DSMC Modeling of the Plume Pele on Io. W. J. McDoniel[1], D. Goldstein[1], P. Varghese[1], L. Trafton[2], and B. Stewart[1], [1]Department of Aerospace Engineering, [2]Astronomy Dept, University of Texas at Austin (mcdoniel@mail.utexas.edu)

Introduction: Volcanic plumes potentially provide us with evidence of some of a planet's dominant geologic and atmospheric processes, and can be the primary agent controlling the environment and the evolution of a planetary surface over modest time scales. This is especially true for Io, where the volcanic plumes are an ongoing phenomenon of nearly global scale that resurfaces the moon at rates estimated at more than 0.02 cm/yr and possibly as high as 2 cm/yr. The morphology and composition of these plumes is our prime clue to the subsurface geologic processes and composition, which is critical to understanding Io's formation and evolution.

Progress has been made in modeling Io's plumes realistically by using Direct Simulation Monte Carlo (DSMC) techniques [1]. Until recently, simulated plumes have been treated as evolving from disk-like circular vents, but many of Io's volcanoes do not conform to this simple geometry and require fully three-dimensional simulation. Last year we introduced a "C"-shaped source [2], demonstrating some of the complex features of asymmetric vent geometries, and since then we have simulated a close approximation of Pele's vent.

Modeling: *DSMC*: Except for planetary surface regions extremely close to the physical vents, Io's plumes are of very low density. We simulate rarefied atmospheric flow with the DSMC molecular method. This method is the engineering approach of choice for modeling a wide range of rarefied flows around spacecraft when the mean free path is large. Such flows commonly involve high temperatures, chemical reactions, droplet formation, and radiation – many of the same phenomena of interest in Ionian plumes. In DSMC the motions and collisions of a relatively small number ($O(10^7)$) of representative molecules are computed, from which the flow of the entire gas is statistically extrapolated. The multiple time scales involved in the different physical phenomena can be handled with spatially variable time steps and grids, and with different overlay techniques.

Sources: With the possible exception of some Pillanian and stealth types, plumes probably do not evolve from disk-like sources. Those that arise from lava impinging on pre-existing ice exude material from the boundary between a lava flow and surface frost, while those which evolve directly from hot rock can come from long fissures in the ground or from multiple individual sources close together.

In Pele's case, we can use infrared images from Galileo to identify those regions where the gas is hottest, which are expected to correspond to the plume's sources.

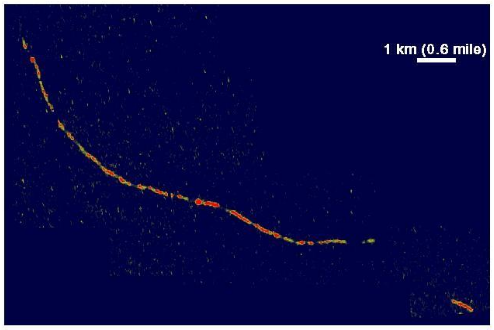

Fig 1: Galileo image of Pele's source, regions with temperature higher than 873K are visible in red.

If this is the true source, then gasdynamic processes are acting on the flow so as to produce a fairly symmetric far-field and a heart-shaped deposition ring, and our DSMC model of the plume evolving from this source should reproduce these as well.

Fig 2: Galileo image of Pele's deposition ring

We model this source as a series of 28 discrete disks with very small, non-overlapping radii (~50m). Simulated molecules are created in virtual vents just above the predicted liquid rock at a given density and temperature and are allowed to drift upwards over the course of a single time step.

Many more simulated molecules are required to capture the fully three-dimensional, as opposed to the axisymmetric, problem, and so our simulation is run on multiple processors. If the plume is on the equator, then the processor boundaries are lines of constant longitude, and the grid resolution varies from ~50m near the plume source to ~500m in the canopy.

