

GLOBAL SENSITIVITY ANALYSIS OF A LOW PERMEABILITY MEDIA GAS FLOW MODEL WITH MULTIPLE TRANSPORT MECHANISMS

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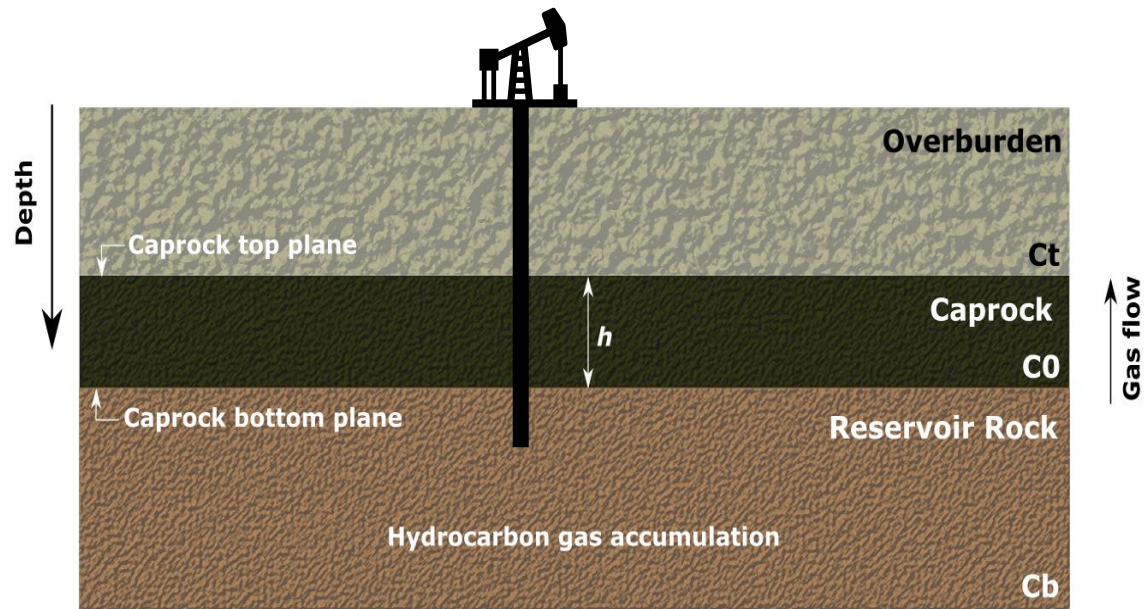
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OVERVIEW

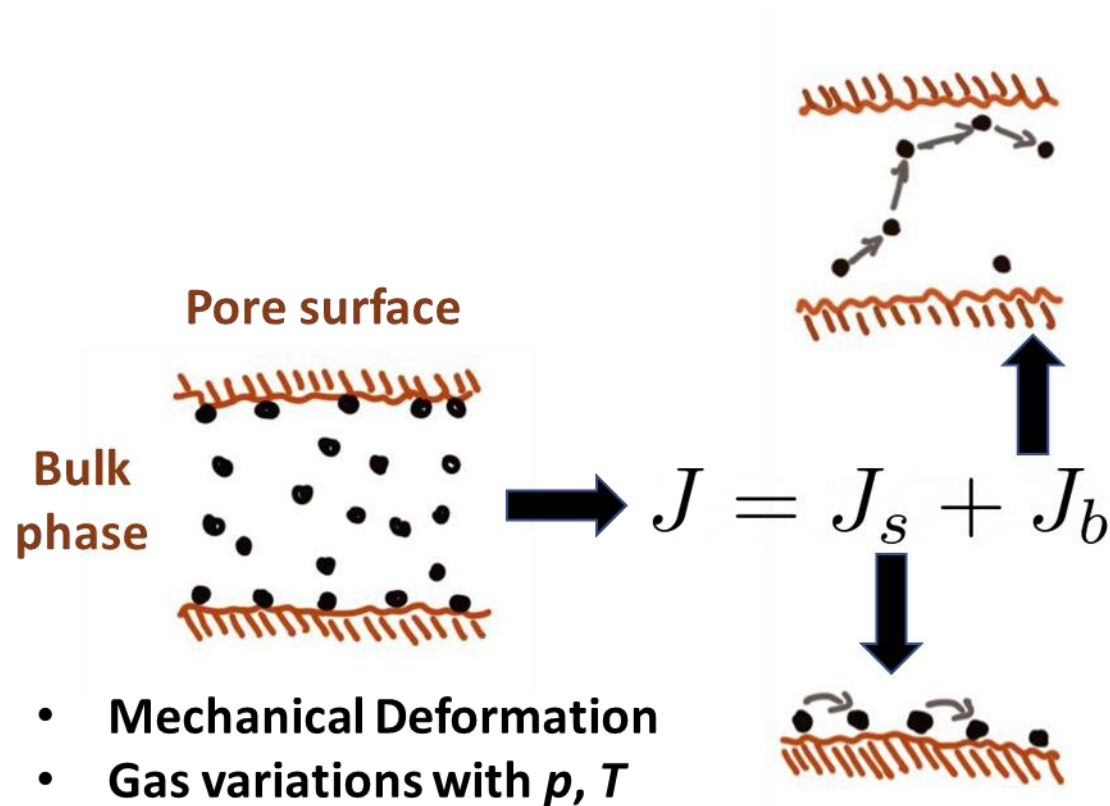
- 1. Motivation**
- 2. Gas Flow Model**
- 3. Global Sensitivity Analysis**
- 4. Results**
- 5. Summary and Conclusions**

