Probabilistic characterization of targeted model output for focused scenarios related to hydraulic fracturing

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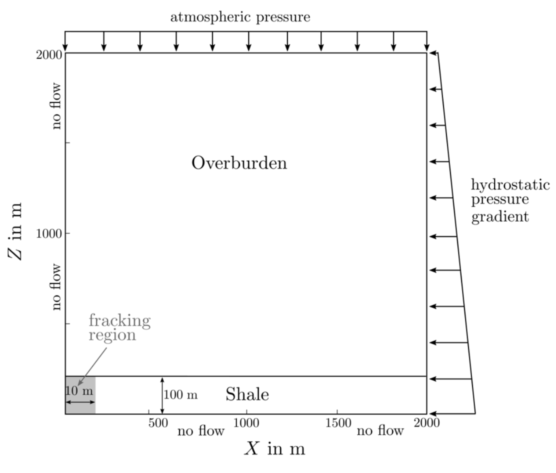
Introduction

We present some of the key results stemming from the development of a comprehensive approach targeting the quantification of environmental risks associated with hydraulic fracturing. Our analyses are framed in the context of the EU Horizon 2020 project FracRisk - Furthering the knowledge base for reducing the environmental footprint of shale gas development - and include the development of decision support methods for risk quantification of the environmental impacts of hydraulic fracturing technologies. A significant modeling-related segment of the analysis we present, targets six focused exemplary conceptual scenarios. These represent generic risk scenarios during and after fracking operations. Major aspects covered in the scenarios are the flow of fracking fluid, the migration of methane, the geomechanics of frack development, the driving forces of flow, diverse spatial and temporal scales, and the general conceptual picture linking source, pathways and receptors.

For each of these generic scenarios, a model concept that is able to describe the relevant processes is selected and, where necessary, developed and implemented. All of the exemplary scenarios we illustrate are implemented in the numerical simulator Dumux [2]. Our modeling strategy combines a forward modeling step with a probabilistic characterization of selected target model output based on global sensitivity metrics. The latter include the expected value, the spread around the mean and the degree of symmetry and tailedness of the model output probability density function (pdf), see also [1]. This approach allows assessing the impact of uncertain model parameters on main features of the pdf of a target model output, not being limited, as is typically done, e.g. when considering the popular Sobol' indices, to considering the variance of the pdf.

Exemplary Scenarios and Methods

Here, we focus on scenarios S2 and S4, which are depicted in Fig. 1.



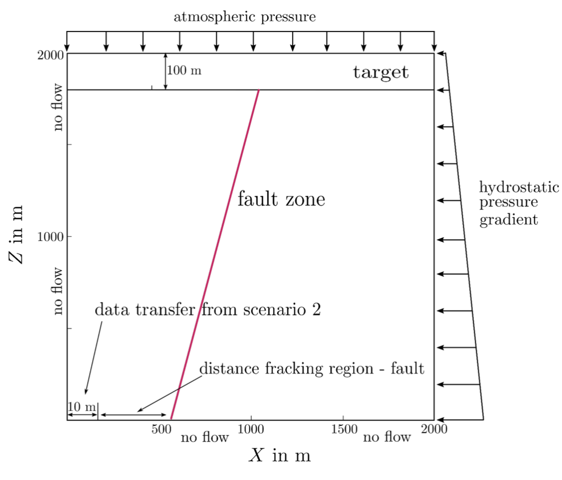


Figure 1: Exemplary focused scenarios S2 and S4 of the EU FracRisk project.

Scenario 2 emphasizes the source of fracking fluid or methane and its escape from the shale into the overburden, while Scenario 4 is a pathway setting connecting the source and a potential receptor via a permeable geological feature such as a fault zone. Modeling of pathways such as fractures and fault zones can be based on different conceptual approaches, such as equidimensional approaches where faults are conceptualized simply as zones with different hydraulic properties, on the other hand we have also developed a discrete fracture model [4].

A probabilistic characterization of the target model output, such as e.g. pressure in the overburden of the shale or fluxes of fluids leaking out of the shale into the overburden, is achieved by selecting a limited number of variable input parameters, for which global sensitivity measures are then calculated.

