PRESENT-DAY HEAT FLUX VARIATIONS ACROSS THE SURFACE OF MARS

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Introduction: Surface heat flux (or to be more precise, the heat flux density), defined as the rate at which a planetary body looses its interior heat through the surface, is an important quantity that helps understand the thermo-chemical evolution of a planet. At present, the surface heat flux has been measured only for the Earth and the Moon although indirect estimates from lithospheric loading models are available also for other planetary bodies including Mars.

The only available present-day lithosphere thickness estimate for Mars suggests a value larger than 300 km at the north pole [1]. This value corresponds to a heat flux smaller than 15 mW/m^2 which is significantly lower than that predicted by numerical simulations [2, 3] employing the well accepted compositional model of [4]. Therefore, it has been speculated that Mars bulk content of heat producing elements (HPE) could be subchondritic [1] or that secular cooling could be much smaller than predicted [5]. The presence of mantle plumes may introduce significant variations in the average surface heat flux and the north-pole elastic thickness estimate may not be globally representative [e.g., 6], however.

The InSight Discovery-class mission is planned to achieve the first in-situ heat flux measurement on Mars in 2018. Albeit at a single location, this measurement will provide an important cornerstone for the interpretation of the interior heat production rate of Mars and constrain its thermo-chemical history. In a recent study, we have shown that an estimate of the global heat loss derived from the InSight measurement can be used together with an estimate of the planet's Urey ratio, i.e., the heat production rate divided by the total loss of heat as obtained from numerical models, to constrain the heat production rate and thus the bulk abundance of HPE in the Martian interior [7]. However, in order to derive the average surface heat flux from InSight data it is important to estimate the magnitude of heat flux variations across the Martian surface.

Plate-tectonics causes strong spatial variations of the surface heat flux on Earth with values ranging from below 20 mW/m^2 in some continental areas to values above 200 mW/m^2 in volcanically active regions [8]. On the Moon, due to the strong enrichement of HPE in the Procellarum KREEP Terrane (PKT) region on the lunar nearside, models suggest surface heat flux values between 10.6 mWm^2 in the polar regions and 66.1 mW/m^2 within the PKT [9]. Mars, however, shows only limited variations in the surface distribution of thorium and potassium [10]. Therefore, for Mars, the surface heat flux is expected to vary to a lesser extent with geological location, being mainly influenced by variations in the thickness and HPE content of the crust [11], and potentially by mantle plumes [12].

Model: In this study we investigate the present-day surface heat flux variations across the Martian surface by running numerical models of its thermal evolution in 3D spherical geometry. We assume a crust structure as inferred from gravity and topography data [13] and adopt the compositional model of [4]. We distribute the radiogenic elements between mantle and crust to match the present-day surface abundances obtained from gamma-ray measurements [11]. Since the thickness of the Martian crust is estimated to vary laterally between 5 and 100 km [13], while the concentration of HPE only varies between 0.2 and 1 ppm [10], surface heat flux variations are mainly caused by differences in crustal thickness rather than by variations in the HPE distribution within the crust [11]. Therefore, we neglect any lateral variations of HPE concentrations and use an average value of 49 pW/kg similar to the one obtained from gamma-ray data [10, 11].

We test a large number of parameter values and vary the mantle reference viscosity as well as the viscosity distribution with depth. We consider constant and variable thermal expansivity, vary the crust thermal conductivity and the size of the core. Our models account for the decay of radioactive elements and include core cooling across the core-mantle boundary (CMB).

In order to compare our results with the present-day elastic thickness estimate of 300 km at the north pole, we use the strength envelope formalism and calculate the depth at which the lithosphere loses its mechanical strength because of ductile flow. For this calculation, we assume a strain rate of 10^{-14} s^{-1} [1], as apropriate for the timescale of polar cap deposition.

Results: Our results show that the present-day surface heat flux pattern is dominated by the crustal thickness structure. We estimate the surface heat flux to be 25 ± 1.8 mW/m^2 on average and 24.9 ± 3 mW/m^2 at the proposed InSight location in the Elysium Planitia region, at a distance of around 1480 km from the Elysium Mons volcanic center and close to the dichotomy boundary.

Furthermore, we find that the depth dependence of the viscosity can play a significant role for the convection pattern in the interior. This signal may be visible in global heat flow maps if the the radial mantle viscosity increases by more than one order of magnitude with depth (Fig. 1).

