ENCELADUS' SOUTH POLE: CONDUCTION, RADIATION, AND CONDUITS. H. T. Chilton[1,2], K. L. Mitchell[2], B. E. Schmidt[1]. [1]Earth and Atmospheric Sciences, Georgia Institute of Technology, North Ave NW, Atlanta, GA 30332, [2] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109.

Introduction: In 2005, Cassini's Composite Infrared Spectrometer (CIRS) detected a heat signature from the southern hemisphere of Saturn's Moon Enceladus and matched it to four fractures termed 'tiger stripes' and their associated plumes[1]. Much study has been dedicated to constraining the output, with values ranging from ~ 3-5 GW[2,3] up to 15.8 GW[4] ; work is still being done to understand the processes and mechanisms fueling the plumes and power output.

Explanations for and models of the plume system and heating dynamics for Enceladus' South Pole depend on the assumed properties of that system. There is debate over whether the plume source is a liquid water reservoir[1,3,5] , entirely or partially from clathrate decomposition[6,7], or from sublimation[2]. Not all of these preclude other methods; a gas filled conduit with entrained material is thermodynamically plausible[7,8]. Modeling with variable vent properties, including width and temperature, to best-fit observations suggests fracture temperatures as high as 223 K and 22 m vent width[9]. Several different models exist for the eruption of materials forming the plumes observed at Enceladus[1,5,6,8]. Some have been excluded based on inconsistency with the many observables, chiefly ice:vapor ratio[10,11,12], thermal emission[13,14], plume variability[15,16], plume chemistry[17,18] and E-ring spectroscopy[8].

Recent data suggests greater ice:vapor ratios in the jets that feed the plume, rather than for the plume itself[10,12]; thus, a major concern regarding the viability of cryovolcanic (liquid ascent) models has been removed[19]. In fact, no major issues exist with the conduit flow fluid mechanics[20] given observed quantities of volatiles[17,18] that could exsolve and expand from the ascending and decompressing water, and the modeled ~6:1 ice:vapor ratio in the jets[12] correlates extremely well with expectations of a near-freezing liquid exposed to a vacuum (~6.4:1)[19]. We are therefore revisiting cryovolcanic-type models in order to determine if they are viable based on current data.

Methods: We have identified two major concerns for liquid ascent models: (1) That erupting materials will freeze or condense rapidly on the walls, altering the modeled ice:vapor ratio and potentially causing eruption cessation; and (2) That observed thermal emissions cannot be explained using a liquid model, with vapor-dominated models having more available entropy. In order to test these concerns and provide additional boundary conditions to ascent models, we have developed a 2-D finite element model for heat transport within the crust, based on Fourier's Law of Conduction and the Heat Equation. The present iteration holds a 30-km deep fissure and sea boundary conditions constant at 273 K, surrounded by pure Ih ice initialized at 70 K, and allows surface radiation. It does not presently allow any locally-enhanced dissipation of tidal energy in the crust or consider the potential impact of sublimation[22].

At this stage in the work, we are evaluating what aspects of physics are applicable or dominant. In order to evaluate the feasibility and degree of sublimation, we consider surface temperature signatures over time to get at peak temperature/distance relationships. Our initial estimate, based on Andreas' calculations[13], is that temperatures of ~190 K over ~10 m width from the fissures will result in sublimation mass flux dominating observed plumes, which would imply that sublimation is critical to model.

If we neglect the existence of erupting conduits and any local increase in tidal heating, we can also estimate the minimum depth of the subsurface sea for given lifetimes and evaluate the necessity and degree of additional heating sources and sinks beyond conduction and radiation. However, some concerns to address here include relevant timescales over which a number of conditions could have changed substantially, including ocean extent, amount of heat, etc.

Finally, we seek to identify the conductive heat flux along the entirety of the conduit, providing a test for adiabatic and dominantly conductive assumptions.

Status: We report preliminary results of our first phase of the study using a purely conductive and radiative model of a liquid-water filled vent and subsurface reservoir on Enceladus. Although we have very preliminary output results, we are working out errors involved. However, they provide a meaningful series of questions that will be tested upon successful implementation of the code.

Identifying the temperature gradient outward from a vent will provide an evaluation of the existence and extent of sublimation as a dominant heat loss process at the surface. In particular being able to place temporal constraints on the distance temperatures reach or exceed 190 K could bring insights into differing ages of various jets or other relatively hot areas. And example of this comparison is seen in Figure 1. Although the distance component is not resolved, the temperature values relative to each other remain the same

