How can sensitivity analysis help CAT model building and forming your view of risk?

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Aim of my KE Fellowship (Nov 2017 – Oct 2020)

Goal

Improving decision-making under uncertainty by **transferring** state-of-the-art **methods** for **Global Sensitivity Analysis (GSA), tools** (**SAFE software toolbox**) and **expertise** to the (re)insurance sector and catastrophe community.

Objectives

Understand major sources of uncertainty in the insurance modelling process

Demonstrate benefits of using Global Sensitivity Analysis (through case studies)

Transfer knowledge and engage wider insurance sector (through workshops, training material, embedding SAFE on OASIS platform, …)

Partners

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Deliverables

- Developed pilot case study with actuarial team at AXA XL
- Developed training material for actuaries
- Delivered tutorials on GSA/SAFE use for actuaries at AXA XL and Bristol Actuarial Society

Actuarial community

- Developed pilot case studies with JBA Risk Modelling, OASIS and AXA XL on cat models
- Developed training material for cat community
- Delivered presentations/workshops on GSA/SAFE use at OASIS conference and at 3 major re/insurance companies
- Embedding SAFE on the OASIS platform

Catastrophe community

Training material available at*:* www.safe-insurance.uk/Outputs.html

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Outline

- What is Global Sensitivity Analysis (GSA)?
- How does GSA work?
- What are the main benefits of using GSA?
- Examples of GSA applications from insurance and beyond
- Brief tutorial on how to use the SAFE toolbox

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What is Sensitivity Analysis and how does it compare to Uncertainty Analysis?

UA focuses on quantifying the uncertainty in a model output.

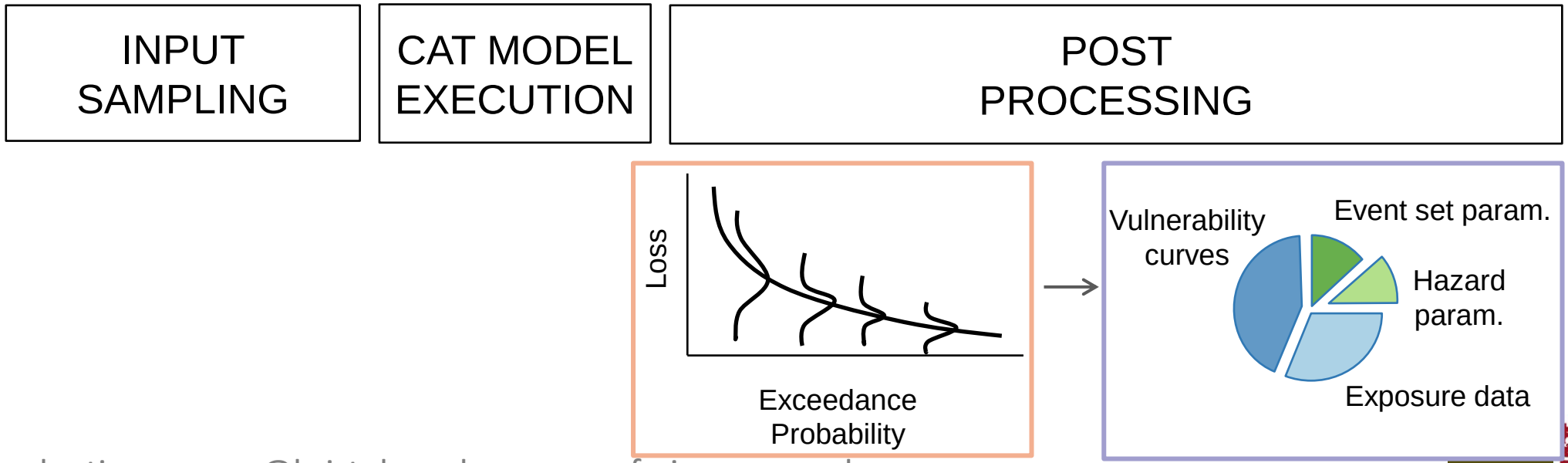
SA focuses on attributing output uncertainty to the different sources of uncertainty.

[1] Characterize uncertainty of input factors

[2] Forward propagate uncertainty

[3] Estimate output uncertainty

[4] Estimate sensitivity indices



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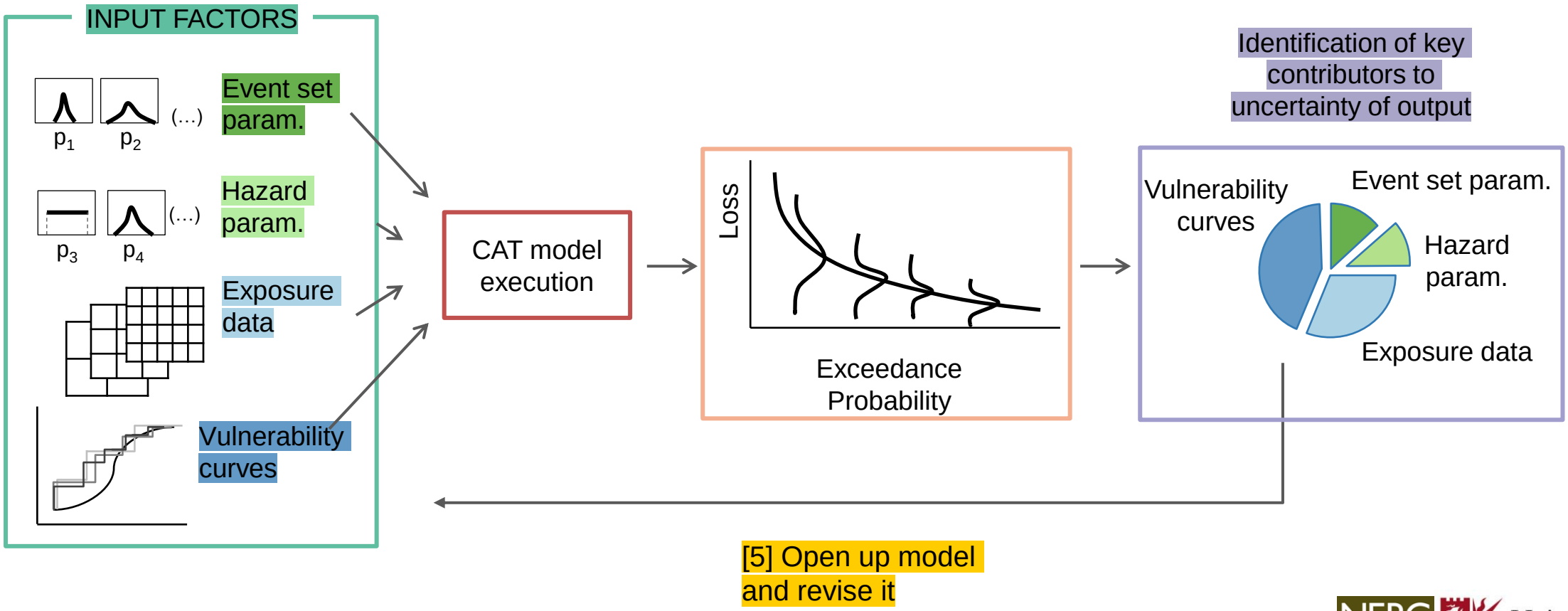
How does it work?

[1] Characterize uncertainty of input factors

[2] Forward propagate uncertainty

[3] Estimate output uncertainty

[4] Estimate sensitivity indices



[5] Open up model and revise it

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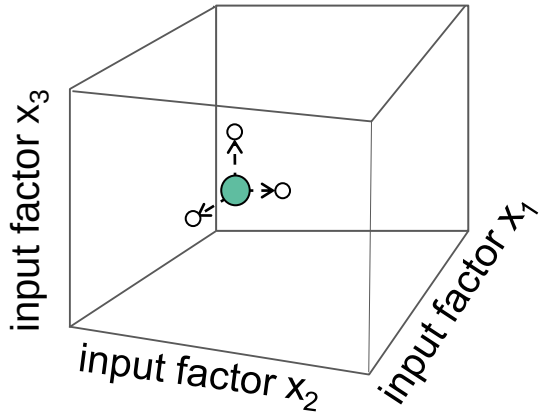
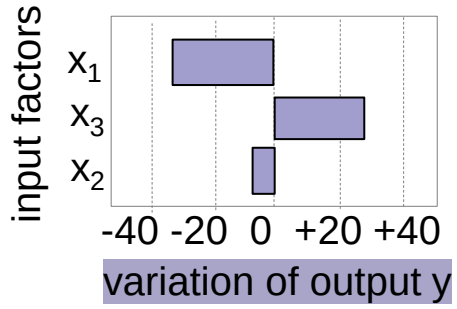
Currently, most SA applications in re/insurance consider variations of the inputs One-At-a-Time (OAT)

With OAT SA, the input factors are varied, one at a time, by a prescribed amount (perturbation) while all others are held constant at their baseline values.



