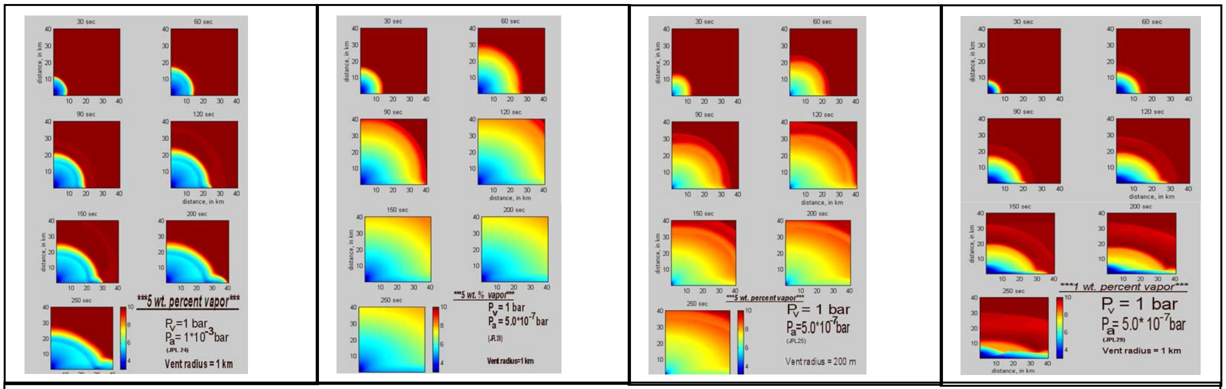
PLUME MODELS AND PYROCLASTIC FLOW ON IO

W. D. Smythe[1], S. W. Kieffer[2], R. Lopes-Gautier[1] [1]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109,wsmythe@lively.jpl.nasa.gov; [2]S. W. Kieffer Science Consulting Inc. Box 520, Bolton, Ont. L7E 5T4,skieffer@geyser.com

Our simulations of Io's plumes suggest that eruptions with low volatile content can form pyroclastic flows on Io. The motivation for these simulations is to understand differences between Ionian and terrestrial plumes, including: How does the low Ionian atmospheric pressure affect plume behavior; What is the Ionian equivalent of a Plinian column; and Are pyroclastic flows possible in a low-pressure environment?

Volcanic plumes on Io may have different appearances depending on their volatile to particle ratio. We simulated a number of cases using a model that treats the plumes as supersonic gas/particle eruptions. The composition of the atmosphere, particle size, gas composition, acceleration of gravity, and initial pressure and temperature of the volcanic mixture and the atmosphere all influence the behavior of the plume; however, the ratio of vent pressure to atmospheric pressure is a first-order effect that must be understood before other variables can be considered.



Effects of ambient atmospheric pressure on plumes (panels 1,2), vent size (panel 3) and volatile content (panel 4): *The simulation colors show the variation of the negative log of the volume fraction of ash particles (see reference color bar). All conditions for the simulations are appropriate to Io EXCEPT that atmospheric pressure is varied from 1 bar (the assumed vent pressure) to lower pressures appropriate to Io. The simulations were run only down to an atmospheric pressure of 5*10^{-7} bar (in contrast to Io's atmospheric pressure of ~10^{-7} bar to insure numerical stability. Parameters: g=180 cm s^{-2}; vent radius 1 km except panel 3; particle radius 10^{-4} cm; vapor weight fraction as shown on figures; gas and ash temperature at the vent 400 K; atmospheric temperature 130 K, atmospheric pressure at surface and exponential decay with height*

