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Numerical Simulation of Explosive Volcanism and Its Effects on the Atmosphere

Greg A. Valentine* and James E. Bossert

Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). The objective of this project was to begin work on combining two modeling approaches in order to advance the state-of-the-art in simulating and predicting explosive volcanic eruption dynamics and their effects. We began applying the CFDLIB family of codes for the near field (high temperature, velocity, and particle concentration) region of an explosive eruption. We also applied the RAMS meteorological code to model the far-field dynamics of eruption clouds and ash fallout. Initial test runs were conducted in preparation for full-scale simulations that would eventually couple the two models for the most comprehensive volcano simulation tool to date. Eventual applications include aviation hazards, risk assessment, and extension to atmospheric collateral effects of conventional and nuclear weapons.

Background and Research Objectives

Explosive volcanism is one of the most dramatic of natural events. During these eruptions a mixture of hot particles and gas flow out of a volcanic vent at speeds of several 100 m/s. The mixture rises into the atmosphere and entrains air. Depending on the eruption conditions (velocity, gas content, particle size range, pressure, and vent size) and atmospheric conditions (cross winds, stratification), the mixture continues to rise to high altitudes or falls back to the ground, producing high-speed density currents that flow out across the landscape. Eruptions affect humans on a variety of time and space scales. Near an eruption site (within 1 - 100 km, the *near field*), eruptive effects are immediate and devastating. They include fast moving (up to 300 m/s), hot, particle-laden density currents, shock waves, and heavy fallout of ash from buoyant plumes. At intermediate distances (10s - 100s of km from eruption sites; *mesoscale*), plumes of ash leave damaging fallout deposits that choke machinery and agriculture and pose threats to aviation for the

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duration of an eruption (hours to weeks). At larger distances (*global* scale) the ash, gases, and aerosols that an eruption injects into the atmosphere can affect the global climate for several years after an eruption.

Los Alamos has a long-standing interest in volcanic and atmospheric processes due to a variety of programs, including geothermal energy, nuclear test containment, hazardous plume dispersion, and global climate change. Laboratory researchers lead the geophysical community in applying two-dimensional, time-dependent, multiphase hydrodynamic modeling to the near-field dynamics of explosive eruptions (Wohletz et al., 1984; Valentine and Wohletz, 1989a,b; Valentine et al., 1991; Valentine et al., 1992). These approaches are now being used in the international geophysics community for both basic research and hazard mitigation (e.g., Dobran et al., 1993, 1994; Neri and Dobran, 1994; Kieffer, 1995), and have played a major role in establishing computational approaches for a range of magmatic processes (Bergantz, 1995). Since our early work, the capability to compute near-field dynamics has been superseded by the work of Dobran and colleagues.

Los Alamos is currently using and developing the most scientifically rigorous modeling systems for the simulation of atmospheric mesoscale processes (Bossert and Cotton, 1994a, 1994b; Margolin et al., 1995). These models have recently been used to examine dispersion processes in regions of highly complex terrain (Poulos and Bossert, 1995; Bossert and Poulos, 1995). To date, the eruption and atmosphere simulation capabilities of the Laboratory have not been combined.

The objectives of this work are two fold. First, we will make a major advance in our ability to simulate the near-field dynamics of explosive eruptions by applying the most sophisticated multiphase hydrodynamics codes available at the Laboratory -- the CFDLIB family of codes. The new capabilities will include three-dimensional, multiple particle sizes, and multicomponent gas. Second, we will combine the eruption modeling capability with our atmospheric transport capability. We will use the near-field modeling to develop rigorous source terms for mesoscale transport of volcanic plumes and ash fallout. This work will constitute the next generation of eruption dynamics and atmospheric effects modeling.

Importance to LANL's Science and Technology Base and National R&D Needs

Forefront Science --Our previous work on the first generation of multiphase numerical eruption modeling was of extremely high visibility in the geophysical community. It introduced numerical simulation into a realm of geological sciences that had previously used only observation and simple theory. The work in this proposal will allow us to retain this high visibility and the programmatic funding that results from a strong technical reputation.

Weapons Effects --The computational approaches and tools developed in this proposal will be directly applicable to modeling of nuclear and conventional weapons effects. Weapons effects modeling in the past has been an important component of the weapons program. Our research will sharpen the appropriate modeling tools in a manner that maintains visibility and reputation in the research community and that addresses real problems.

Aviation Hazards --A direct and highly practical application of this work will be the mitigation of aviation hazards. Explosive volcanic regions such as the Pacific Rim, Indonesia, and the Mediterranean are also areas of heavy air traffic both for civilian and defense purposes. We are pursuing joint work with the Jet Propulsion Laboratory that would couple satellite observations of eruptions with real-time predictive modeling of plumes so that air traffic can be safely rerouted, particularly for flights over and around the Pacific Ocean.

Scientific Approach and Accomplishments

Theoretical Underpinning

A comprehensive review of explosive volcanism modeling to date was conducted and used as part of the basis for a new multifield theoretical framework for describing eruption phenomena. The theoretical framework is based on conservation of mass, momentum, and energy for multicomponent gas with particles and droplets with a range of sizes. This was presented at an international conference in the form of a short course, and is being published as a chapter of a book that is tentatively titled "Physics of Explosive Eruptions."

Near-Field Dynamics

We began using the CFDLIB family of codes for near field (high velocity, temperature, and particle loading regimes) dynamics of explosive eruptions. Much effort was put into learning the codes and their underlying theories in order to be most efficient in applying them to volcanic problems. Results to date include simple gas explosions, and initial work on loading explosions with ash particles. These are essential first steps toward successful application to volcanic conditions.

Far-Field Dynamics

Numerical experiments with the regional meteorological code RAMS (Pielke, 1992) were conducted to determine what, if any, modifications would be necessary for the code to be able to model intense thermal buoyancy effects, ash transport, and fallout in explosive eruption clouds as they are transported downwind. Initial calculations for small-scale (but quite common) types of explosive eruptions were successfully conducted, and we determined that velocities of up to about 80 m/s could be computed without any modification to RAMS. We are exploring the adaptation of the numerical models of precipitation and condensation in rain clouds to fallout and particle coalescence in volcanic plumes.

The scope of this project did not allow achievement of definitive new results. However, we have laid a strong foundation for gaining new levels of understanding and predictive capability for volcanic phenomena using these computer codes. We expect to be ready to present two papers at the next general congress of the International Association of Volcanology and Chemistry of the Earth's Interior (July 1998).

Publication

Valentine, G.A., "Eruption Column Physics," in Physics of Explosive Eruptions (tentative book title), Elsevier Science Publisher, (in press, 1998).

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