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

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[KE Fellowship: NE/R003734/1]

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Topics

- What is Global Sensitivity Analysis (GSA)?
- What can you use GSA for?
- How does GSA work?
- Examples of benefits of using GSA

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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.

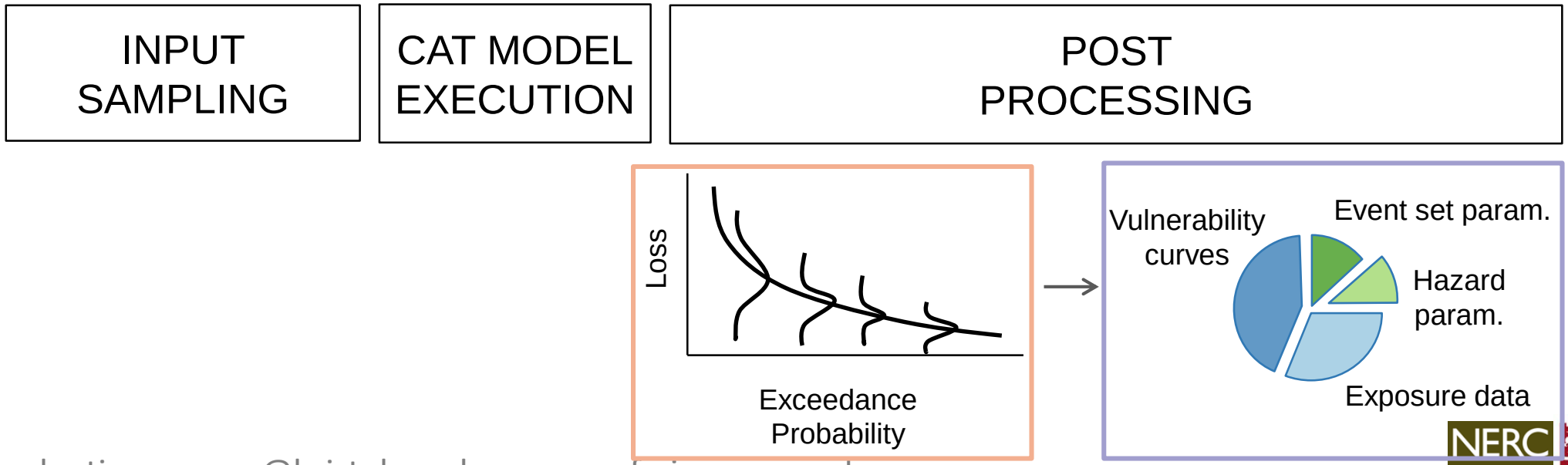
SA focuses on attributing output uncertainty to the different sources of uncertainty.

[1] Characterize uncertainty of input factors

[2] Forward propagation of uncertainty

[3] Uncertainty Analysis

[4] Sensitivity Analysis



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What can you use SA for?

- To increase understanding of the model, beyond default set-up (validation)

  Is the relationship between model inputs and outputs as expected?
  Any odd behaviour?

- To identify priorities for uncertainty reduction (improvement)

  What do I need to make it more robust?

- To support decision-making (use)

  Improve communication between modellers and decision-makers

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

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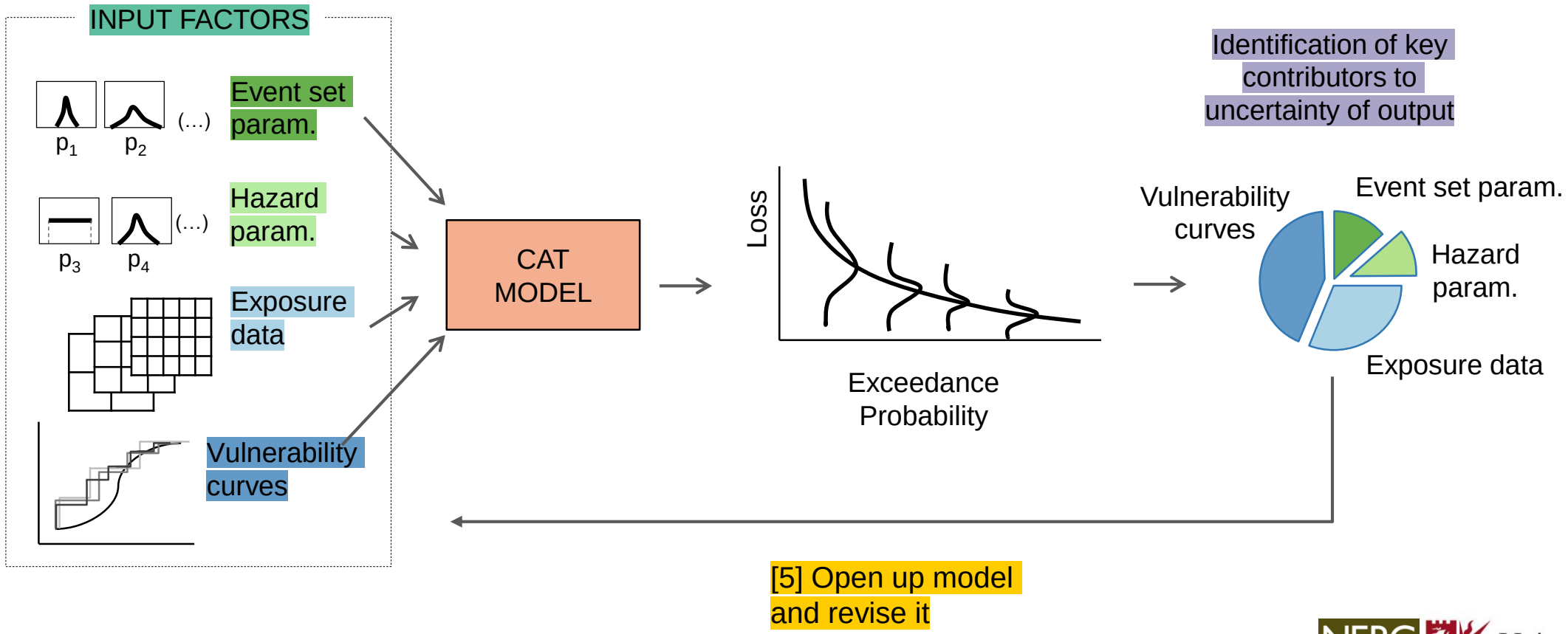
How does it work?

[1] Characterize uncertainty of input factors

[2] Forward propagation of uncertainty

[3] Uncertainty Analysis

[4] Sensitivity Analysis



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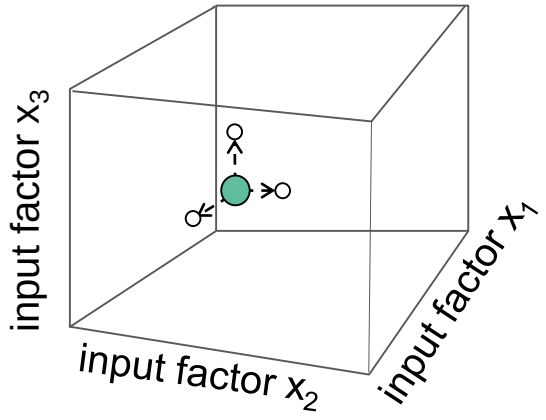
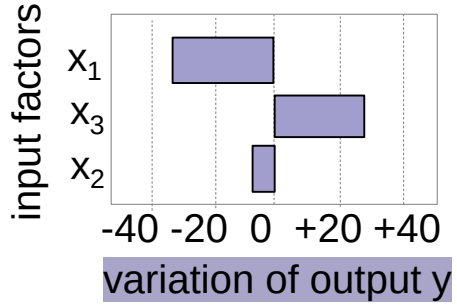
What is the difference between Local and Global SA?

