    3. Simulate a large sample of offshore sea condition data
        - Multivariate non-linear regression model for H_s, U and S
        - Empirical distribution based on H_s, U and S
2. Transform large sample of offshore data to nearshore wave points
    1. Apply MDA to the large dataset to define a subset of *m* offshore design points
    2. Run a wave transformation model (MIKE 21 SW) for the *m* design points
    3. Construct a meta-model and use to transport the large sample of offshore events to nearshore wave points
3. Overtopping of structures evaluated.

De-cluster

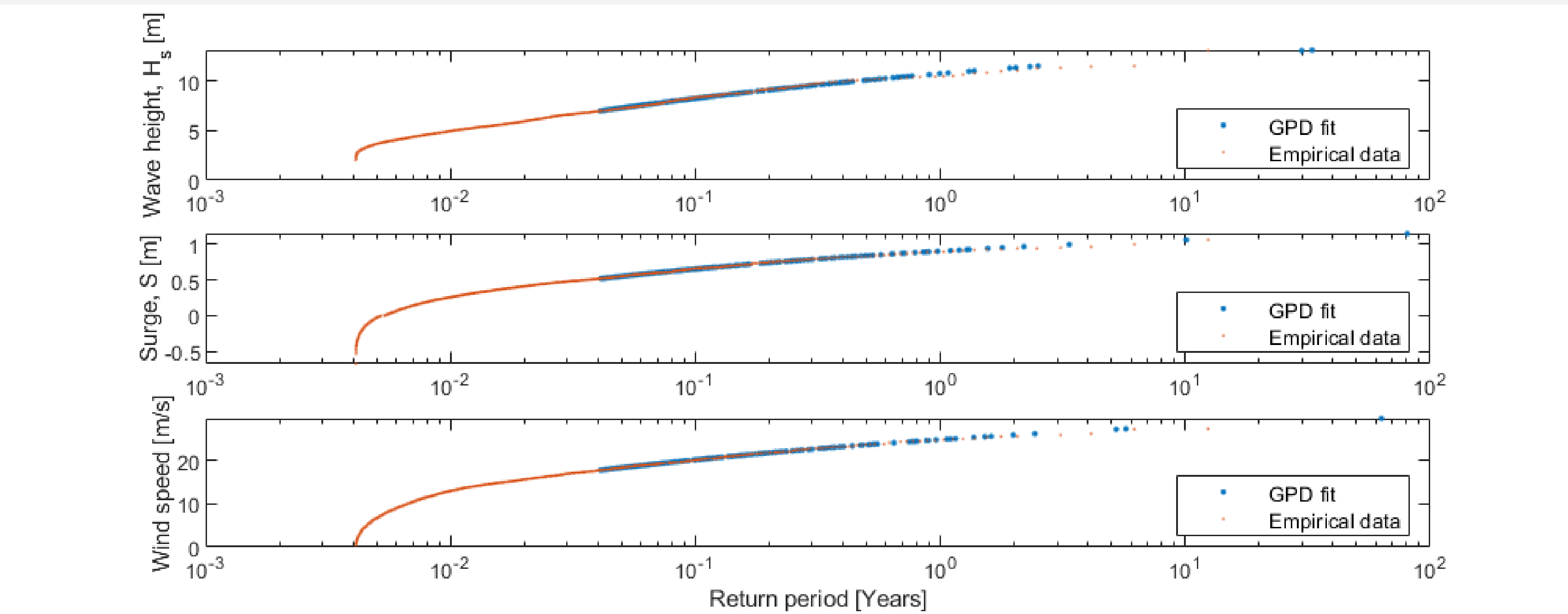
- 2% run-up estimated
- Peak over threshold values found with 36 hous separation
- De-clustered data consists of 3015 events