MOTIVATION



- There is a worldwide increasing energy demand.
- CH_4 is an alternative with low CO_2 emissions.
- Typically, CH_4 is accumulated in geological traps of low permeable materials (caprocks).
- Gas flow modelling through caprocks can assist the feasibility estimation of CH_4 recovery projects.
- Projects of CO_2 sequestration are based on the same physics.

GAS FLOW MODEL



$$J_b = w_v J_v + w_k J_k$$

Symbol	Variable
J	Gas flow
J_s	Surface diffusion
J_b	Bulk diffusion
J_v	Slip flow
J_k	Knudsen flow
w_v	Weight factor of slip flow
w_k	Weight factor of Knudsen flow

FLOW MODEL

$$J_v = -\zeta_{mb} \frac{r^2 M}{8\eta RT} \frac{p}{Z} (1 + \alpha Kn) \left(1 + \frac{4Kn}{1 - bKn} \right) \frac{dp}{dl}$$

$$J_k = -\frac{2}{3} \zeta_{mb} r \delta^{D_f-2} \left(\frac{8ZM}{\pi RT} \right)^{0.5} \frac{p}{Z} C_g \frac{dp}{dl}$$

$$J_s = -D_s \frac{\zeta_{ms} C_{sc}}{p} \left(\frac{\partial p}{\partial l} \right)$$

Parameter - (Units) - Symbol	Range (CV%)
*Reference pore radius - (nm) - r_o	2-100 (55)
*Reference porosity - (-) - ϕ_o	0.005-0.1 (52)
*Pore pressure - (MPa) - p	0.5-50 (57)
*Tortuosity - (-) - τ	2.8-5.8 (20)
*Temperature - (K) - T	337-473 (10)
* Overburden pressure - (MPa) - p_c	51-90 (16)
*Porosity exponent - (-) - q	0.014-0.056 (35)
*Pore radius exponent - (-) - t	0.02-0.04 (19)
*Block/migration ratio - (-) - κ	0.1-2 (52)
***Fractal dimension - (-) - D_f	2.1-2.9 (9)
*Isosteric heat - (J/mol) - ΔH	12000-16000 (8)
*Langmuir pressure - (Pa) - p_{L_o}	41-128 (30)
* Parameter - (-) - α_0	1.02-1.36 (8)
** Parameter - (-) - α_1	2-6 (30)
** Parameter - (-) - β	0.2-0.6 (30)

