

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

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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

# 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

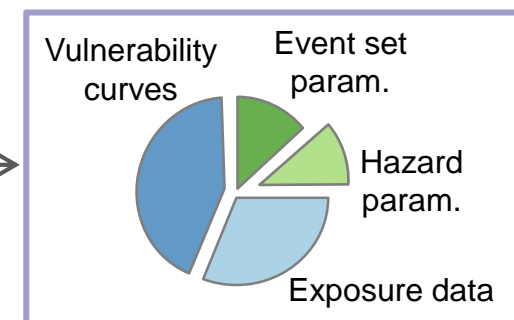
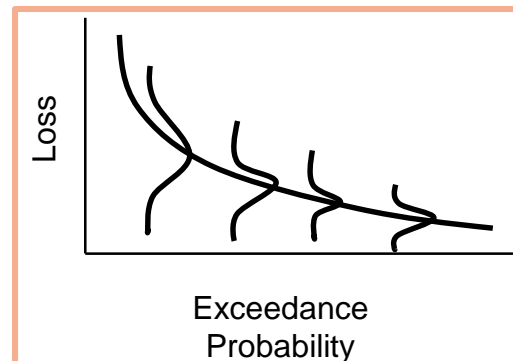
[3] Uncertainty  
Analysis

[4] Sensitivity Analysis

INPUT  
SAMPLING

CAT MODEL  
EXECUTION

POST  
PROCESSING



# 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

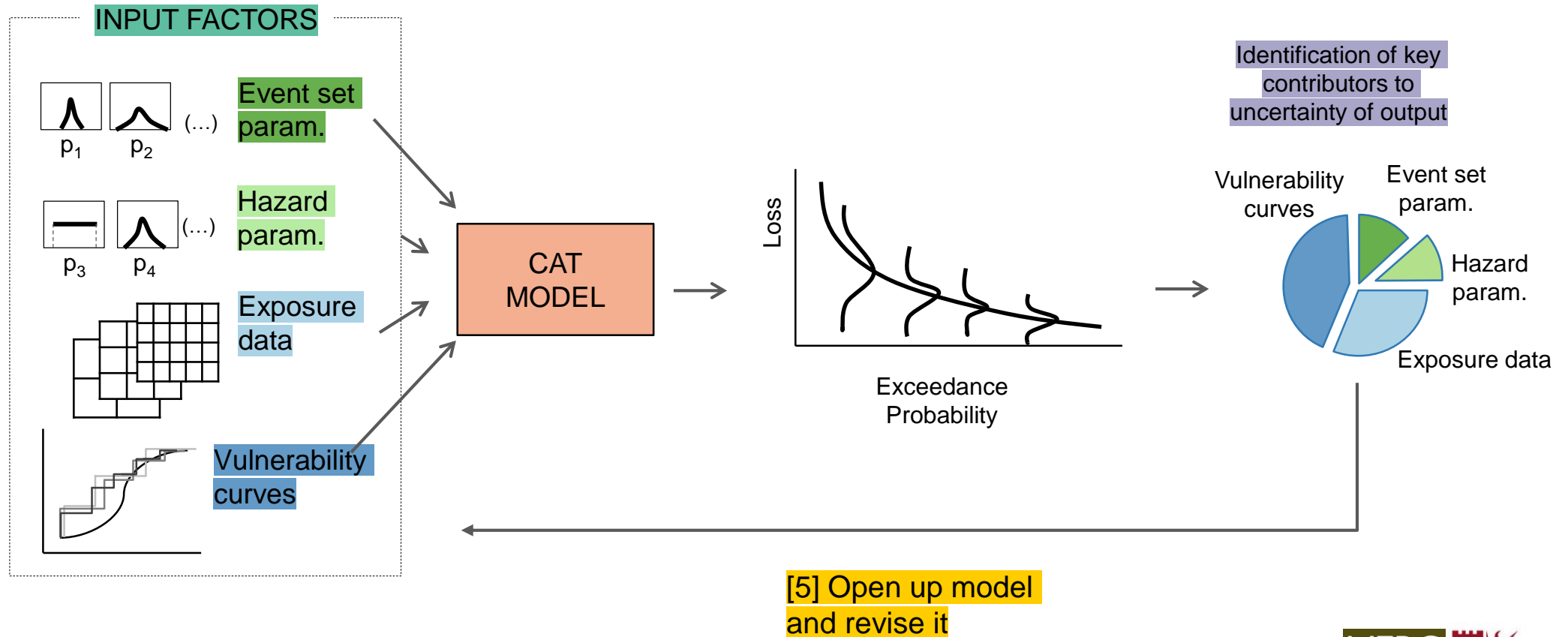
# How does it work?