$$l = S + 0.043\left(\frac{H_s g\, T_m^2}{2\,\pi}\right)^{1/2}$$



General pareto distribution

- General pareto distribution fitted to de-clustered data
- A threshold of 97.5%

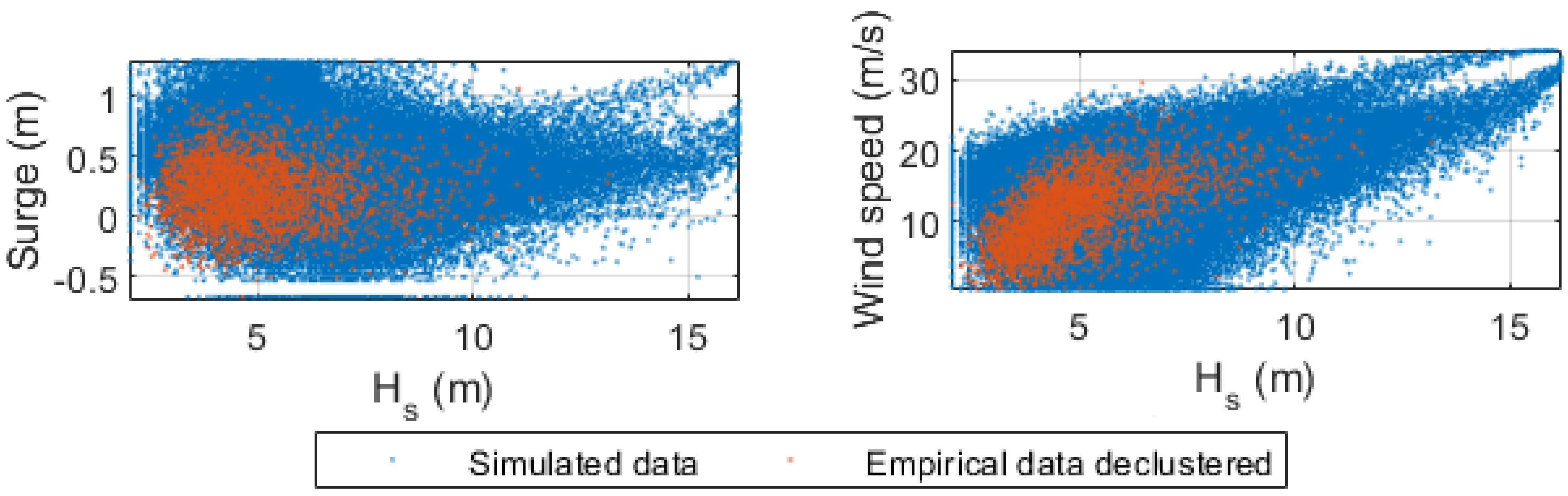


Simulating H_s, U and S

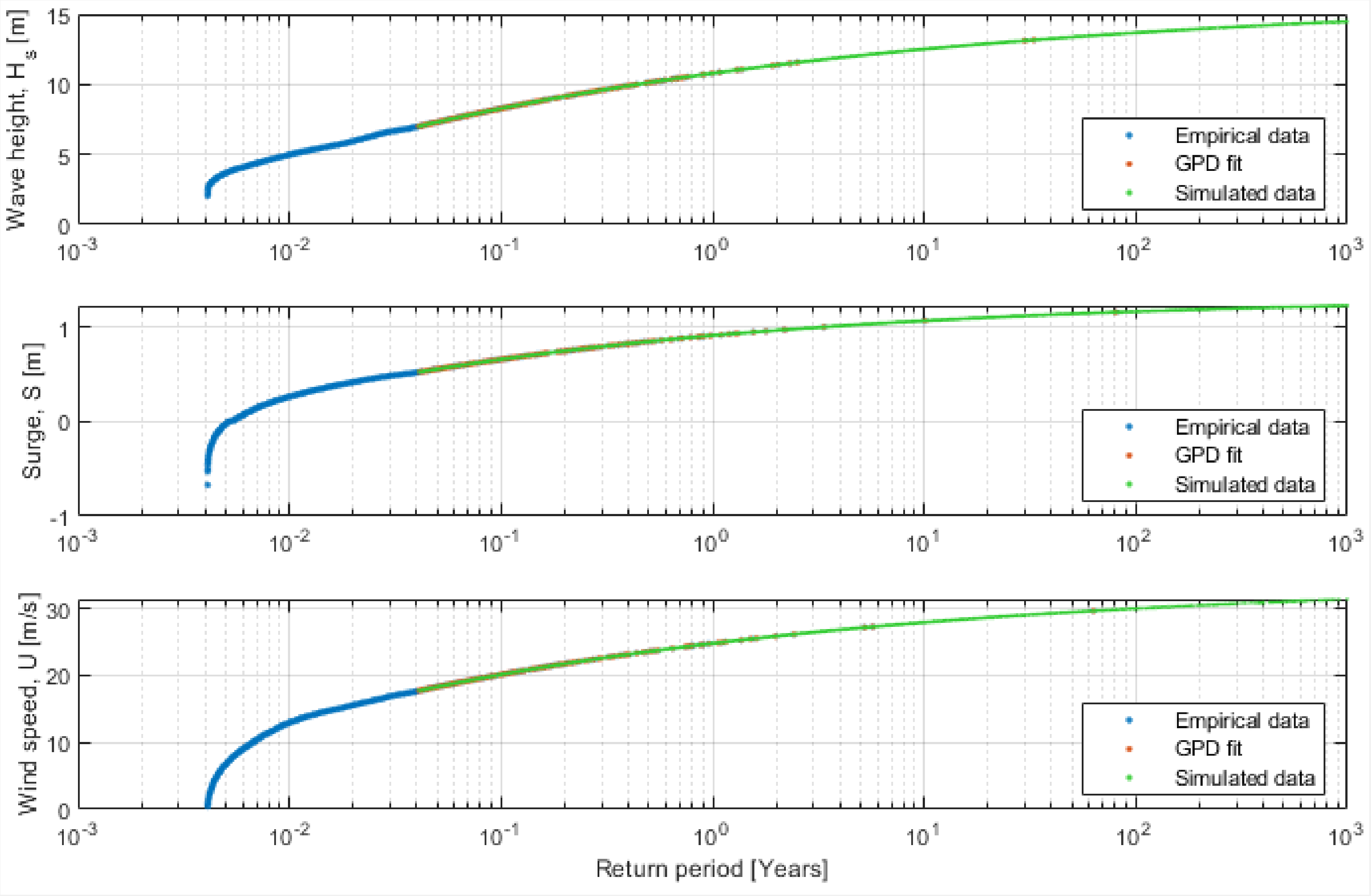
- A multivariate non-linear regression model is fitted to the declustered data of H_s, U and S, i.e. $\boldsymbol{Y}$

$$\boldsymbol{Y}_{-\boldsymbol{i}}|Y_i = \boldsymbol{a}Y_i + Y_i^b\boldsymbol{W} \qquad \text{for } Y_i > v$$