FLOW MODEL

$$\zeta_{mb} = \frac{\phi}{\tau} \left(1 - \frac{r_{ad}}{r}\right)^2$$

$$\zeta_{ms} = \frac{\phi}{\tau} \left(1 - \frac{r_{ad}}{r}\right)^2 \left[\left(1 - \frac{r_{ad}}{r}\right)^{-2} - 1 \right]$$

$$r_{ad} = r - d_m \frac{p/Z}{p_L + p/Z}$$

$$r = r_o \left(\frac{p_c - p}{p_o} \right)^{-t}$$

$$\phi = \phi_o \left(\frac{p_c - p}{p_o} \right)^{-q}$$

$$D_s = D_s^0 \frac{(1 - \theta) + \frac{\kappa}{2}\theta(2 - \theta) + H(1 - \kappa)(1 - \kappa)\frac{\kappa}{2}\theta^2}{(1 - \theta + \frac{\kappa}{2}\theta)^2}$$

$$D_s^0 = 8.29 \times 10^{-7} \exp \left(-\frac{\Delta H^{0.8}}{RT} \right)$$

$$\theta = \frac{p/Z}{p_L + p/Z}$$

$$p_L = p_{L_o} \exp \left(-\frac{\Delta H}{RT} \right)$$

$$H(1 - \kappa) = \begin{cases} 0, & \text{if } \kappa \geq 1 \\ 1, & 0 \leq \kappa \leq 1 \end{cases}$$

$$C_{sc} = \frac{4\theta M}{\pi d_m^3 N_A}$$

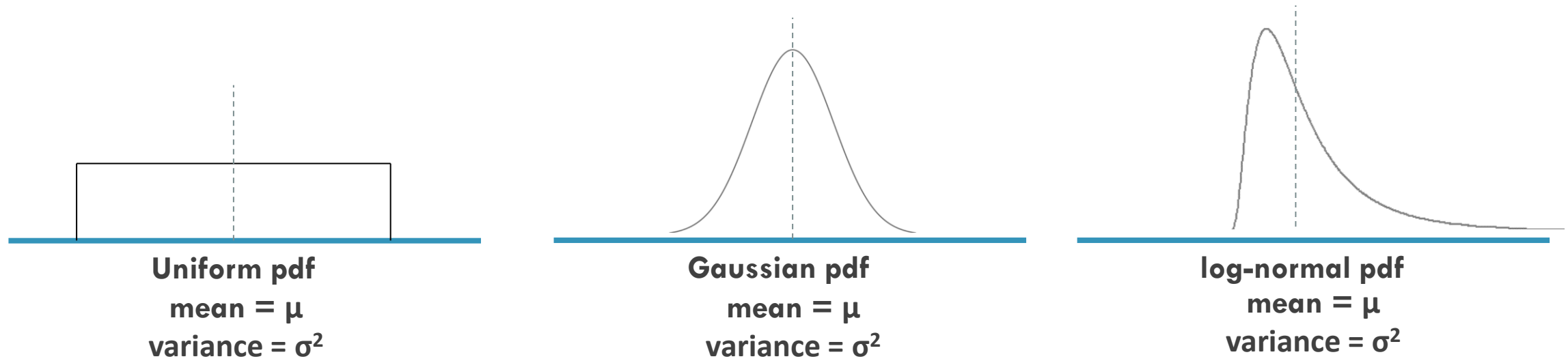
$$\alpha = \alpha_0 \frac{2}{\pi} \tan^{-1} (\alpha_1 K_n^\beta)$$

GLOBAL SENSITIVITY ANALYSIS



- Which model parameters have the largest contribution to the model output uncertainty?
- If resources are limited, which parameter allocation prioritize?

GLOBAL SENSITIVITY ANALYSIS – UNCERTAINTY IN PARAMETER PDF



What is the influence of the parameter pdf assigned to a given parameter on the GSA results?

