Predicting Reservoir Performance: A New Multiscale Method for Well Modeling

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Multiple strongly coupled space and time scales pose a significant challenge for high-fidelity simulations of real-world applications, including power generation in fission reactors and carbon dioxide sequestration in geologic formations. Here system response is measured at engineering-length scales (meters to kilometers) and yet depends crucially on information at microscopic-length scales. A simulation that fully resolves the microscopic details in a large-scale application is well beyond the computational power of modern supercomputers. A naive simulation that does not address the influence of the fine scales is terribly inaccurate. In [1] we developed a novel multilevel multiscale mimetic (M^3) method that strives to balance these extremes, and recently we enhanced its temporal adaptivity [2].

The M^3 method recursively builds a problem-dependent *multilevel hierarchy of models*. Each model preserves important physical properties of the system, such as local mass conservation. In contrast with classical two-level methods that achieve a total coarsening factor of approximately 10 in each coordinate direction, the multilevel hierarchal approach facilitates large total coarsening factors of 100 or more. Maintenance of the hierarchy of models incurs only a modest computational overhead due to the efficiency of recursive coarsening and adaptive update strategies. The M^3 method supports unstructured polyhedral meshes and accommodates general coarsening strategies to capture the geometric complexity of the heterogeneous subsurface environment.

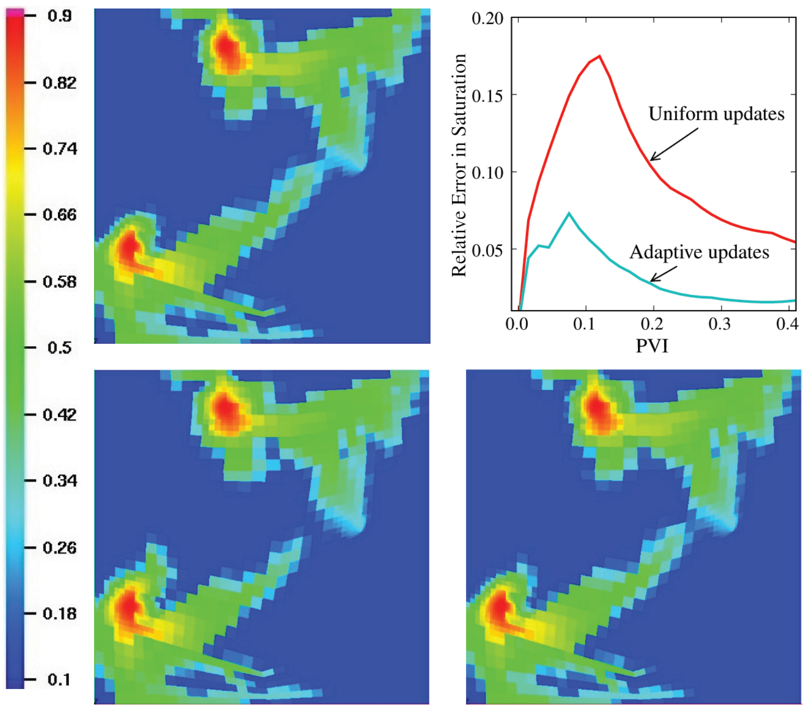

Fig. 1. Using the composite grid (Fig. 2), the reference water saturation in a two-phase immiscible flow model after 240 days with injection of 200 ft^3 of water per day was generated (top left). The multiscale solution obtained using temporally uniform updates of the coarsening factors is shown at the bottom left. Although some features are captured well, later breakthrough of water moving along the low permeability barrier situated in the middle of the domain is apparent. The new adaptive strategy (bottom right) captures this feature precisely, achieving a 3 to 4 times reduction in the saturation error without increasing the computational cost (top right).