Local SA investigates the effects of variation of uncertain inputs from a baseline point



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



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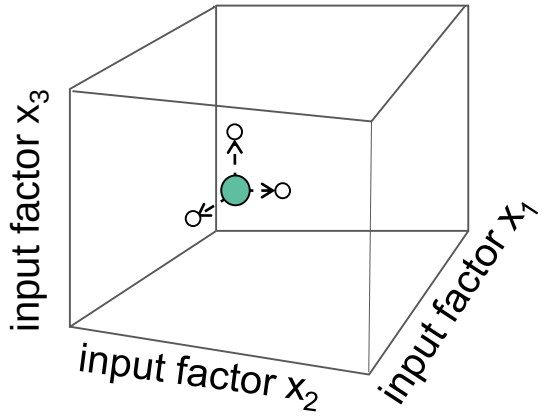

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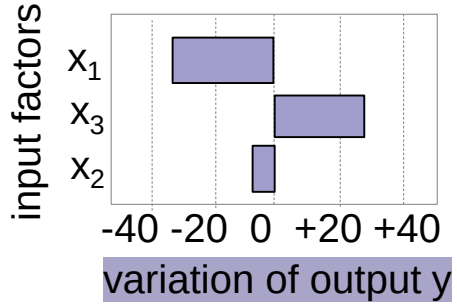

Useful when you have a clear baseline point and are only interested in what happens for small deviations from it

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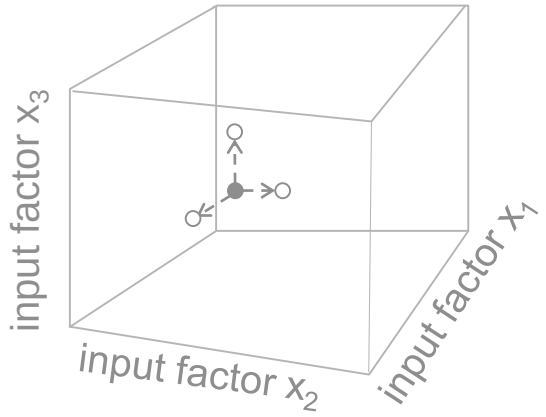
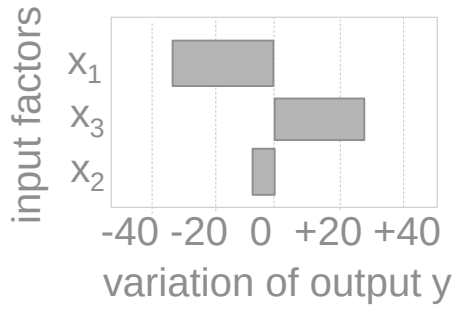
GSA investigates model response independently of baselines

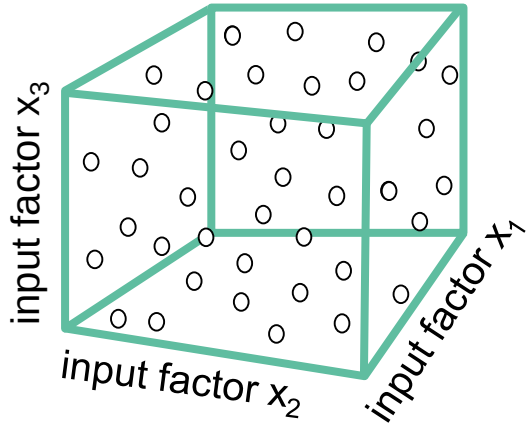
Local SA investigates the effects of variation of uncertain inputs from a baseline point

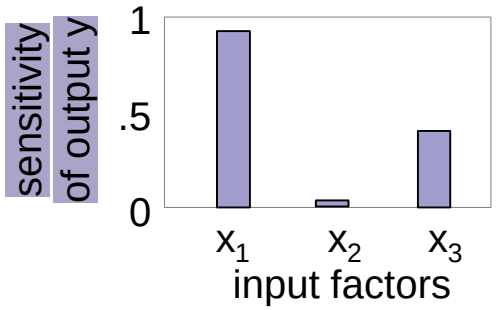




$y = f(x_1,x_2,x_3)$

Global SA investigates the effects of variation of uncertain inputs across their entire variability space





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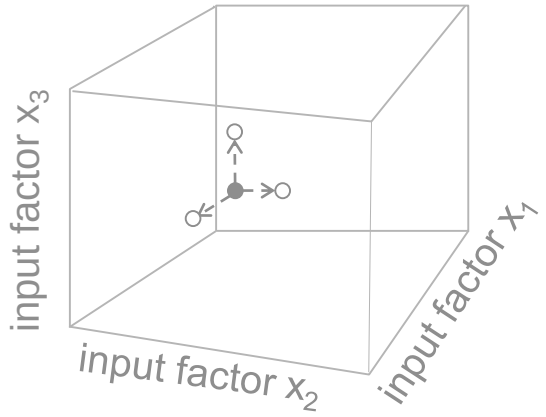

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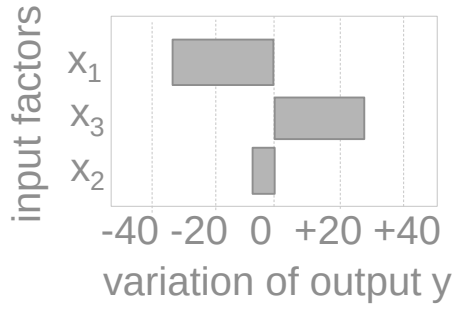

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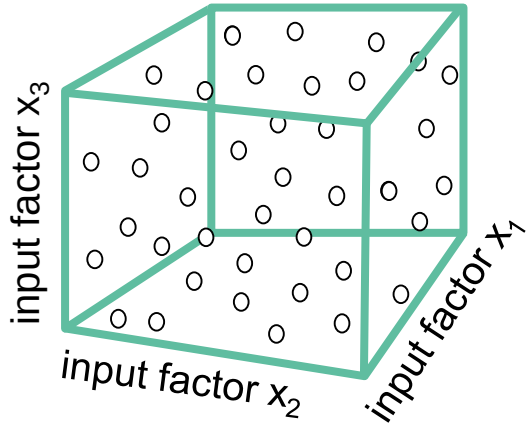

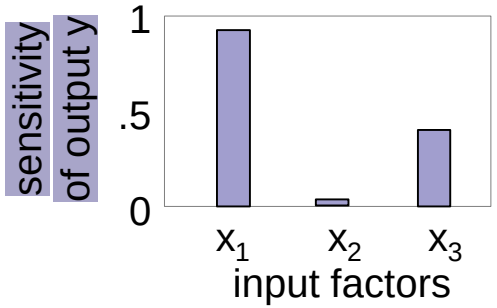

Useful when there is no specific baseline but one is interested in exploring the model response against different combinations of inputs

