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Io's heat flux and implications for the distribution of tidal heating in its interior

Walter S. Kiefer, Lunar and Planetary Institute/USRA, Houston TX, USA (kiefer@lpi.usra.edu)

Abstract

Comparison of models of mantle convection driven by tidal heating at high Rayleigh number with observations of Io's volcanic heat flux as a function of latitude suggest that about 50% of Io's tidal heating occurs in a shallow asthenosphere, with the remainder of the tidal heating distributed throughout the mantle.

1. Introduction

Io's prodigious volcanic output is driven by tidal heating. Two fundamentally different distributions of tidal heating as a function of depth within Io have been proposed, which produce very different patterns of the surface heat flux [12]. Deep tidal heating has surface heat flux maxima at the poles and minima at the equator, whereas shallow tidal heating in a low viscosity asthenosphere has surface heat flux maxima near the equator and goes to zero at the poles. Based on a Voyager-era stereo topography model for Io [4], it was concluded that about 1/3 of Io's tidal heating was generated in the deep interior and about 2/3 in the asthenosphere [11]. This ratio remains widely cited in the literature today. However, a far more detailed topography model for Io based on Galileo stereo imaging and limb profiles [17] is not consistent with the earlier Voyager-era topography map. This calls into question how well we actually know how tidal heating is distributed with depth inside Io.

2. Heat Flux Observations

An alternative approach to constraining tidal heating inside Io is to use recent compilations of Io's volcanic heat flux. The Galileo spacecraft measured heat flux as a function of location using both the Near Infrared Mapping Spectrometer (NIMS) and the Photopolarimeter Radiometer (PPR) between 1996 and 2003 [2, 10, 16]. Spatially resolved observations from terrestrial telescopes extend this time frame to include 2001-2016 [1, 3]. A limiting factor is that the heat flux at high latitudes is poorly observed in these data sets. However, Galileo PPR data suggests that both of Io's poles are hotter than expected based on the latitude dependence of incident sunlight [9], which is possibly due to elevated polar heat flux from the interior [15]. The Juno spacecraft, now in polar orbit around Jupiter, can occasionally image Io's poles with its Jovian Infrared Auroral Mapper (JIRAM) [8]. Such observations may ultimately help to better constrain the polar heat flux on Io.

3. Convection Models

In order to better understand the expected spatial distribution of heat flux out of Io's interior, the tidal heating models of [12] have been used as an input forcing function for a finite element mantle convection model [6]. To ensure that the models are spatially well resolved, initial modeling is being done in spherical axisymmetric geometry using a zonally averaged version of the tidal heating. Results shown here are based on an internal heating Rayleigh number (Ra) of 10^{10} and are performed on a grid with a spatial resolution of ~4 km on a side. Models with higher Ra and finer grid spacing, corresponding to more vigorous convection, are in development.

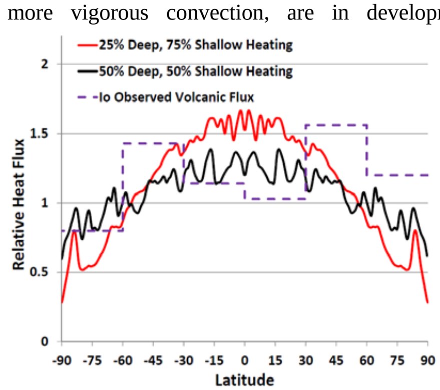

Figure 1: Comparison of the variation of the relative heat flux with latitude inferred from Galileo observations (dashed purple line) with convection models having 25% deep tidal heating (red line) and 50% deep tidal heating (black line).

Figure 1 shows the variations in heat flux as a function of latitude at representative timesteps for models with 25% deep tidal heating (red line) and 50% deep tidal heating (black line). Both models have a strong equator to pole flow (similar to [13]). Numerous convective instabilities in the upper thermal boundary layer are present and develop into cold, sinking downwellings, creating local minima in the convective heat flux. The purple dashed line shows Io's measured volcanic heat flux [2] combined with an estimate of the enhancement in the polar heat flux [15]. The relatively flat pattern of Io's measured heat flux is a better fit to the model with 50% deep and 50% shallow tidal heating (black line) than it is to a model with 25% deep and 75% shallow tidal heating (red line).

4. Summary and Conclusions

The results presented here favor a model in which tidal heating is approximately 50% deep and 50% asthenospheric, consistent with the recent conclusions of [1, 2, 10]. This results contrasts with other studies that favor roughly 1/3 deep and 2/3 asthenospheric tidal heating [5, 7, 11, 14]. Improved observations of Io's polar heat flux can further test this conclusion.

Acknowledgements

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