We test three cases

- All parameters represented by uniform distributions (Uniform in the results)
- All parameters represented by normal distributions (Normal in the results)
- Reference pore radius represented by a lognormal pdf, the remaining parameters represented by uniform pdfs (Mixed in the results)

GLOBAL SENSITIVITY ANALYSIS — GSA APPROACHES

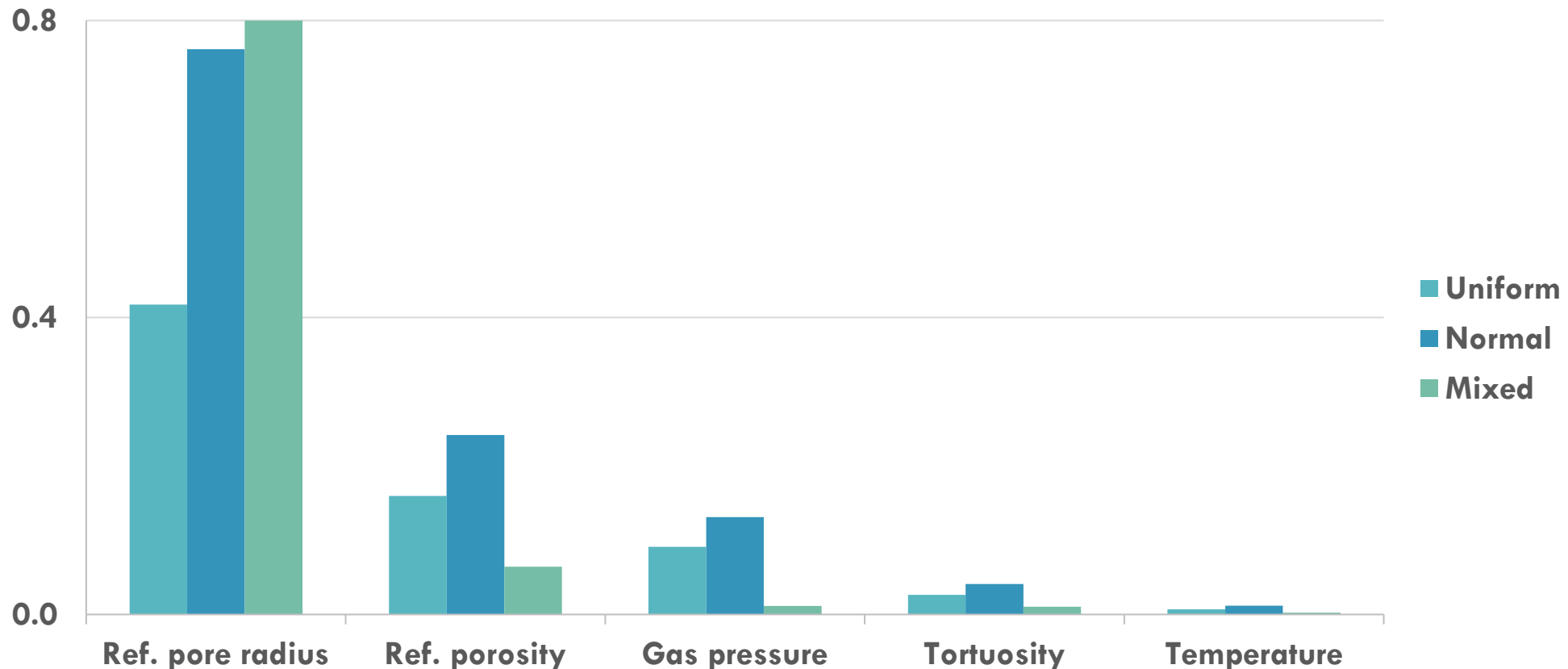
Sobol Principal Indices

Quantify the expected reduction of the variance of a model output due to the knowledge of a given model parameter

