CONVECTION IN IO'S PARTIALLY MOLTEN MANTLE. C. M. Elder[1], P. J. Tackley[2] and A. P. Showman[1] [1]Lunar and Planetary Lab., University of Arizona, 1629 E. University Blvd. Tucson, AZ 85721, USA (cmelder@lpl.arizona.edu), [2]ETH Zurich, Institute of Geophysics, Sonneggstrasse 5, 8092 Zurich, Switzerland.

Introduction: Io is the most volcanically active body in the solar system. This volcanism is the result of tidal dissipation that heats Io's interior [1] and produces a surface heat flux of 1.5-4 W m^{-2} [2]. Most planets lose internal heat through convection, but on Io, convection alone cannot produce Io's high observed surface heat flux [3]. However, volcanism can transport a significant fraction of Io's surface heat flow [4, 5]. The detection of an induced magnetic field by the magnetometer on the Galileo spacecraft supports this theory as it is best explained by a global conducting layer at least 50 km thick and at least 20% molten [6]. However, the Galileo measurements cannot probe more deeply into Io's interior [6] so little is known about the state of Io's mantle. To develop a better understanding of convection, melting, and melt migration in Io's mantle, we turn to numerical modeling. Here we present preliminary two-dimensional (2D) numerical simulations of mantle convection in Io including the formation, segregation and eruption of partial melt. We are currently considering different viscosities, permeabilities, and numerical approximations of eruption in order to understand the range of radial melt profiles, convective velocities, heat loss through conduction and eruption that Io might be experiencing today. In future work, we plan to consider a range of internal heating rates to understand the transition from convective heat loss to heat loss through melt migration and volcanic eruptions.

Model: To model Io's mantle we use the code StagYY [7]. StagYY uses a combined Eulerian-Lagrangian method with a finite volume discretization for calculating velocities and particles to track advection of composition and melt. At each time step, it calculates the bulk velocity field satisfying the Stokes and continuity equations, melt-solid segregation satisfying Darcy's law, and melting and/or freezing using a simplified petrological model. Formation of dikes and movement of melt through the solid crust is not included in this model, so to approximate eruption we consider a range of eruption modes including eruption of all melt above a certain depth to the surface, eruption of any melt above a certain threshold melt fraction to the surface, intrusion of all melt above a certain depth into the crust, and eruption of only melt that would otherwise freeze. For the results presented here, we used 2-D Cartesian geometry, but StagYY is also capable of modeling a 3-D spherical shell using the yin-yang grid. We consider a region approximately the width of ¼ of Io's mantle with a resolution of 256x64 cells and 4 million tracers. We use an average heating rate of 1.4×10^{-9} W/kg and distribute the heating such that the heating rate decreases horizontally as a sine wave to approximate non-uniform tidal dissipation in Io's mantle. Future work will also test a uniformly distributed heating rate. All our modeling thus far assumes a composition similar to Earth's mantle in which the basalt fraction is approximately 20% [8]. Partial melting generates a basaltic crust and leaves behind a depleted component, harzburgite [8]. In the case of Io, the intense heating due to tidal dissipation will likely also melt some of the harzburgite.

Results: More modeling is needed to estimate the full range of behavior that could be expected for Io's mantle, but preliminary results are consistent with observational constraints. In all cases considered thus far, most of the heat loss occurs through magmatic eruption rather than conduction through the lithosphere which is consistent with the observations of abundant volcanism and with previous suggestions that the heat pipe mechanism of heat loss might dominate on Io [4, 5]. Although the mean mantle melt fraction is often as low as ~1%, the maximum melt fraction in localized regions reaches 100% for all conditions we have considered. Average radial profiles of the melt fraction typically indicate a region of the mantle below the lithosphere with a melt fraction ranging from 10% to 100% depending on the eruption mode prescribed. Crustal and lithospheric thicknesses also vary with prescribed eruption mode. A thick lithosphere can be obtained by prescribing a large depth above which all melt can erupt (figures 1 and 2). Overall, our preliminary models demonstrate the viability of the heat pipe mechanism and show how tidally heated mantle convection with partial melting can naturally explain Io's high heat flux, extensive volcanism, upper-mantle conductivity, and thick lithosphere.