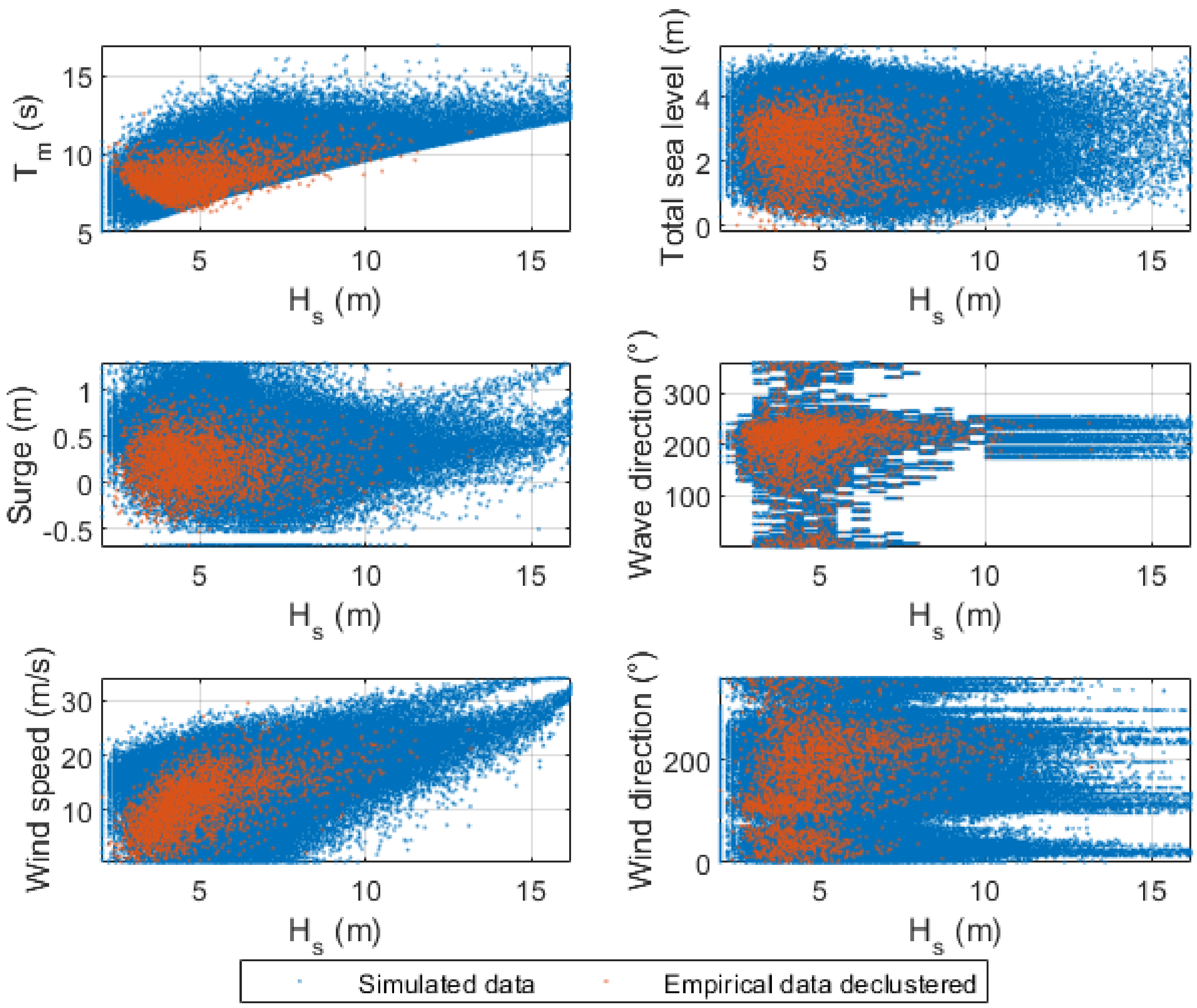
- Monte Carlo procedure based on the regression model was used to generate a large sample of offshore data