$y = f(x_1,x_2,x_3)$

Tornado plot



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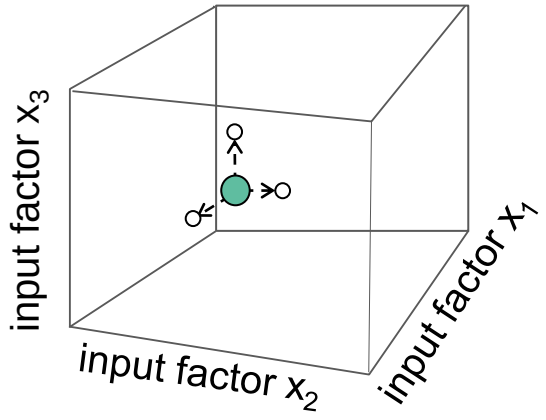
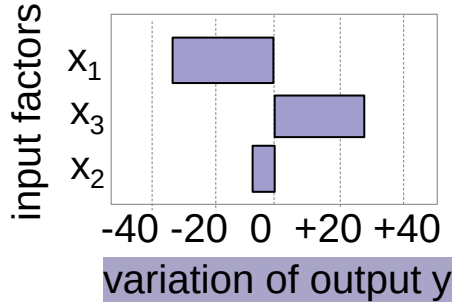


$y = f(x_1,x_2,x_3)$

Useful when baseline value has a clear meaning for the model user

(e.g. 'optimal' set-up after model calibration).

Tornado plot



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SA methods using All-At-a-Time (AAT) investigate model response independently of baselines

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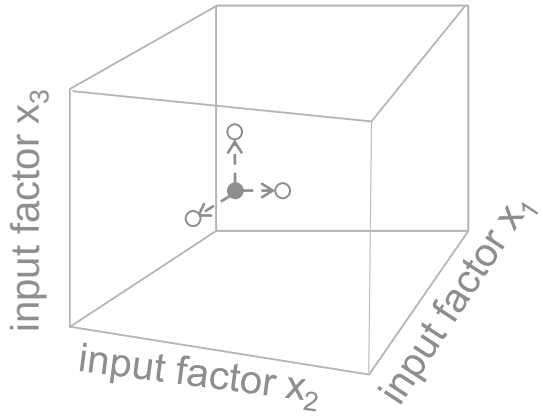
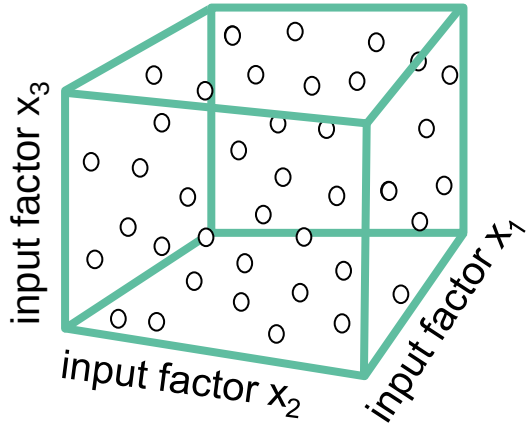


AAT SA investigates the effects of variation of uncertain inputs across their entire variability space, by varying all the input factors simultaneously.



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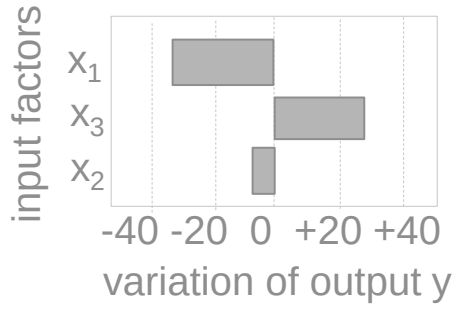

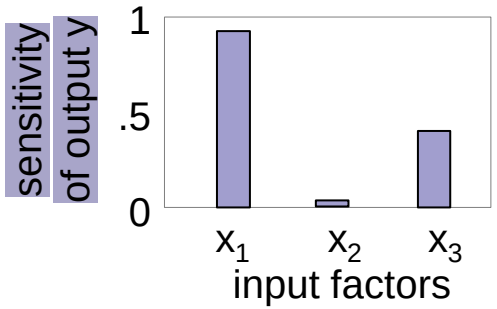

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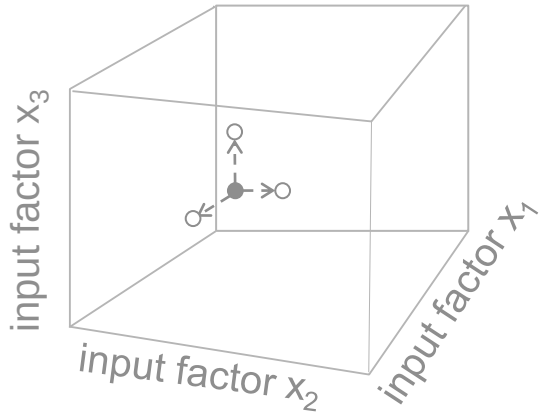

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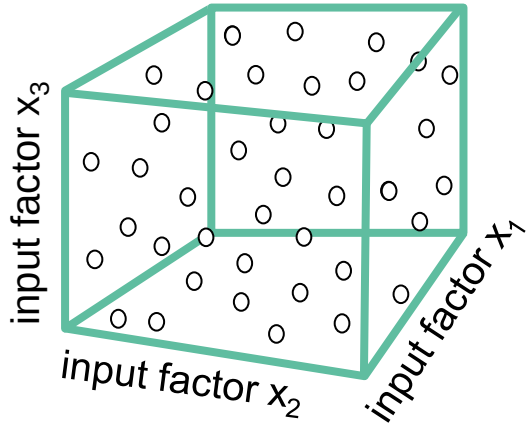

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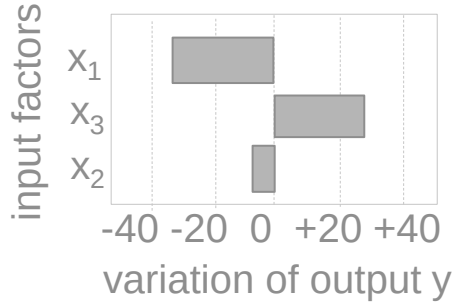

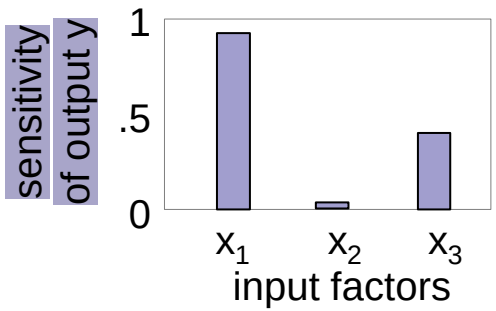

The sensitivity to each inputs factor considers the direct influence of that input as well as the joint influence due to interactions.

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What are the main benefits of using GSA?

- Allows to identify most influential input factors:
  - Where is the acquisition of new data going to be most useful?
  - Which parameters should be the focus of a more detailed calibration?
  - What is the impact of different modelling choices?

- Supports model validation
  - How does the model behave when run beyond the default set-up?
  - Do the outputs respond to input variations as expected and physically reasonable?

