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Variable-density effects on the worth of pressure data for characterizing aquifer permeability

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We investigate variable-density effects on the worth of pressure data for estimating aquifer permeability. In variable-density flow and transport in porous media, the pressure distribution is transient even without changes in boundary conditions because the variable-density gradient itself can induce gravity currents. This means that the transient pressure distribution is implicitly coupled with additional information from the variable-density gradient, and consequently the data can be more informative than in density invariant cases for aquifer characterization. To systematically investigate the informativeness of the transient pressure data, we analyze the performance of permeability characterization employing the pressure data under various levels of variable-density effects. The variable-density effects can be controlled by a mixed convection ratio, which is a ratio between two characteristic convections: free convection due to a density gradient and forced convection due to a hydraulic gradient. A 2D density-dependent flow and transport model is established to simulate a coastal aquifer system where density flow occurs due to density difference between saline seawater and fresh water. An ensemble Kalman filter (EnKF) with convariance localization and inflation is used to sequentially estimate heterogeneous aquifer permeability fields by conditioning on real-time pressure head data. The performance of the permeability estimation is analyzed in terms of accuracy of estimated permeability fields, and predictability of arrival times of breakthrough curves in a push-pull setting. The analysis shows that the accuracy and predictability of the inverse estimation can be most improved when the free convection is balanced with the forced convection, which corresponds to the mixed convection ratio being one. This demonstrates that the pressure data is most informative for characterizing aquifer permeability fields when the two characteristic convections are balanced.