Simulating H_s, U and S

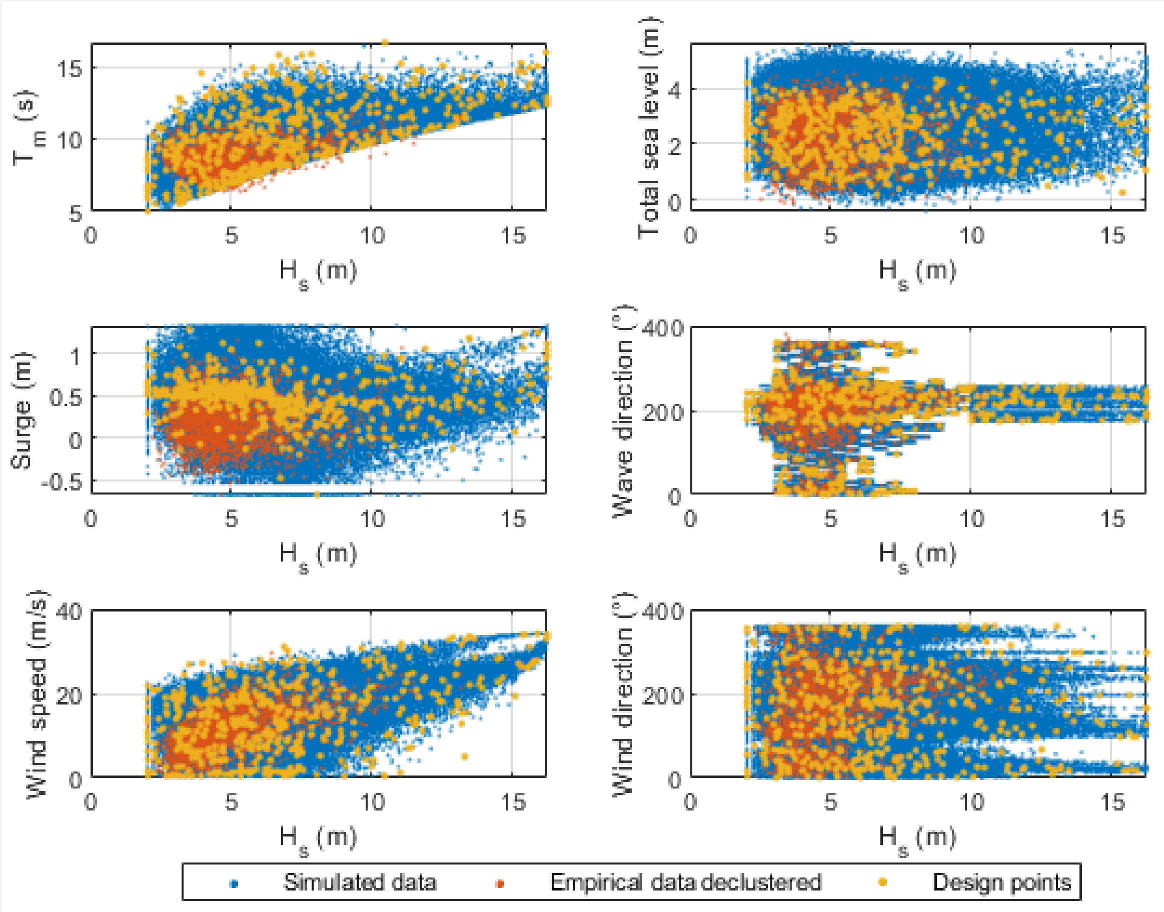


Large sample of extreme offshore events

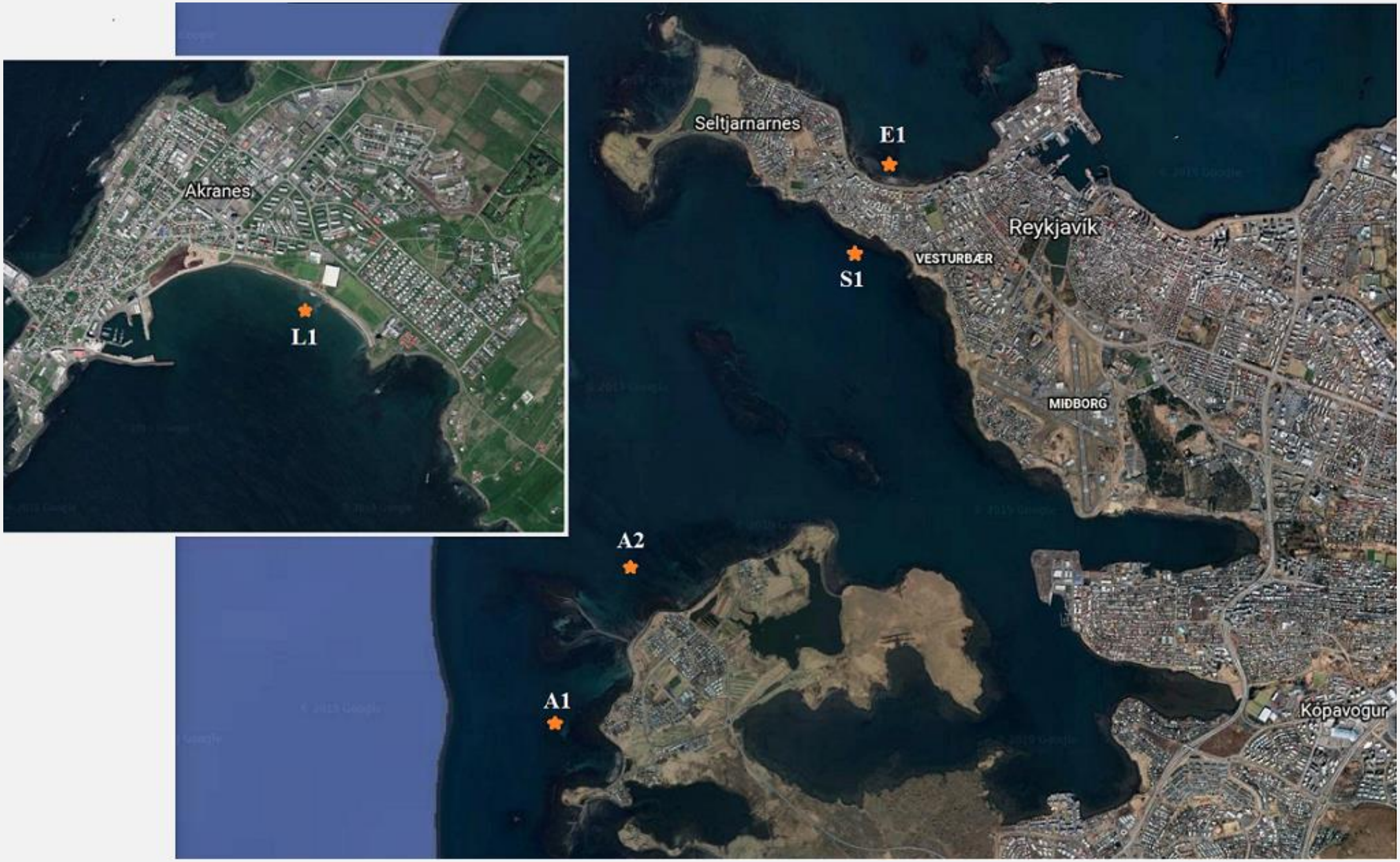


Offshore to nearshore transformation

- Maximum Dissimilarity Algorithm used to select 500 design events
- The 500 events are run through MIKE 21 SW wave transformation model