Pianosi et al 2016, *Environmental Modeling & Software (open access)*
Wagener and Pianosi, 2019, *Earth-Science Reviews (open access)*

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Application to JBA's Global Flood Model

Input factors considered:

- Vulnerability function
- Buffer size
- Number of disaggregation points

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Application to JBA's Global Flood Model

Input factors considered:

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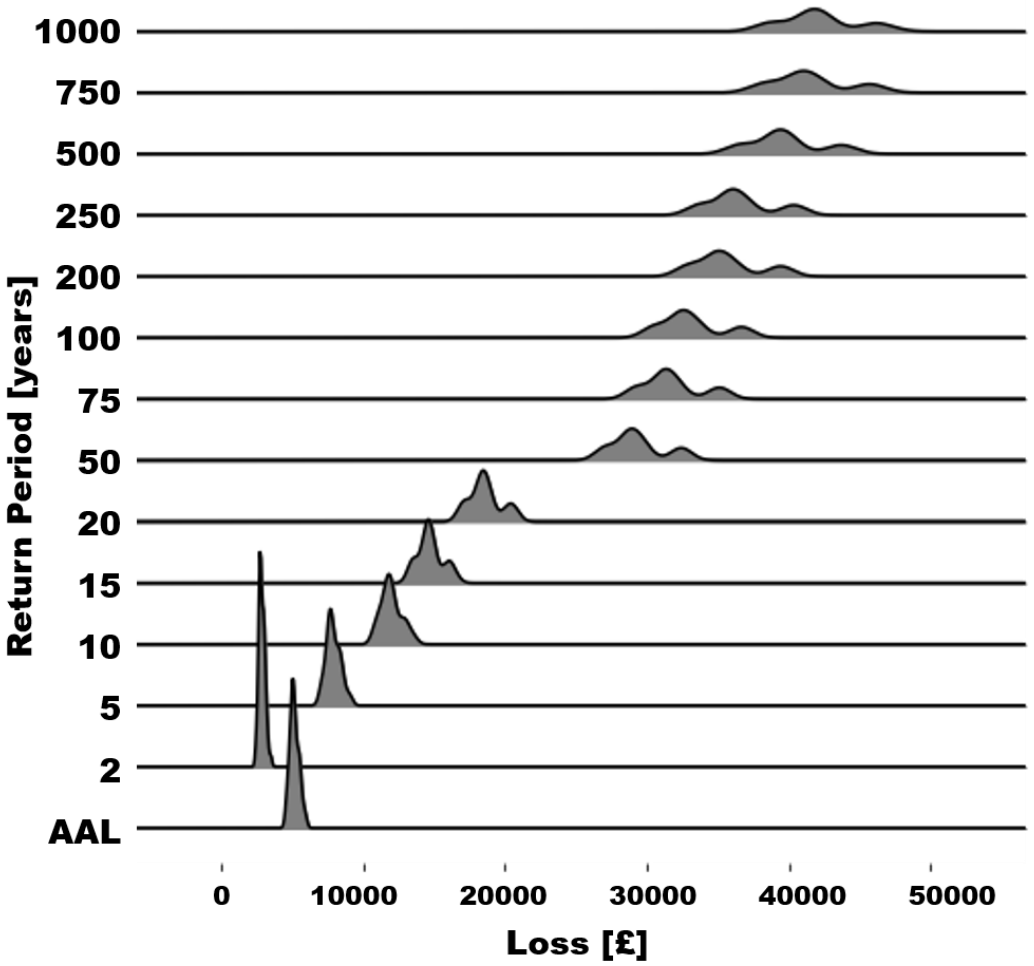
Before

They used predefined distributions to inform uncertainty.

Now

They can estimate the output uncertainty based on the inputs factors' ranges of variability they think are sensible.



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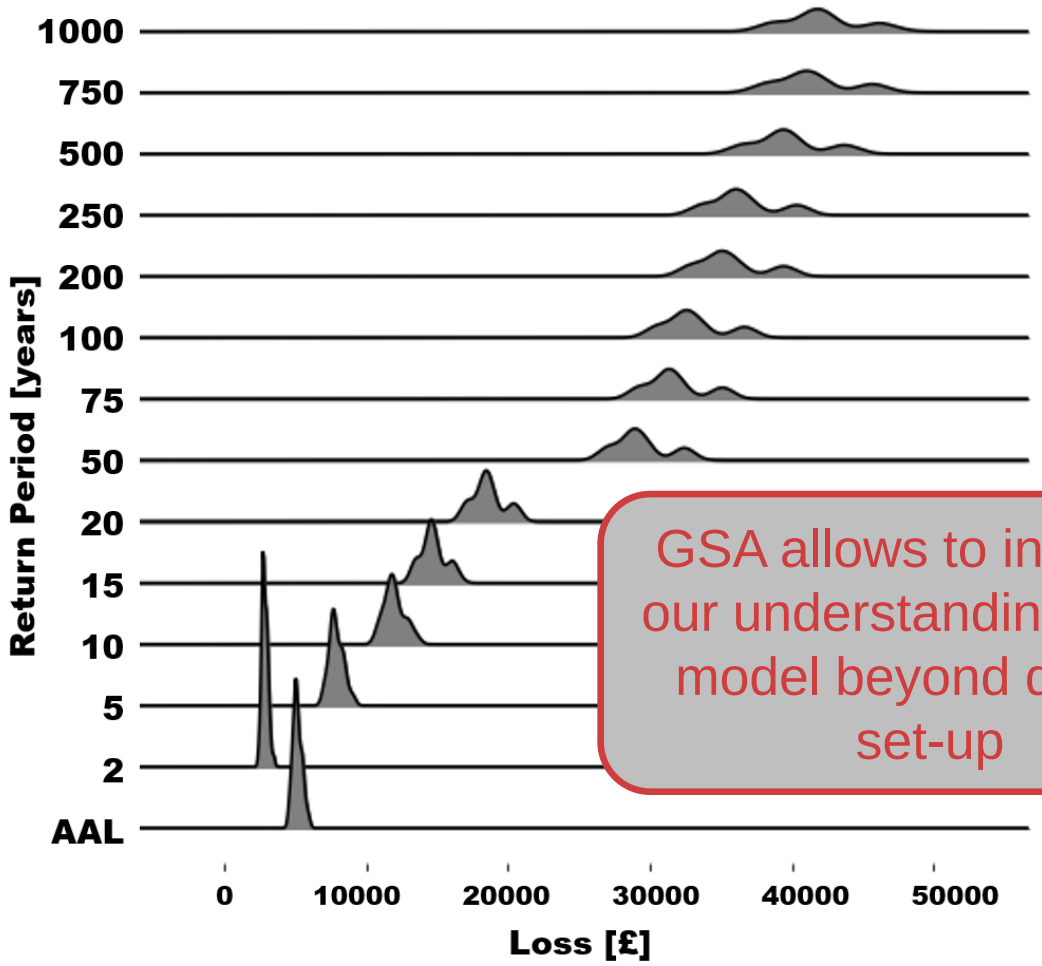

GSA allows to increase our understanding of the model beyond default set-up

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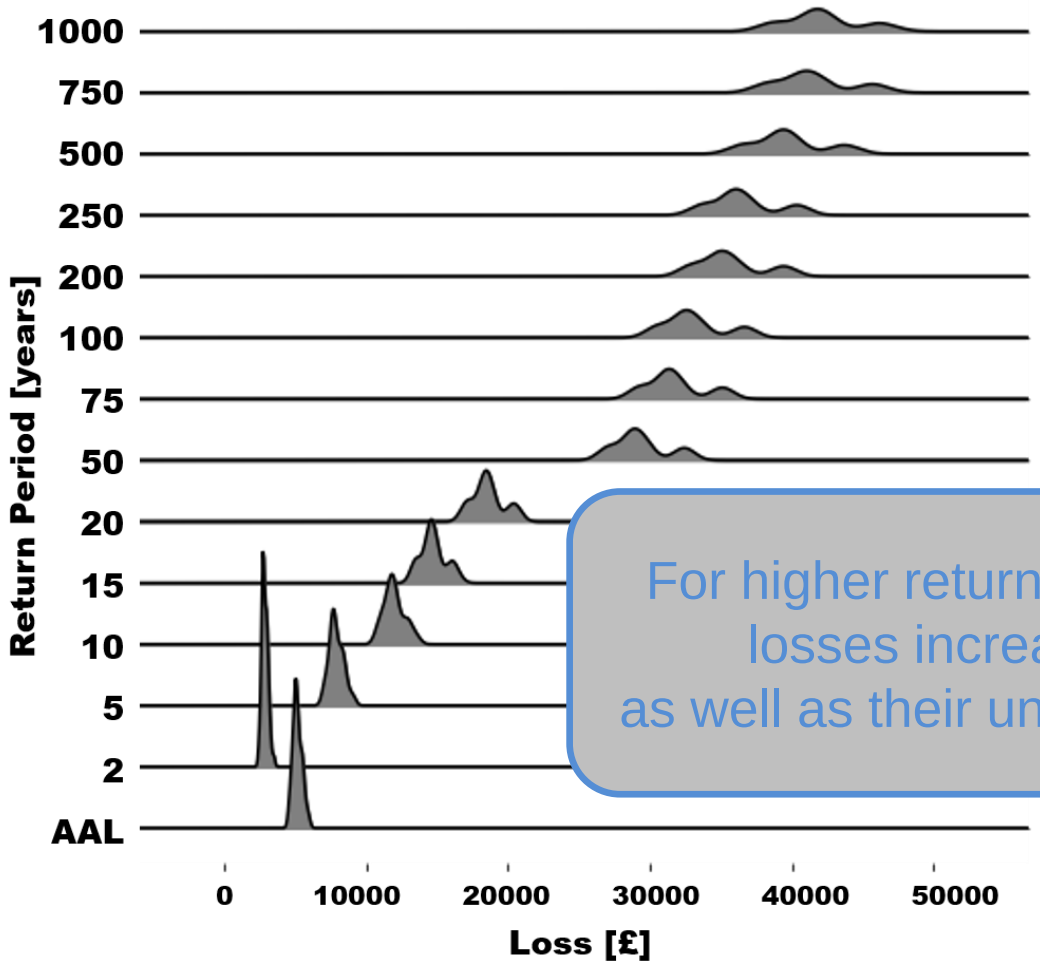

For higher return periods losses increase, as well as their uncertainty.

