**HYBRID MODEL OF GAS/PARTICLE PLUME OF ENCELADUS.** T. A. Chapman[1], S. K. Yeoh[1], D. B. Goldstein[1], P. L. Varghese[1] and L. M. Trafton[2], [1]Computational Fluid Physics Laboratory, The University of Texas at Austin, Austin, TX 78712 (skyeoh@mail.utexas.edu, tac688@mail.utexas.edu), [2]Department of Astronomy, The University of Texas at Austin, Austin, TX 78712.

**Introduction:** Cassini first detected a water vapor plume near the warm south pole of Enceladus in 2005 [1-4]. Since then, more flybys have been made over the moon and have yielded spectacular images, details of the plume structure and composition, as well as the possible locations of the plume sources [5]. Observations suggest the plume is composed of gas with tiny entrained ice particles [3-8]. Based on the images and data from Cassini, we construct a hybrid model of the gas/particle plume. The model divides the plume into two regimes. The direct simulation Monte Carlo (DSMC) method is used in the region near the vent where the plume is relatively dense and collisional. The DSMC output is fed into a computationally less-expensive free-molecular model to simulate the far-field where collisions are negligible and the assumption of non-collisional dynamics is adequate. The outcome is directly compared to the in-situ measurements from the Cassini. Stellar occultation measurements during the flybys are also modeled. Simulation results may be used to deduce the physical conditions at the plume sources, such as temperature, velocity, vent geometry and plume generation mechanism.

**DSMC Model:** The source of the water vapor composite plume is modeled as a series of smaller axisymmetric vents along the tiger stripes [1]. The conduit underneath the vent is modeled as a converging-diverging nozzle (Figure 1). Water vapor expands isentropically from stagnation conditions in the reservoir to the vent exit. The resulting conditions at the vent exit are taken as the simulation parameters for DSMC. DSMC is used to simulate the expansion of the water vapor from the vent exit into vacuum until the flow becomes effectively collisionless, or free-molecular, and the dust particles are no longer affected by the gas flow. Simulation data are then passed on as an input to the free-molecular code which runs the plume into outer space.

Dusts grains of various sizes, from nanometers to microns, are incorporated into the gas flow. They are entrained by the gas flow initially before separating from it at a certain height above the vent as the gas density drops and gravity starts to dominate (Figure 2). To determine this height, the ratio of the gas dynamic drag force on the grains to the gravity force is calculated. However, there are difficulties in finding this ratio due to the large Brownian accelerations experienced by the smaller particles. A low mass loading is assumed; only the gas affects the dusts and not vice-versa.

**Free-Molecular Model:** The free-molecular model simulates particle (molecule and grain) trajectories about Enceladus by generating virtual particles from eleven point sources located along the tiger stripes in the south polar region of Enceladus [5]. Since the plume composition is approximately 90% H20 [3], the gas is modeled as purely water vapor.

To simulate the plumes, we assume water vapor effuses from an orifice with a mass flux distribution determined by the DSMC model. Each virtual particle simulates a specified number of real gas molecules. The spreading plumes merge with a global sublimation atmosphere and background E-ring gas. When the plumes reach steady state conditions, Cassini trajectory data is utilized to simulate a flyby [7]. INMS density data collected during the E3, E5, and E7 flybys of Enceladus allow the simulations to be compared to *in situ* data [6] (Figures 4a, b, and c). Furthermore, the occultations of lambda Scorpii and gamma Orionis can be simulated and compared to data taken from Cassini's UVIS instrument [2].

Raw flyby simulations results agree well with the general magnitude and shape of *in situ* measurements, but there are noticeable discrepancies in the peaks and tails of the simulated flybys (Figures 5a, b, and c). This is due to the fact that the free-molecular model does not account for instrument delay effects like adsorption/desorption [9]. By convolving with an exponential decay function, for adsorption, plus a constant to account for prolonged desorption, $f(t) = A\left(\frac{t}{\tau}\right)^2 e^{-t/\tau}+C$, a model of the true instrument response can be obtained (Figure 6). Convolution with this instrument function delays the initial rise, lowers the peak values, and slows the drop off of the tail. Alternatively, an inverse Fourier analysis technique can be used to develop a more general instrument response. Dividing the fast Fourier transform (FFT) of the observed data by the FFT of the simulated data yields the FFT of the instrument response. Taking the inverse FFT of this gives the desired instrument response.

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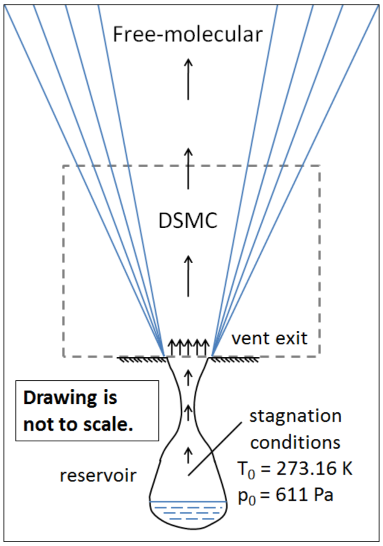
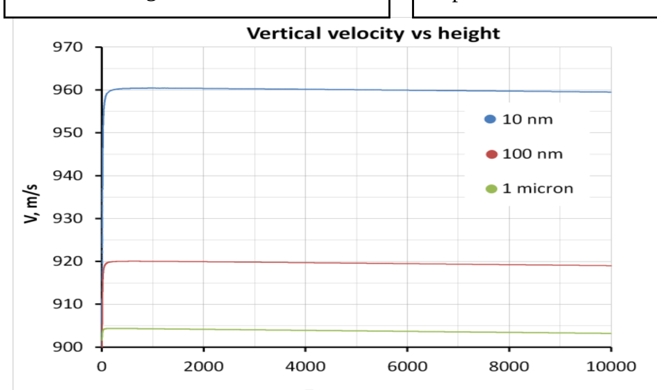



**Figure 1:** A schematic of the simulation regimes. DSMC is used in the collisional flow near the vent while the free-molecular model is used further out where the flow is mostly collision-less. The reservoir conditions are assumed to be the triple-point of water.

