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An adaptive multiphysics model coupling vertical equilibrium and full multidimensions for the simulation of underground gas storage

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Modeling underground gas storage for energy storage purpose (e. g., synthetic natural gas storage, compressed air energy storage) requires simulations on a large domain over the whole time of plant operation, including local features such as heterogeneous zones and pressure propagation beyond the plume extend. The boundary conditions and resulting pressure reversal are driven by external fluctuations in energy demand and supply over a wide range of time scales. In addition, often a large number of simulation runs need to be conducted to quantify parameter uncertainty (e. g. Monte Carlo simulation). In practice, this cannot be achieved with full multidimensional multiphase multicomponent models due to limited computational resources.

In contrast to that, less computational resources are required by numerous simplified mathematical models. One class of these models is based on the assumption of vertical equilibrium [1], [2], which demands that the phase pressures have reached gravity-capillary equilibrium in the vertical direction. However, this assumption may be invalid in the area around the well during injection and extraction of gas, near geological heterogeneities and at the tip of the plume, and in general only holds after a certain timescale in the rest of the domain. In addition, simplified models do not provide the accuracy desired for some parts of interest in the domain, e. g., near the well. The individual benefits of simplified models such as a vertically integrated model and more complex and thus more accurate models such as a full multidimensional multiphase model are combined by coupling both model types in one domain (multiphysics model). The boundary between the submodels is adapted during the simulation to capture transient processes. Stability, applicability and efficiency of the new multiphysics model for different injection scenarios and domain features will be analyzed and discussed. Physically motivated coupling criteria to determine the subdomains where the assumption of vertical equilibrium is valid during simulation will be presented and compared. It will be analyzed how the threshold parameter of the criterion influences accuracy and computational cost of the new multiphysics model. Furthermore, recommendations for the choice of an optimal threshold parameter will be given. It will be shown how the multiphysics model maintains a high degree of accuracy where necessary while being at the same time efficient to be applied for real case scenarios of underground gas storage.

[1]: Lyle, S., Huppert, H. E., Hallworth, M., Bickle, M., & Chadwick, A. (2005). Axisymmetric gravity currents in a porous medium. Journal of Fluid Mechanics, 543, 293-302.

[2]: Nordbotten, J. M., & Celia, M. A. (2011). Geological storage of CO_2: modeling approaches for large-scale simulation. John Wiley & Sons.