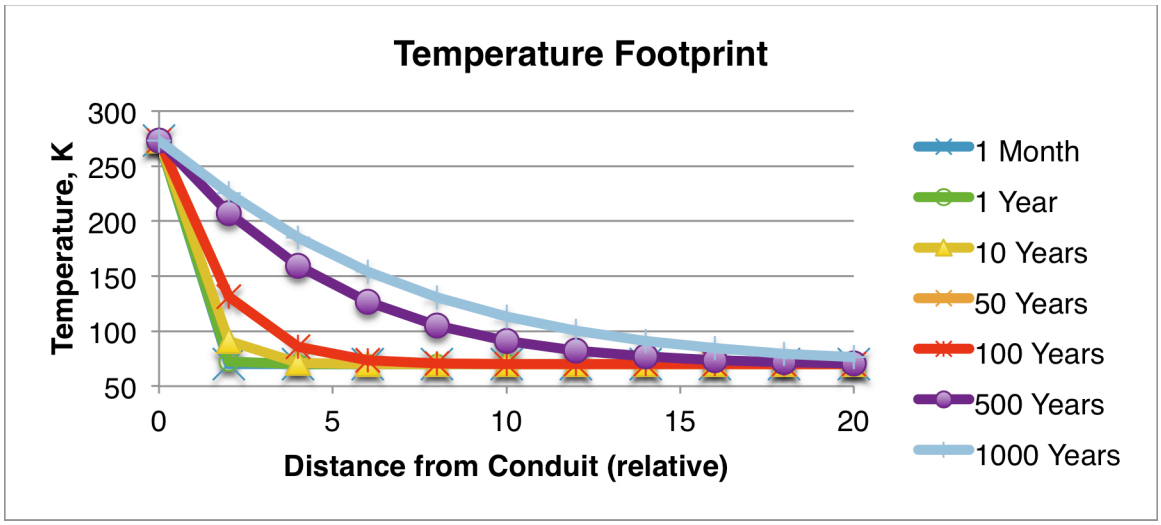

Figure 1: Plots of surface temperature as a function of relative distance from conduit for multiple durations.

across different model differential distance and time parameters. Using the numbers shown as a thought exercise example, we explore an example condition: By 500 years, near the vent reach temperatures of 207, high enough to allow sublimation to dominate heat loss. By a few times this distance, however, temperatures have dropped to 72 K and become nearly indistinguishable from the background ice temperature of 70 K. Shorter durations of 10 years or less quickly taper off very near the conduit, but minimal datapoints of discrete blocks suggest further runs at higher spatial resolutions to appropriately flesh out the near-vent temperatures. At longer timescales of 1,000 years, drop-off temperatures occur over an order of magnitude away from the vent.

Temperature footprints indicate that sublimation, which only dominates at T~200K on Enceladus, requires 500 years in this example to be observable within 2 m of an active vent. Vents may be active longer than this, which would propagate that boundary to a few tens of meters. Regardless, relative heat signatures might be used to track any differing ages of jets. Heat signatures beyond this would indicate the necessity of additional sources of heat to swamp conduction-radiation levels.

Duration	***100 kyr***			***10 kyr***		
Temp, K	*71*	*75*	*80*	*71*	*75*	*80*
Dist., km	*4.04*	*3.8*	*0.4*	*4.04*	*1.92*	*0.25*
Duration	***1 kyr***			***100 yr***		
Temp, K	*71*	*75*	*80*	*71*	*75*	*80*
Dist., km	*1.3*	*0.9*	*~.05*	*0.42*	*0.30*	*0.17*

Table 1: The distance away from a conduit for 71 K, 75 K, and 80 K for four different timescales.

A future step is looking at the heat flux through the conduit wall after various durations and to a vent system in surrounding ice that has already undergone a degree of conductivity instead of all surrounding ice at 70 K. Future work will incorporate sublimation, smaller distances near the vent, coupling with eruption models and further parameters.

References:

[1] Porco, C. C. et al. (2006) *Science*, *311*. [2] Spencer, J. R. et al. (2006) *Science, 331*. [3] Spencer, J. R. et al. (2009), *Saturn from Cassini-Huygens,* Springer, New York, Chap. 22. [4] Howett, C. J. A., et al. (2011) *JGR Planets*, *116*, EO3003. [5] Matson, D. L. et al. (2012) *Icarus, 221*. [6] Keiffer, S. W. et al. (2006), *Science, 314*. [7] Kieffer, S. W., et al. (2009) *Icarus, 203*. [8] Postberg, F. et al. (2009) *Nature, 459*. [9] Abramov, O., and Spencer, J. R. (2009) *Icarus, 199*. [10] Hansen et al., (2011). *GRL, 38*. [11] Ingersoll & Ewald, (2011) *Icarus, 216*. [12] Porco et al. (2014) *Astron J., 148*. [13] Spencer et al., (2013) *EPSC Abstracts, 8*. [14] Goguen et al., (2013) *Icarus, 226*. [15] Hurford et al., (2007) *Nature, 447*. [16] Nimmo et al., (2014), *Astron. J., 148*. [17] Waite et al., 2009, *Nature, 460.* [18] Waite et al. (2011) *EPSC Abstracts, 6*. [19] Mitchell K. L. (2014) *EOS Trans. AGU Fall Meeting, Abstract, #P52A-02* [20] Mitchell K. L. (2005). [21] Nimmo et al., (2007) *Nature, 447*. [22] Andreas, E. L. (2006) *Icarus, 186.*

Acknowledgments: Most of this research was carried out at the California Institute of Technology Jet Propulsion Laboratory under a contract with NASA. We acknowledge support of the Europa Clipper project.