Estimation of environmental contours using a block resampling method

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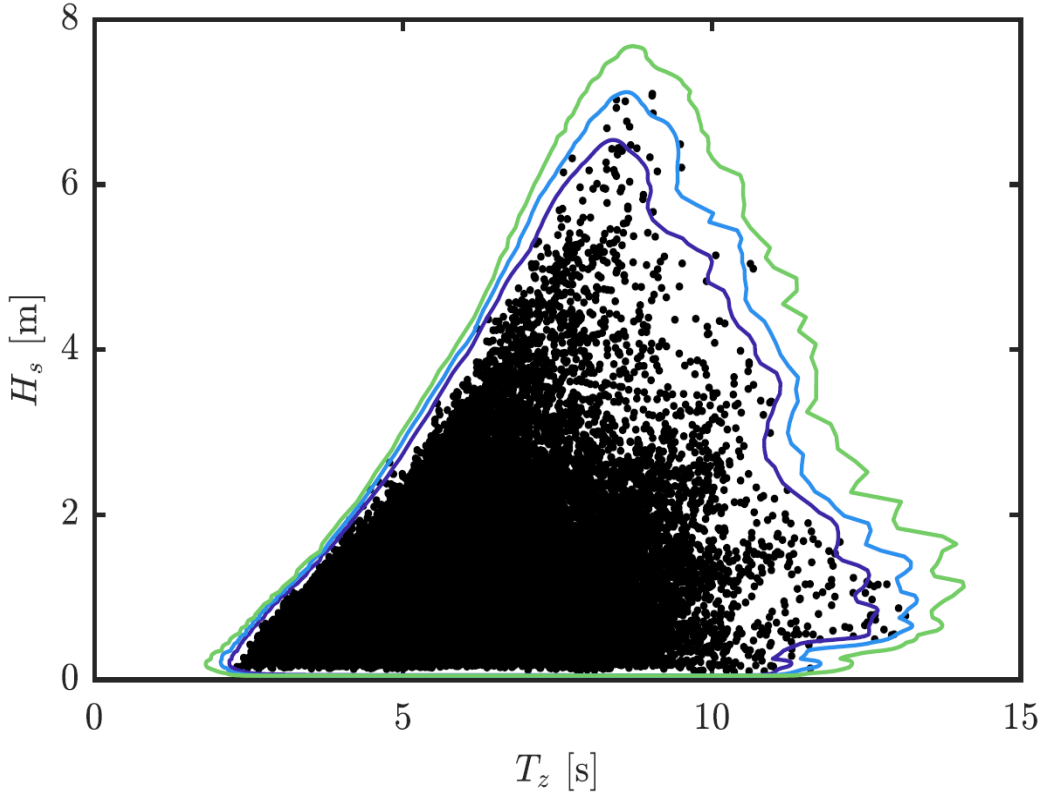

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Overview

- Motivation and assumptions for block resampling method
- Application of method
  - Significant wave height and zero-crossing period
  - Significant wave height and wind speed
- Conclusions

Motivation

- Common approach for deriving environmental contours is to fit a global model to all observations
- Several disadvantages to this approach
  - Fit to all observations doesn't guarantee good fit to tail
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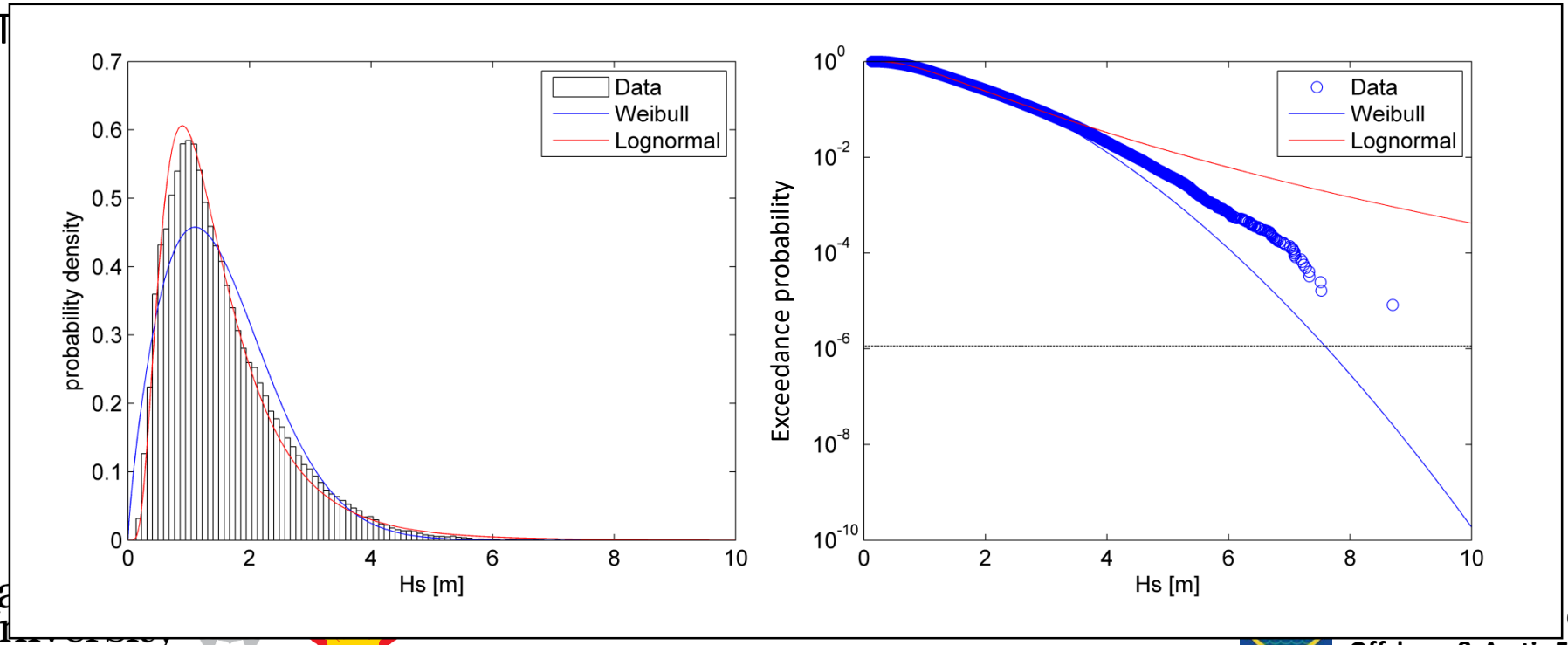

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    - This is the region we are most interested in
  - Does not account for serial correlation in data
    - Leads to positive bias in estimates of occurrence of extreme conditions

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  - Fit to all observations doesn't guarantee good fit to tail
    - This is the region we are most interested in
  - Does not account for serial correlation in data
    - Leads to positive bias in estimates of occurrence of extreme conditions
  - Often require prior assumptions about dependence structure between variables
    - Many datasets exhibit complex dependence structures