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EXAMPLES OF USING GSA

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GSA can help to prioritise efforts to reduce uncertainty

Application to a flood inundation model

Abily et al. 2016 *Environmental Modeling & Software*

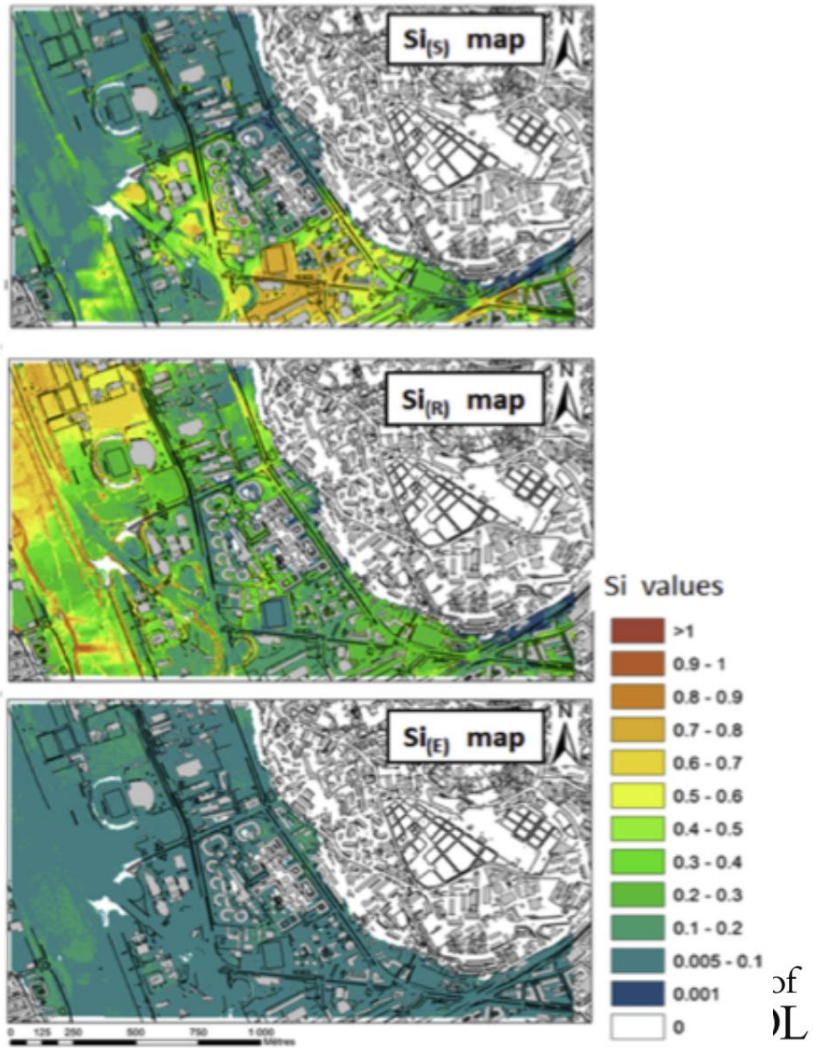
Input:

1. Level of details in representing above ground features

2. Spatial resolution

3. Measurement errors in topographic data

Output: water depth



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No need to worry about measurement errors here

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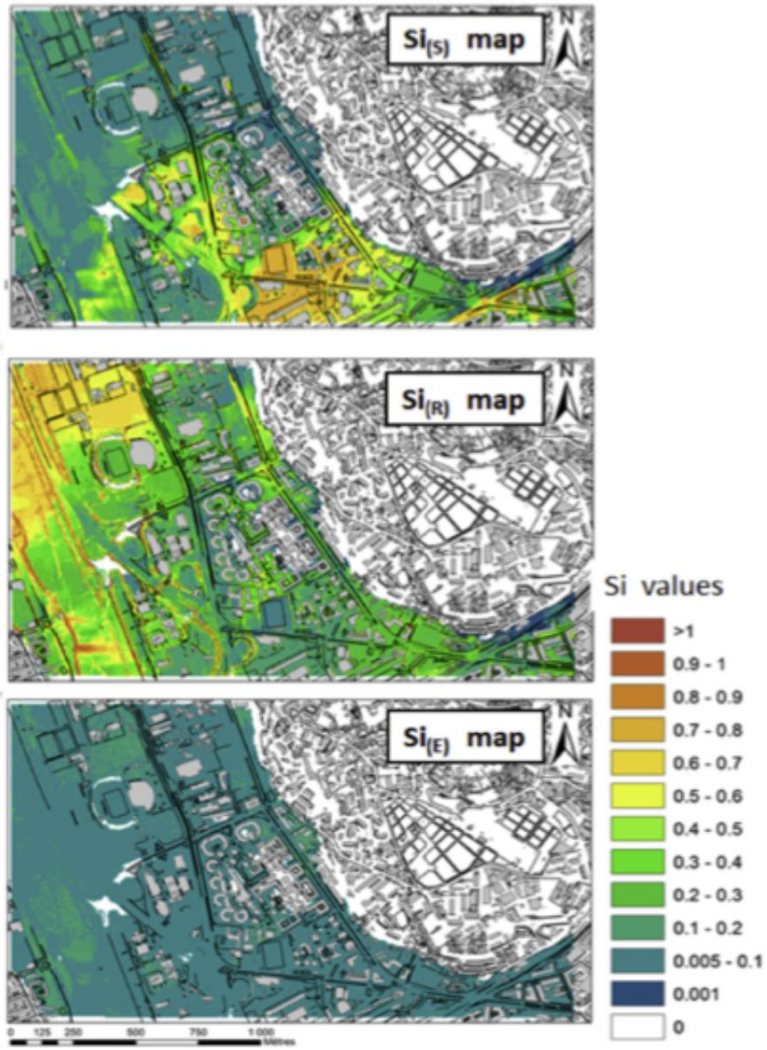

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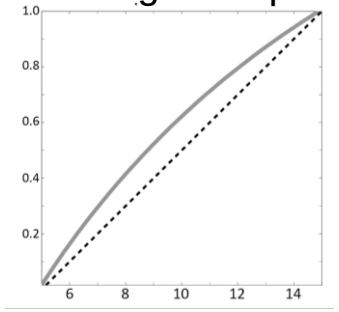
GSA can help to understand which input values lead to ‘significant’ outputs

Application to an integrated assessment model of climate change

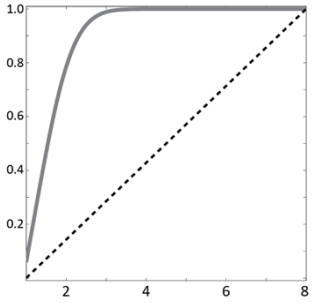
Model runs producing global temperature increase < 2°C (17%)

Model runs producing global temperature increase > 2 °C

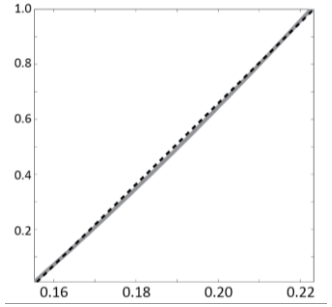
Population growth param.