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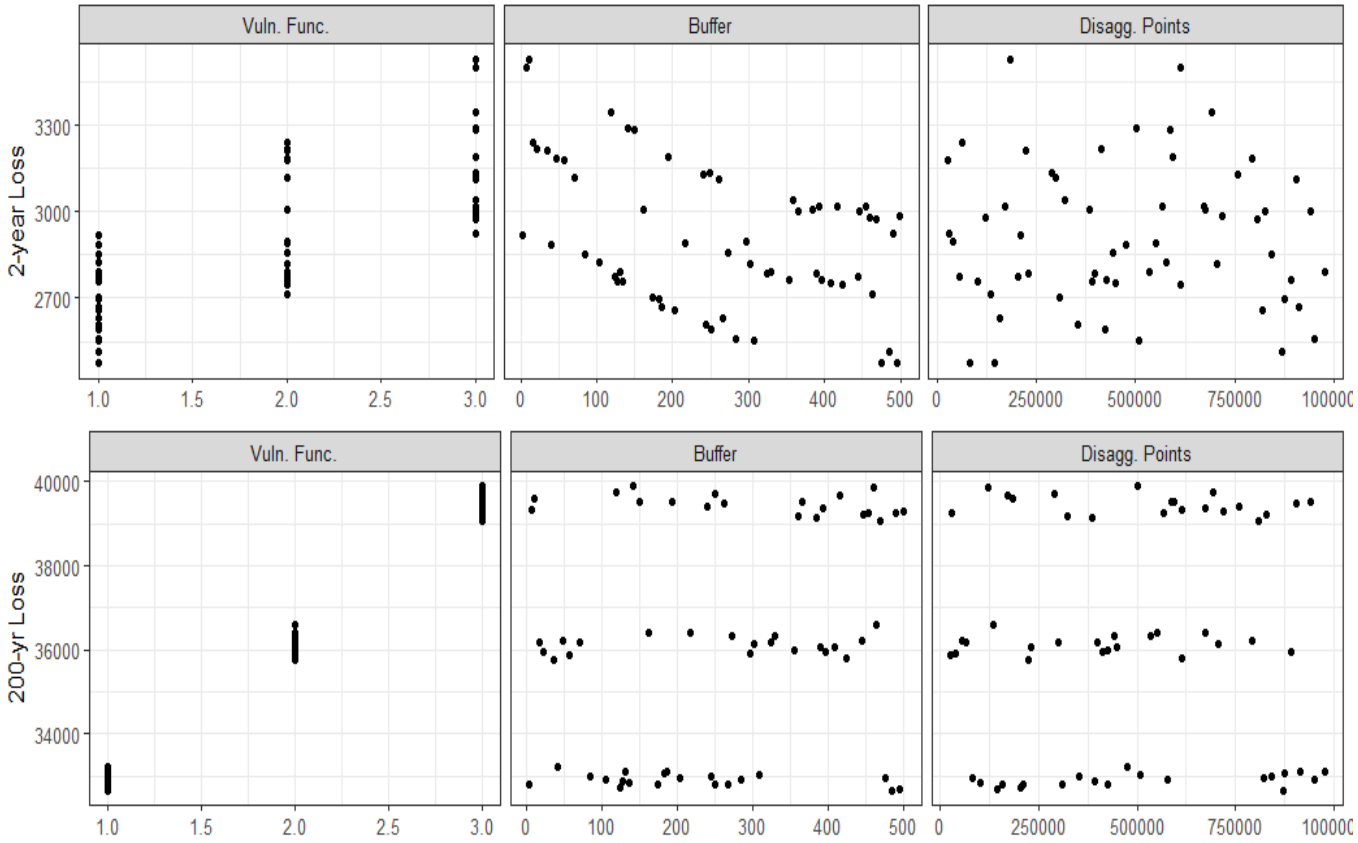
Application to JBA's Global Flood Model



We can visually inspect the relationships between input factors and the losses for the return periods we are most interested in.

And check if they meet our expectations.

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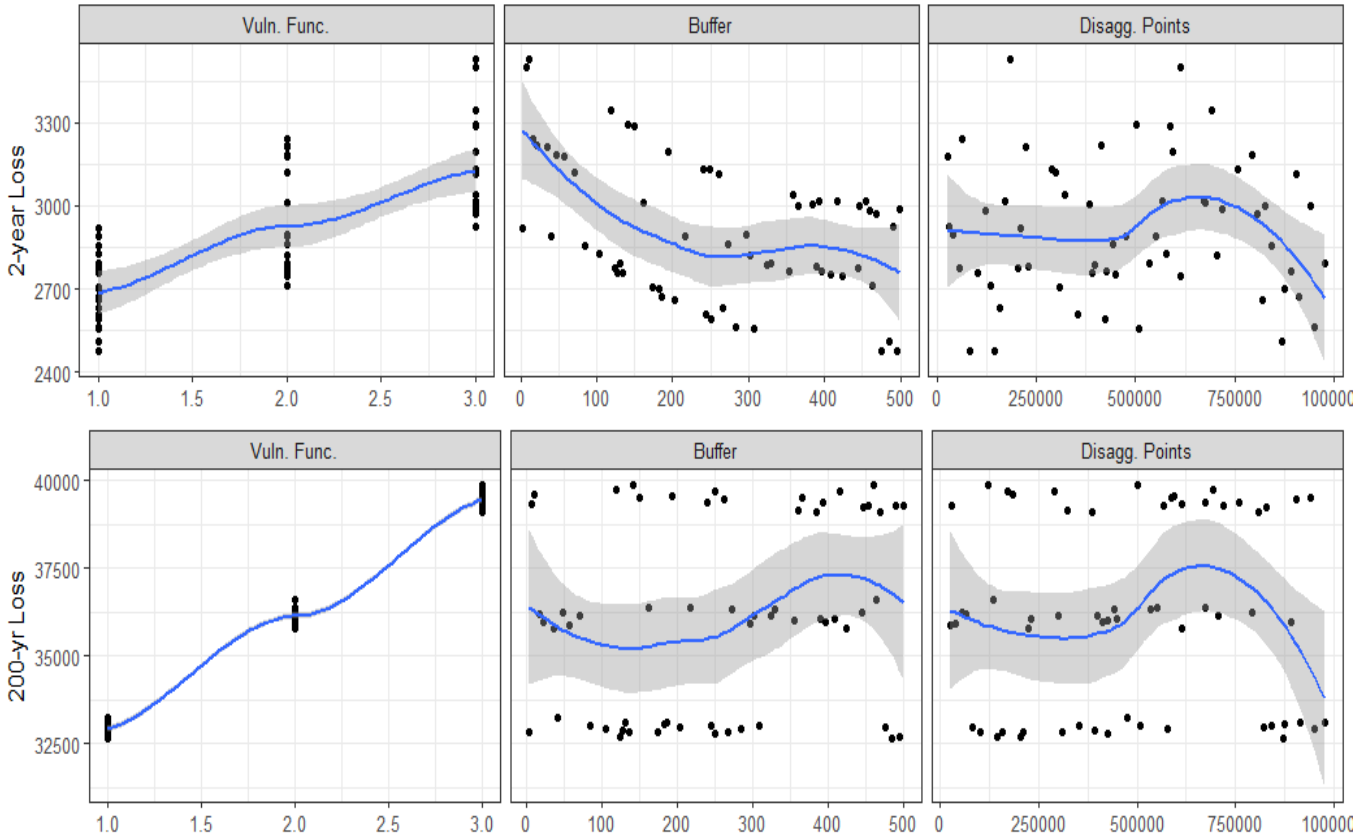
Application to JBA's Global Flood Model



An input is influential when its pattern varies across the x-axis.

