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Multiphase flow modelling of explosive volcanic eruptions using adaptive unstructured meshes

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Explosive volcanic eruptions generate highly energetic plumes of hot gas and ash particles that produce diagnostic deposits and pose an extreme environmental hazard. The formation, dispersion and collapse of these volcanic plumes are complex multiscale processes that are extremely challenging to simulate numerically. Accurate description of particle and droplet aggregation, movement and settling requires a model capable of capturing the dynamics on a range of scales (from cm to km) and a model that can correctly describe the important multiphase interactions that take place. However, even the most advanced models of eruption dynamics to date are restricted by the fixed mesh-based approaches that they employ.

The research presented herein describes the development of a compressible multiphase flow model within Fluidity, a combined finite element / control volume computational fluid dynamics (CFD) code, for the study of explosive volcanic eruptions. Fluidity adopts a state-of-the-art adaptive unstructured mesh-based approach to discretise the domain and focus numerical resolution only in areas important to the dynamics, while decreasing resolution where it is not needed as a simulation progresses. This allows the accurate but economical representation of the flow dynamics throughout time, and potentially allows large multi-scale problems to become tractable in complex 3D domains.

The multiphase flow model is verified with the method of manufactured solutions, and validated by simulating published gas-solid shock tube experiments and comparing the numerical results against pressure gauge data. The application of the model considers an idealised 7 km by 7 km domain in which the violent eruption of hot gas and volcanic ash high into the atmosphere is simulated. Although the simulations do not correspond to a particular eruption case study, the key flow features observed in a typical explosive eruption event are successfully captured. These include a shock wave resulting from the sudden high-velocity inflow of gas and ash; the formation of a particle-laden plume rising several hundred metres into the atmosphere; the eventual collapse of the plume which generates a volcanic ash fountain and a fast ground-hugging pyroclastic density current; and the growth of a dilute convective region that rises above the ash fountain as a result of buoyancy effects.

The results from Fluidity are also compared with results from MFIX, a fixed structured mesh-based multiphase flow code, that uses the same set-up. The key flow features are also captured in MFIX, providing at least some confidence in the plausibility of the numerical results in the absence of quantitative field data. Finally, it is shown by a convergence analysis that Fluidity offers the same solution accuracy for reduced computational cost using an adaptive mesh, compared to the same simulation performed with a uniform fixed mesh.