[1] Characterize uncertainty of input factors

[2] Forward propagation of uncertainty

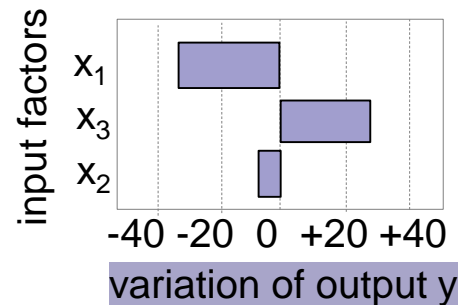
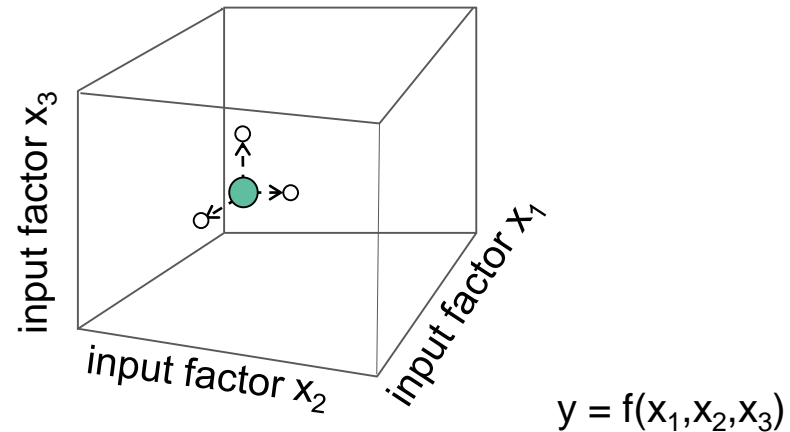
[3] Uncertainty Analysis

[4] Sensitivity Analysis



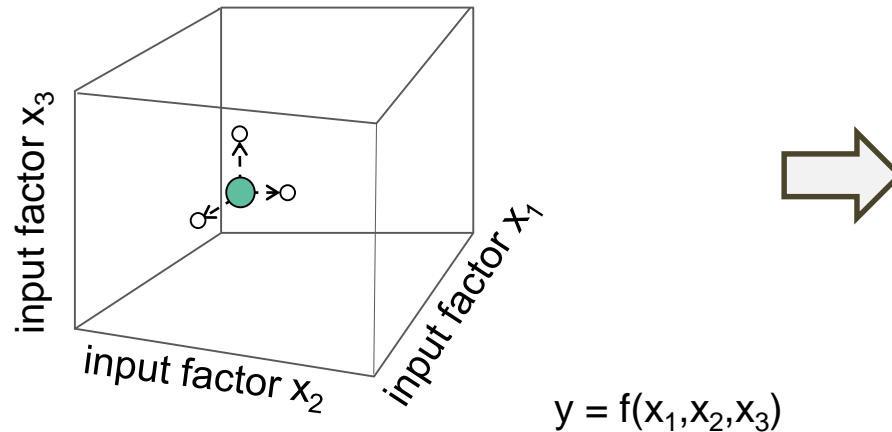
# What is the difference between Local and Global SA?

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

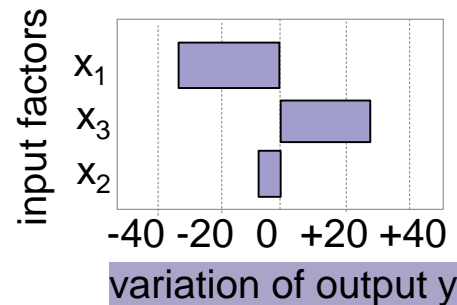


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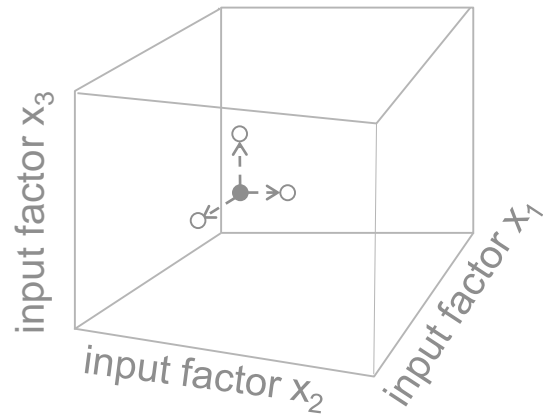


Useful when you have a clear baseline point and are only interested in what happens for small deviations from it

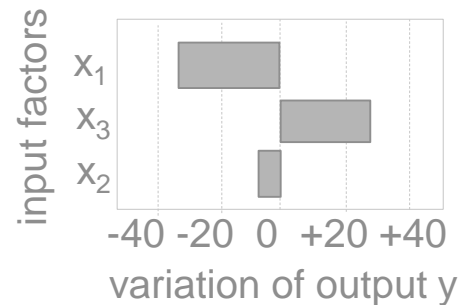


# GSA investigates model response independently of baselines

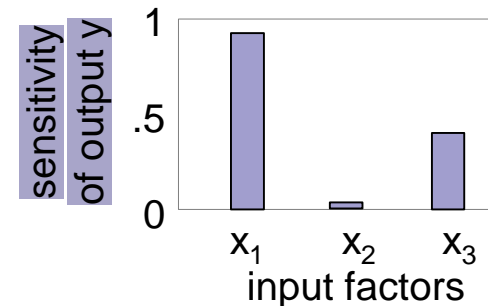
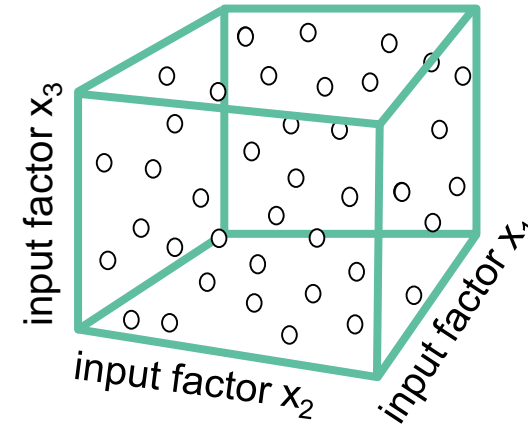
Local SA investigates the effects of variation of uncertain inputs from a baseline point