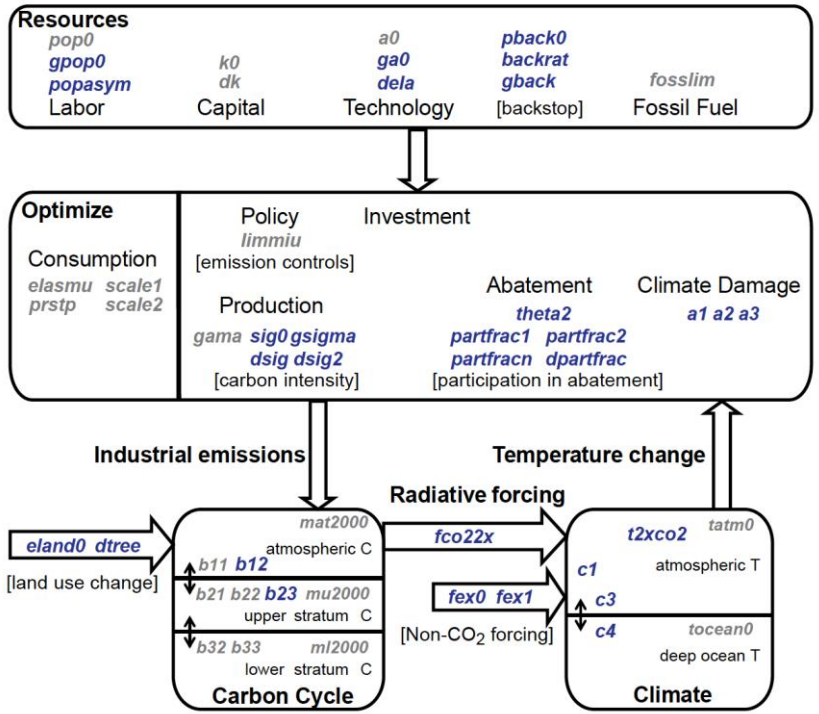
Climate sensitivity param.



Carbon cycle model param.



Butler et al. 2014 *Environmental Modeling & Software*



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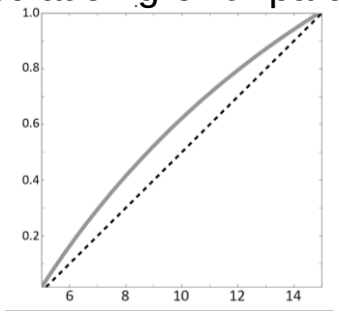

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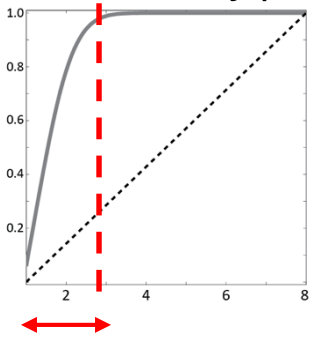

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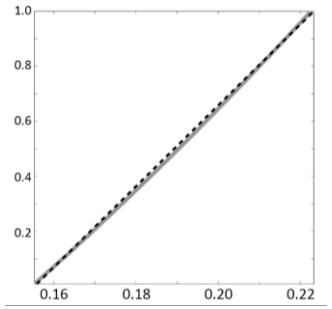
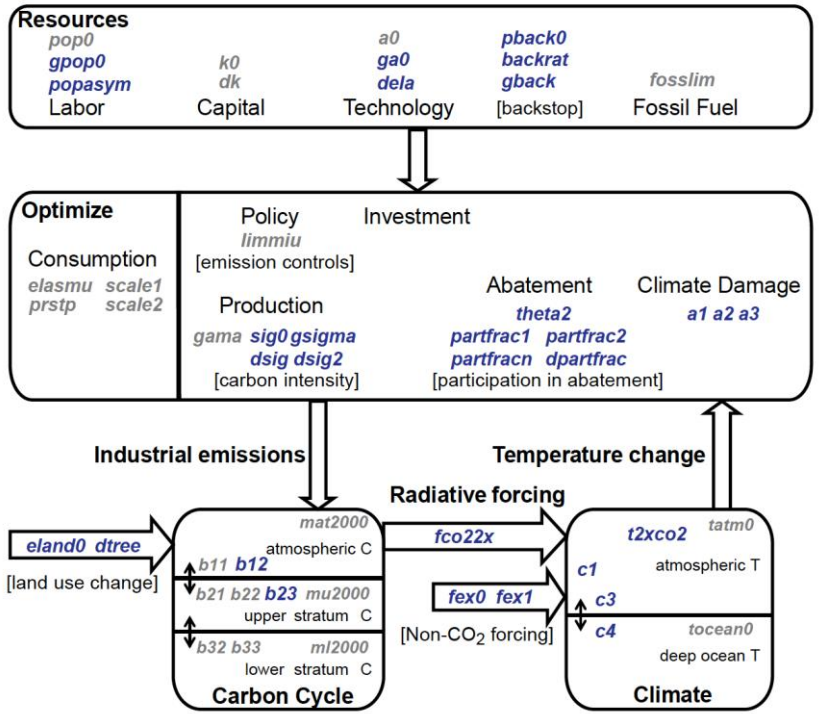


