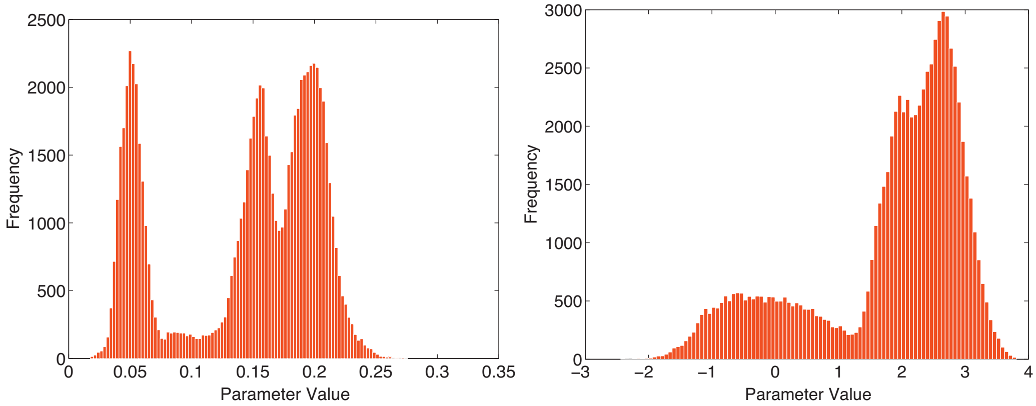

(a) Porosity, fraction.

(b) Horizontal Permeability, log(mD).

Fig. 2. The histograms of hydrological parameters shown for a realization with low levels of heterogeneity. The vertical permeabilities are approximately one order of magnitude lower than the horizontal permeabilities.

geometry is considered. The injection well is screened in the lower part of the model.

3.2. Analyzed model predictions

We seek to maximize the CO_2 storage volume and minimize the risk of leakage. These quantities are measured by various simulation outputs that are described in Table 2 and discussed in the following.

CO_2 pressure is considered as the spatial average of the pressure distribution in the entire domain, weighted by the CO_2-filled pore volume in each model cell. Monitoring or predicting the pressure response within the CO_2 plume is important to avoid over-pressurized injection operations.

Residual CO_2 volume is the volume of trapped CO_2 that is left in the small pores in an imbibition process. This volume is crucial for the long-term storage capacity of reservoirs.

Mobile CO_2 volume is the volume of CO_2 that can move in a continuous phase in the medium. It is considered as one of the important flow responses, because only mobile CO_2 volumes can lead to leakage through any failure in the sealing cap-rock or ill-plugged well.

Finally, we consider leakage risk through cap-rock failure. Cap-rock integrity is a major concern for the safety of CO_2 storage operations. An over-pressurized injection can lead to fractures that may extend up to the cap-rock, penetrate through the cap-rock, or activate pre-existing faults and fractures, and finally lead to CO_2 leakage. In addition, the capillary barrier effect of the cap-rock can be overcome by a local pressure build-up. Thus, the probability of cap-rock failure can depend on the geomechanical properties of the cap-rock and of the medium, on the topography of the cap-rock, and on the pressure build-up resulting from the CO_2 injection and migration. More details about failure mechanisms and failure criteria can be found in the literature (e.g., Zweigel and Heill, 2003; Aker et al., 2013; Rohmer and Seyedi, 2010). However, geomechanical modeling and knowledge about pre-existing features that can be activated during injection would be required to take these processes into account.

Here, we demonstrate how cap-rock integrity can be considered in the workflow of sensitivity analysis and uncertainty assessment in a simplified manner. To avoid detailed studies of multiphase flow coupled with geomechanical simulations and fracture mechanics, we follow a pragmatic approach. The idea is to assign a spatial probability distribution of cap-rock failure over the area of the cap-rock layer, such that each point of the cap-rock has its own failure probability. In principle, this probability could be assigned in correspondence with the current pressure distribution and with geological features such as varying cap-rock thickness, material properties, faults and fractures. For the means of demonstration, we simply assign a spatial Gaussian function as a scenario assumption to provide the cap-rock failure probability for each point of the cap-rock (see Fig. 3). Leakage risk is defined as the probability of leakage (due to cap-rock failure) times the amount of escaping CO_2 in case of leakage. Thus, we spatially integrate the product between cap-rock failure probability and the volume of mobile CO_2 below each point of the cap-rock over the entire area of the cap-rock.

3.3. Uncertain parameters

The most apparent uncertainty in CO_2 storage is the lack of geological knowledge. Large geological scales and diversity of rock properties make it impossible to obtain the whole descriptive picture for a study. A geological study will therefore be accompanied

Table 2
Important model responses and their brief description. For more information, see Ashraf et al. (2010a,b).

Response	Description
Average CO_2 pressure	Volume average of pressure, weighted by CO_2 volume
Mobile CO_2	Volume of CO_2 in places with saturation above critical value
Residual CO_2	Volume of CO_2 in places with saturation below critical value
Leakage risk	A risk value for the leakage through the cap-rock

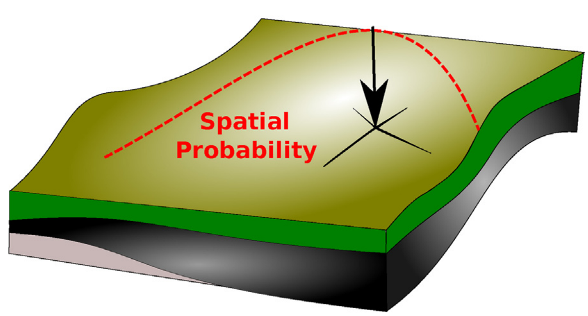

Fig. 3. CO_2 leakage risk is computed as the product of a cap-rock failure probability and the amount of mobile CO_2 beneath the cap-rock, integrated over the entire surface area of the cap-rock. Here, we use a Gaussian function as simple scenario assumption for the cap-rock failure probability (indicated schematically by the color shading and the dashed red line with the black coordinate system). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Please cite this article in press as: Ashraf, M., et al., Geological storage of CO_2: Application, feasibility and efficiency of global sensitivity analysis and risk assessment using the arbitrary polynomial chaos. Int. J. Greenhouse Gas Control (2013), http://dx.doi.org/10.1016/j.ijggc.2013.03.023