Improvement of the Reliability and Robustness of Variance-Based Sensitivity Analysis of Final Repository Models by Application of Output Transformation

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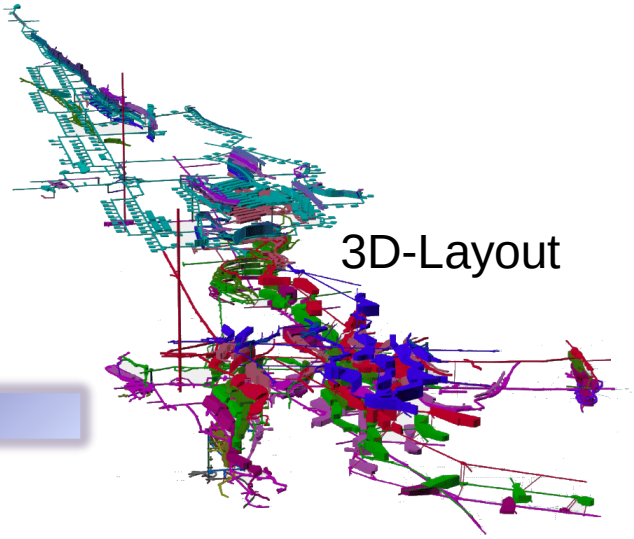
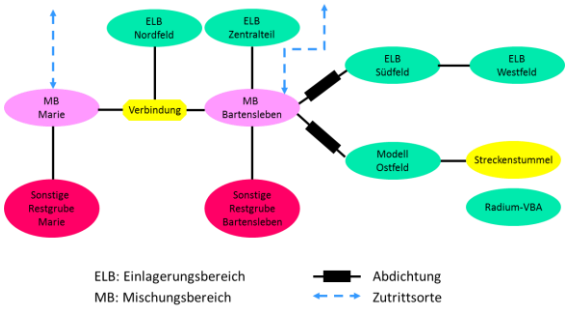
Introduction

Final disposal of radioactive waste in deep underground
Numerical modelling of long-term safety



3D-Layout

- Simplified coupled modelling of
  - fluid intrusion into emplacement chambers
  - mobilization of radionuclides
  - corrosion
  - gas production
  - rock movement
  - fluid movement
  - dissolution processes
  - contaminant transport and retention in different geological layers



compartment model

- *Result: A model with lots of uncertainties and complex behavior*

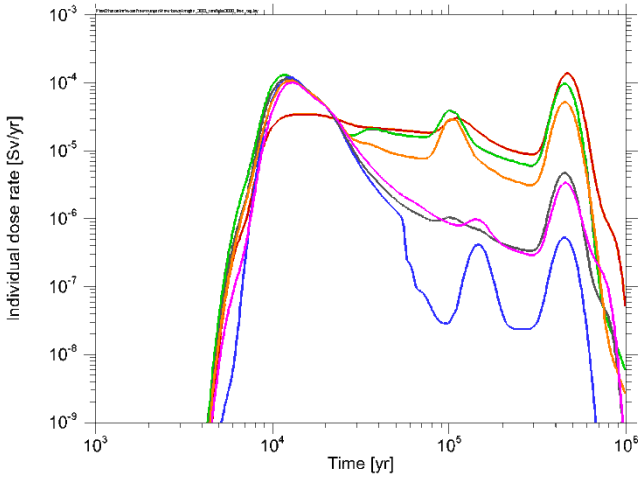
Demonstration models: calculation of radiological consequences

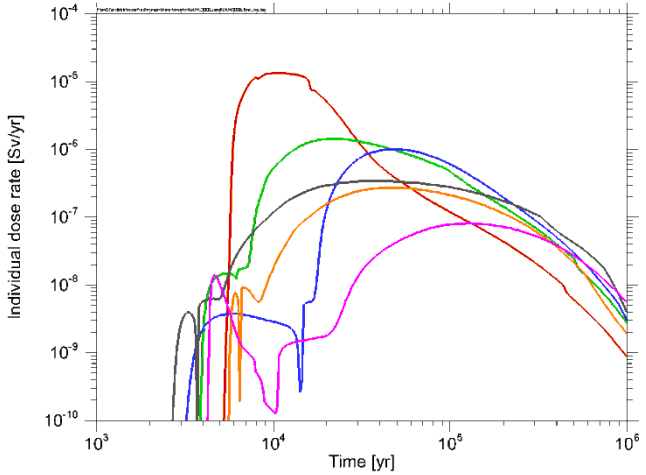
Model HLW

- based on a former planning
- high-level waste
- 31 uncertain parameters
- 84 % zero-output