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



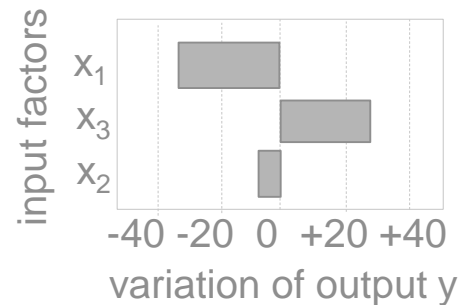
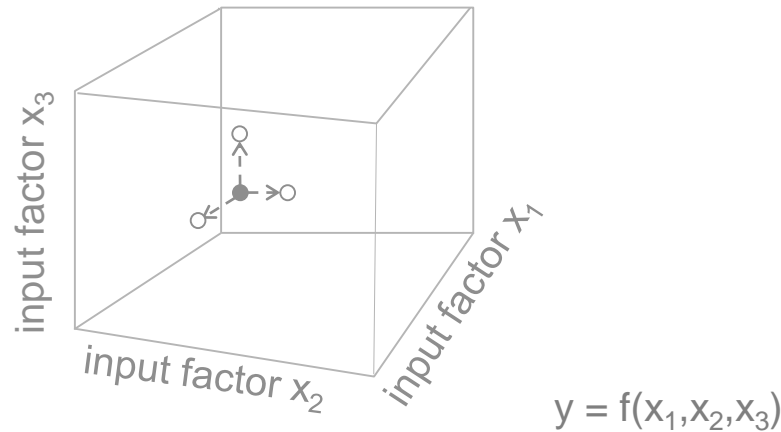
Global SA investigates the effects of variation of uncertain inputs across their entire variability space



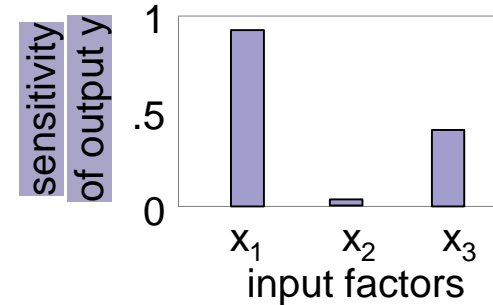
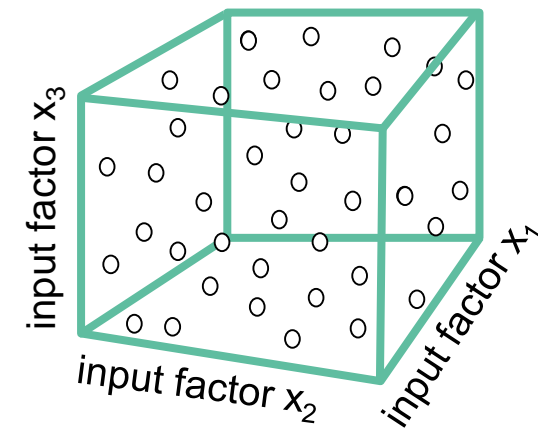


# GSA investigates model response independently of baselines

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



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



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

# EXAMPLES OF USING GSA

# GSA can help to prioritise efforts to reduce uncertainty

Application to a flood inundation model

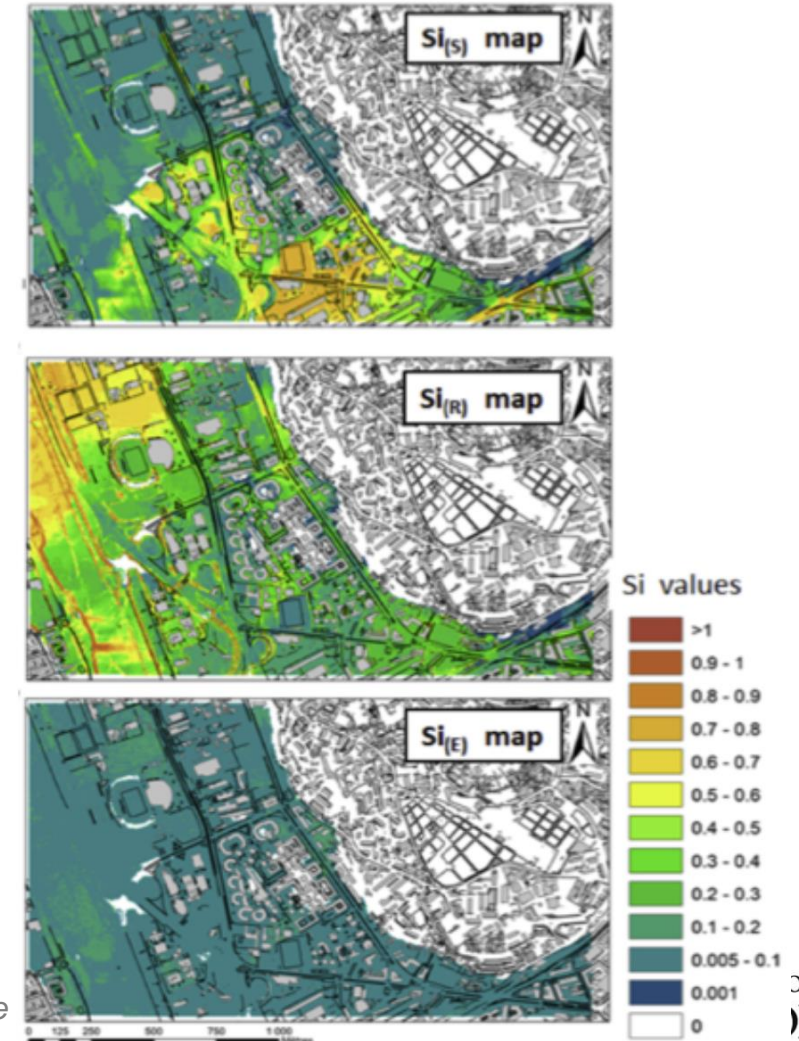
Input:

