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Benchmarking computational fluid dynamics models for lava flow simulation

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Numerical simulations of lava flow emplacement are valuable for assessing lava flow hazards, forecasting active flows, interpreting past eruptions, and understanding the controls on lava flow behavior. Existing lava flow models vary in simplifying assumptions, physics, dimensionality, and the degree to which they have been validated against analytical solutions, experiments, and natural observations. In order to assess existing models and guide the development of new codes, we conduct a benchmarking study of computational fluid dynamics models for lava flow emplacement, including VolcFlow, OpenFOAM, FLOW-3D, and COMSOL. Using the new benchmark scenarios defined in Cordonnier et al. (Geol Soc SP, 2015) as a guide, we model viscous, cooling, and solidifying flows over horizontal and sloping surfaces, topographic obstacles, and digital elevation models of natural topography. We compare model results to analytical theory, analogue and molten basalt experiments, and measurements from natural lava flows. Overall, the models accurately simulate viscous flow with some variability in flow thickness where flows intersect obstacles. OpenFOAM, COMSOL, and FLOW-3D can each reproduce experimental measurements of cooling viscous flows, and FLOW-3D simulations with temperature-dependent rheology match results from molten basalt experiments. We can apply these models to reconstruct past lava flows in Hawai‘i and Saudi Arabia using parameters assembled from morphology, textural analysis, and eruption observations as natural test cases. Our study highlights the strengths and weaknesses of each code, including accuracy and computational costs, and provides insights regarding code selection.