Range of values leading to below 2°C increase

Butler et al. 2014 *Environmental Modeling & Software*



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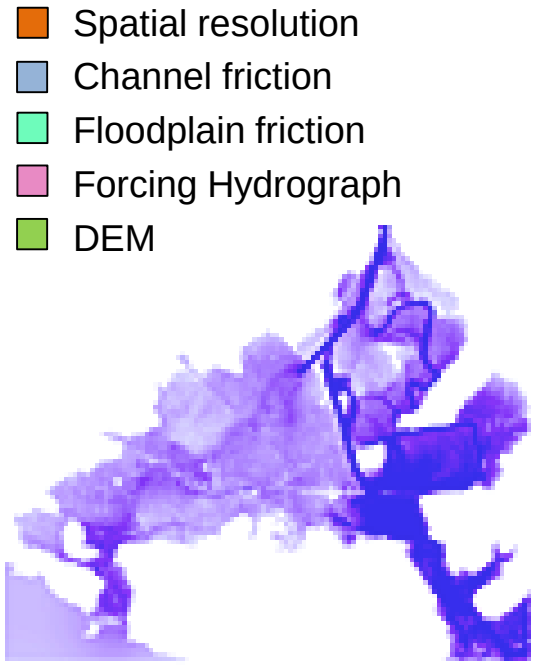
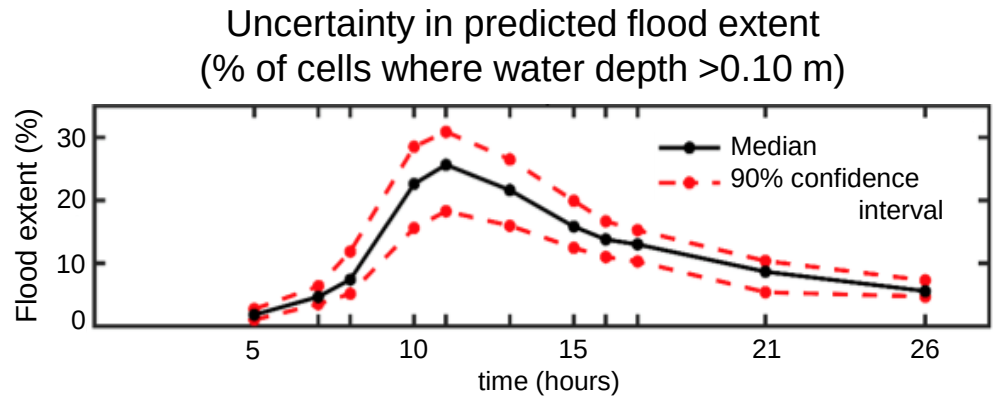
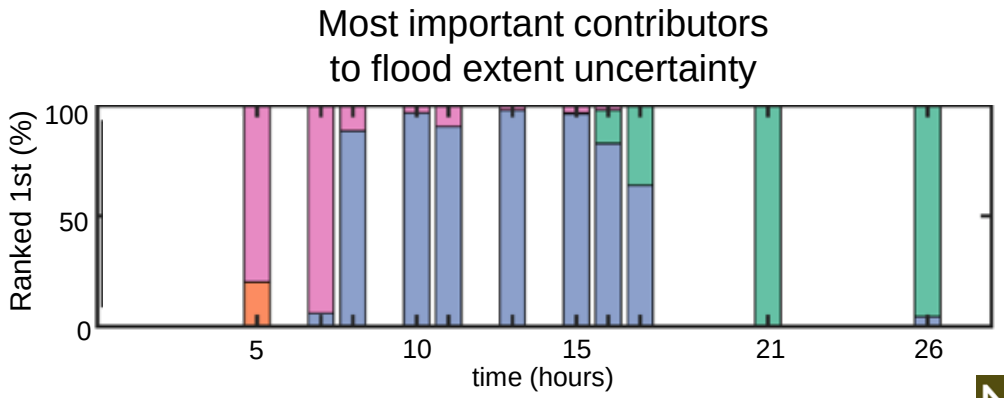
GSA can be used to test models and inform decision-making

Application to a flood inundation model

Savage et al. 2016 *Water Resources Research*







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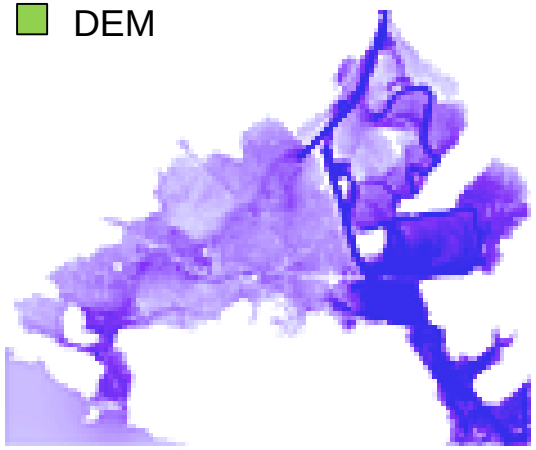
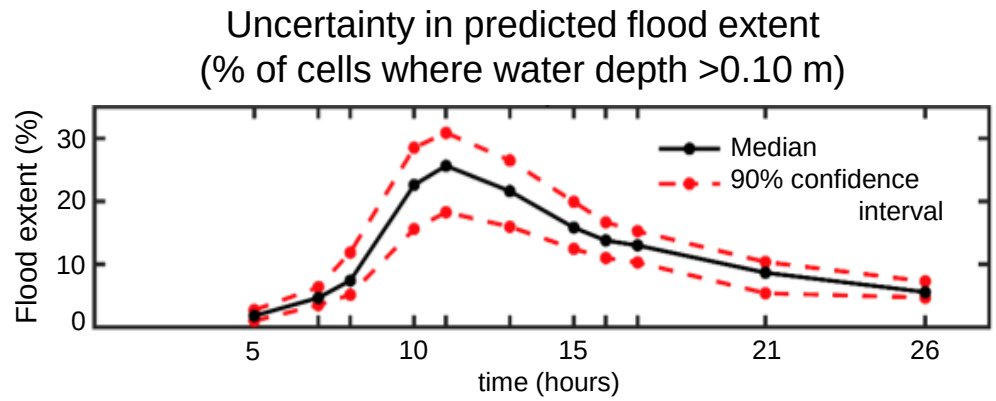
GSA can be used to test models and inform decision-making

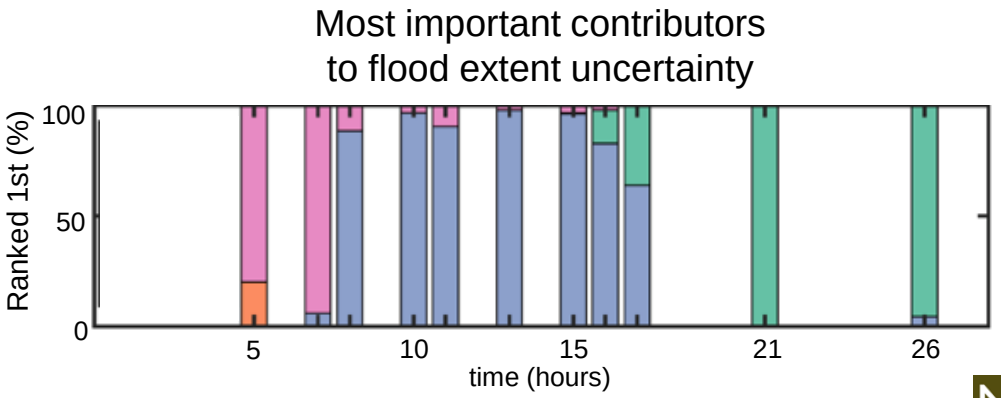
Application to a flood inundation model

Most influential inputs change during the flood event

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







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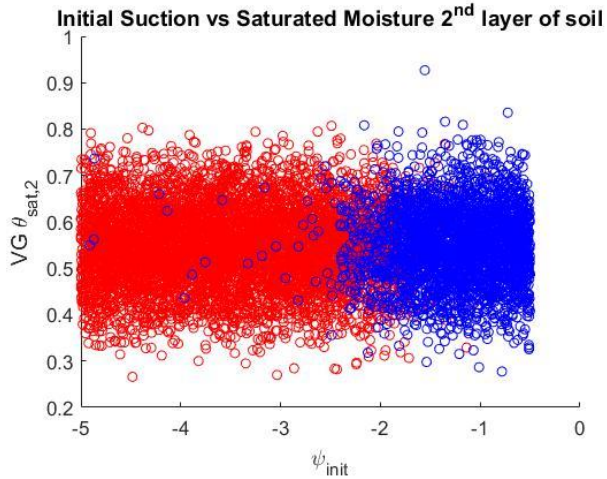
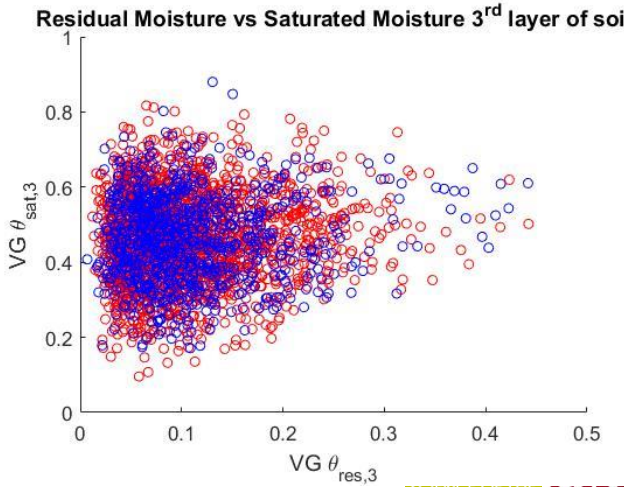
GSA can be used to validate models –
If it doesn't meet expectation it can help debugging