1. Level of details in representing above ground features

2. Spatial resolution

3. Measurement errors in topographic data

Output: water depth



# GSA can help to prioritise efforts to reduce uncertainty

Application to a flood inundation model

No need to worry about measurement errors here



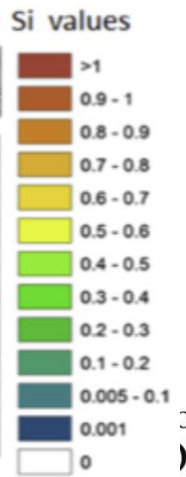
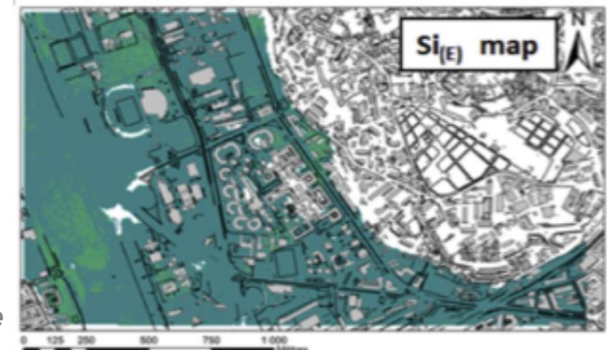
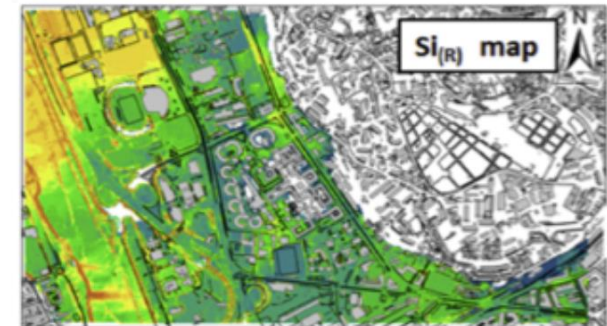
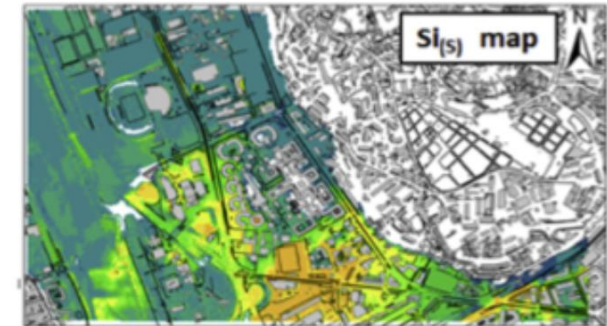
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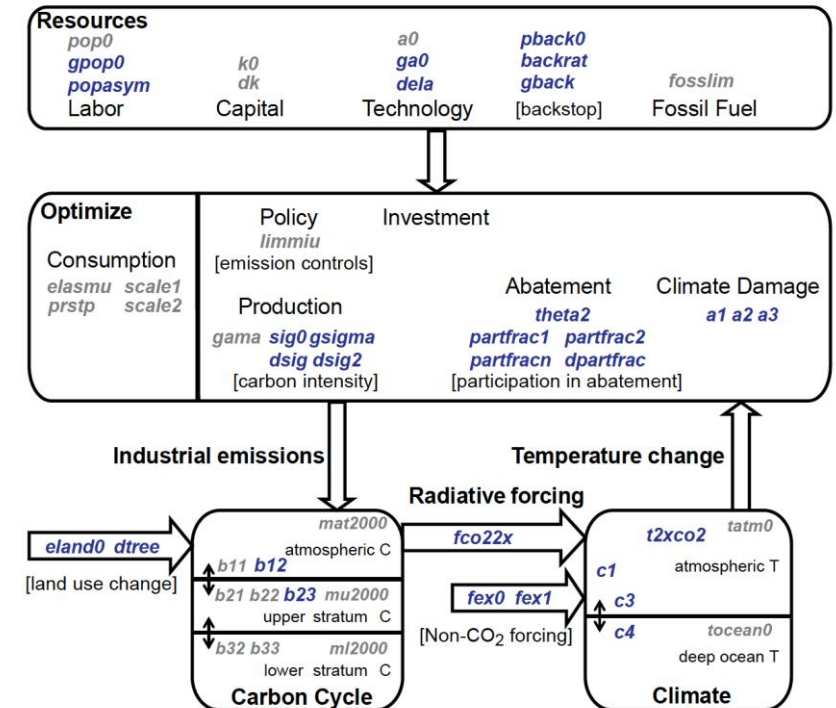
Output: water depth