The shape of the vulnerability function strongly conditions the output for both return periods.

The buffer size is more influential for the 2year-loss.

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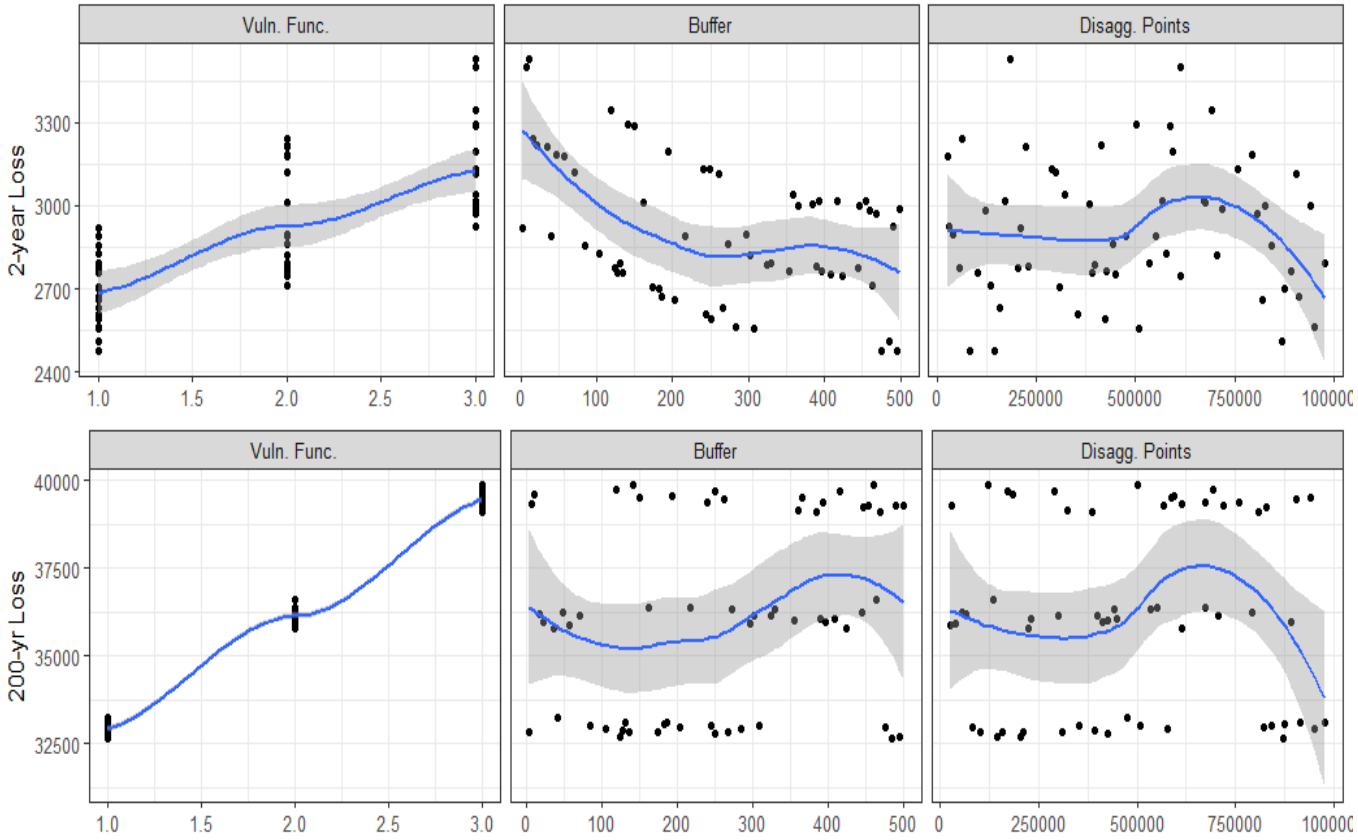
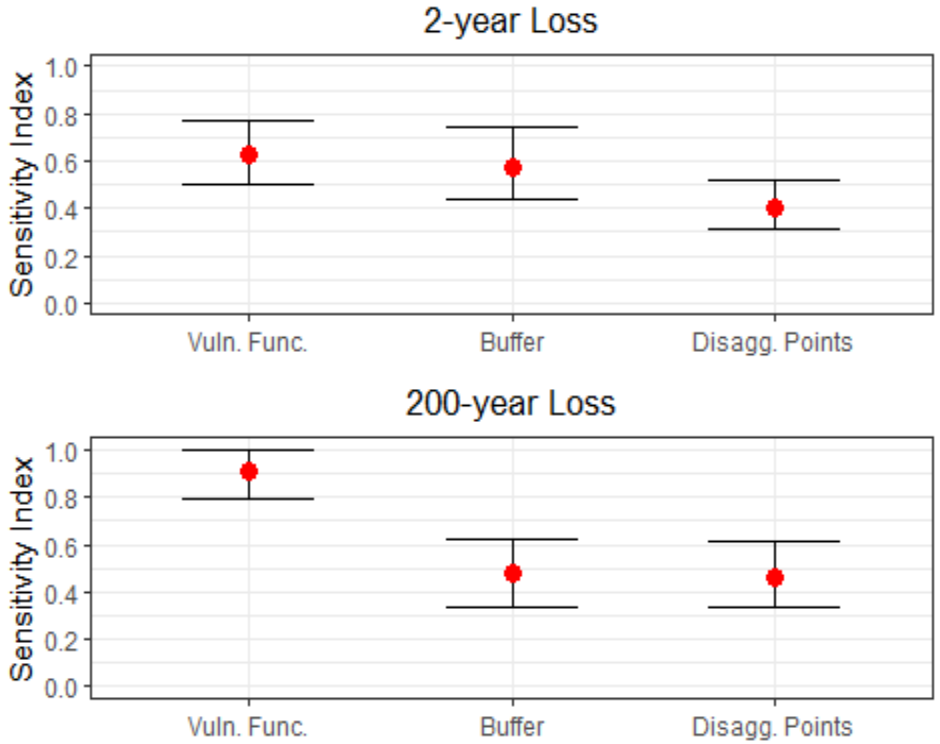
Application to JBA's Global Flood Model

GSA allows to automatically estimate the most influential inputs.





The most influential input factors vary with the RP.
If the 200-year loss is of interest, special focus should be given to the vulnerability function.