**Figure 2:** DSMC results of the plume near-field. Three dust particles are launched at the vent, normal to the surface, at the bulk gas exit speed (~900 m/s). The vertical velocity components of the dust particles are plotted against height. Initially the dust particles are accelerated by the gas. As gas density drops with height, gravity starts to dominate and the dust velocities begin to decrease.



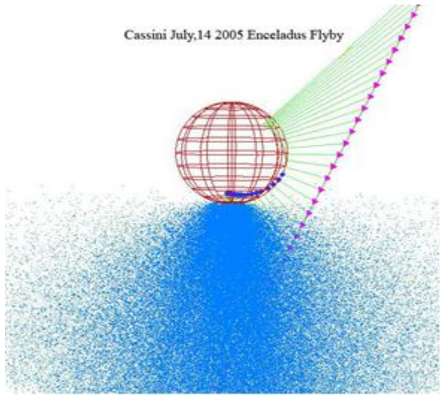




**Figure 3:** Visualization of Cassini E5 flyby through free-molecular south polar plumes of Enceladus. The green lines and red arrows indicate the spacecraft trajectory, while the blue squares represent the spacecraft groundtrack.

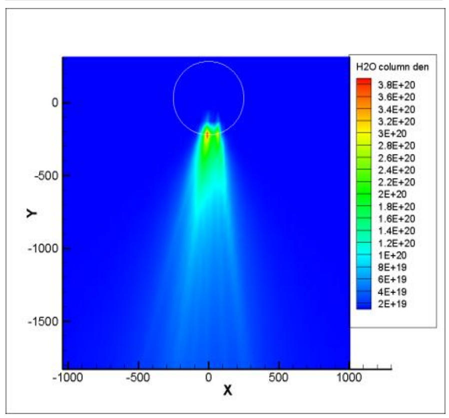



**Figure 4:** Water column density, as viewed from Saturn, of South Polar plumes as simulated by free-molecular model with DSMC initialization (axis values are in km). The white circle represents Enceladus.

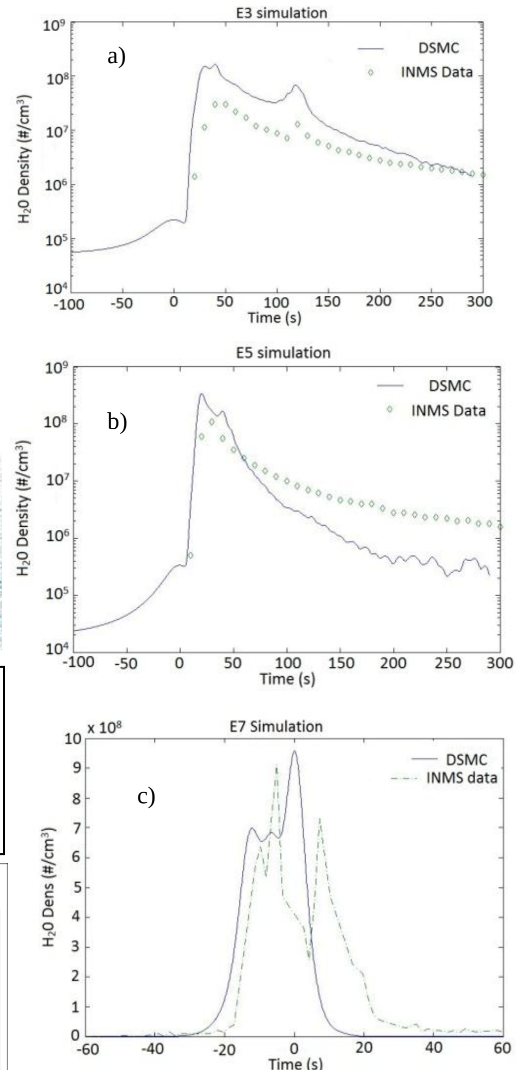



**Figure 5a, 5b, and 5c:** Comparison of *in situ* INMS data [6] and raw simulation results for a) E3 flyby, b) E5 flyby, and c) E7 flyby utilizing DSMC particle initialization.

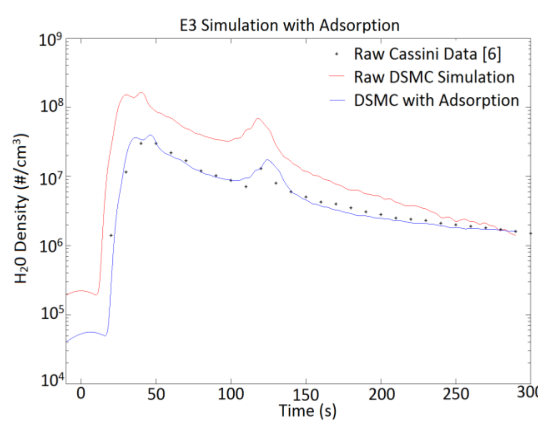



**Figure 6:** E3 simulation accounting for adsorption in the INMS antechamber by convolution with assumed instrument function.