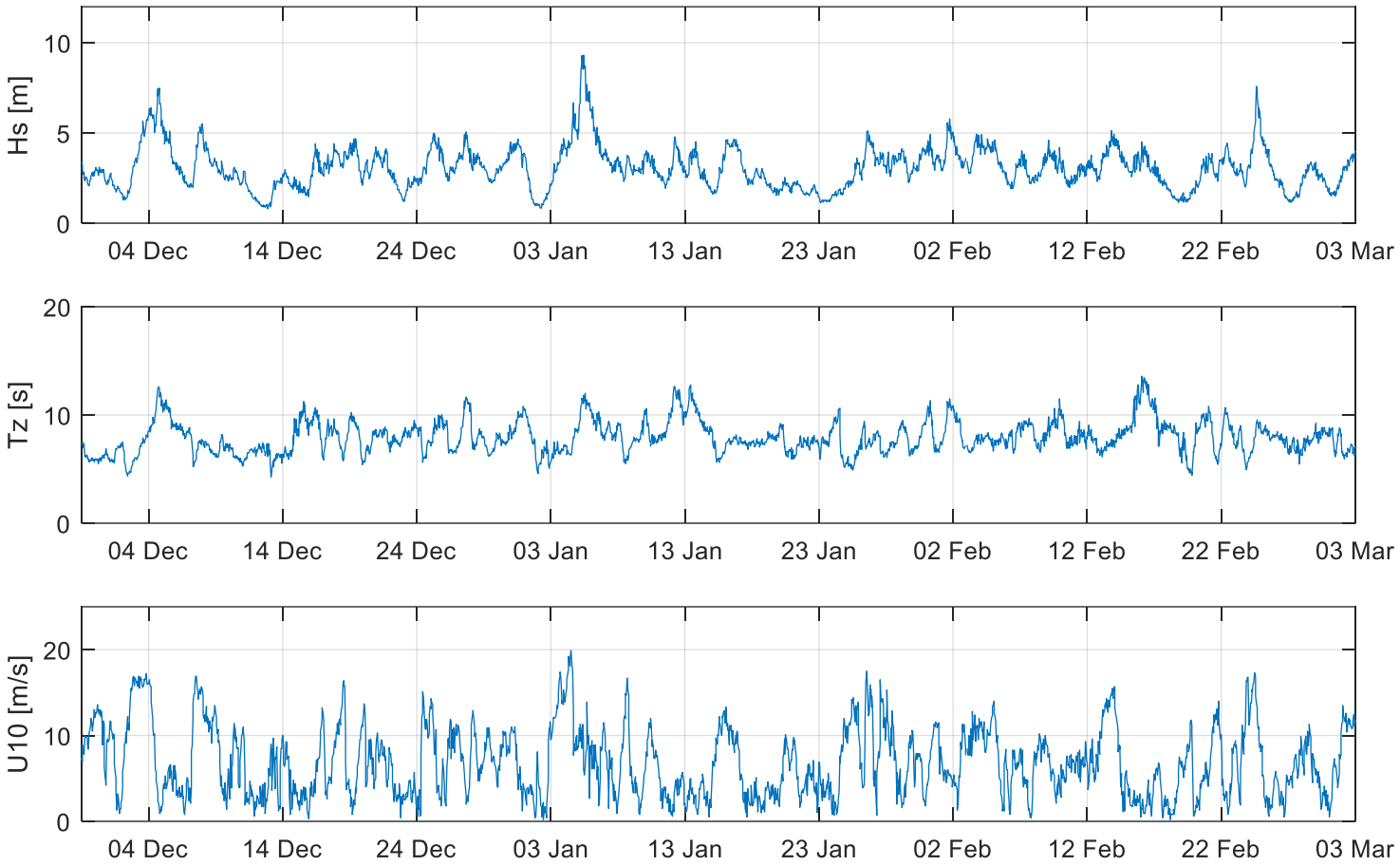
Block resampling method

1. Time series divided into non-overlapping blocks
2. Models fit to block-peak variables
3. Joint distribution of all data recovered by:
   a) Simulation of peak variables under fitted model
   b) Resampling measured blocks with “similar” peak values
   c) Rescaling measured blocks to match simulated peak values

Advantages

- Better justification for asymptotic models
- Creates time series outputs for analysis of long term extreme response
- Short-term dependence structure resampled rather than modelled explicitly

Blocking method



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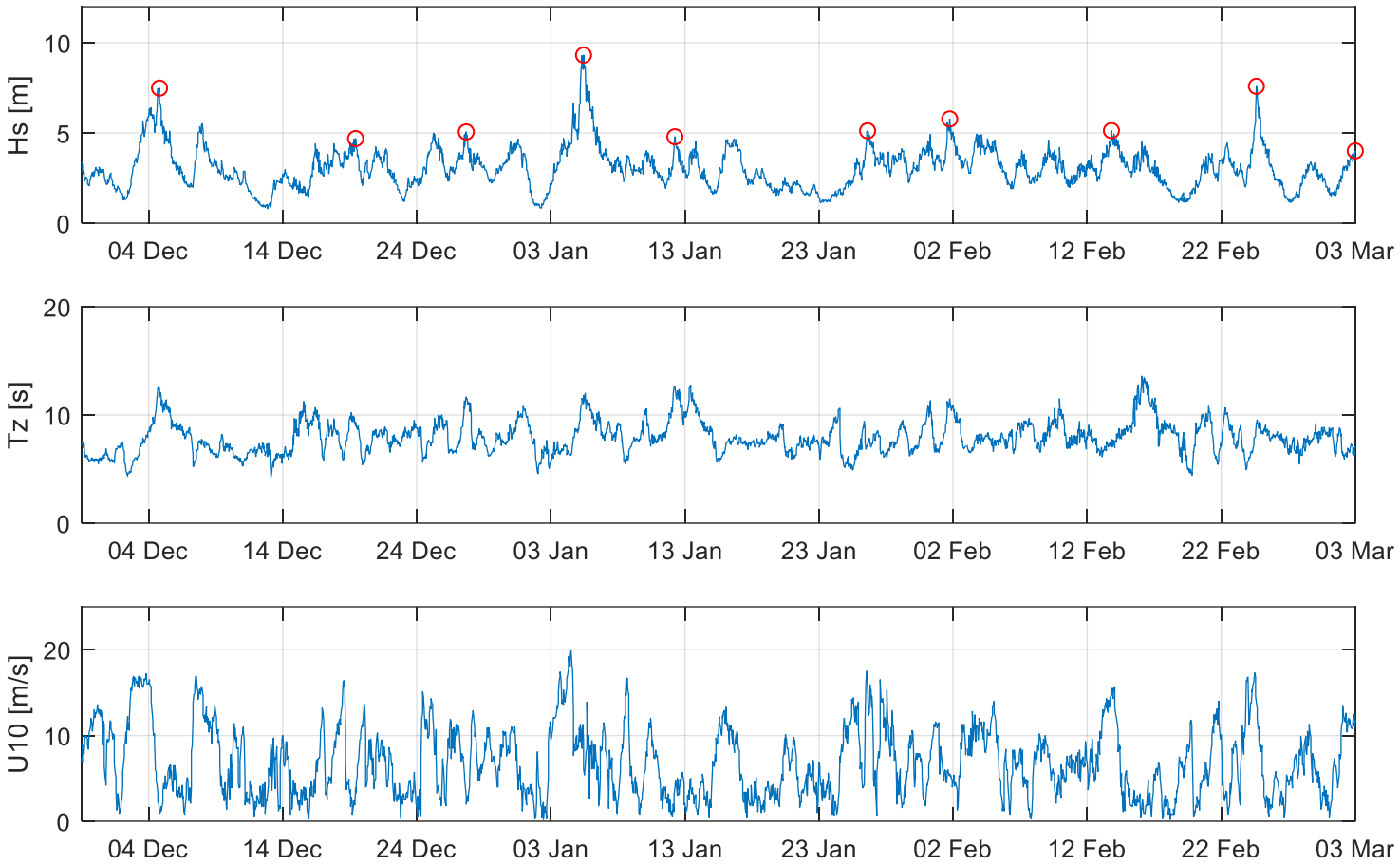

1. Identify peaks in one variable
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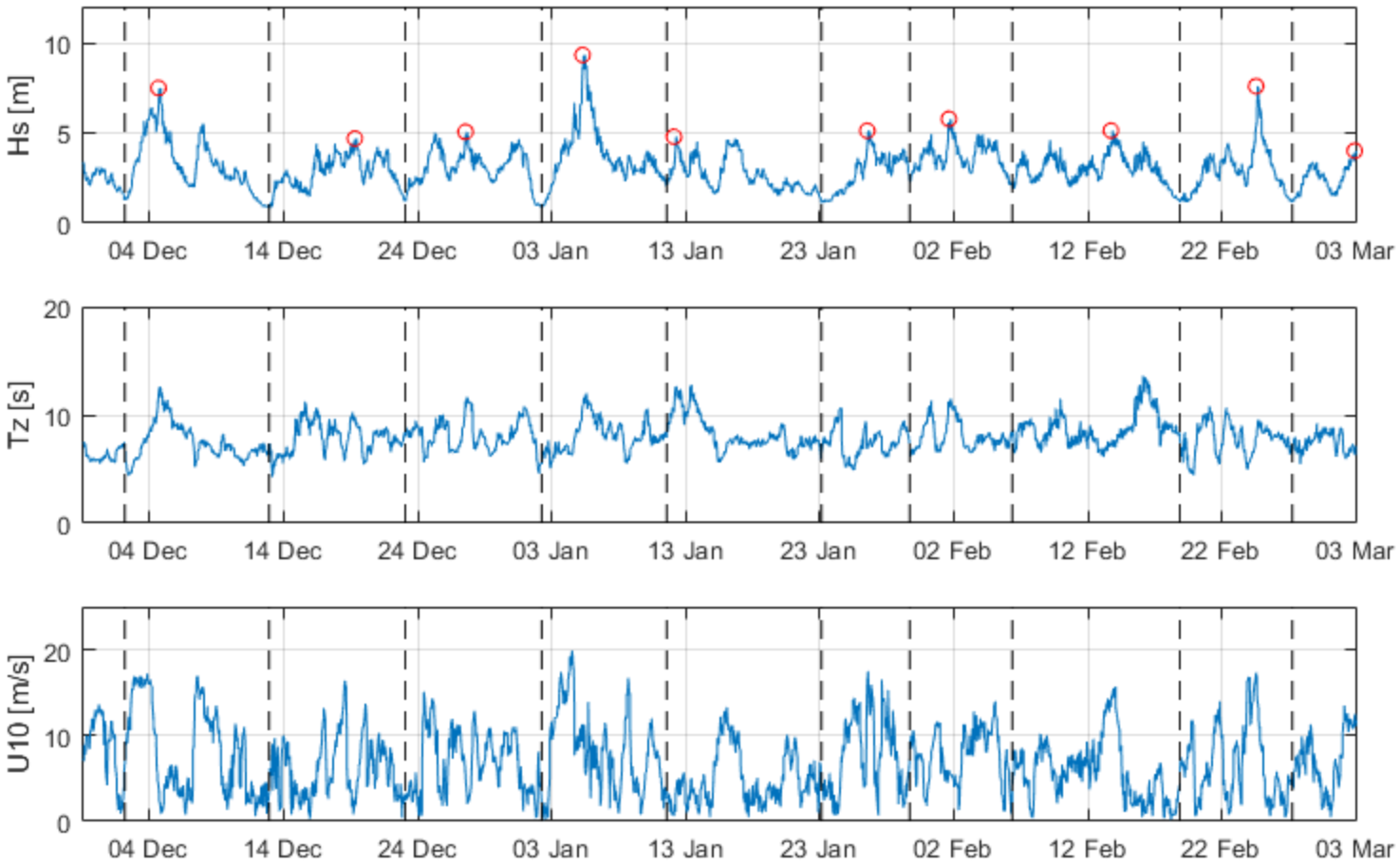
Blocking method