The calculations are for cylindrically symmetric eruptions from a central vent. The approach used is that of Wohletz, Valentine, and colleagues (1,2,3,4,5) which is based on explicit numerical solutions of the equations of conservation of mass, momentum, and energy (6). A two-component mixture of gas and dispersed ash particles (a fluid) is assumed to erupt from the vent. The gas is described by the ideal gas equation of state and the ash particles are assumed to be incompressible. Conservation equations are applied to the ash and gas components separately, so that they may have different temperatures and velocities. The components interact with each other through drag forces and heat transfer. The governing equations of motion and constitutive relations form a system of eight partial differential equations and eight algebraic equations with 16 dependent variables and are approximated by finite difference methods (7). The gas and ash enter the computational domain at time t=0 through the vent. The proportions of ash and gas are specified by the weight fraction of gas, and the initial velocity, temperature, and pressure are assumed. The atmosphere is initially isothermal and its pressure and density decrease exponentially with height. The symmetry axis is defined as a reflecting boundary. The top and right-hand boundaries are outflow boundaries. The bottom boundary is treated as a frictionless substrate.

The effect of the ratio of vent to atmospheric pressure is illustrated in panels (1,2), in which a hypothetical case of relatively high atmospheric pressure (10^{-3} bar, panel 1) is compared with a lower atmospheric pressure ($5*10^{-7}$ bar, panel 2).

A strong atmospheric shock, closely followed by the expanding supersonic flow field, propagates rapidly away from the vent, carrying ash radially outward, and along the ground. Under near-Ionian conditions of low pressure (right panel), volcanic ash and gas flow out of the 40-km domain within two minutes. The simulation in panel 3 is for the lowest pressure ratio (atmosphere/vent = $5*10^{-7}$) but with the vent size reduced to 200 m. The phenomenology is qualitatively similar to that of the larger vent, but the complex shock structure behind the expanding front is more visible because the flow develops on a smaller spatial scale. The shock structure is shown by the alternating red/red-yellow bands, which represent a variance in particle concentration resulting from the shocks. The simulation at the far right has low volatile content (1%). At low volatile contents, the numerical simulations suggest that it is possible that erupting columns of ash and gas on Io will collapse back to the ground and produce outwardly moving pyroclastic flows. At higher volatile content, extremely nonlinear and non-intuitive results are obtained. The eruptions emerge rapidly into a vacuum. The radially diverging shock wave displays the classic shock-rarefaction-shock phenomenon known as an N-wave (well known from Krakatoa's eruption). This phenomenon is best seen on density or pressure plots, but on the log theta snapshots shown here, the N-wave is indicated by the oscillating shades of red and orange near the shock front. The front of the volcanic eruption is not well defined numerically because of the use of an eddy viscosity, and is difficult to relate directly to observed spacecraft parameters, but if it is taken as the +7 contour by analogy with terrestrial optical depths, the green/yellow boundary would delimit the strongly volcanic component. The Ionian equivalent of an expanding Plinian column is a radially accelerating supersonic flow field. Even at high volatile contents (>a few percent) a laterally moving basal flow also is formed. We tentatively interpret this as a flow that is stabilized in a high-pressure basal layer formed by oblique shocks reflected from the ground surface.

1. K.H. Wohletz, T.R. McGetchin, M.T. Sanford II, E. M. Jones, J. Geophys. Res., 89, 8269, 1984.; **2.** G.A. Valentine and K.H. Wohletz, J. Geophys. Res., 94, 1867, 1989; **3.** *Ibid* and S.W. Kieffer, Geol. Soc. Am. Bull., 104, 154, 1992.; **4**. K.H. Wohletz and G.A. Valentine, in Magma Storage and Transport, M. Ryan, ed. (Wiley, New York, 1990). **5.** G.A. Valentine, K.H. Wohletz, S.W. Kieffer, J. Geophys. Res., 96, 21887, 1991.; **6**. F.H. Harlow and A.A. Amsden, J. Comput. Phys., 17, 19, 1976.; **7.** The original computer code DASH was developed at Los Alamos National Laboratory to study Dusty Air Shocks. DASH was adapted to low atmospheric pressure conditions and renamed JPL/IO for these calculations. This work was supported by the NASA JSDAP program, the GEM project and an AAS grant.