# GSA can help to understand which input values lead to 'significant' outputs

## Application to an integrated assessment model of climate change

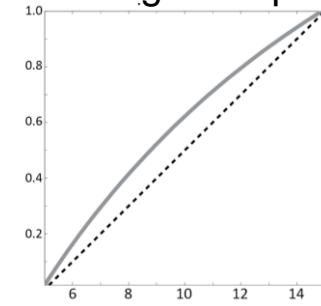
Butler et al. 2014 *Environmental Modeling & Software*



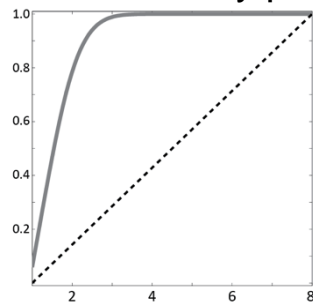
—— Model runs producing global temperature increase < 2°C (17%)

..... Model runs producing global temperature increase > 2 °C

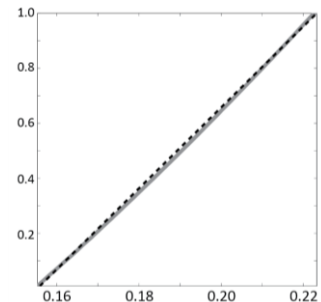
Population growth param.



Climate sensitivity param.



Carbon cycle model param.





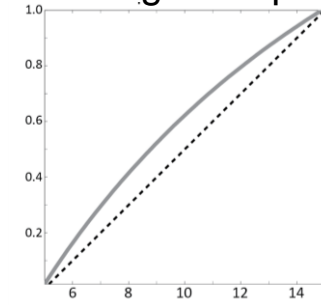
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## Application to an integrated assessment model of climate change

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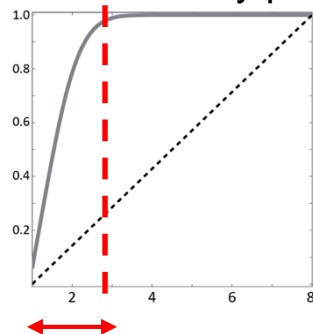
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Population growth param.

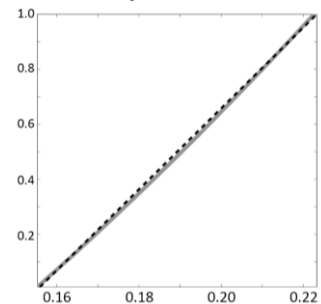


Climate sensitivity param.

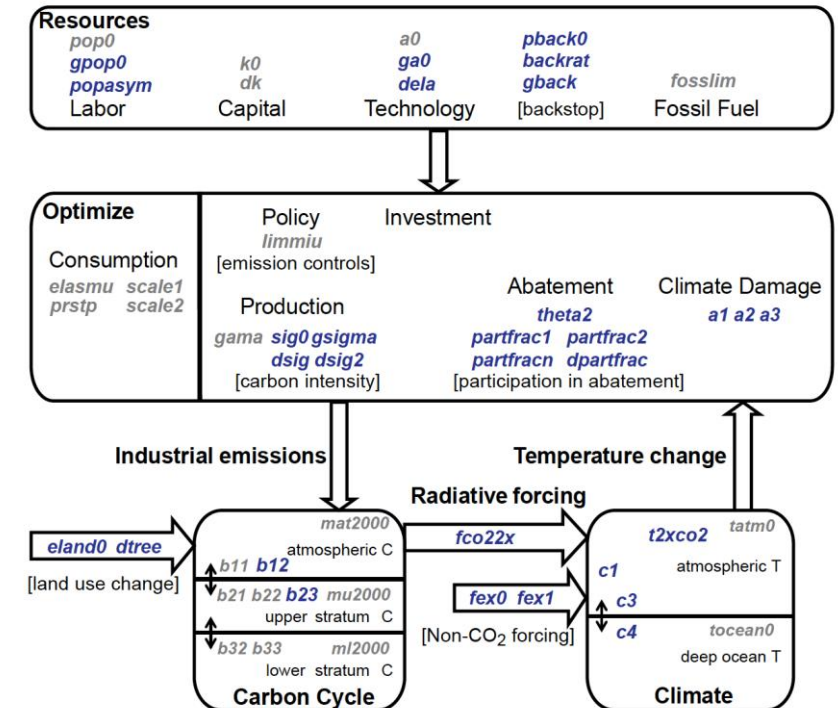
Range of values leading to below  $2^{\circ}\text{C}$



Carbon cycle model param.