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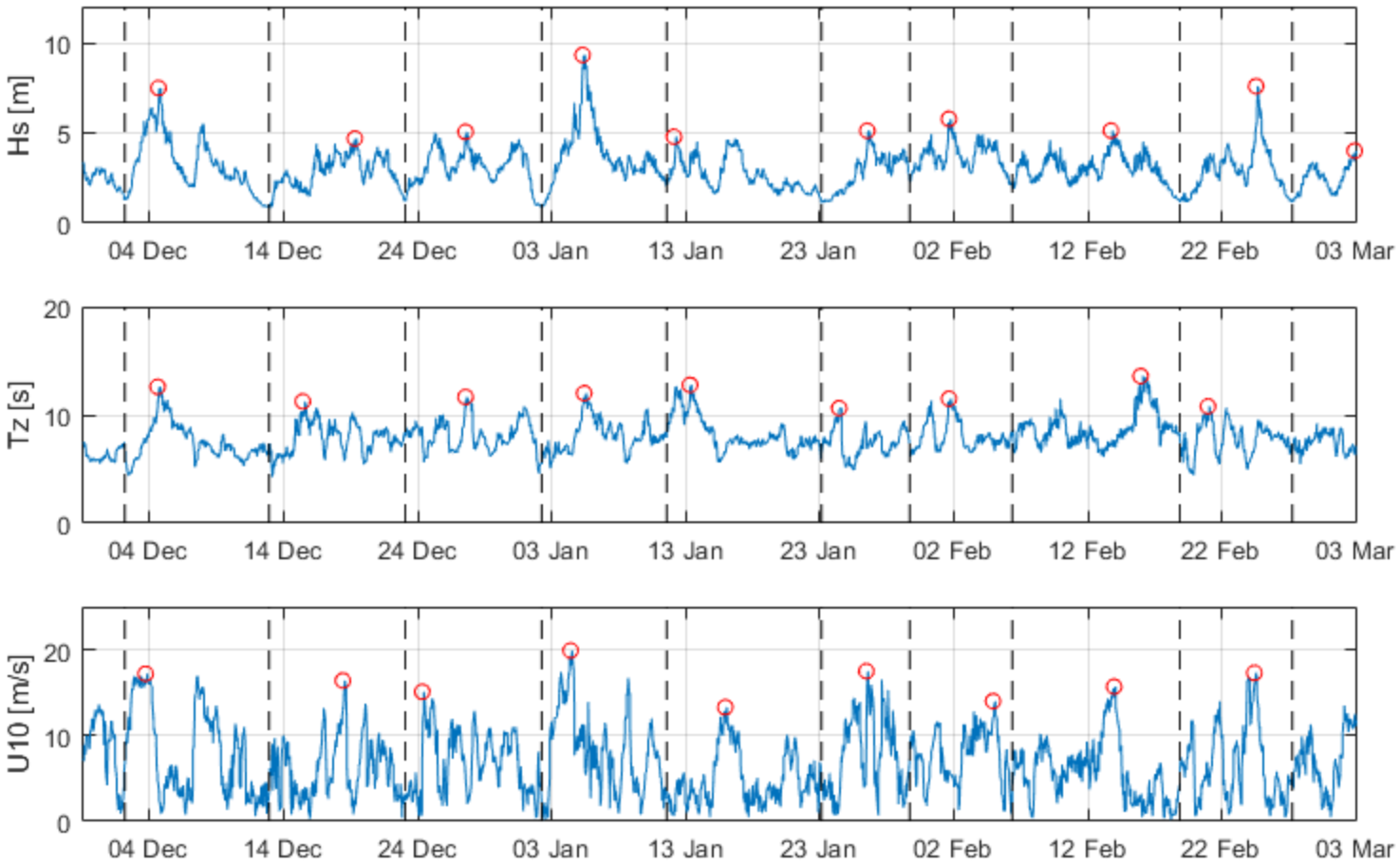
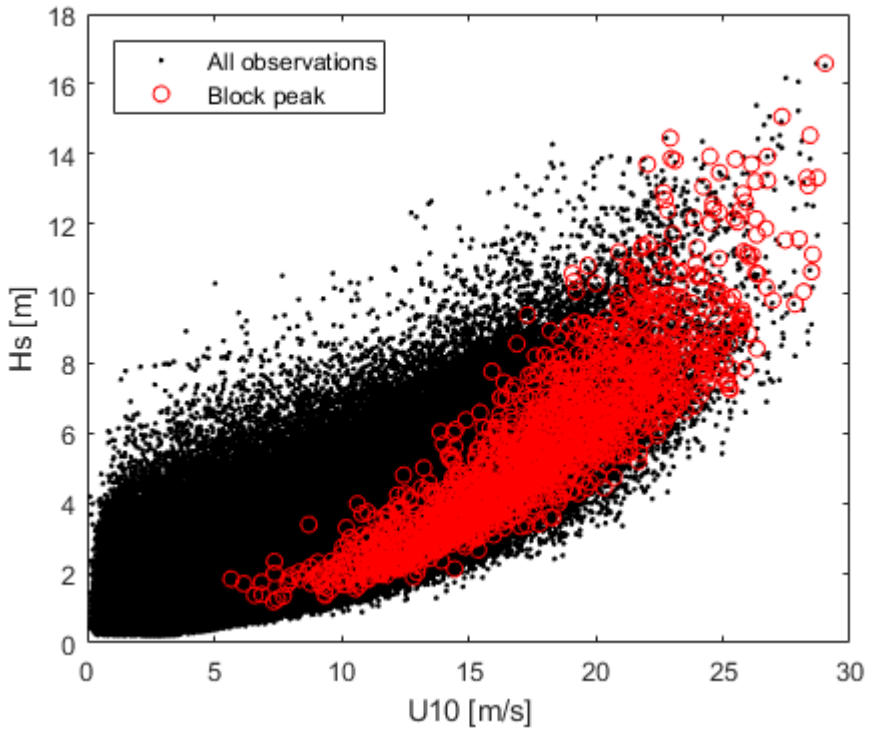


