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Prior ensemble based on geomechanical proxy model for data assimilation in naturally fractured reservoirs

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Fractures can facilitate or alter fluid flow and transport in subsurface reservoirs. Consequently, their accurate characterisation is crucial for various applications, including geothermal heat extraction and carbon sequestration. Yet, direct measurement of relevant fracture parameters is difficult. Access is limited to wells, leading to significant uncertainties, particularly in estimating fracture aperture and length –key factors influencing flow and transport. The application of indirect methods, including outcrop analogue studies, geophysical imaging, tracer tests and production logging, is vital to mitigate these limitations. It is particularly effective when combined with data assimilation techniques like ensemble Kalman filters.

This study uses a fracture pattern with more than 3500 individual fractures mapped on aerial photographs (Odling, 1997). We assume that the fracture geometry is known *a priori* and focus on fracture aperture as the uncertain parameter. The fractures are subjected to a constant far-field stresses, causing critically stressed ones to shear and dilate. We represent this behaviour with the empirical joint constitutive model of Barton & Bandis (Barton et al., 1985). However, the exact aperture values remain unknown, as they depend on uncertain model parameters like fracture roughness and rock properties. Our goal is to reduce these uncertainties using an ensemble smoother with multiple data assimilation (ES-MDA) (Emerick & Reynolds, 2013) that will be informed with synthetic flow and transport data. Particular attention is given to the influence of the prior ensemble on the performance of the data assimilation framework.

Calculating individual realisations of the prior ensemble with a geomechanical simulator can become prohibitively expensive, especially when a large ensemble size is required. A cheaper, purely stochastic approach on the other hand does not incorporate all geological knowledge. As a compromise between these two methods, we generate the prior ensemble based on the far-field stress approximation (FFSA), a proxy model which projects the far-field stresses onto the fracture planes and approximates shear displacement with linear elastic theory. The FFSA is computationally efficient as it does not rely on geomechanical simulations, while still incorporating geological knowledge to some degree.

Our results demonstrate that FFSA-based prior ensembles significantly outperform stochastic ones, leading to more accurate estimations of fracture aperture and an improved alignment with synthetic reference data. Further, the FFSA requires smaller ensemble sizes than the stochastic approaches as it models aperture more accurately. We expect that these results can be generalised to other ensemble-based DA methods, for example particle filters.

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