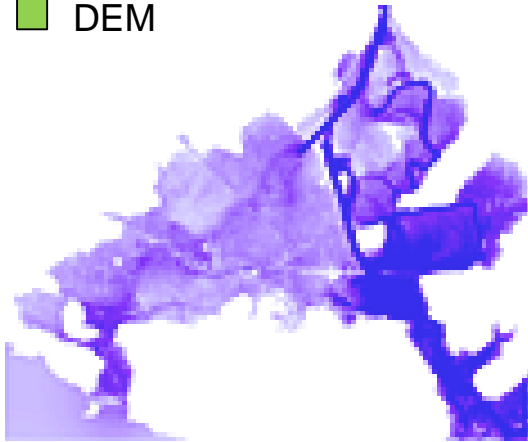
Butler et al. 2014 *Environmental Modeling & Software*



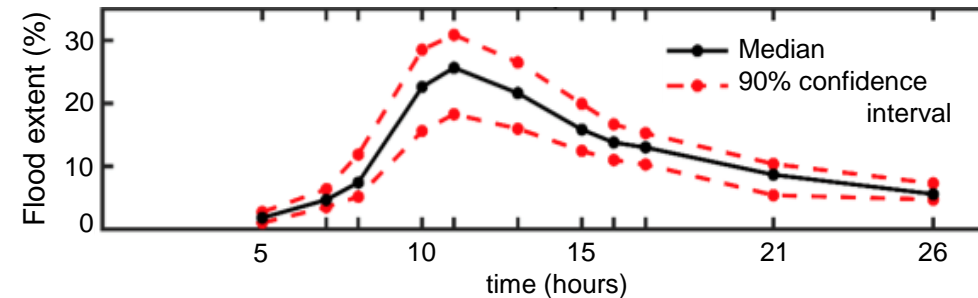
# GSA can be used to test models and inform decision-making

## Application to a flood inundation model

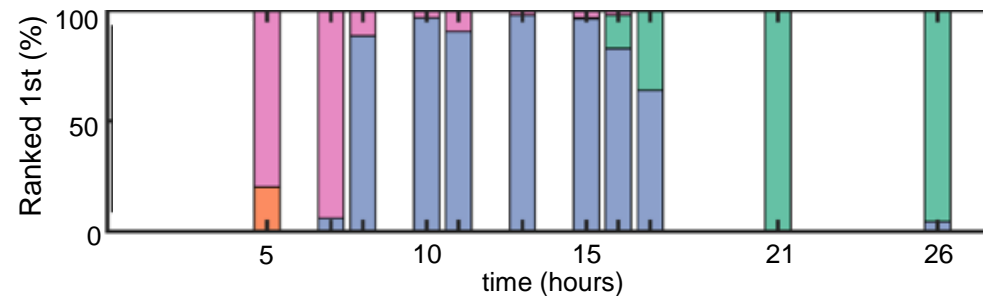
- Spatial resolution
- Channel friction
- Floodplain friction
- Forcing Hydrograph
- DEM



Uncertainty in predicted flood extent  
(% of cells where water depth >0.10 m)

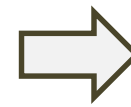


Most important contributors  
to flood extent uncertainty



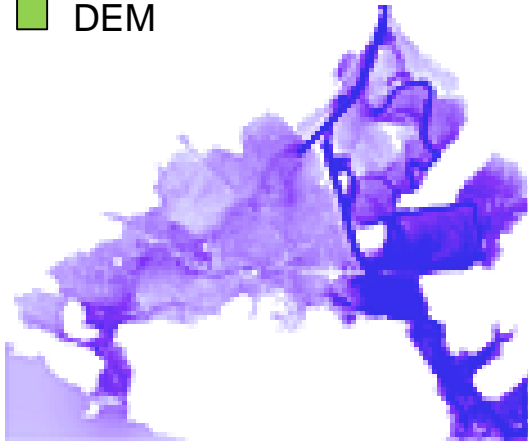
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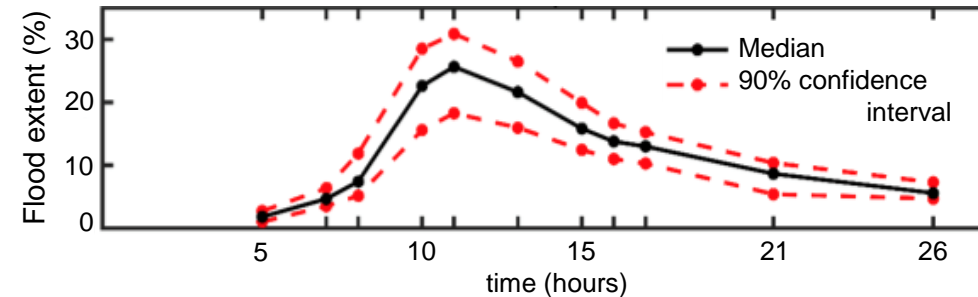


