Multiphase models of explosive volcanic eruptions: a review of important milestones and examination of future prospects for hazards assessment.

A. B. Clarke, School of Earth and Space Exploration, Arizona State University, amanda.clarke@asu.edu.

Introduction: The primary aims of this talk are (1) to review the history of, and recent progress in, multiphase modeling of pyroclastic dispersal associated with explosive volcanic eruptions, and (2) examine its future as a hazard assessment tool which may aid eruption prediction (timing and scale), as well as be used to produce maps of areas impacted by pyroclastic density currents. Numerical and physical modeling of volcanic processes have become invaluable in developing our understanding of essential eruptive mechanisms [1] illustrating parametric relationships [2], [3], [4], [5], [6], illuminating non-intuitive and unexpected behavior [7], [8] and, in some cases, improving our ability to predict eruptions and their impact [9]. One modern approach is multiphase modeling which treats solid and gas phases independently and attempts to simulate the details of the natural system by accounting for a range of particle sizes, calculating momentum and heat transfer between phases, quantifying spatial and temporal changes in turbulent entrainment, and accounting for phase changes due to chemical reactions and temperature evolution. Such models have the potential for positive socio-economic impact by predicting the inundation area and subsequent impact of hazardous volcanic flows. However, demonstrating the ability of multiphase models to match complex *natural* phenomena remains a significant challenge.

Multiphase models have generally been used to increase intuition about physical processes, and have been limited in their use as predictive or hazard assessment tools. For example, the effects of grain size and grain-size distribution are important to macroscale evolution of eruptions [10], [11]; total energy of the volatile phase significantly controls collapse characteristics and corresponding pyroclastic density current formation [8], [12]; total solid mass controls current runout distance and inundation area, e.g., [12]; the substrate (water vs. land) also affects runout distance, as do deposition algorithms [13]; and grid resolution may play a non-negligible second-order role [12]. Recent studies link subsurface magma ascent dynamics to pyroclastic dispersal, providing a means by which standard geophysical monitoring data may be used to make first-order predictions about the style and impact of subsequent explosive eruptions [8], [14], [15] (Figure 1). Particularly valuable studies examine systems where both input parameters such as magma chemistry, chamber depth, volatile content, and output parameters such as pyroclastic current velocity or dynamic pressure and runout distance are known or well-constrained. Such well-constrained systems allow model results to be compared against observations of flow dynamics for small explosive eruptions (e.g., Soufrière Hills volcano, Montserrat [8], [14]; Figure 2) or against estimates based on eruption deposits for large historic eruptions (AD 79 eruption of Vesuvius [16], and the 161 ka Kos Plateau Tuff eruption [17]). One of the most important model developments which may help to bridge the gap between theory and real-time hazards assessment is the development of fully three-dimensional codes in which realistic topography is included [18], [12]. Esposti-Ongaro et al. [12] compare model results to field-based estimates of dynamic pressure in lateral blasts, e.g., [19], focusing in part on lateral variations caused by channeling effects – effects which can not be resolved in two-dimensional or axisymmetric formulations (Figure 3). Consistency between observations and model results may be improved via such field comparisons in combination with refinement of constitutive relationships and development of new physical theory through laboratory experiments, e.g., [20], [21].

In summary, the physical relevance and practical utility of numerical models of volcanic processes is continually growing via increased computational power, new solution algorithms, and code development. An essential means of improvement are careful comparisons against natural events and laboratory experiments, which serve to illustrate circumstances under which theoretical descriptions fail to capture natural behavior, and therefore require reformulation and code improvement.

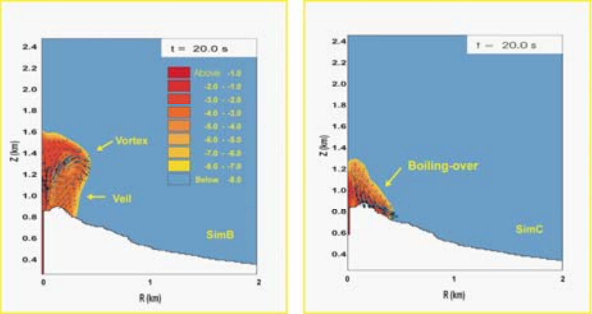

Figure 1. Simulation results accounting for permeability during magma ascent. Top: low subsurface permeability. Bottom: high subsurface permeability [14].