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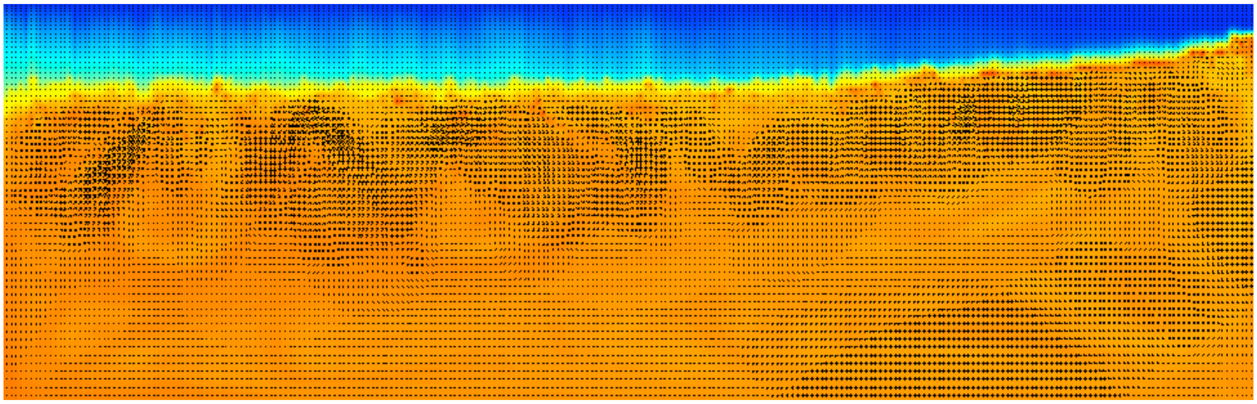

Figure 1: The temperature field for the case in which all magma above a depth of 50 km erupts to the surface. Dark blue represents cold temperatures and red represents hot temperatures. Vectors indicate the direction of flow.

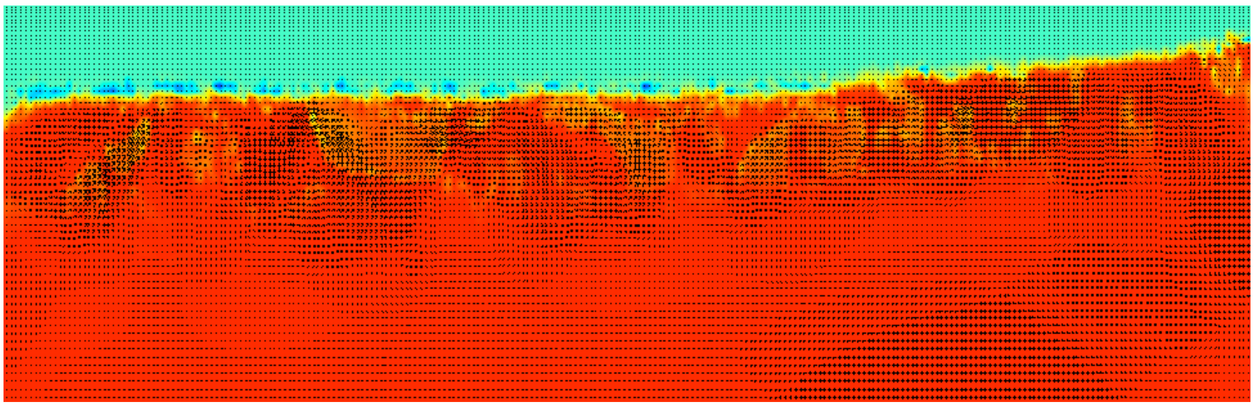

Figure 2: The composition field for the case in which all magma above a depth of 50 km erupts to the surface. Dark blue represents basalt and red represents harzburgite. Vectors indicate the direction of flow.

Acknowledgements: A NASA Earth and Space Science Fellowship funded this work. The Shandel Travel Award partially funded CME's travel to ETH.