Offshore to nearshore transformation



Offshore to nearshore transformation

- A Metamodel based on radial basis function was fitted to the 500 offshore and nearshore events

$$\boldsymbol{X}_j^N = p\left(\boldsymbol{X}_j^0\right) + \sum_{i=1}^{m} a_i \Phi\left(\left|\left|\boldsymbol{X}_j^0 - \boldsymbol{D}_i\right|\right|\right)$$

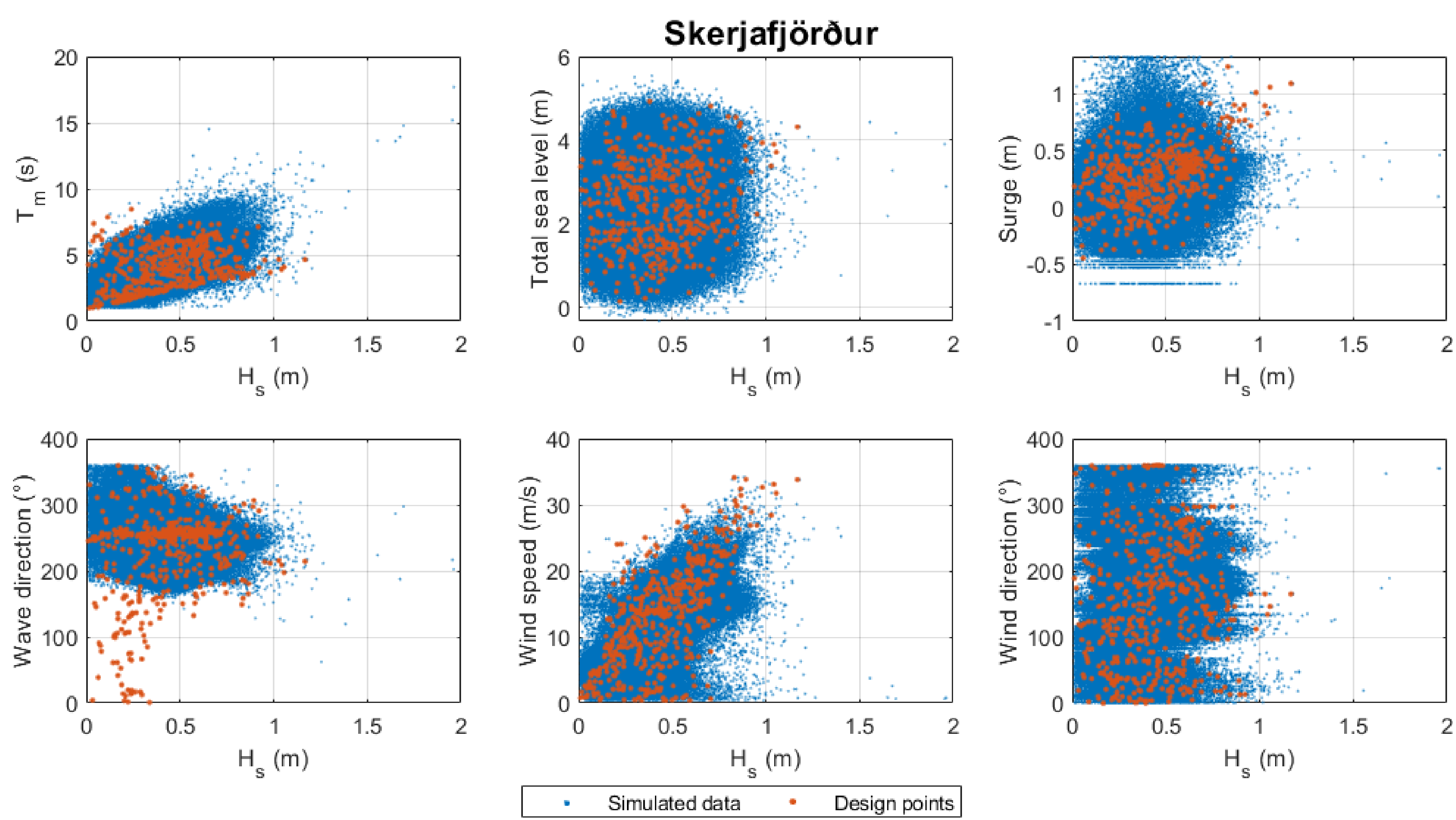
  - Where

$$p\left(\boldsymbol{X}_j^0\right) = b_0 + b_1 X_{1,j}^0 + b_2 X_{2,j}^0 + \cdots + b_k X_{k,j}^0$$