Wells in reservoir simulations, which are several centimeters in diameter, are effectively singular features on the reservoir scale and require special treatment to capture the nearby flow accurately. The popular Peaceman well model [3] assumes a homogeneous permeability field and a simple analytic form of the near-well flow in order to approximate its influence on the reservoir. However, these simple approximations are inadequate in practice because heterogeneities often exist near wells, and their influence is accentuated by the rapidly changing flow. To address this problem, various flow-based upscaling methods have been developed that use the solution of a local well-driven flow problem to define the well model. Unfortunately, this localization of the well-driven flow is achieved with approximate internal boundary conditions that often generate large uncontrolled errors.

To overcome these deficiencies we propose combining local mesh refinement around the wells, which naturally provides a multilevel structure, with the

M^3 method. It is important to note that unlike typical mesh refinement applications, a coarse-scale model is not known a priori. Instead, the M^3 method must build the hierarchy of scale-dependent models, including the coarsest-scale model, from the fine-scale data.

To efficiently maintain fine-scale accuracy in the multiscale solution, the M^3 method incorporates two *adaptive strategies.* First, the hierarchy of models is updated locally when the relative permeability, which depends on the water saturation, changes significantly. Second, an efficient error indicator, which was recently developed in [2], controls the temporal updates of the flux coarsening parameters. In contrast with the uniform updates used in [1], this new strategy concentrates updates around critical times when the invading fluid (water) first enters key features of the reservoir.

In this study we considered cell-based mesh refinement around four wells in a highly heterogeneous permeability field (see Fig. 2). Using the IMplicit Pressure and Explicit Saturation (IMPES) time-stepping scheme, we simulated 3000 days of water injection at 200 ft^3 per day. The numerical results (Fig. 1) demonstrated that with the new adaptive updating strategy [2] and a large coarsening factor, close to 250 in each coordinate direction around the wells and 8 far from the wells, the M^3 solution remained within 7% of the fine-scale solution. Moreover, the computational cost was reduced by a factor of 5.

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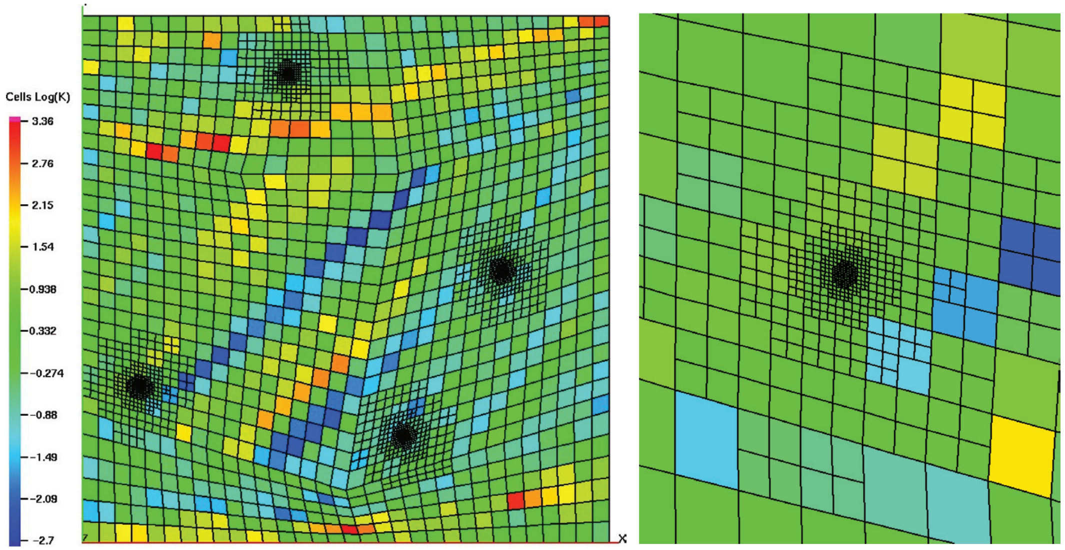

Fig. 2. We considered a highly heterogeneous field that is aligned with the distorted, logically structured, 32 x 32 base grid (left). Five levels of local refinement are used around each of the four wells. For the left-most well, the local refinement is shown more clearly in the zoomed image on the right. Two injection wells are on the left, and two producing wells are on the right of the domain.

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