Model LILW

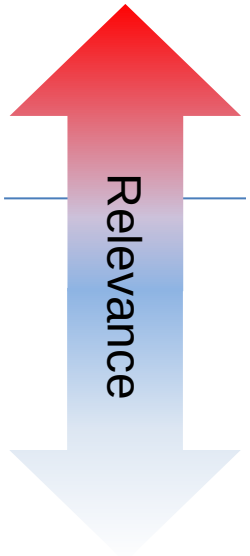
- based on an actual site in Germany
- low-and intermediate-level waste
- seal failure after some time
- 11 uncertain parameters
- no zero-output





Sensitivity analysis of final repository models

- Typical model properties
  - model uncertainty mapped to parameter uncertainty
  - non-monotonic behavior
  - non-continuous behavior
  - large span of possible output values
  - zero output possible
  - different relevance of variations in “low” and “high” output



- Problems with sensitivity analysis (SA)
  - variance-based SA gives strong overweight to values far away from expectation
  - model output does not reflect radiological relevance

- Solution idea: Appropriate output transformation

Adequate output transformation

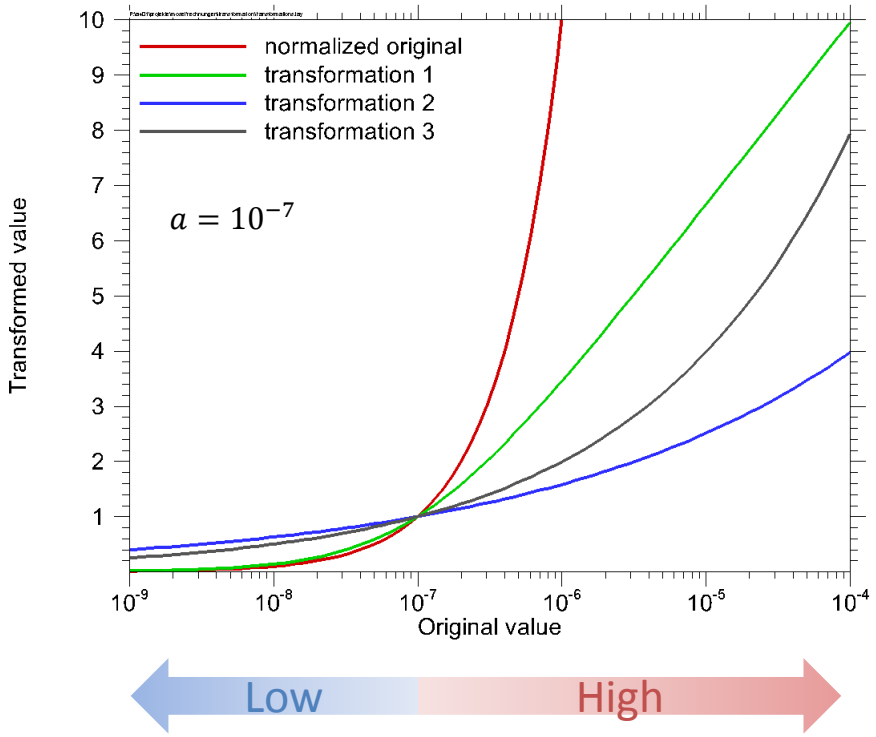
- Log-transformation? – Bad idea!
  - overvaluation of very low values,
  - not applicable to zero-values.
- The transformation should
  - discriminate between “low” and “high” values (threshold value a),
  - nevertheless be continuous and monotonic,
  - allow zero,
  - treat very low values as if they were zero,
  - prohibit overvaluation of very high values.
- Look for a continuous transformation that maps
  - zero to zero,
  - very low values to values near zero,
  - the threshold value a to 1,
  - high values to moderately increasing values above 1.