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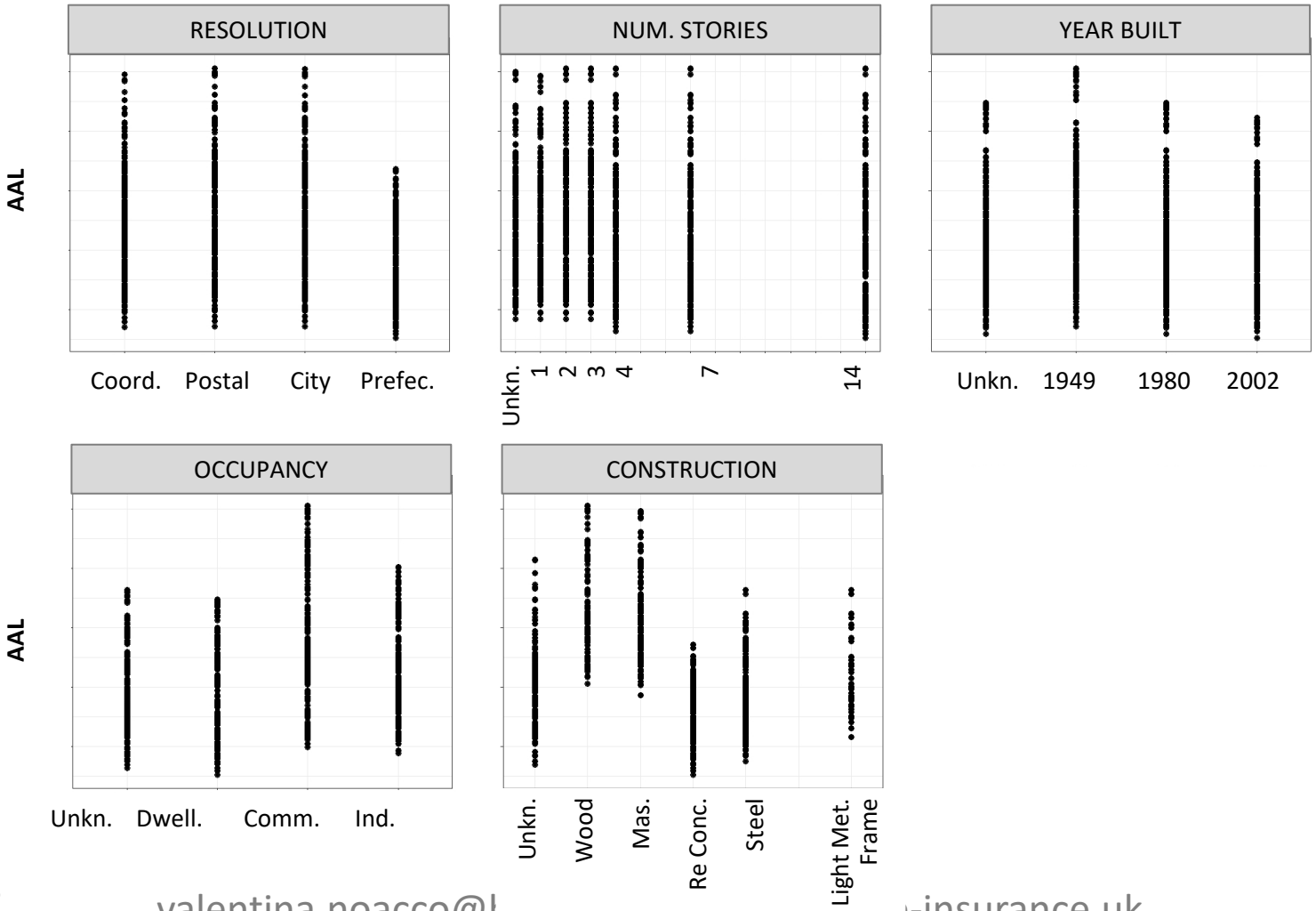
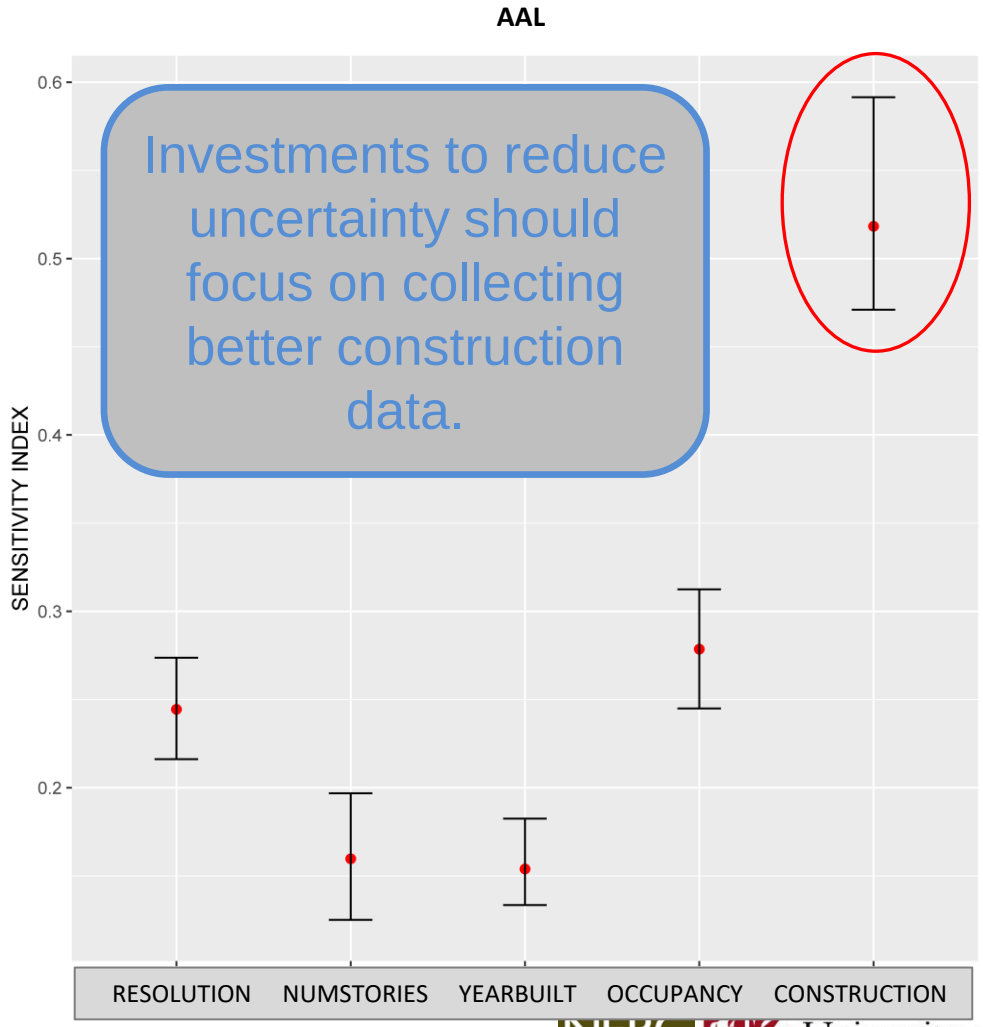
Application with AXA XL on a 3rd party wind peril model





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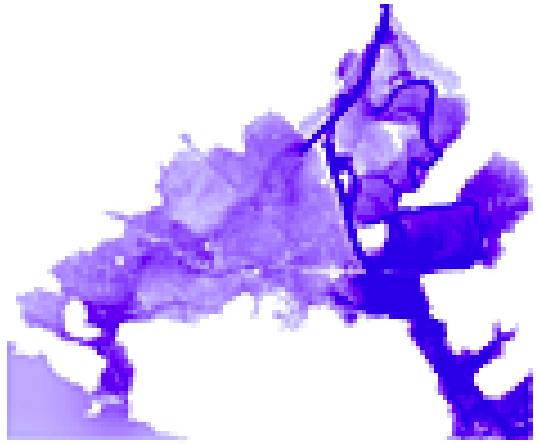
Application to a flood inundation model

Savage et al. 2016 *Water Resources Research*



Input factors

- Forcing Hydrograph
- Channel friction
- Floodplain friction
- Spatial resolution
- DEM

Input datasets, parameters and modelling choices

GSA can be applied to a range of input factors,
Both continuous and discrete

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Application to a flood inundation model

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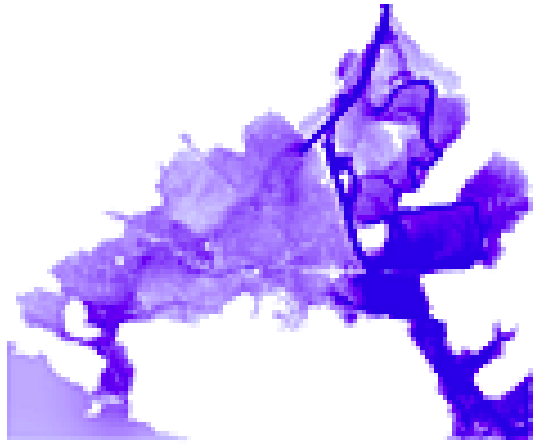

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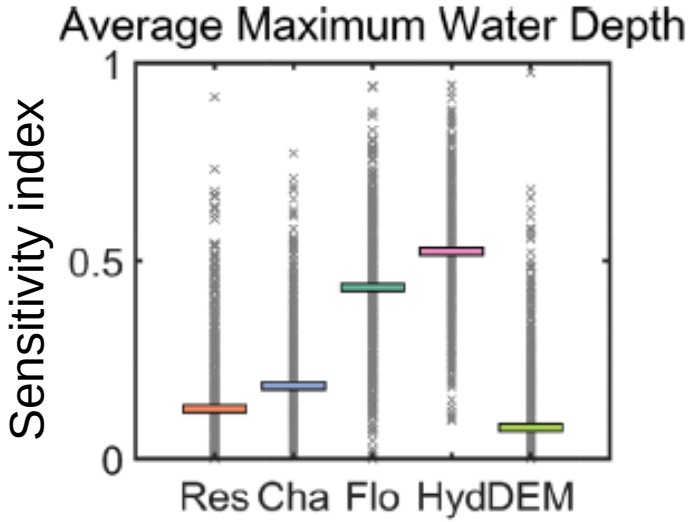

The forcing hydrograph being the most influential validates our understanding of the model.