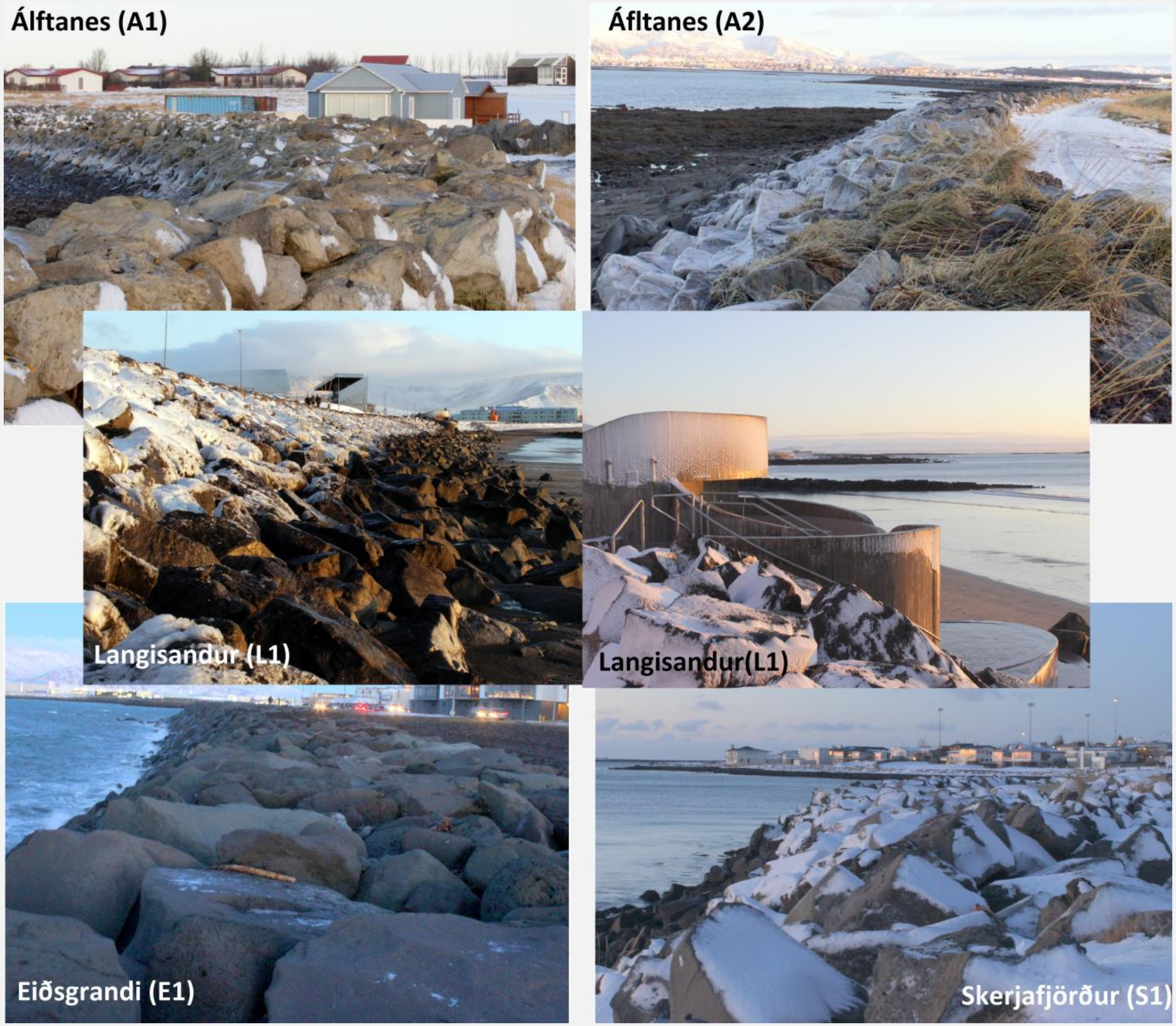
$$\Phi\left(\left|\left|\boldsymbol{X}_j^0 - \boldsymbol{D}_i\right|\right|\right) = \exp\left(-\frac{\left|\left|\boldsymbol{X}_j^0 - \boldsymbol{D}_i\right|\right|}{2c^2}\right)$$

- Model was fitted by selecting *a* and *b* variables that minimise the RMSE

Large sample of nearshore events



Overtopping for coastal structures



Overtopping for coastal structures

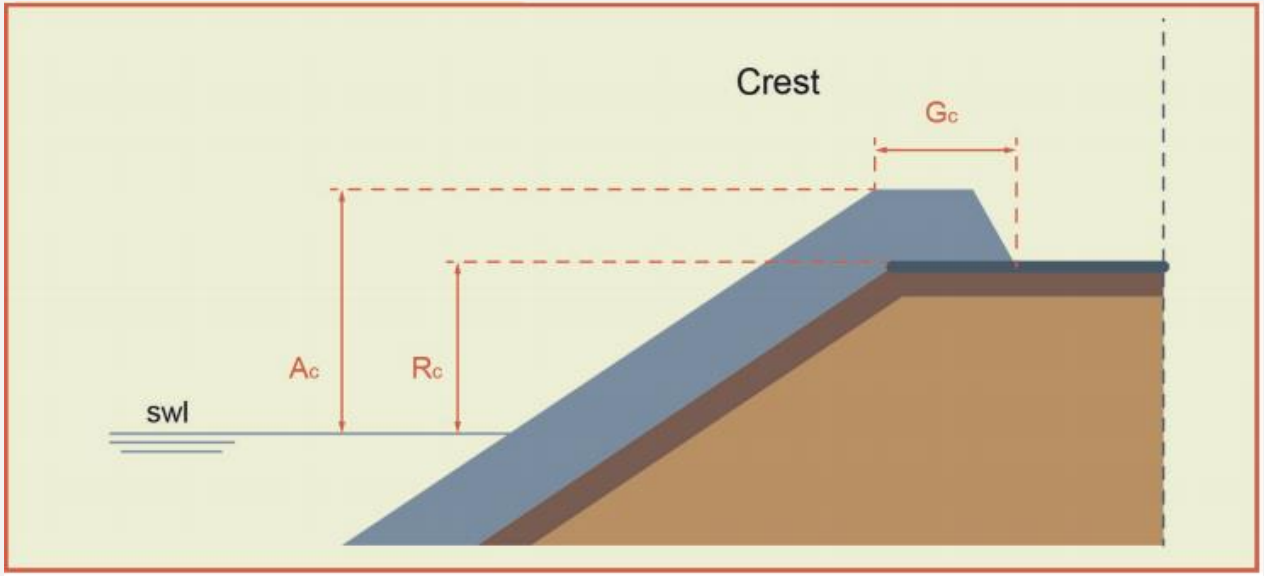
- Overtopping discharge based on EurOtop 2018 manual.