Application to a landslide model

Bozzolan et al. in preparation





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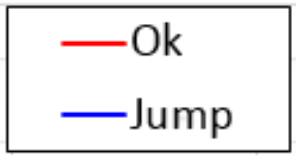
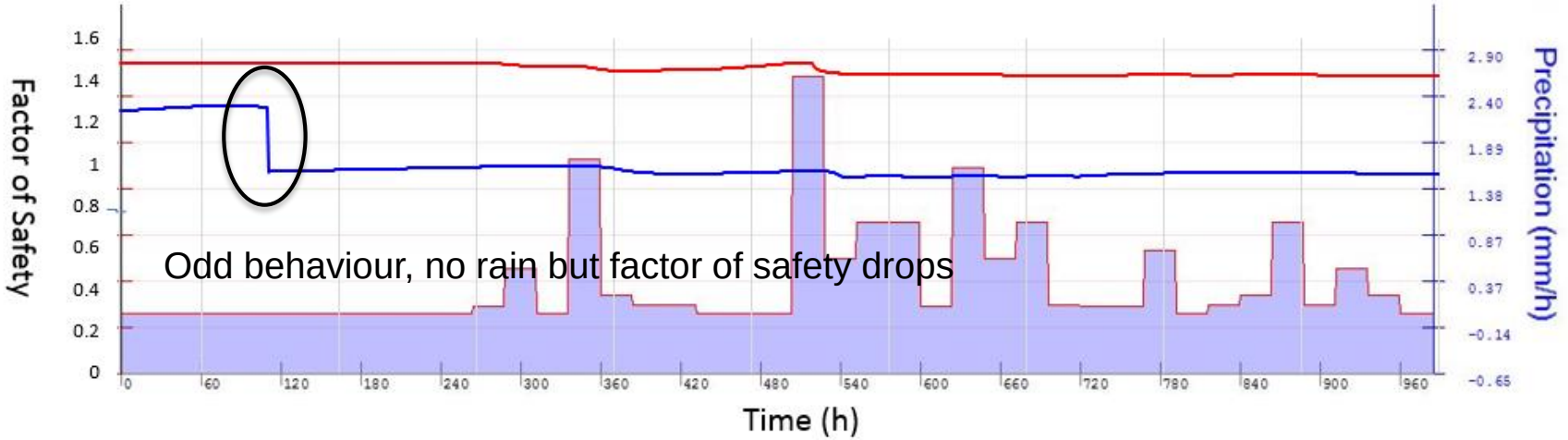
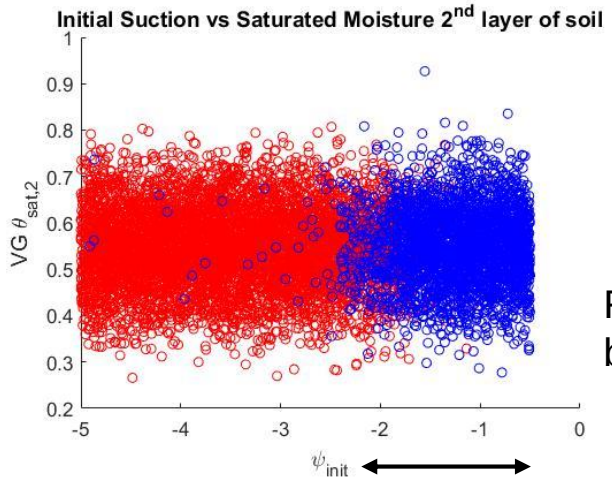
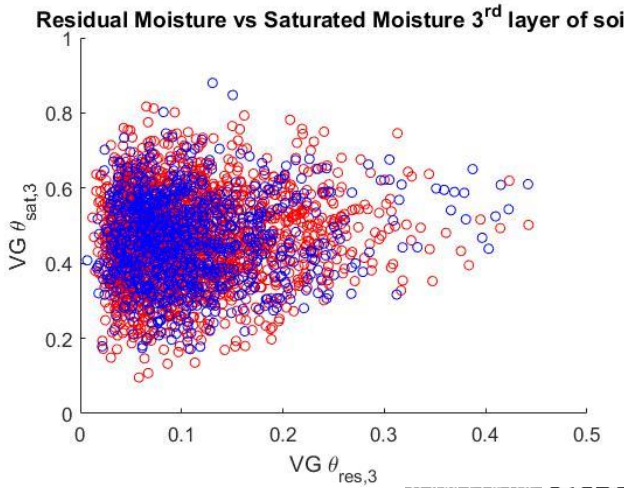






Range of values that should be avoided



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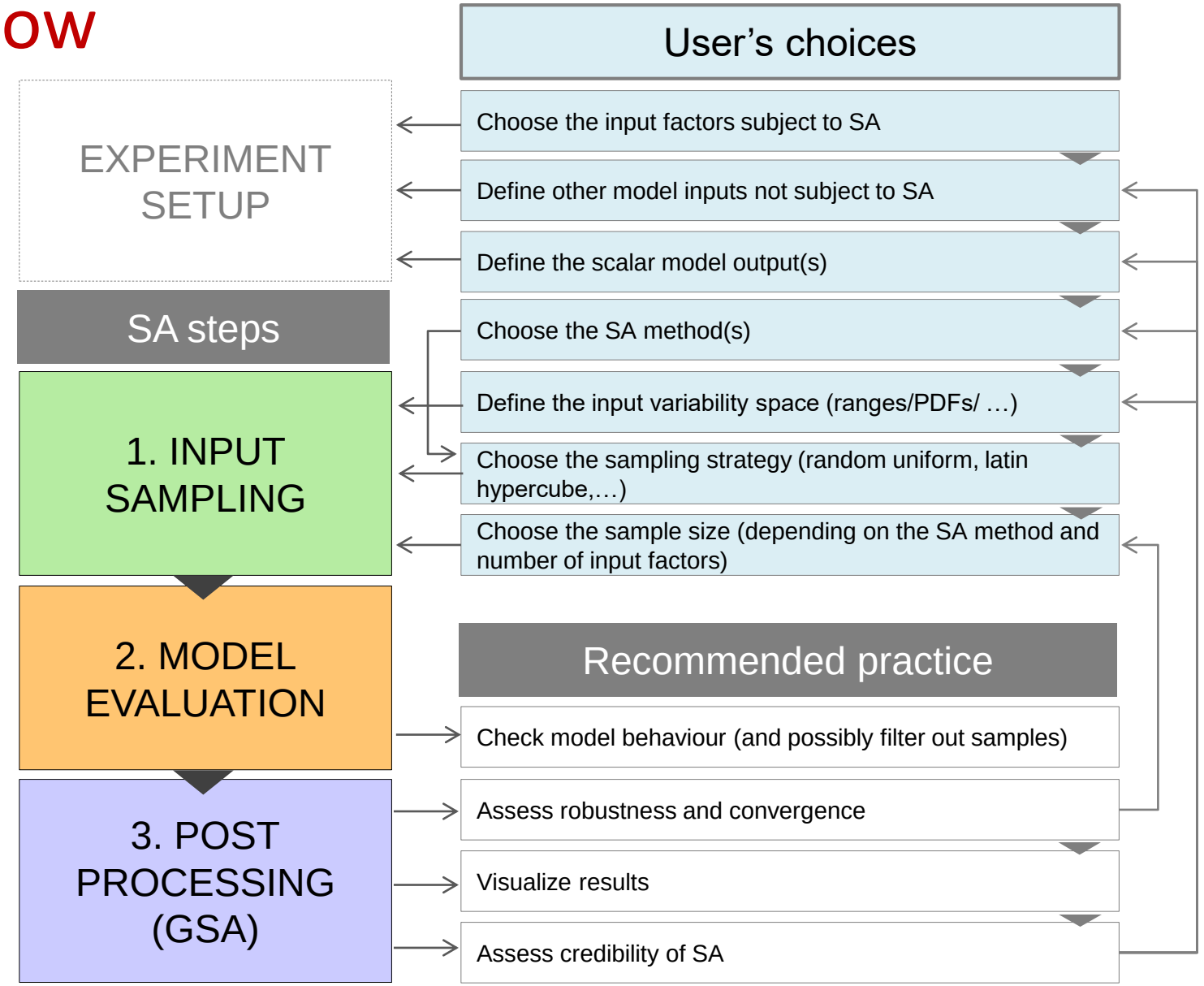
GSA Workflow