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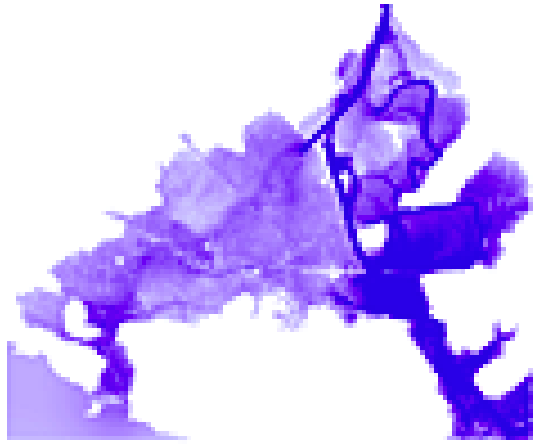
Application to a flood inundation model

Savage et al. 2016 *Water Resources Research*



Input factors

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- Channel friction
- Floodplain friction
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- DEM

} Input datasets, parameters and modelling choices

Maximum Water Depth

Modelling choices become influential when looking at individual locations.

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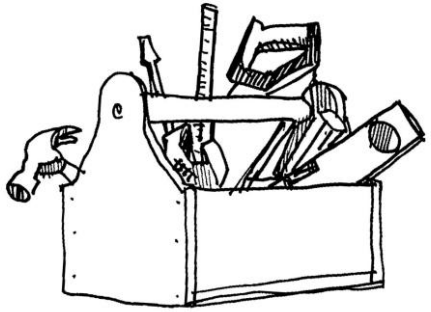
The SAFE toolbox

- Developed in 2014 by Pianosi *et al.*
- Over 2000 users in academia in 50+ countries
- Python, R and Matlab versions available
- Easy to use, flexible, modular structure, easy to integrate with models running outside Python, R or Matlab
- Open access and open source
- Variety of case studies available
- Many **visualisation** functions
- Lots of commented code and **workflows**



www.safetoolbox.info

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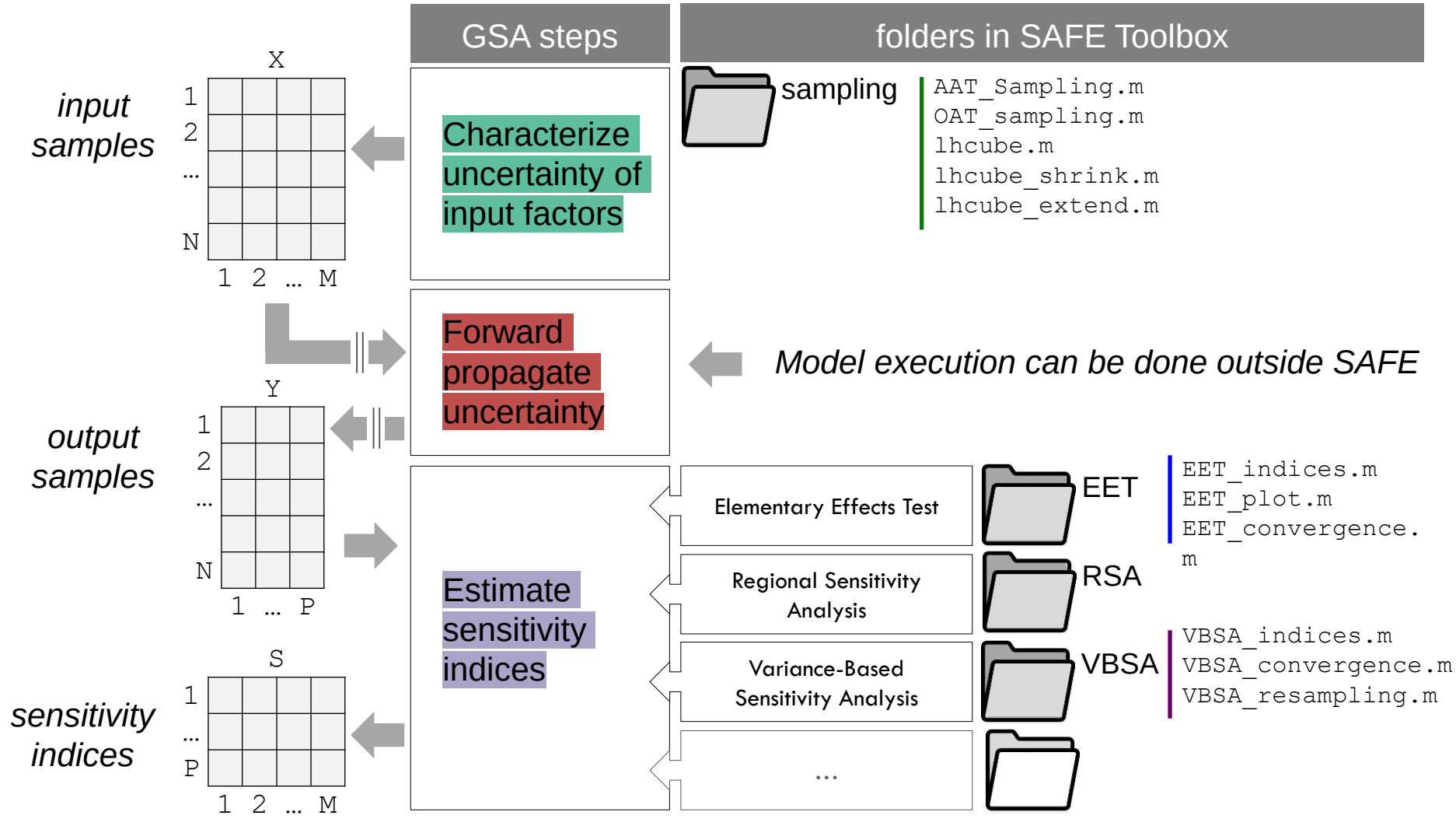
The modular structure of SAFE enables easy coupling to stand-alone models



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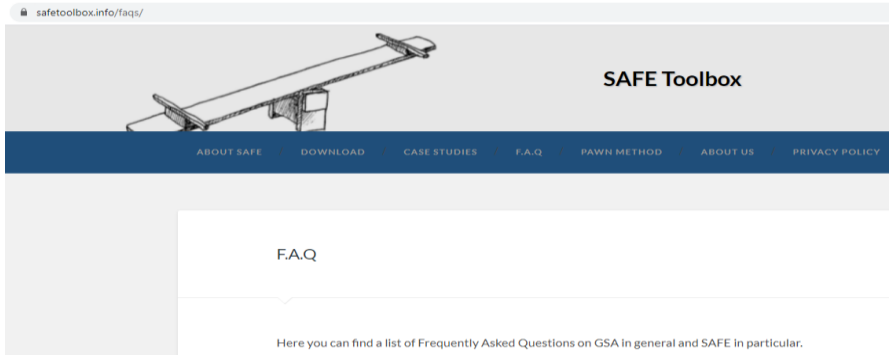
Resources available

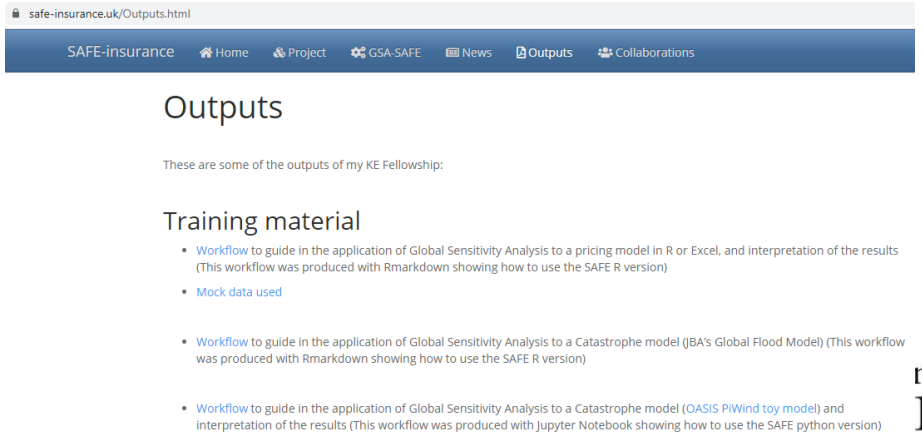
- Inside SAFE toolbox (no manual, documentation embedded in scripts as comments, workflow scripts guide you through the steps to perform GSA)

```
%% Step 1: set paths

my_dir = pwd ; % use the 'pwd' command if you have already setup the Matlab
% current directory to the SAFE directory. Otherwise, you may define
% 'my_dir' manually by giving the path to the SAFE directory, e.g.:
% my_dir = '/Users/francescapianosi/Documents/safe_R1.0';

% Set current directory to 'my_dir' and add path to sub-folders:
cd(my_dir)
addpath(genpath(my_dir))

%% Step 2: setup the model and define input ranges

% Load data:
load -ascii LeafCatch.txt
rain = LeafCatch(1:365,1)   ;
evap = LeafCatch(1:365,2)   ;
flow = LeafCatch(1:365,3)   ;

% Define input distribution and ranges:
M  = 5 ; % number of uncertain parameters [ Sm beta alfa Rs Rf ]
DistrFun  = 'unif'  ; % Parameter distribution
DistrPar  = { [ 0 400 ]; [ 0 2 ]; [ 0 1 ]; [ 0 0.1] ; [ 0.1 1 ] } ; % Parameter ranges
```