- For simple armored slopes

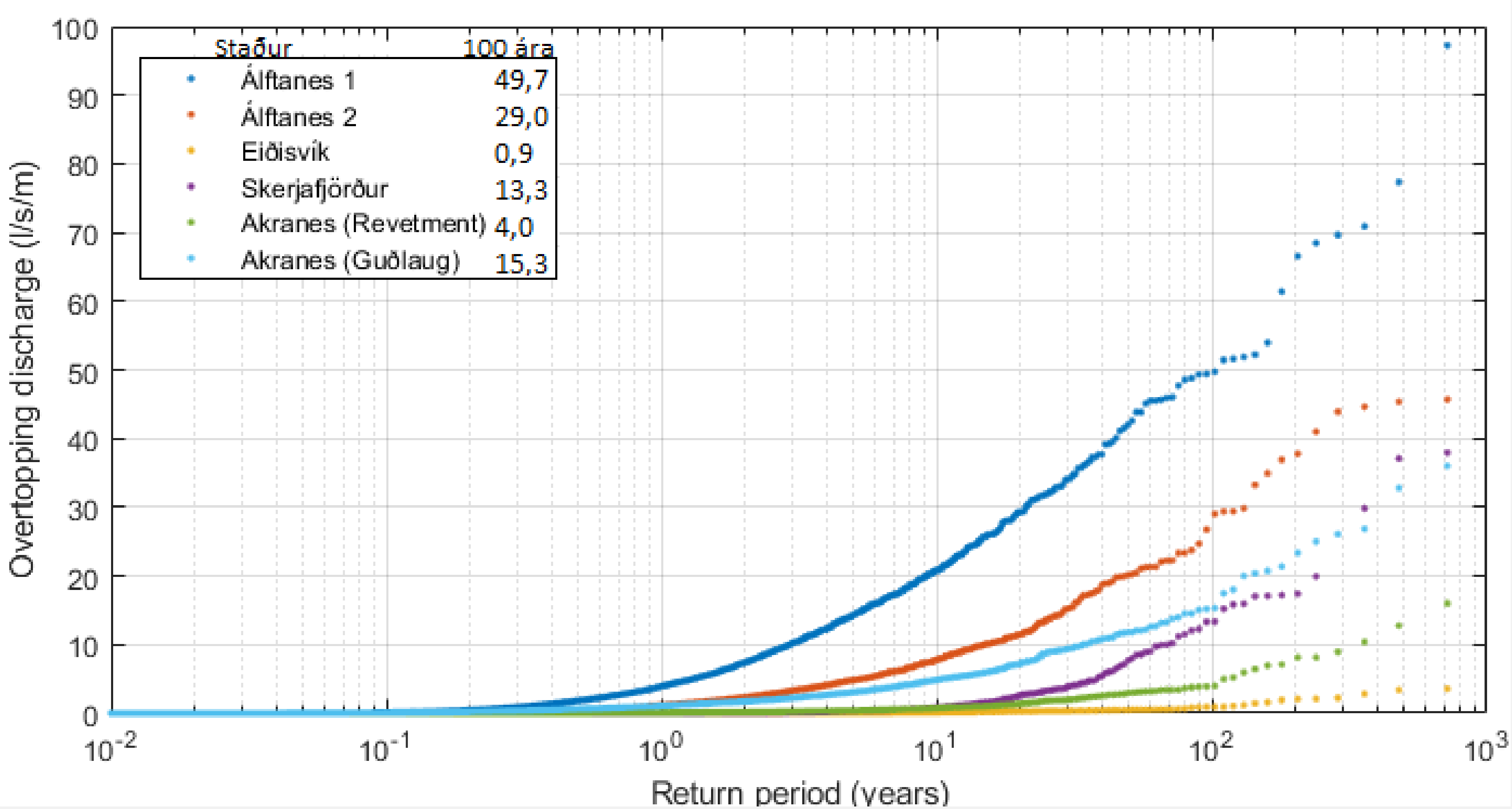
$$q = 0.09 \cdot \exp\left(-\left(1{,}5\frac{R_c}{H_s \cdot \gamma_f \gamma_\beta}\right)^{1{,}3}\right) \cdot \sqrt{g \cdot H_s^3}$$