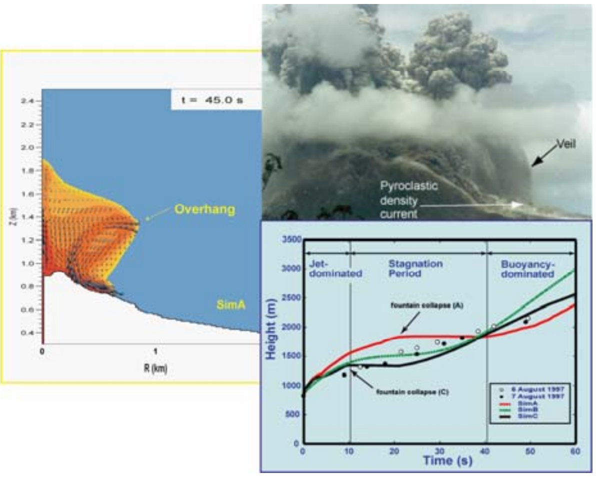

Figure 2. Qualitative and quantitative comparison between multiphase simulations and small explosive volcanic eruptions at Soufrière Hills volcano, Montserrat.

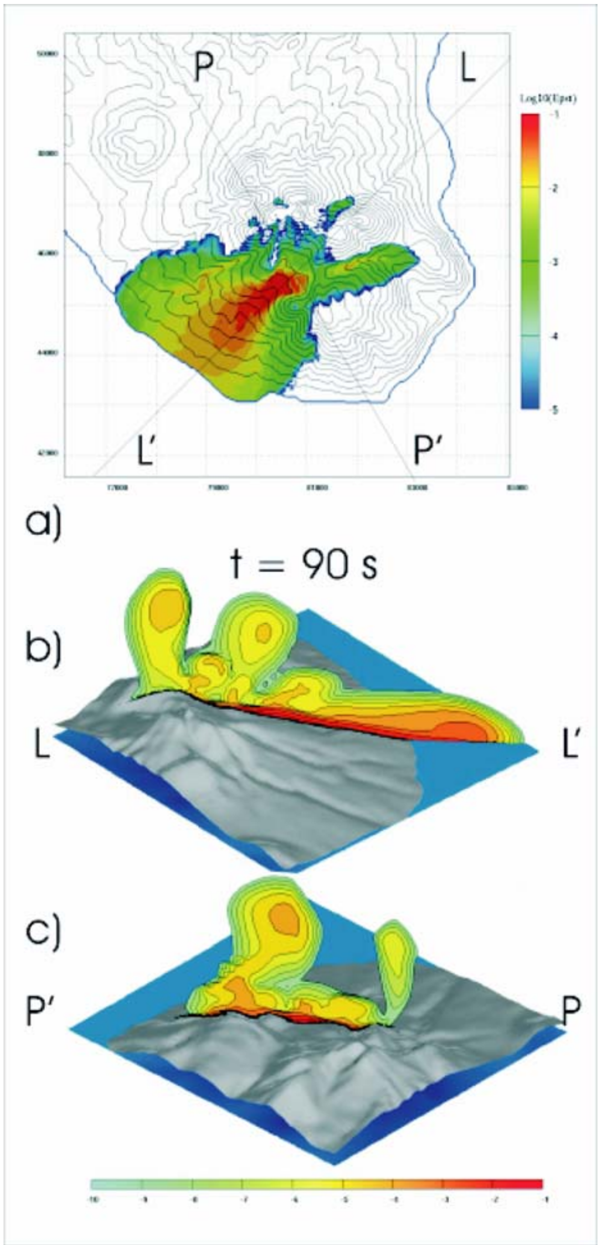

Figure 3. a) Map of the $\log_{10}$ of total particle concentration 10m above ground, 90 s into a simulation of the 1997 lateral blast at Soufrière Hills volcano; b) longitudinal LL' section of the $\log_{10}$ of total particle concentration along the flow direction (seen from NW), demonstrating that particles concentrate near the base of the flow; c) transversal PP' section (seen from NE), illustrating that particles concentrate along channel axes [12].

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