- SAFE Toolbox website www.safetoolbox.info (FAQ page contains explanations, references and code to answer common questions)



- My website www.safe-insurance.uk (Outputs page contains re/insurance case studies + code)



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References

Review papers to get started:

- Pianosi et al. 2016 Sensitivity analysis of environmental models: A systematic review with practical workflow. *Environmental Modelling and Software*, 79 (https://doi.org/10.1016/j.envsoft.2016.02.008)
- Wagener and Pianosi 2019 What has Global Sensitivity Analysis every done for us? … *Earth-Science Reviews*, 194 (https://research-information.bris.ac.uk/ws/portalfiles/portal/189945689/Wagener_Pianosi_ESR_11.pdf)

Technical guidelines:

- Noacco et al. 2019 Matlab/R workflows to assess critical choices in Global Sensitivity Analysis using the SAFE toolbox. *MethodsX* (https://doi.org/10.1016/j.mex.2019.09.033)

Introduction to the SAFE toolbox:

- Pianosi et al. 2015 A Matlab toolbox for Global Sensitivity Analysis. *Environmental Modelling and Software*. 70 (https://doi.org/10.1016/j.envsoft.2015.04.009)

Examples:

- Savage et al. 2016 Quantifying the importance of spatial resolution and other factors through global sensitivity analysis of a flood inundation model. *Water Resources Research.* 52 (https://doi.org/10.1002/2015WR018198)

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APPENDIX

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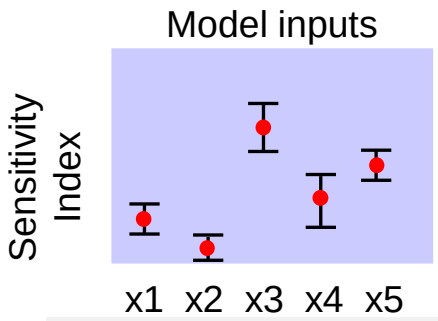
GSA allows to achieve different objectives

Ranking

Which input factors have more influence on the model's response?

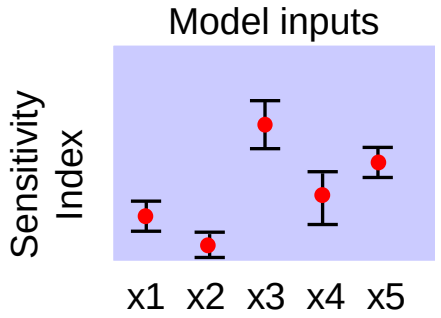


Then possible SA methods:
- Regional Sensitivity Analysis
- Elementary Effects
- Variance Based

→ $x_3 > x_5 > x_4 > x_1 > x_2$

Screening

Is there any input factor that has negligible influence on the model's response?

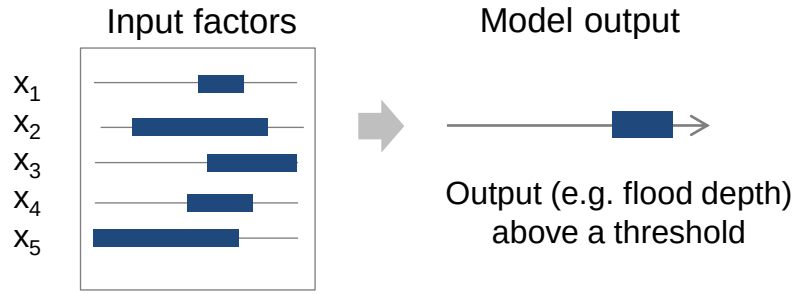


Then possible SA methods:
- Elementary Effects
- Variance Based

→ x_2 non influential

Mapping

Are there subranges of the input factors that map into "significant" (e.g. extreme) output values?



Then possible SA methods:
- Regional Sensitivity Analysis
- Classification and Regression Trees

→ specific subranges of the inputs give a flood depth above a threshold

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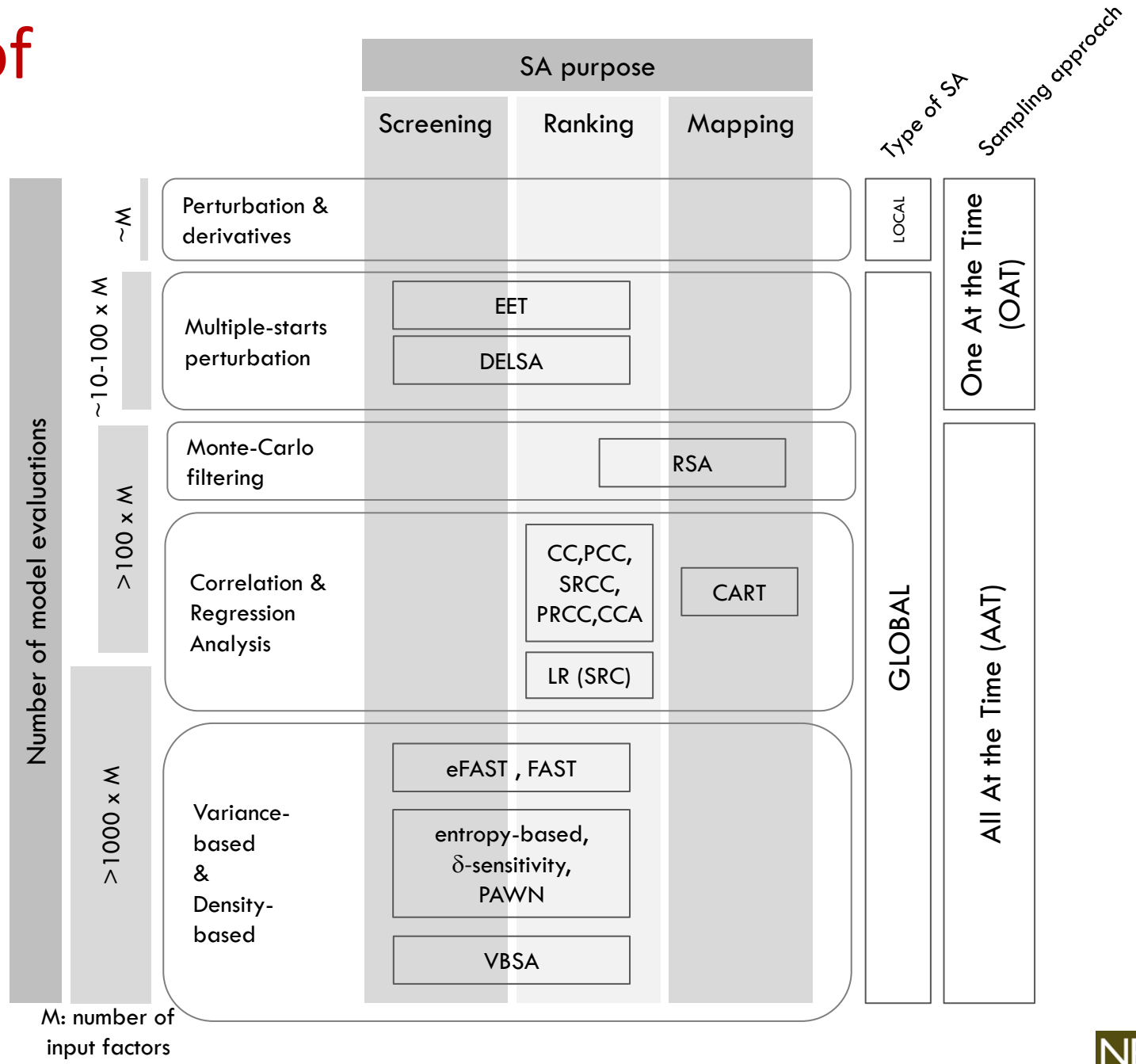
Classification of GSA methods



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