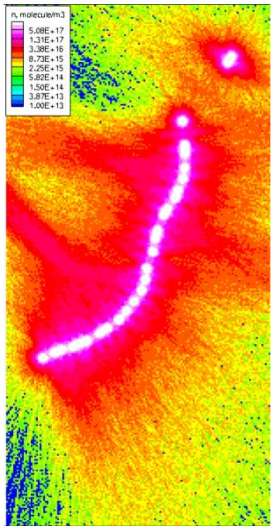

Fig 3a: Near-field ground-level number density contours.

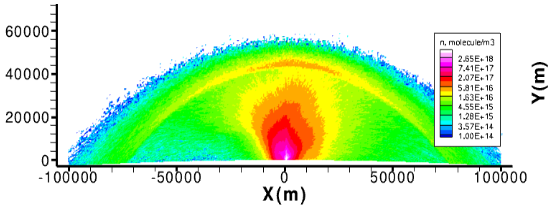

Fig 3c: Number density contours of a constant longitude slice of the plume.

Results: The figures above are time-averaged slices of plumes evolving from our model of Pele's source at steady state. In Fig 3a, molecules are generated in the regions in white with an upwards velocity of 200 m/s, a temperature of 180K, and a density of 5.315×10^{16}. The ground temperature is set to 50K so that there is no sublimation, and all molecules impacting the surface are assumed to stick. On the final poster, the vent conditions will be updated to values more appropriate for Pele and the simulation will be run on many more processors. Note that the ground-level images are rotated 90 degrees from the source in Fig 1 so that the deposition ring aligns with Fig 2.

The near-field demonstrates many features not seen in simple disk-source plumes. As seen in Fig 3a, focused jets of gas emerge from concave regions of the vent. These jets result when gas rising off of a concave region of the vent encounters gas coming in from different directions at the focal point of the concave region. The flow then shocks and turns outward. This model clearly does a better job of capturing Pele-type far-field phenomena than does the disk-source model.

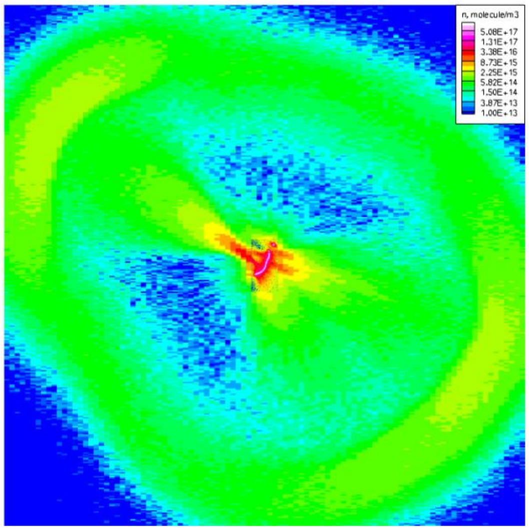

Fig 3b: Far-field ground-level number density contours

Fig 3b shows how the deposition ring elongates because of the focused jets, with the diverging jets on one side creating a gentler curve than the converging jets on the other side, which could form the point seen on the top of Fig 2.

The density of the deposition ring also varies somewhat, also corresponding to the focused jets. The near-field jets also result in significant differences in density around the plume source inside of the deposition ring, which compares well with the asymmetries seen around the vent in Fig 2.

Fig 3c shows the development of the roughly symmetric canopy shock. While the vent geometry causes asymmetric features inside of the canopy, the canopy itself changes very little as one rotates around the plume, and its height is almost constant The effect of the jets can also be seen here, sending more material up and out further to the right side of the vent than the left.

Acknowledgments: This work was made possible by grant #NNH07ZDA001N-PATM from NASA Planetary Atmospheres.

References:

[1] Zhang J. et al. (2003) Icarus, 163, 182-197.
[2] McDoniel, W.J. et al. (2009), DSMC Modeling of an Irregular Vent Geometry for Ionian Plumes, LPSC (Poster).
[3] Geissler P. E. and Goldstein D. B. (2006), Io After Galileo, 163-188.