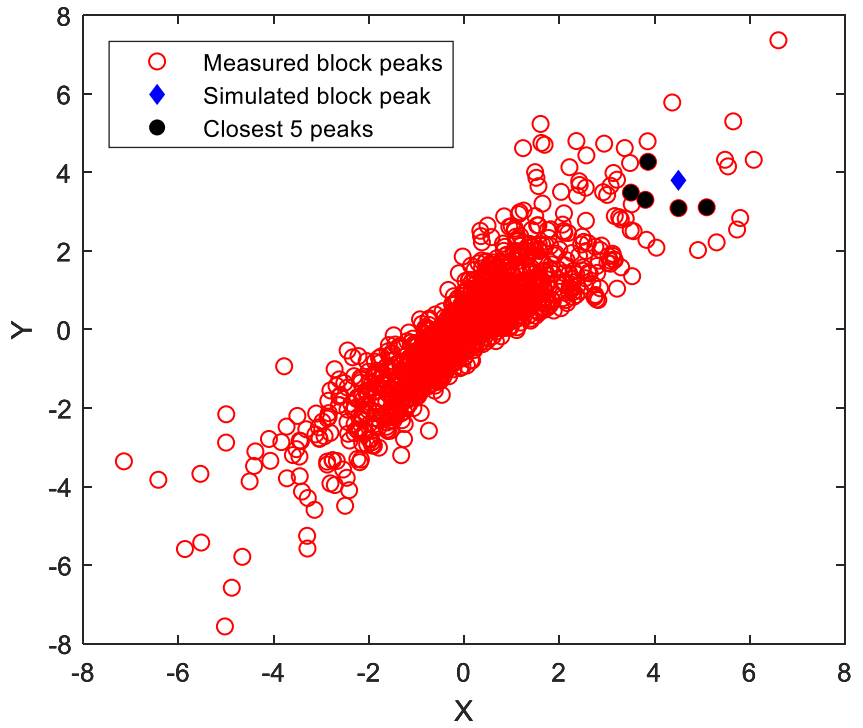
1. Identify peaks in one variable
   - Defined as local maxima separated by min 5 days
2. Define dividing points of blocks as times of min Hs between adjacent peaks
3. Find peaks of other variables within each block
   - Peaks within blocks need not be concurrent

Resampling of measured blocks



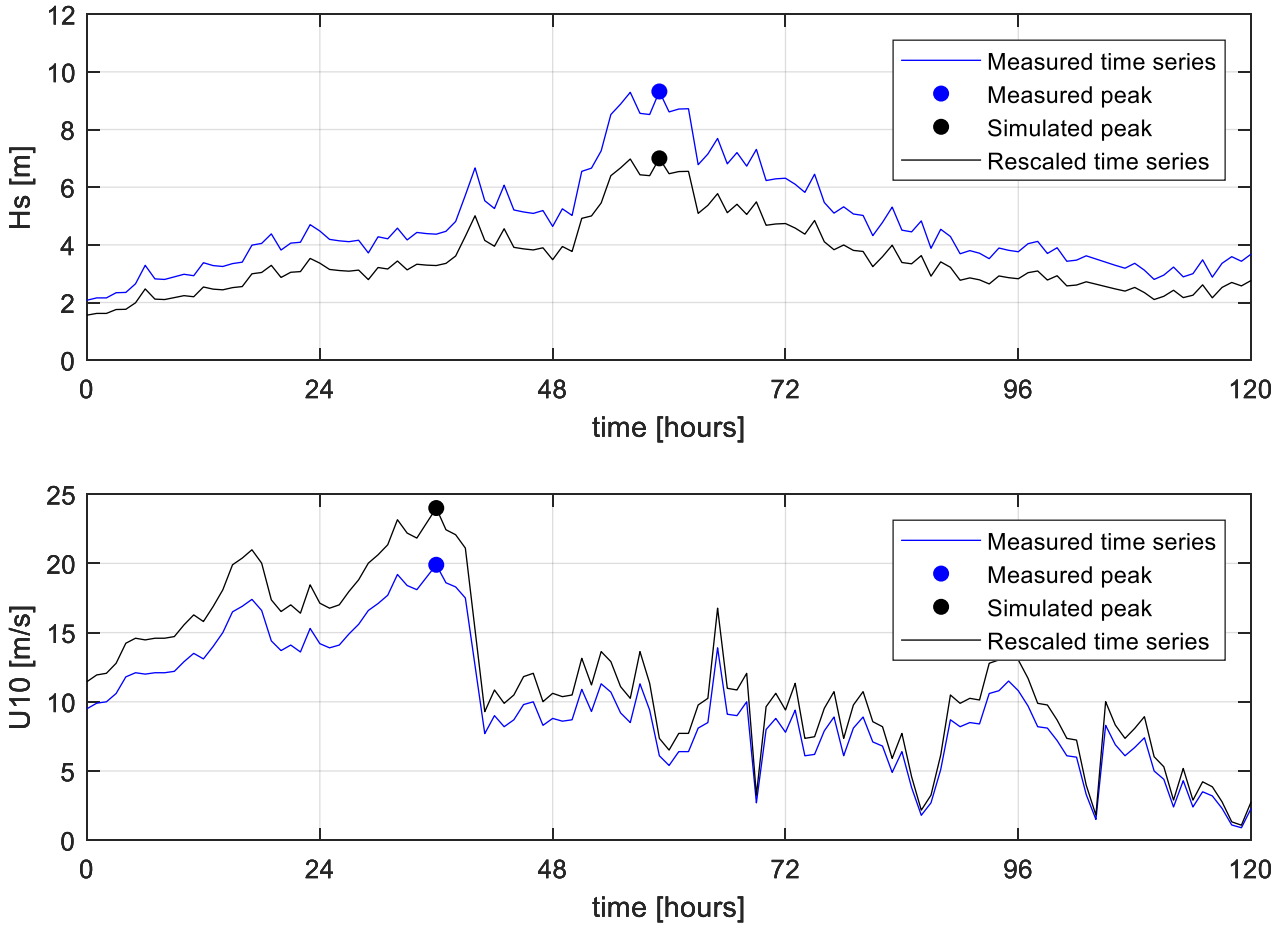
1) Find block-peak values
2) Fit marginal models to peaks

3) Transform to standard Laplace margins



4) Fit joint model
5) Simulate from joint model
6) Identify n blocks with closest peaks (Euclidean distance on Laplace margins)
7) Select one of n closest blocks at random
8) Scale block so that peak values match

Rescaling of measured blocks



- Blocks rescaled by ratio of simulated to measured peaks:

$$H_{s,rescaled} = \frac{H_{s,sim}^{peak}}{H_{s,meas}^{peak}} H_{s,meas}$$

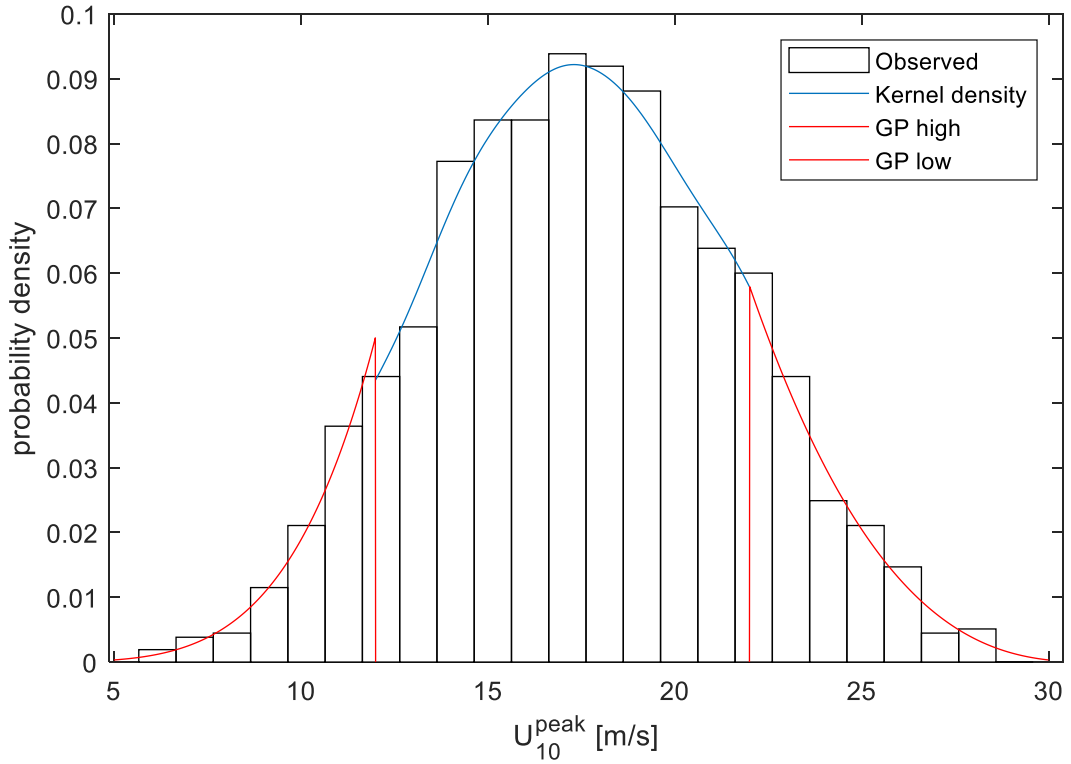
$$U_{10,rescaled} = \frac{U_{10,sim}^{peak}}{U_{10,meas}^{peak}} U_{10,meas}$$