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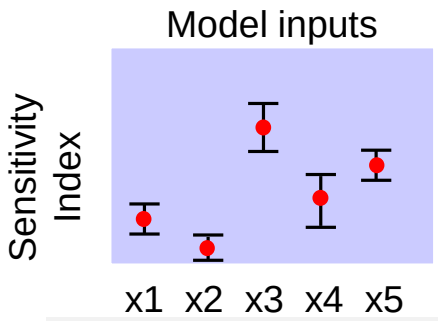
GSA allows to achieve different objectives

Ranking

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

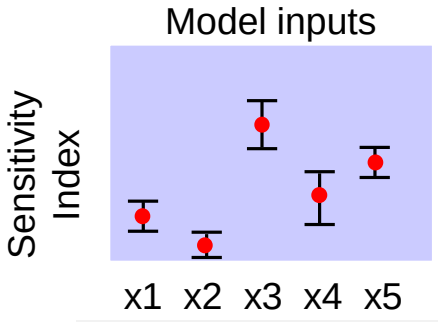


Then possible SA methods:
- Regional Sensitivity Analysis
- Elementary Effects
- Variance Based

→ $x_3 > x_5 > x_4 > x_1 > x_2$

Screening

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

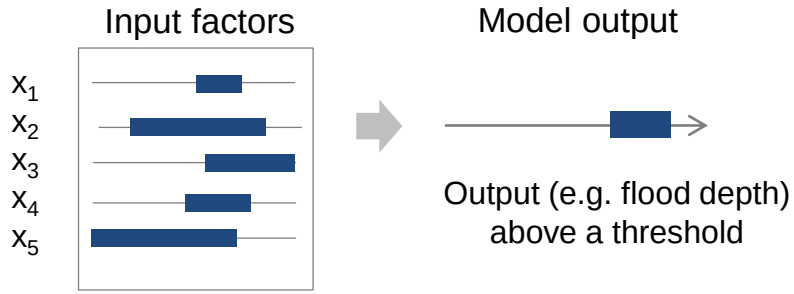


Then possible SA methods:
- Elementary Effects
- Variance Based

→ x_4 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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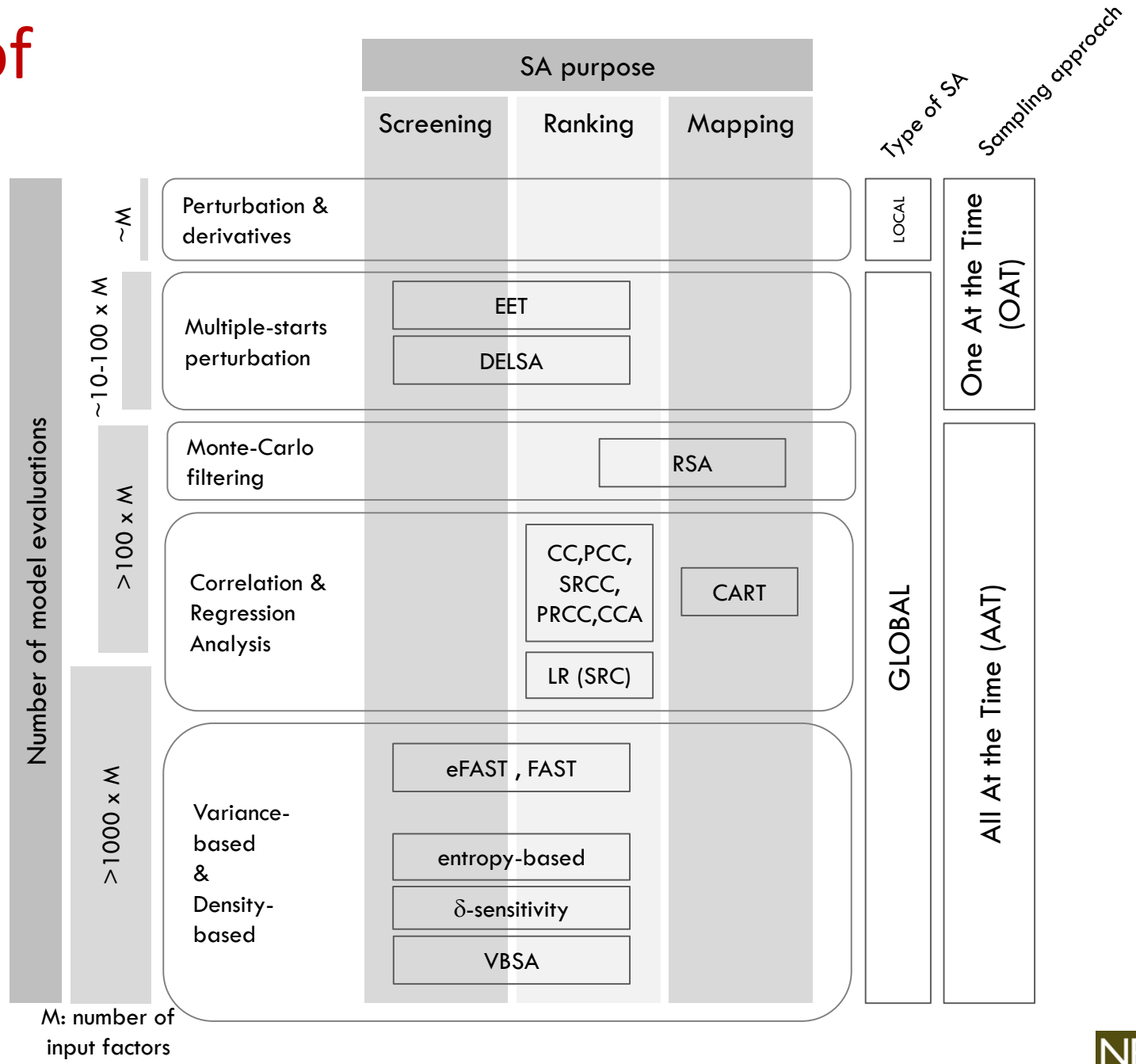
Classification of GSA methods



