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The effect of caprock topography on long-term CO_2 migration

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The mathematical modeling of long-term CO_2 migration in deep saline aquifers is challenging because of the large spatial and temporal scales that must be considered. Consequently, full-scale numerical simulations can be too expensive to perform detailed risks assessment of potential storage sites. The use of simplified mathematical models that can be solved with analytical methods has been proposed as an alternative to reduce the computational overhead. Yet, it is difficult to develop simplified models that are able to capture the most important aspects of the CO_2 plume dynamics. Our main objectives are: i) to demonstrate that current analytical models fail to estimate key parameters such as plume speed and maximum migration distance for realistic scenarios and ii) to propose improvements to those models to obtain more accurate results.

First, we discuss how measurements performed in real storage sites indicate that the shape of the aquifer caprock controls the direction and speed of the CO_2 plume. Second, we use full-scale numerical simulations to demonstrate how variations of the aquifer caprock can result in important differences in migration distance and plume speed in comparison with results predicted by simple analytical models that approximate the aquifer caprock as a flat sloping surface. Third, we explain why it is crucial to account for the volume of CO_2 that can be potentially trapped underneath the aquifer caprock to get realistic estimates of the maximum migration distance of the plume. Based on theses observations, we conclude that mathematical models of long-term CO_2 migration should always include the effects of the topography of the aquifer caprock.

Since including a high-resolution description of the caprock elevation is difficult in large-scale models, we discuss alternative modeling approaches to take into account the effects of the small-scale fluctuations of the aquifer boundaries. We propose an alternative modeling approach based on an upscaled transport equation with effective parameters that capture the effect of the caprock variability on the plume speed and trapped CO_2 volume. Finally, we discuss the advantages of the proposed effective model versus existent analytical and numerical approaches.