Block resampling: Key assumptions

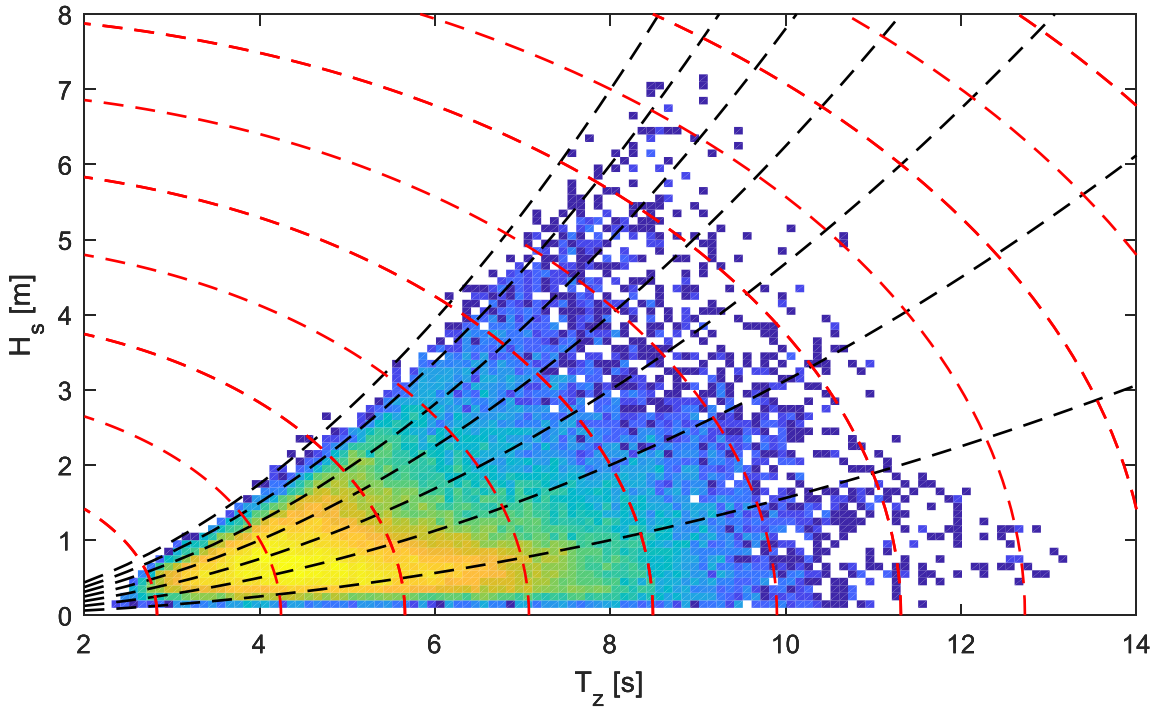
- Multivariate time series can be decomposed into non-overlapping blocks, where block-peak values are independent
- Peak values of each variable not required to coincide in time
  - blocks are sufficiently long that peaks in adjacent blocks are independent
  - blocks are sufficiently short that peaks within blocks are correlated
- Rescaling measured blocks relative to peak values gives an equally realistic storm history, provided the peak values are not changed too much

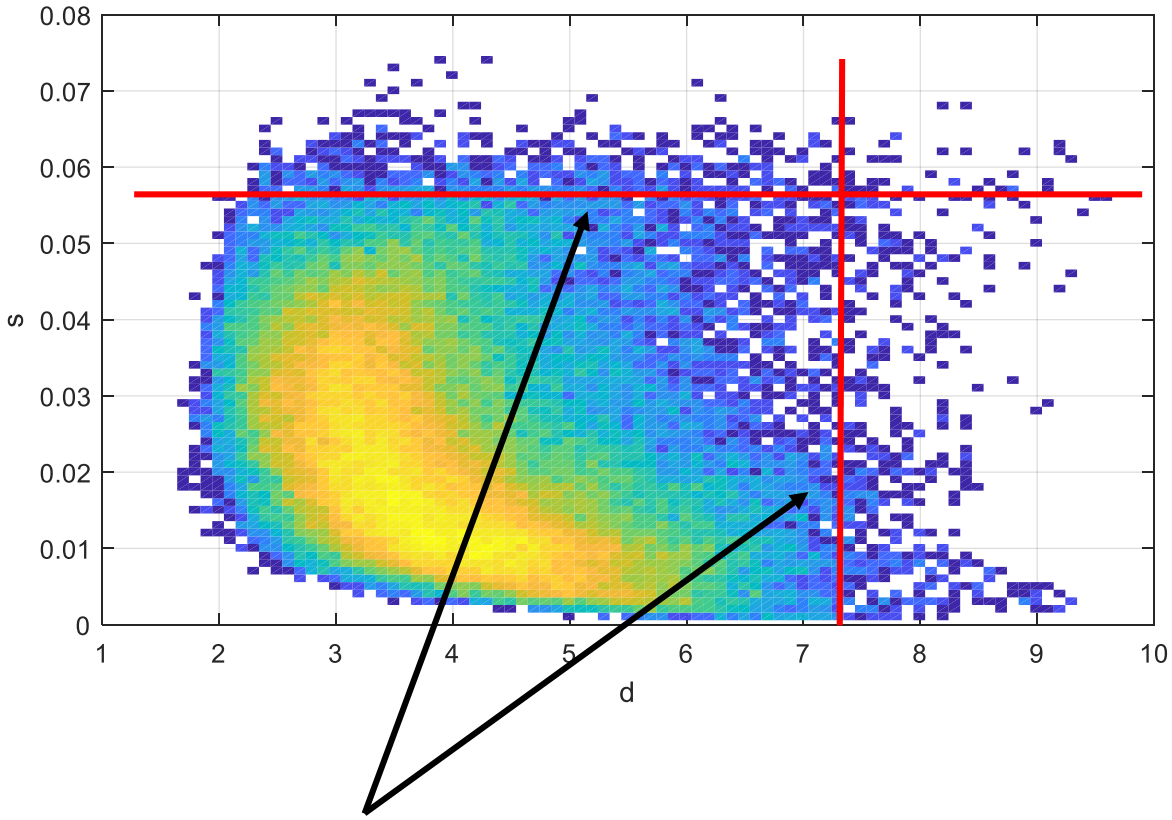
Marginal models

- Kernel density with GP tails



Joint models – example for Hs and Tz





$$s = \frac{2\pi H_s}{g T_z^2}$$

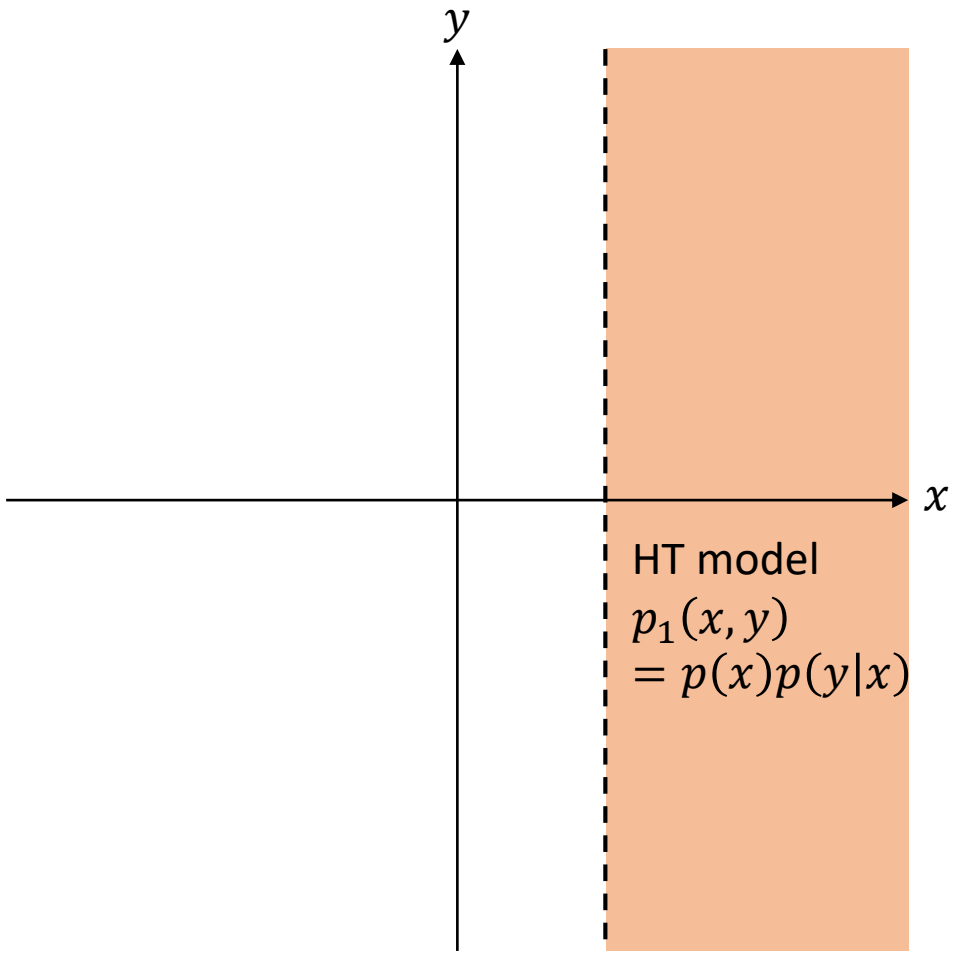
$$d^2 = H_s^2 + \frac{1}{2} T_z^2$$

Frontiers of interest for extreme responses

Dataset A from [1]