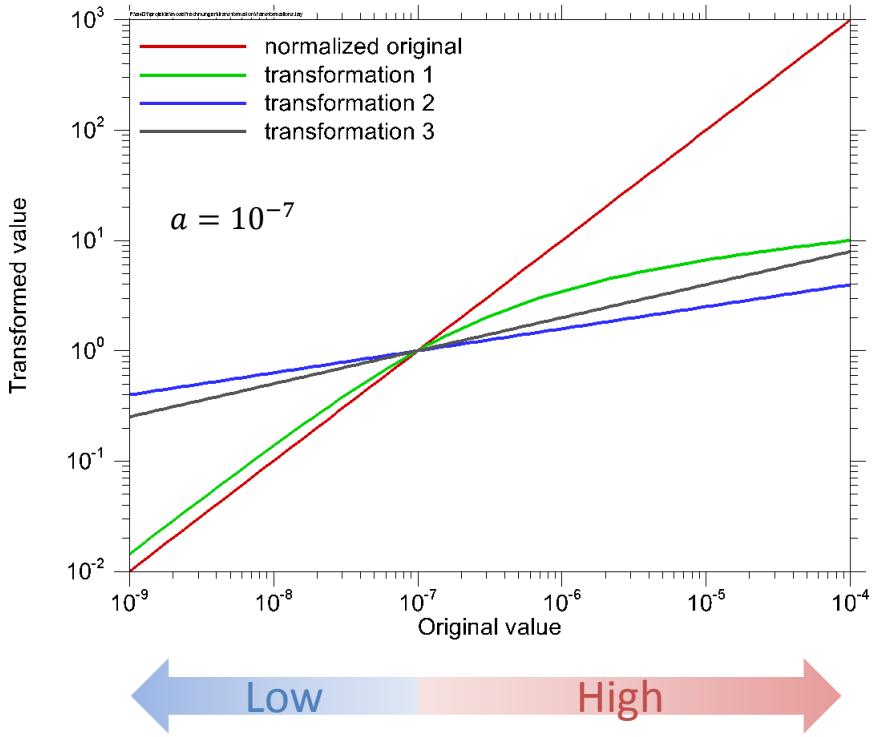
Three proposed transformations

Transformation 1: $y \mapsto \log 2\left(1 + \frac{y}{a}\right)$

Transformation 2: $y \mapsto \left(\frac{y}{a}\right)^{0.2}$

Transformation 3: $y \mapsto \left(\frac{y}{a}\right)^{0.3}$





Sensitivity analysis

Calculation of first-order sensitivity indices:

$$\mathrm{SI1}_j = \frac{\mathrm{Var}(\mathrm{E}(Y|X_j))}{\mathrm{Var}(Y)}$$

Y is the entirety of model output values,

X_j is the entirety of input values for parameter j,

$\mathrm{Var}(\mathrm{E}(Y|X_j))$ is the expectation of Y under the condition that X_j is held constant.

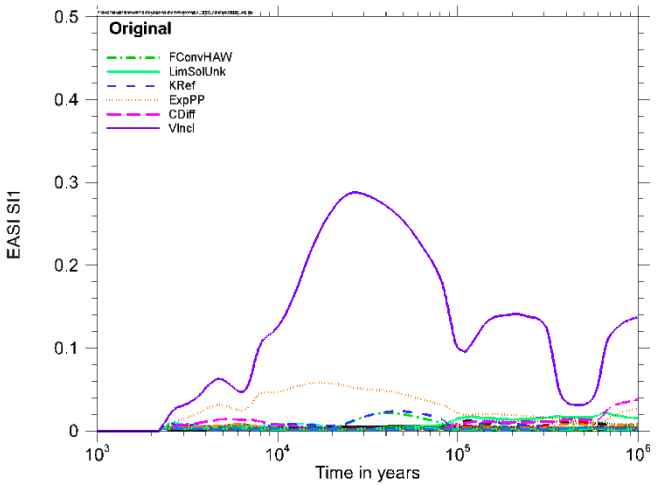
Analysis of 300 points in time

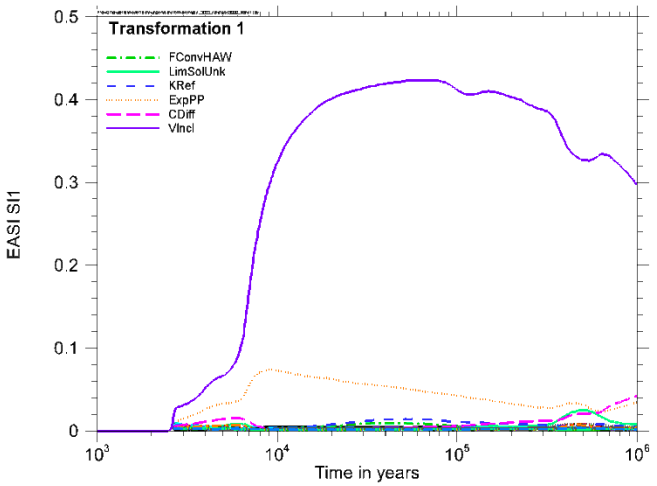
Applied method:

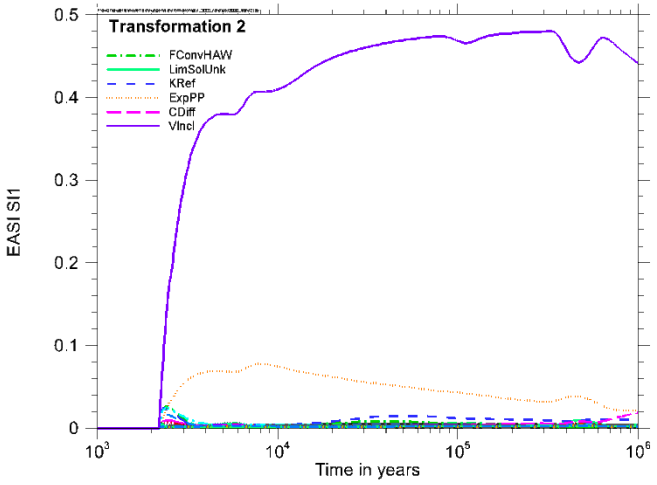
EASI (a simple **E**ffective **A**lgorithm for calculating global **S**ensitivity **I**ndices)

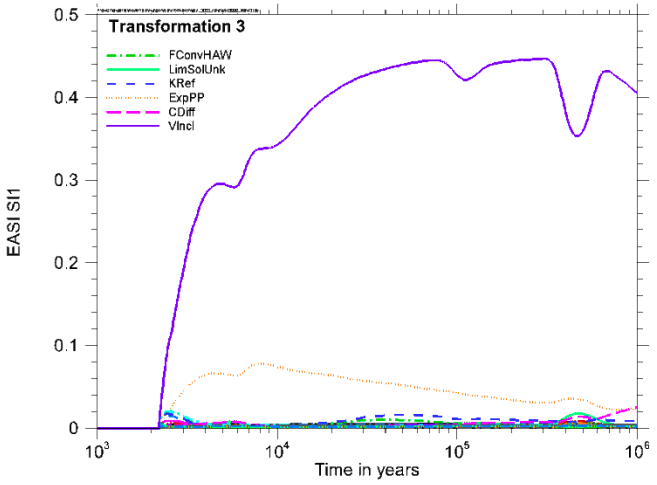
- very quick and numerically cheap
- applicable with any kind of sample
- seems to yield robust and reliable results
- see: E. Plischke, RESS 95, pp. 354–360, (2010)