- For vertical walls

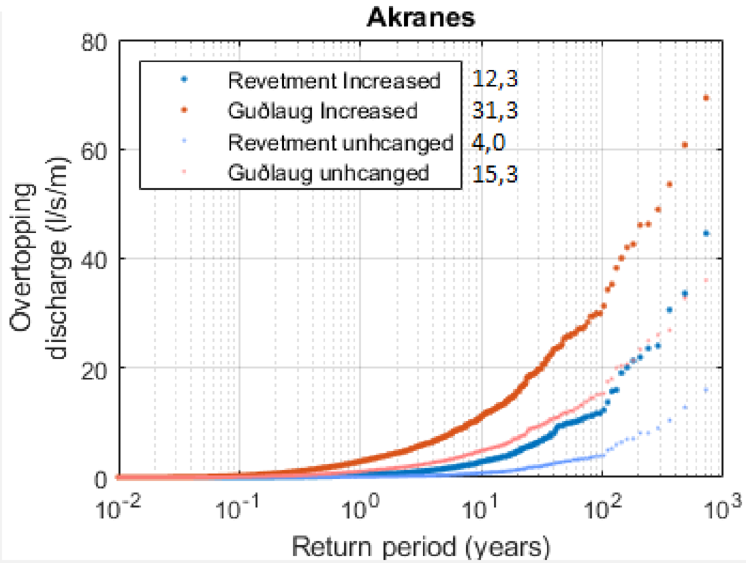
$$q = 0.047 \cdot \exp\left(-\left(2{,}35\frac{R_c}{H_s}\right)^{1{,}3}\right) \cdot \sqrt{g \cdot H_s^3}$$

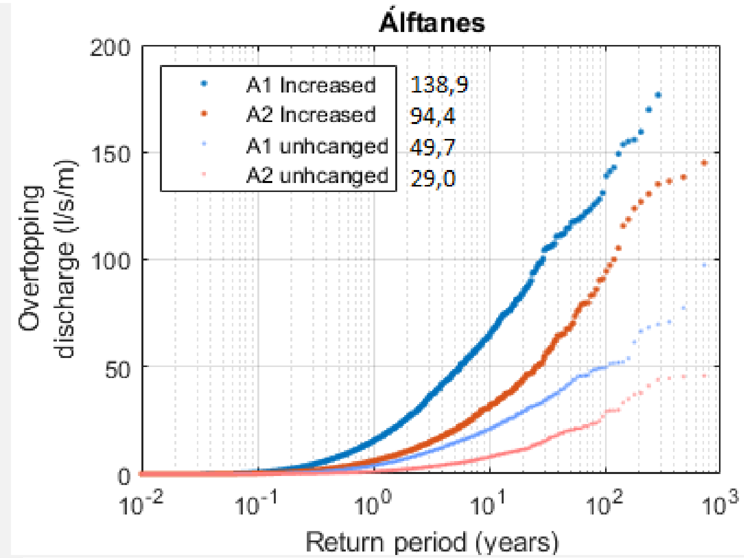


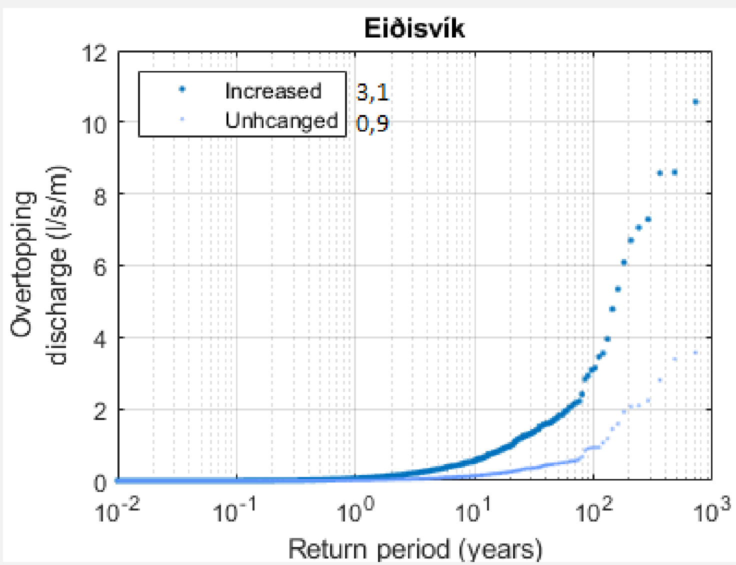
Overtopping of coastal structures

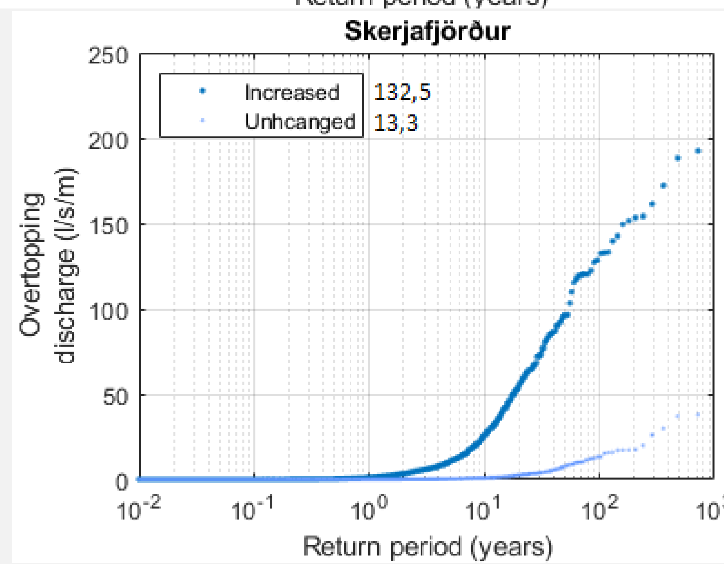


Increased sea level









Next steps

- Improvements needed
  - Meta model
  - Wind and wave surge
  - Bathymetric mapping near the coast
- The large sample of data can be used to determine the return period of events:
  - Básendaflood, 1799
  - Recent storm in December 2019

Thank you

The thesis will be accessible on https://skemman.is/handle/1946/34935 (opens 22.February 2020)