Due to the computational effort associated with the simulation of the scenarios, the Dumux flow models were used to construct a reduced complexity (or surrogate) model, which is then employed to perform the complete global sensitivity analysis and uncertainty quantification. As a surrogate model, we select the generalized Polynomial Chaos Expansion (gPCE), other choices being fully compatible with our methodological framework. The computational effort required to construct the gPCE increases with the number of uncertain model parameters, the desired precision as embedded in the degree of the PCE, and the complexity of the flow models. The constructed surrogate model is then used in a numerical Monte Carlo framework to propagate model parameter uncertainty into the pdf of the target model outputs. The basic concepts underlying the work-flow has been demonstrated in [3].

Preliminary Results

For focused scenario S2, where we investigated the methane escape into the overburden as one of several subscenarios, we have constructed a surrogate model based on the following uncertain model parameters: the injection rate during the fracturing process, the number of connecting fractures in the shale that reach into the overburden, the anisotropy of the overburden, and the residual methane saturation in the overburden as well as the van Genuchten α parameter, both characterizing the two-phase flow system. We have sampled the parameter space upon defining ranges for each parameter. All other model parameters are fixed.

Global sensitivity metrics of the parameters and the pdf for the pressure in the overburden and the methane flux into the overburden are characterized through the constructed surrogate model. Sobol' indices as sensitivity measures suggest that the injection rate in the fracking operation as well as the number of connecting fractures into the overburden are the critical quantities for potentially hazardous events. Interestingly, the new metrics for the global sensitivity analysis introduced by [1] provides the possibility of analyzing the influence of the parameters in more detail. As an example, Fig. 2 indicates the way the shape of the probability density functions can vary when new information on model parameters is introduced. We demonstrate that our approach can be very valuable to deal with the uncertainties associated with such scenarios, by determining, e.g. the increased confidence level one would gain by collecting additional information for a certain parameter.

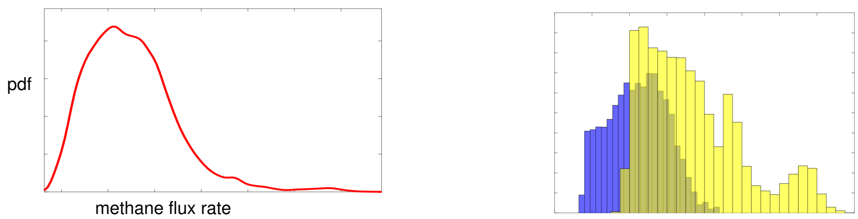


Figure 2: Scenario S2: Exemplary shape of the probability density function (pdf) of the methane flux into the overburden (left figure); modified shape of the pdf conditional to fixed values of the originally variable parameters (right figure), where blue means here conditional to high residual methane saturation and yellow conditional to low residual methane saturation.

It is further interesting to combine Scenarios S2 and S4 on the basis of their respective polynomical density functions. For the overall quantification of risk by considering the source of the problem (S2), the pathway (S4) and the receptor, the pdfs can be combined to a joint pdf, which has the advantage that computational complexity is reduced.

References

[1] A. Dell'Oca and M. Riva and A. Guadagnini, Moment-based metrics for global sensitivity analysis of hydrological systems, *Hydrology and Earth System Sciences*, in press, (2017).

[2] B. Flemisch and M. Darcis and K. Erbertseder and B. Faigle and A. Lauser and K. Mosthaf and S. Müthing and P. Nuske and A. Tatomir and M. Wolff and R. Helmig. DUMUX: DUNE for multi-{phase, component, scale, physics, ...} flow and transport in porous media, *Advances in Water Resources*, *34* (9), 1102-1111, (2011).

[3] D. Gläser and A. Dell'Oca and A. Tatomir and J. Bensabat and H. Class and A. Guadagnini and R. Helmig and C. McDermott and M. Riva and M. Sauter. An approach towards a FEP-based model for risk assessment for hydraulic fracturing operations, *Energy Procedia*, *97*, 387-394, (2016).

[4] D. Gläser and R. Helmig and B. Flemisch and H. Class. A discrete fracture model for two-phase flow in fractured porous media, *Advances in Water Resources*, **110**, 335-348, (2017).

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