International Journal of Greenhouse Gas Control xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

Geological storage of CO_2: Application, feasibility and efficiency of global sensitivity analysis and risk assessment using the arbitrary polynomial chaos

Meisam Ashraf[a,b,*], Sergey Oladyshkin[c,1], Wolfgang Nowak[c,2]

[a] Department of Mathematics, University of Bergen, 5028 Bergen, Norway
[b] SINTEF ICT, Department of Applied Mathematics, P.O. Box 124 Blindern, N-0314 Oslo, Norway
[c] SRC Simulation Technology, Institute for Modelling Hydraulic and Environmental Systems (LH2), University of Stuttgart, Pfaffenwaldring 61, 70569 Stuttgart, Germany

ARTICLE INFO

Article history:
Received 20 July 2012
Received in revised form 1 March 2013
Accepted 23 March 2013
Available online xxx

Keywords:
CO_2 storage
Global sensitivity analysis
Probabilistic risk assessment
Uncertainty quantification
Arbitrary polynomial chaos
Sobol indices

ABSTRACT

Geological storage of CO_2 is a proposed interim solution for mitigating the climate change. Modeling CO_2 storage is accompanied by huge geological uncertainties and excessive computational demands. However, the considerable costs and potential hazards of the technique require feasibility studies to assess all possible risks. This makes computationally efficient methods for sensitivity analysis, uncertainty quantification and probabilistic risk assessment indispensable.

Our goal is to demonstrate the application and feasibility of the arbitrary polynomial chaos expansion (aPC) for these tasks under realistic conditions. We model a typical CO_2 injection scenario in realistic geological realizations of a shallow marine deposit. Our scenario features uncertain parameters that control the structure of geological heterogeneities, including the density of barriers, the aggradation angle, fault transmissibility and regional groundwater effects. The aPC approximates the models by a polynomial-based response surface to speed up the involved statistical analysis of an otherwise expensive simulation tool.

We demonstrate how such an analysis can guide further exploration and the design process of finding suitable injection rates. Our case study demonstrates clearly that the aPC is an efficient, feasible and hence valuable approach in this context, and we strongly encourage its future use. A key advantage of the aPC over more conventional polynomial chaos methods is the flexibility to work with arbitrary probability distributions of uncertain parameters. From our featured parameters, we found the aggradation angle to be the most and the regional groundwater effect to be the least influential one. To the best of our knowledge, this is the first analysis of structural parameters for geological heterogeneities in the CO_2 context and within a probabilistic setting.

1. Introduction

In the context of climate change mitigation, geological storage of CO_2 has been proposed as interim solution. The idea has been challenged during the last decades for its costs and potential hazards (Lenzen, 2011; Viebahn et al., 2007). A large number of studies have been performed in the industry and research communities to evaluate the safety and feasibility of CO_2 storage, addressing issues such as the status and barriers of CO_2 storage (Bachu, 2008), screening and ranking of geological storage sites (Bachu, 2003), large-scale impacts of CO_2 injection in deep saline aquifers (Birkholzer et al., 2009), new solution methodologies for CO_2 leakage (Nordbotten et al., 2005), the capture project (Thomas, 2005), and leakage estimates (Celia et al., 2004). Furthermore, many pilot projects have been installed, like In Salah (Riddiford et al., 2004), Ketzin (Förster et al., 2006), and Johansen (Eigestad et al., 2009). A discussion on the experiences from the existing pilot projects is reported in Michael et al. (2010).

Yet, there is a big demand for studies which demonstrate the appropriateness of the storage operation. Transparent scientific results are required to communicate the facts and evidences about feasibility and possible risks within public and industry. The large involved time and space scales, however, cause substantial

* Corresponding author at: Department of Mathematics, University of Bergen, 5028 Bergen, Norway. Tel: +47 9987 2717; fax: +47 7351 4037.
E-mail addresses: meisam@resman.no (M. Ashraf), Sergey.Oladyshkin@iws.uni-stuttgart.de (S. Oladyshkin), Wolfgang.Nowak@iws.uni-stuttgart.de (W. Nowak).
[1] Tel: +49 711 685 60116; fax: +49 711 685 60430.
[2] Tel: +49 711 685 60113; fax: +49 711 685 60430.

1750-5836/$ – see front matter
http://dx.doi.org/10.1016/j.ijggc.2013.03.023