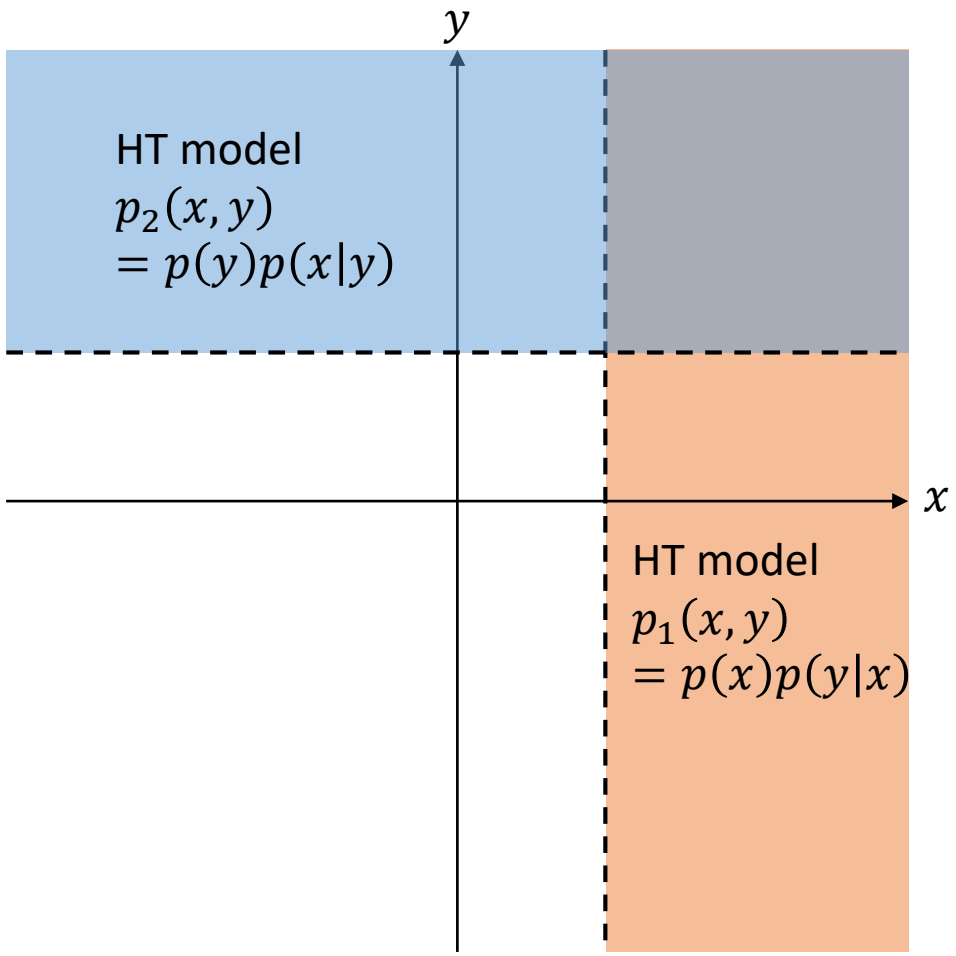
[1] Haselsteiner et al. "A benchmarking exercise on estimating extreme environmental conditions". OMAE2019–96523.

Joint modelling approach



- Heffernan & Tawn (2004) model used to describe distribution of y conditional on extreme value of x

Heffernan-Tawn model



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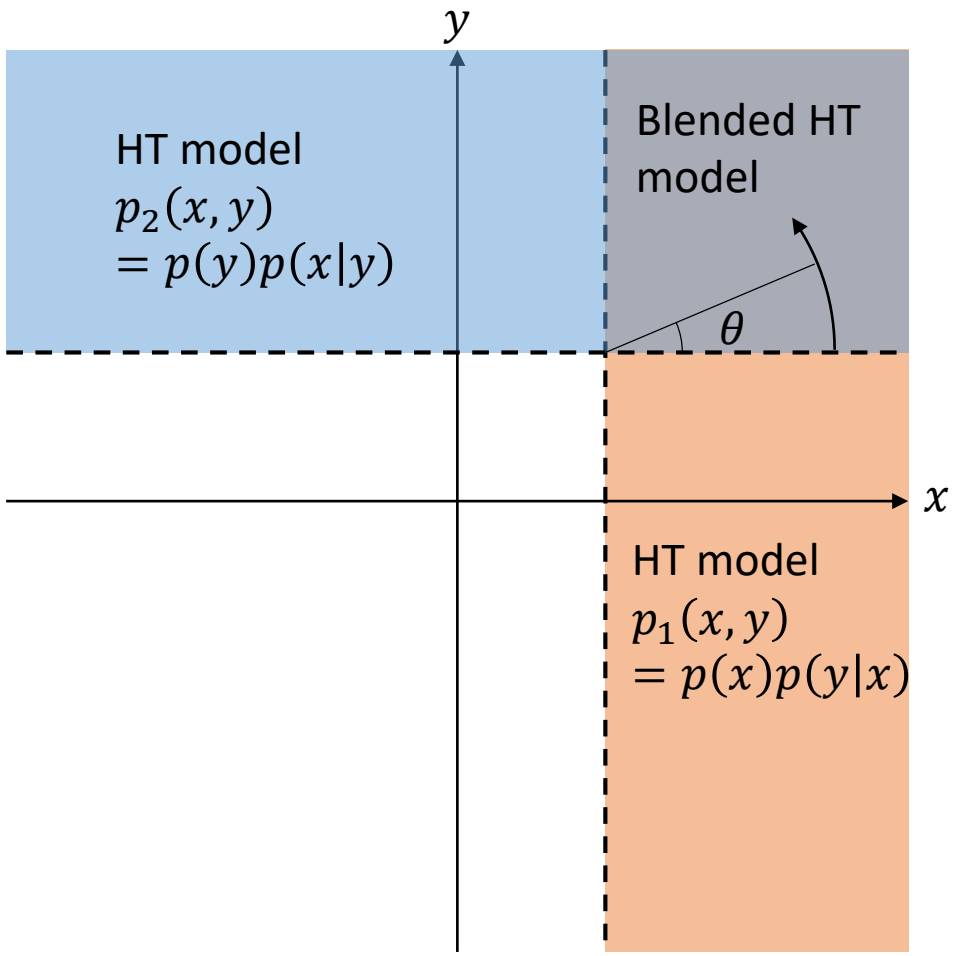