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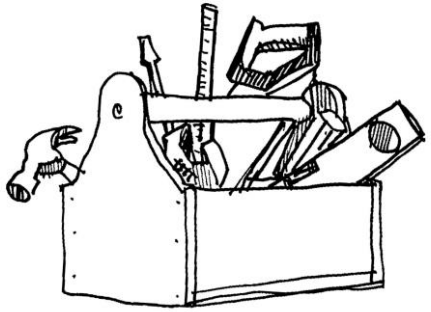
SAFE Toolbox for Sensitivity Analysis

- Developed in 2014 by Pianosi *et al.*
- Over 1800 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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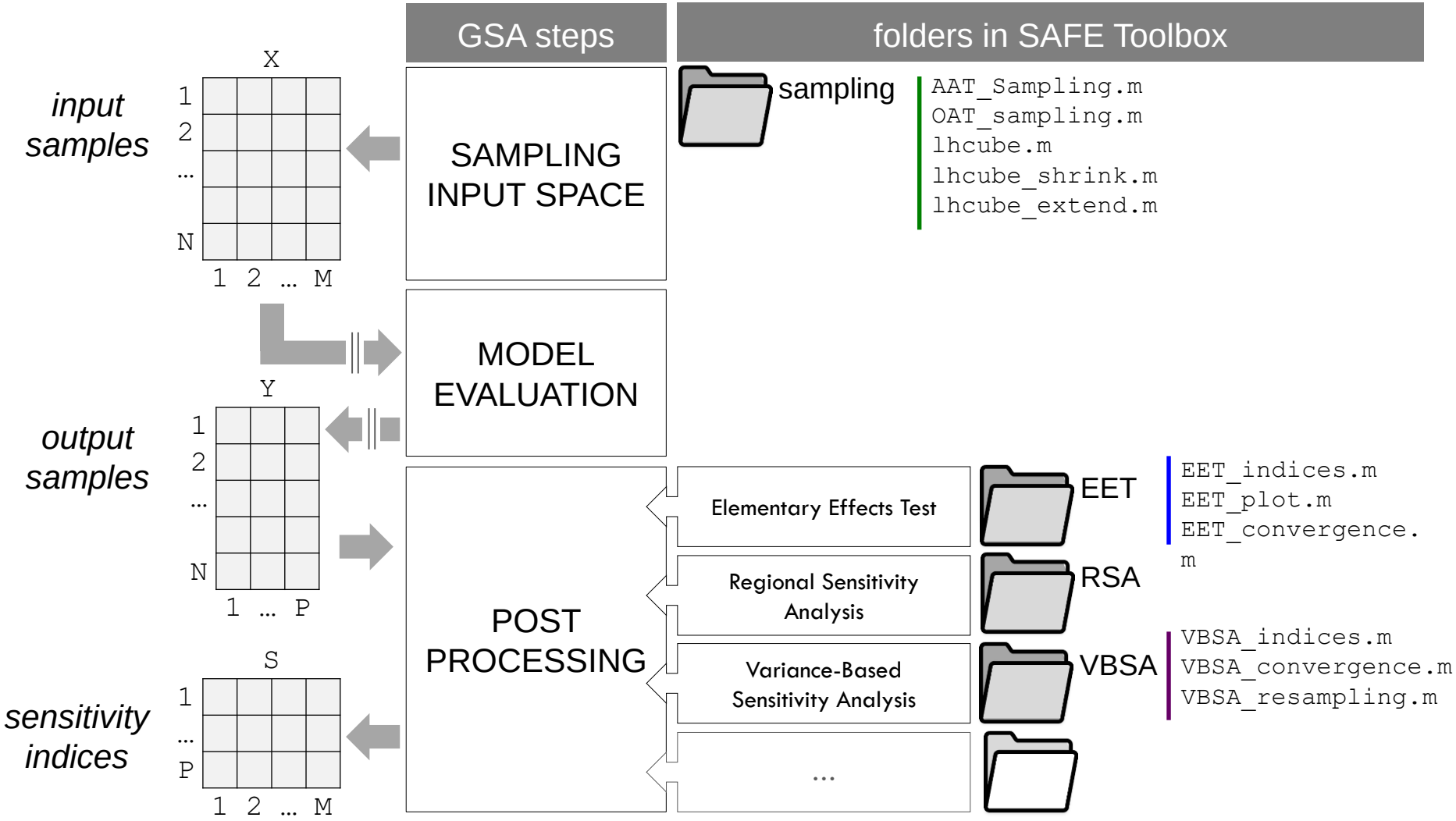
Modular structure of SAFE



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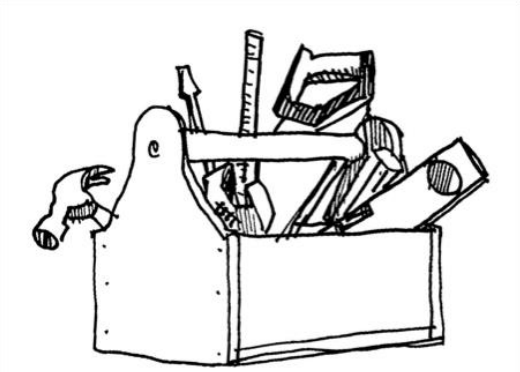
Conclusions

Uncertainty and Sensitivity Analysis are very useful to investigate the propagation of uncertainty through a model and hence support their improvement, validation and use for inference or decision-making



www.safetoolbox.info
(Python, R, matlab)

The key to a successful application often lies in
making 'good' set-up choices
(definition of input variability space, choice of outputs, etc)

Some guidance in:

Noacco et al. (in press). Matlab/R workflows to assess critical choices in Global Sensitivity Analysis using the SAFE toolbox. *MethodsX*
(currently accessible at: https://eartharxiv.org/pu83z/)

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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.
- Wagener and Pianosi 2019 What has Global Sensitivity Analysis every done for us? … *Earth-Science Reviews*, 194.

Technical guidelines:

- Noacco et al. in press Matlab/R workflows to assess critical choices in Global Sensitivity Analysis using the SAFE toolbox. *MethodsX* (currently accessible at: https://eartharxiv.org/pu83z/)

Introduction to SAFE toolbox:

- Pianosi et al. 2015 A Matlab toolbox for Global Sensitivity Analysis. *Environmental Modelling and Software*. 70.

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.
- Abily et al 2016 Spatial Global Sensitivity Analysis of High Resolution classified topographic data use in 2D urban flood modelling. *Environmental Modelling & Software*, 77.
- Butler et al. 2014 Identifying parametric controls and dependencies in integrated assessment models using global sensitivity analysis. *Environmental Modelling & Software*, 59.
- Bozzolan et al. in preparation. Exploring the effect of informal urban activities on rainfall triggered landslides hazard

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