Results for HLW model





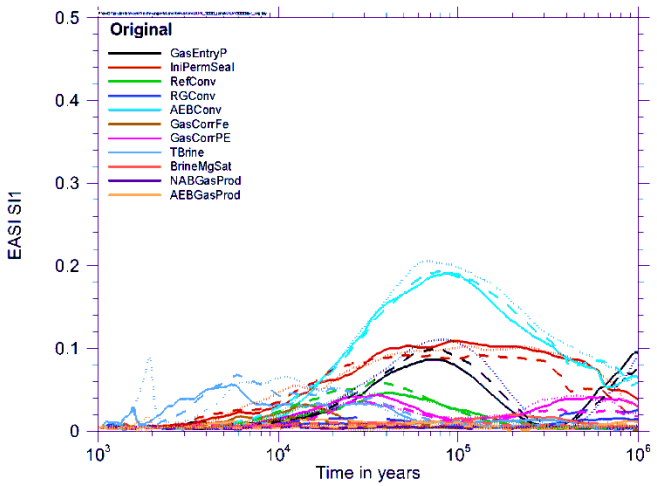


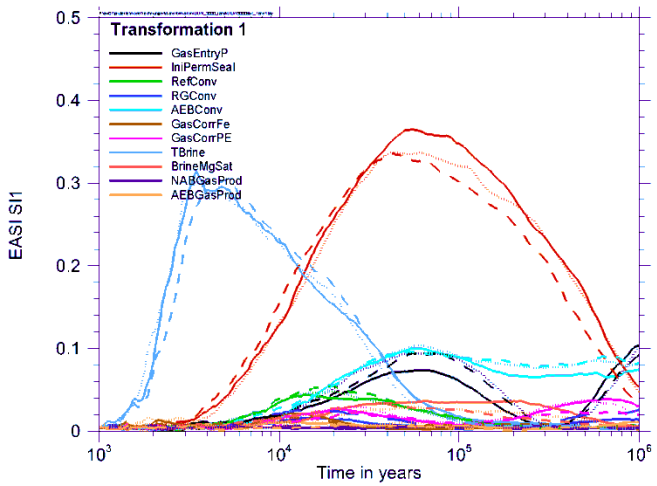


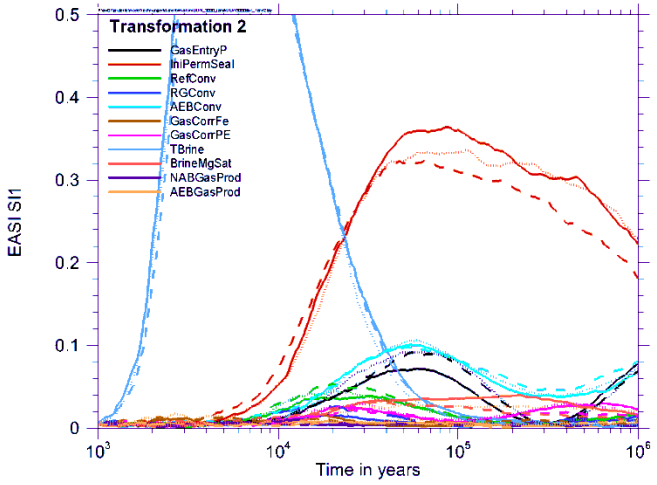
$a = 10^{-7}$ Sv/a

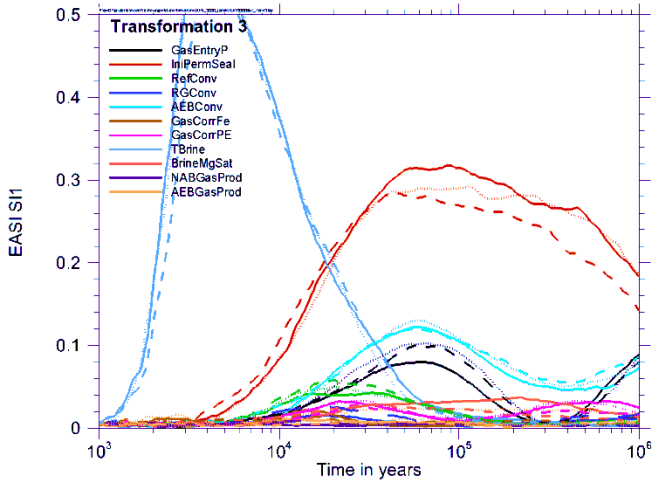
- Parameter *VIncl* dominates in all investigations
- Domination of *VIncl* is more pronounced for transformed data
- Sum of all SI1 is closer to 1 for transformed data
- Considerable qualitative difference during time phase from 4e5 to 6e5 years
- Transformation makes results clearer

Results for LILW model









- *AEBConv* seems to lose importance by transformation
- *TBrine* clearly dominates the early phase
  - physically plausible,
  - not reflected in the evaluation of original data
- SI1 *IniPermSeal* increases by a factor of 3-4
  - parameter triggers time of seal failure
- *BrineMgSat* becomes visible
  - reflects system understanding

$a = 10^{-8}$ Sv/a

Line styles represent three different random samples

Summary and Conclusions

- Three transformations were applied to the output of two final repository models
- A threshold parameter was introduced to discriminate “low” from “high” values
- Also an adaptive transformation was tried (not presented)
- Application of output transformation yielded interesting results
  - generally, the differences in sensitivity seem to become more pronounced:
  - high sensitivities increase, low sensitivities decrease
  - the sum of all first-order sensitivity indices gets closer to 1
  - significance and robustness of sensitivity analysis might increase
- SI calculated from transformed data seem to better reflect system understanding
- An “optimal” transformation cannot be recommended so far

Project MOSEL

Subject:

- Identification and testing of modern numerical methods for sensitivity analysis with regard to final repository performance assessment

Organization:

- Gesellschaft fuer Anlagen- und Reaktorsicherheit (GRS) mbH, Braunschweig, Germany

Collaboration with

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Thank You for Your Attention!