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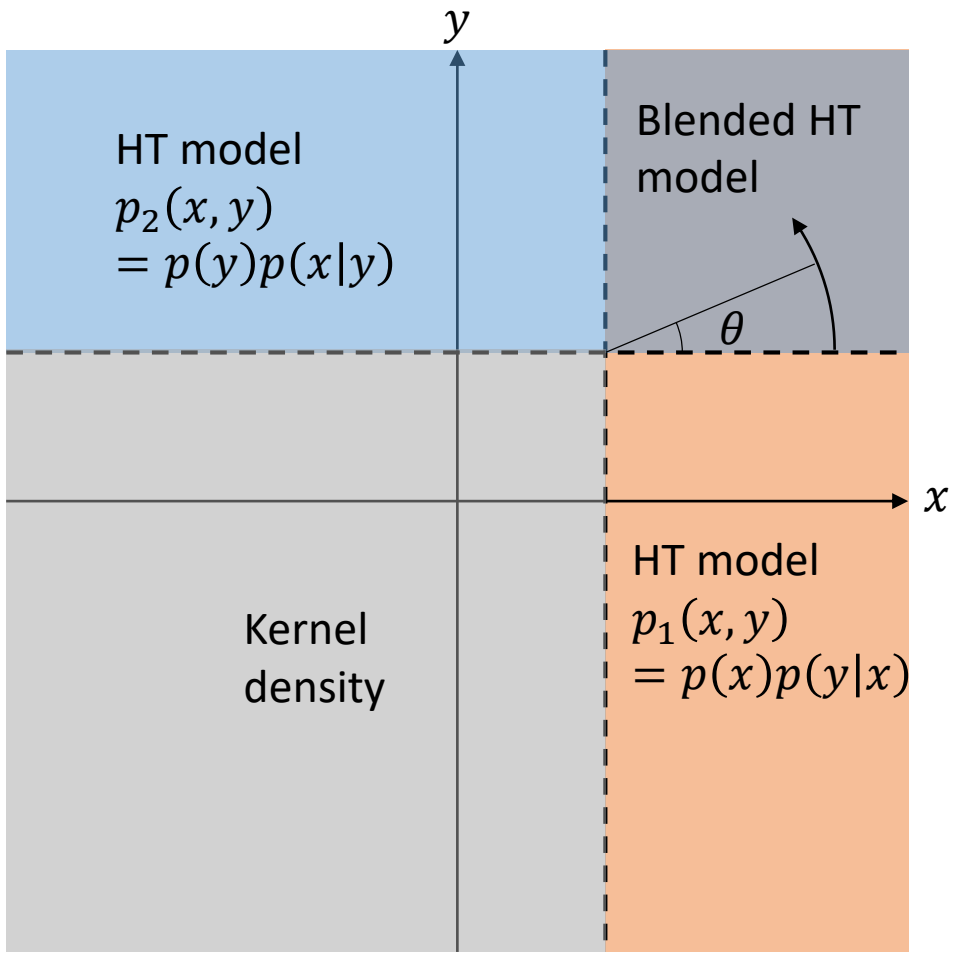
- HT model also used for x given y
- HT models blended in overlapping region:

$$p(x,y) = \left(1 - \frac{2\theta}{\pi}\right) p_1(x,y) + \frac{2\theta}{\pi} p_2(x,y)$$

Heffernan-Tawn model



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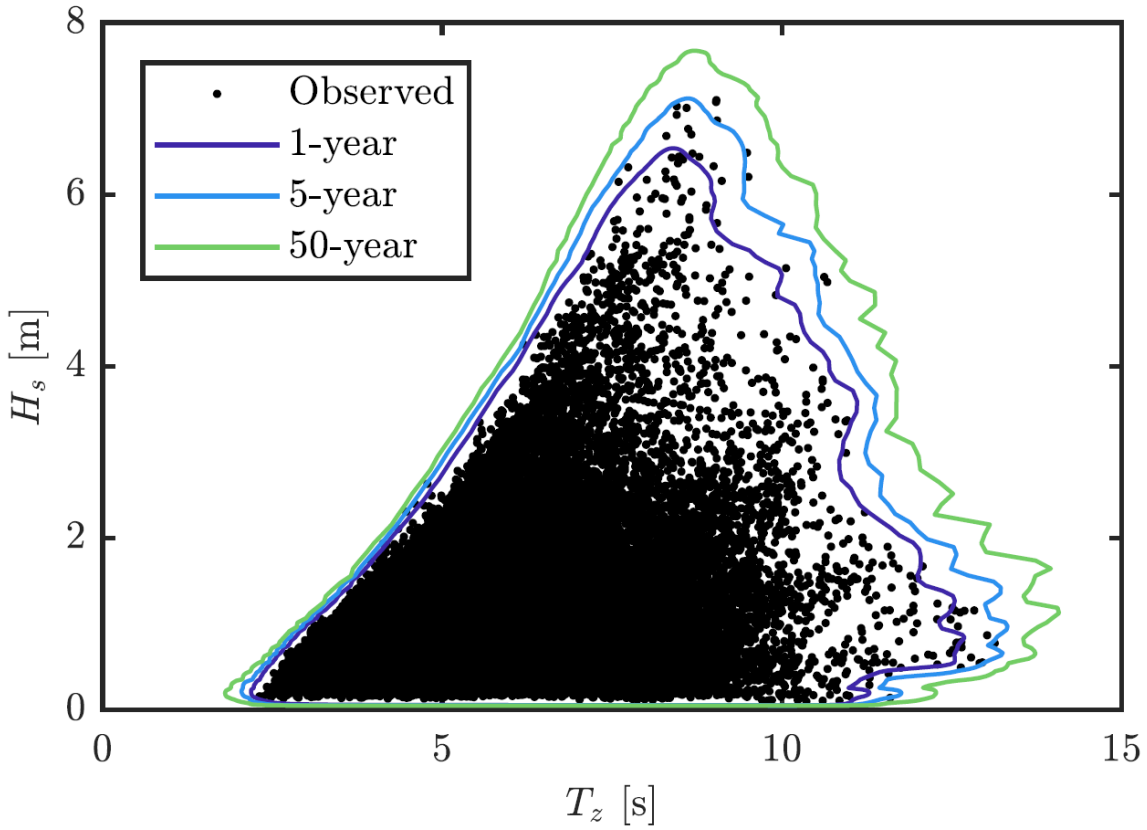
- Kernel density model used for non-extreme regions