Morris indices

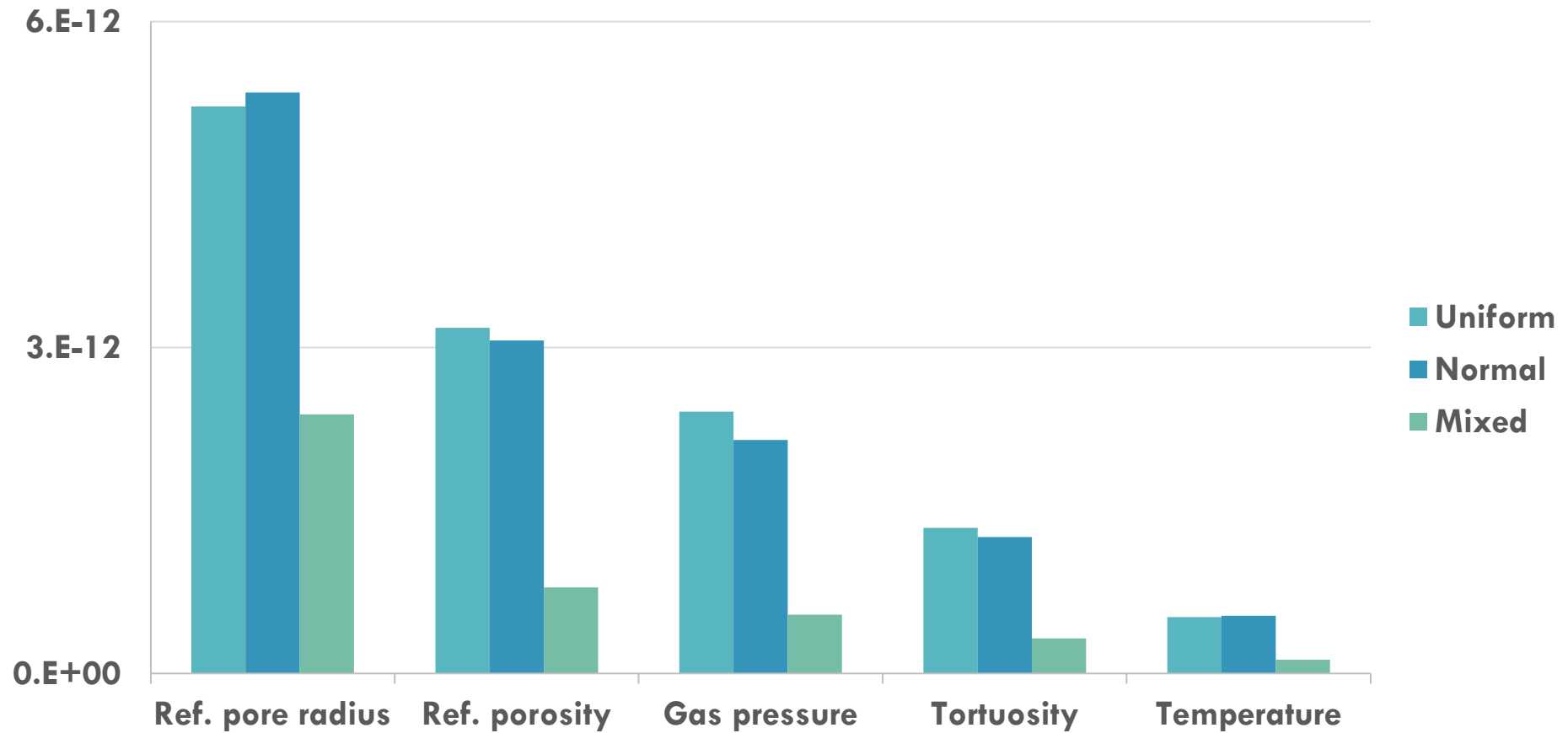
Quantify global sensitivities by aggregating individual sensitivities based on derivatives.

RESULTS — PRINCIPAL SOBOL INDICES



- Only parameters with a significant contribution to model output uncertainty are plotted, the remaining parameters have marginal effects to the model output.
- Value of the Sobol' principal index corresponding to reference pore radius on the mixed case actually is 2.8 but it was trimmed for graphical representation purposes.

RESULTS — PRINCIPAL SOBOL INDICES



*** Only parameters with a significant contribution to model output uncertainty are plotted, the remaining parameters have marginal effects to the model output.**

REMARKS

- We identify five (of the 15) model parameters as influential to model output uncertainty. These being: Reference pore radius, reference porosity, pore pressure, tortuosity and temperature.
- The probability density function of the model parameters quantitatively modify the results of the GSA, however, qualitatively the results remain unaltered.
- Both sensitivity analysis techniques identify the same group of parameters as those with the largest contribution to model output uncertainty.
- We also implemented other modern GSA technique and analyze the importance of diverse flow mechanisms to the model.