Most influential inputs change during the flood event

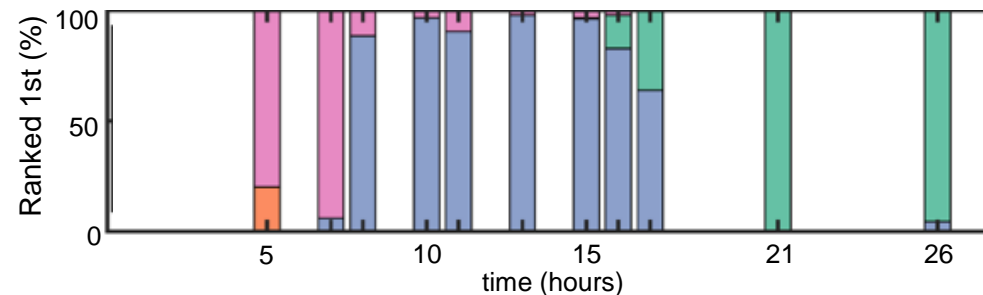
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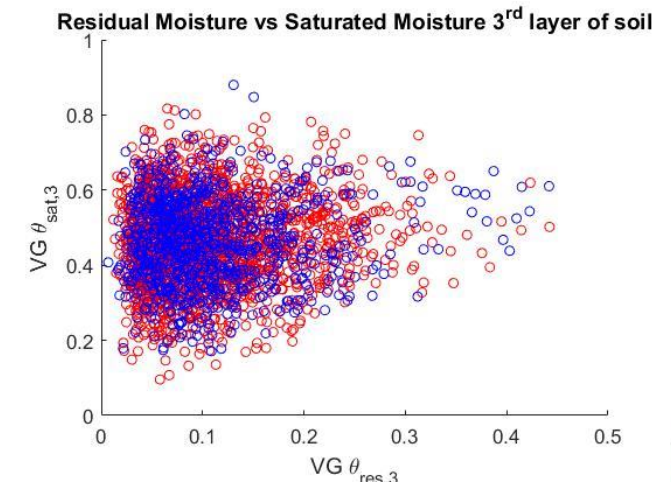
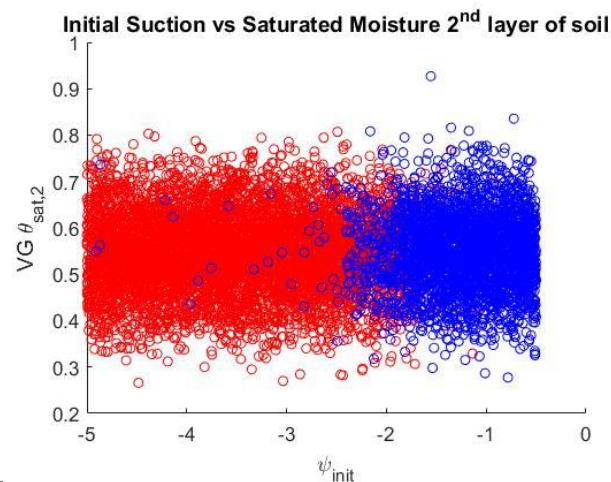
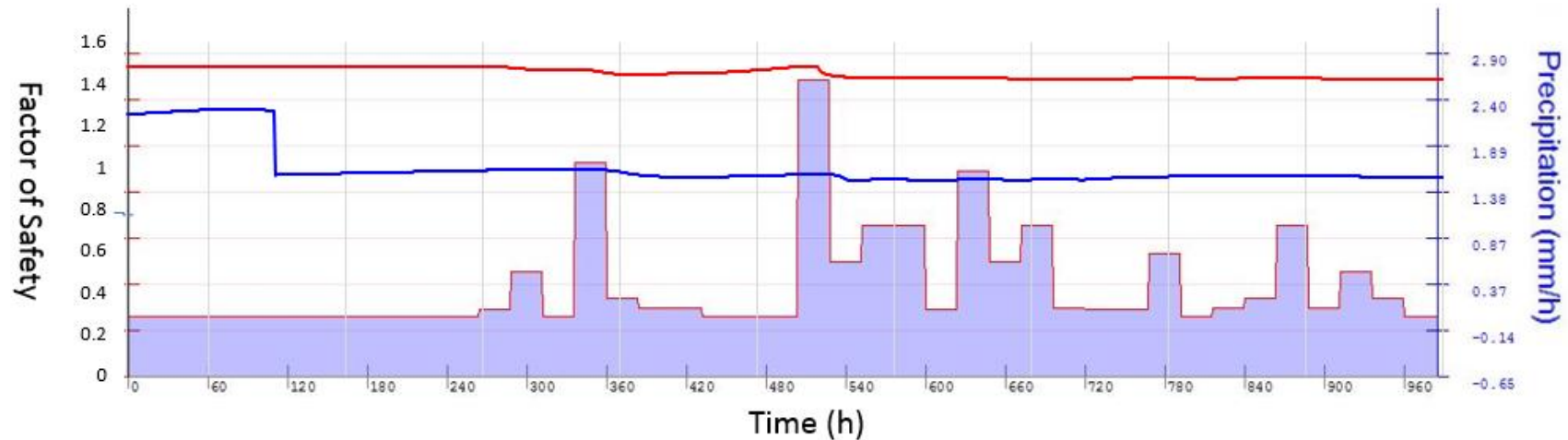
Most important contributors to flood extent uncertainty