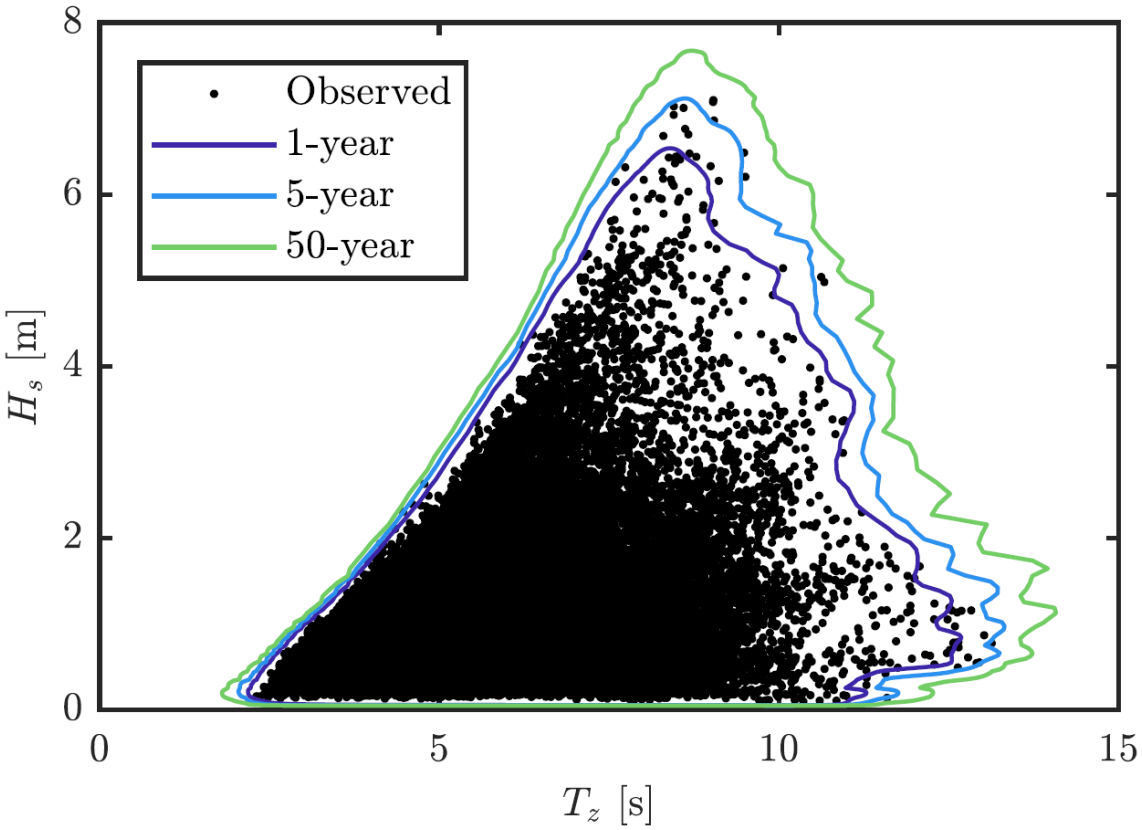
Example contours

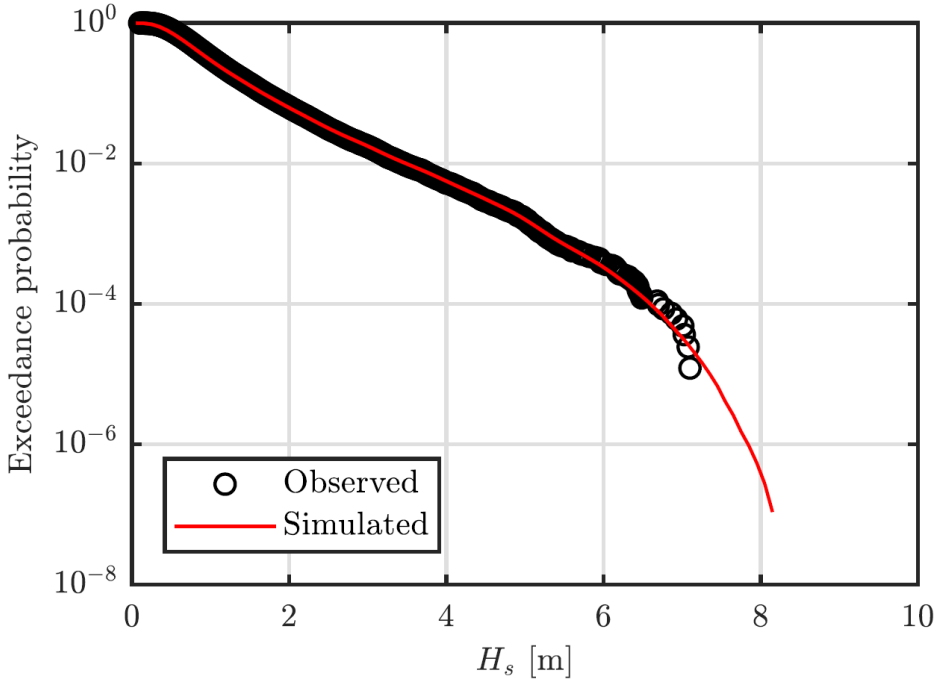


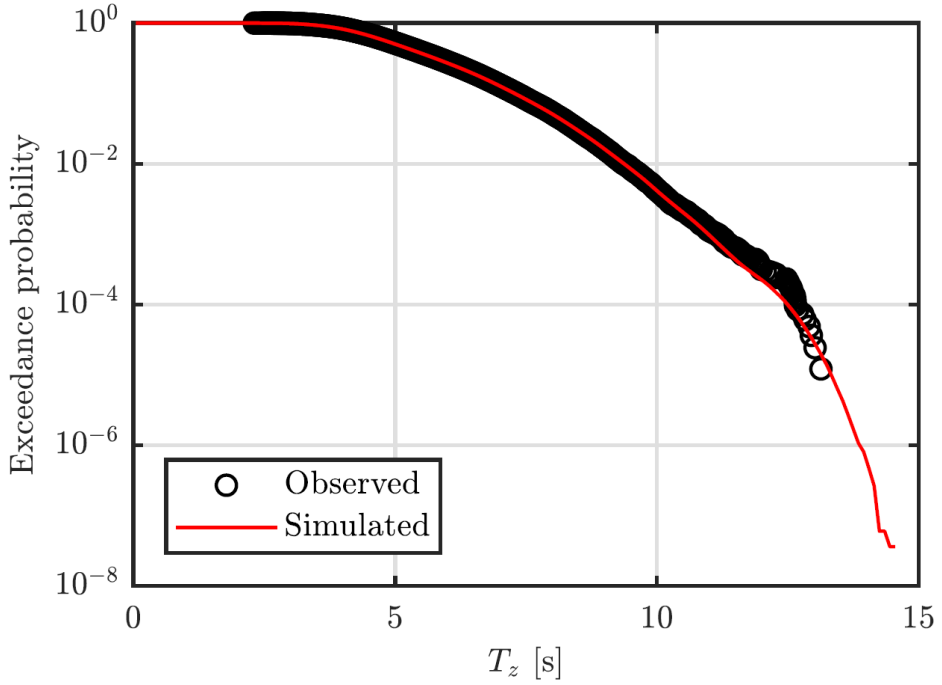
- Blocks resampled from 10 closest blocks
- 1000 years of simulated data
- IFORM contours for 1, 5 and 50 years
- Note: IFORM not uniquely defined
  - Rosenblatt transformation for $T_z|H_s$ gives different contours to transformation of $H_s|T_z$
  - See [2] for details

[2] Mackay & Haselsteiner, 2020. "Marginal and total exceedance probabilities for environmental contours". Marine Structures (under review)

Example contours







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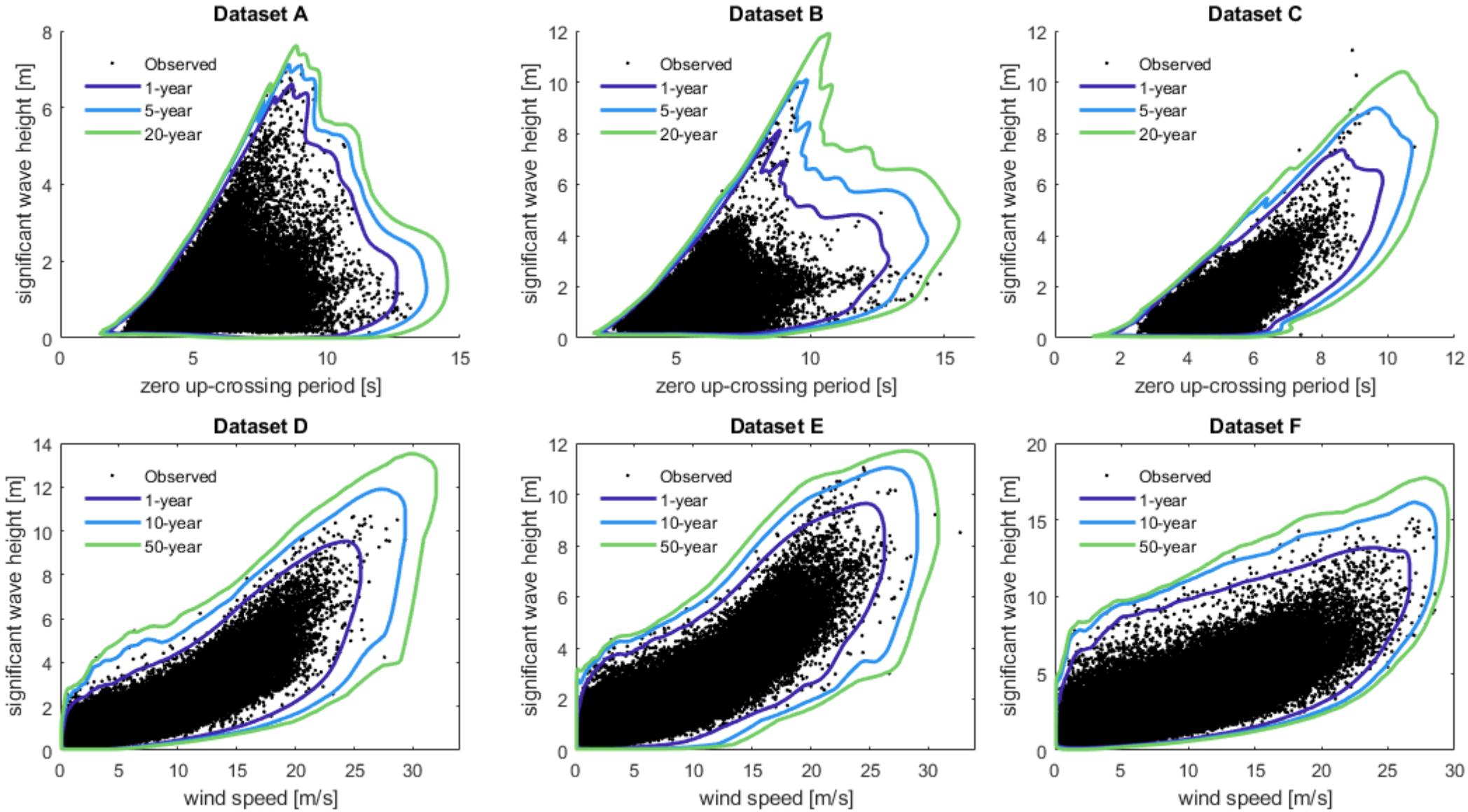
Other results for contour benchmarking exercise



Conclusions

- Block resampling approach is capable of accurately reproducing both marginal and joint extremal characteristics of observed data
- Time series outputs – preserves ‘clustering’ properties of extremes
- Future work:
  - Resampling method without the need for pre-defining blocks
  - Modelling of joint distribution without the need for multiple blended models

Acknowledgement

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