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An efficient hybrid SBI-FD method for modeling fluid migration and fault-fluid interactions

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The interactions between fluids and fault structures play a pivotal role in understanding fault slip behavior. Over the years, various numerical methods have been developed to simulate these interactions. Volume-based methods, like the finite difference method (FDM), excel in their capacity to handle the intricacies of real-world fault structures, including material heterogeneity. On the other hand, the spectral boundary integral method (SBIM) is renowned for its computational efficiency. Recently, a hybrid approach has garnered significant attention, offering the benefits of both volume-based and SBI methods. This hybrid method allows for the consideration of fault structures' heterogeneity while maintaining computational efficiency. In this study, we introduce a novel hybrid method that bridges the SBIM and the FDM to model fluid migration in fault structures. Through rigorous model verification, we establish that our hybrid method can achieve a remarkable speedup of up to one thousand times compared to the FDM. Furthermore, we conducted two parametric studies to address open questions in fluid migration modeling within fault structures. First, we investigate the mobility contrast ratio between the host rock and the damage zone to determine the limits under which we can assume a zero-leak-off interface. Second, we explore the role of fault zone width in maintaining the validity of this zero-leak-off assumption. Building upon these foundational investigations, we demonstrate the possibility of extending the numerical framework to describe fault-fluid interactions considering poroelastic coupling.