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Hybrid Mathematical Modelling and Uncertainty Quantification of Underground Hydrogen Storage

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In order to slow the rapidly deteriorating climate crisis we need to drastically increase our use of cleaner, more renewable energy sources. Given that renewable sources are often subject to seasonal variations, the question of what to do with the excess energy has the potential to be answered by underground hydrogen storage systems. The transport of CO2 and natural gases in underground reservoir systems has been widely studied (Ma et al., 2021), however due to hydrogen's unique physico-chemical properties new problems and uncertainties arise. The storage security of underground hydrogen is largely determined by the quality of the dense porous-rock formation known as the caprock which sits on top of the storage site. To assess the potential for leakage, theoretical models need to be developed which can propagate the uncertainty in the spatially varying structure of the caprock (Ma et al., 2018) through to the macroscopic hydrogen transport dynamics. Our approach is to model the transport of hydrogen in the caprock as a diffusion-uptake process with an oscillatory boundary condition to account for the seasonal variations. We quantify the spatio-temporal variations in hydrogen distribution by modelling the diffusivity as a Gaussian random field. Using a Green's function approach (Price et al., 2022) we derive a perturbative solution for the time-averaged variance in the 1D concentration profiles of hydrogen and compare the solution to numerical approximations from Monte-Carlo simulations. Our results show that the uncertainty in the concentration of hydrogen increases non-monotonically with the correlation length of the diffusivity fluctuations. The peak variance in hydrogen concentration occurs when the correlation length is comparable to the steady-state penetration depth of hydrogen into the caprock. The predicted variance can be used to bound the uncertain concentration profile in a credible interval and our method provides a computationally cheap way to achieve this.

Participation

In-Person

References

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