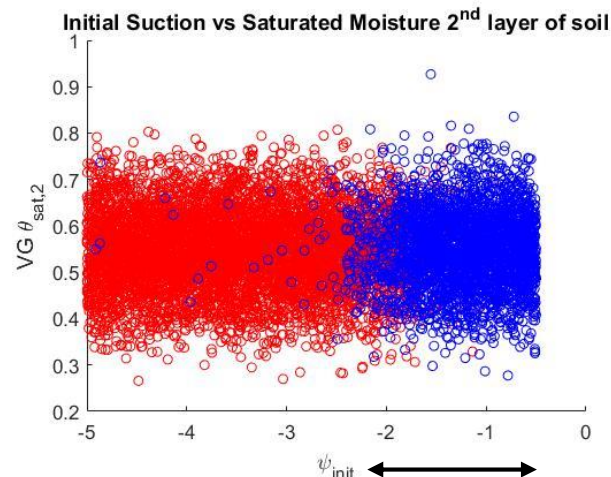
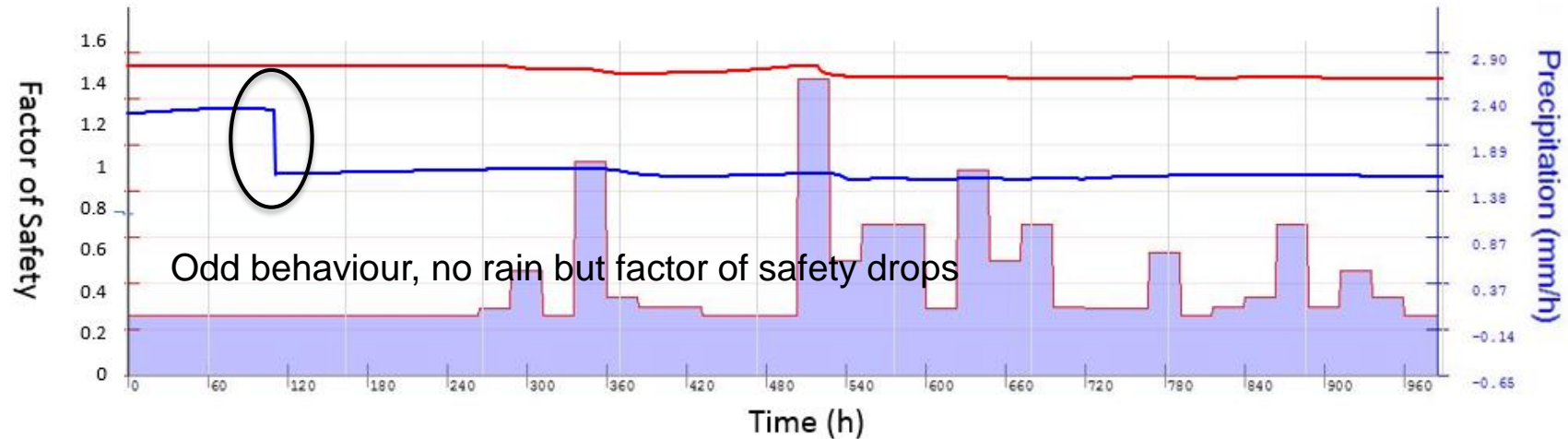
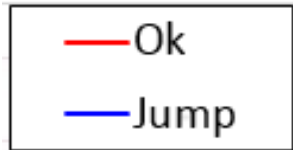
# GSA can be used to validate models – If it doesn't meet expectation it can help debugging

## Application to a landslide model

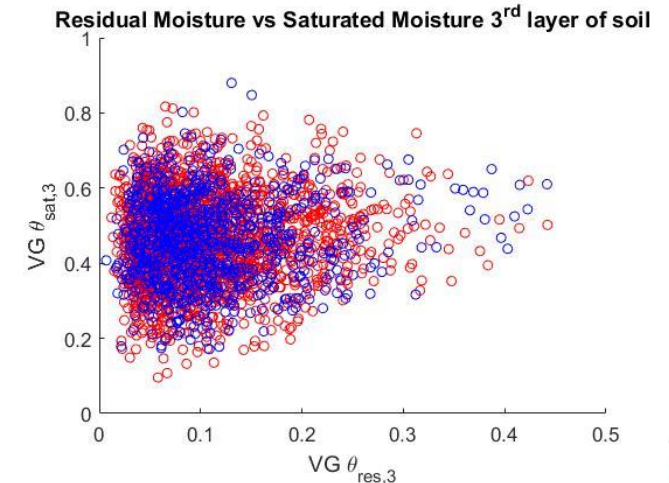


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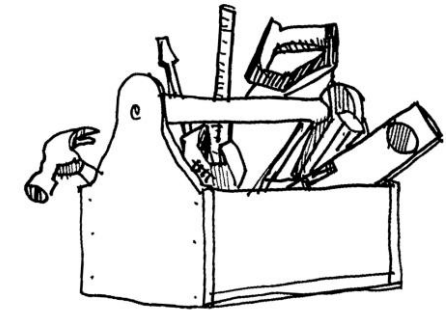


Range of values that should  
be avoided



# 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**

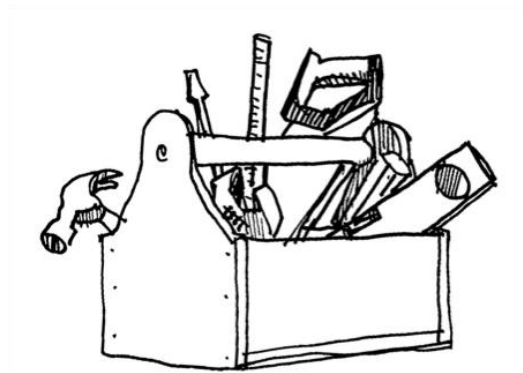


[www.safetoolbox.info](http://www.safetoolbox.info)



# 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](http://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/>)

# 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