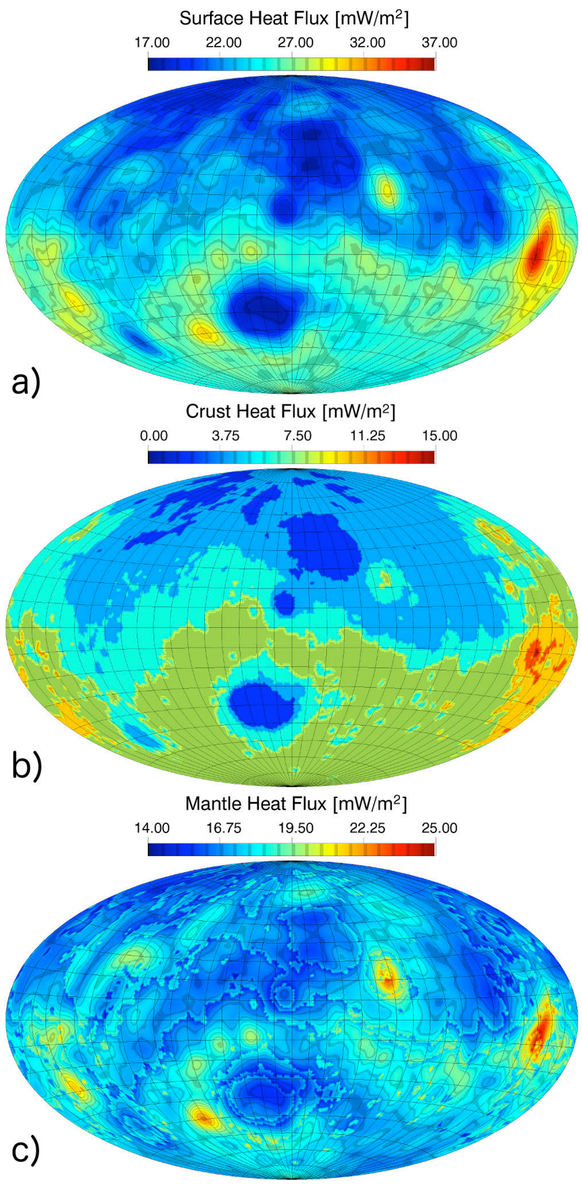

Figure 1: Total surface heat flux (a), crustal contribution (b), as well as mantle contribution (c) to the heat flux for a representative case using a reference viscosity of $5x10^{20}$ Pa s and a viscosity increase with depth of about 2 orders of magnitude.

The largest surface heat flux variations observed in our models show peak to peak values between 17.2 and 49.9 mW/m^2, with the latter being associated with the occurrence of prominent mantle plumes. However, such heat flux anomalies caused by mantle plumes remain confined to narrow regions at significant distances from the proposed InSight landing site.

Elastic lithosphere thickness values obtained in our models exceed 250 km at the north pole and are close to the present-day estimate. Lateral variations of the elastic thickness exceed 100 km, with the highest values reached in regions of thin crust (i.e., the Hellas basin and regions close to the north pole in Accidalia Planitia and Utopia Planitia). The lowest elastic thickness values are found in the Tharsis area, where values as low as 60 km are obtained. Moreover, in most of our models a mechanically incompetent layer is present today around Arsia Mons. This leads to a small elastic thickness due to crust-lithosphere decoupling and supports previous studies that have proposed the presence of a local decoupling layer of incompetent crust to cause the low elastic thickness of this region [6].

Conclusions: We have obtainted globally averaged surface heat fluxes of 25 ± 1.8 mW/m^2 and predict a value of 24.9 ± 3 mW/m^2 for the InSight landing site. Therefore, the heat flux value measured by InSight will be representative of the global average. Maximum values of the surface heat flux measured above the center of mantle plumes can reach 50 mW/m^2, but such high values remain confined to small regions and are unlikely to affect the InSight measurement. The spatial variability of the surface heat flux is reflected in the elastic lithosphere thickness, which varies laterally by more than 100 km with peak-to-peak differences as high as 244 km. The largest present-day elastic thickness that we obtain at the north pole is about 270 km, a value close to the 300 km estimate of [1]. Our results thus suggest that a large elastic thickness at the north pole is compatible with the compositional model of [4]. If, however, Mars is subchondritic with respect to its HPE abundances, the surface average heat flux as well as the value provided by the InSight measurement are expected to be significantly lower than those presented here. The InSight landing site would still be expected to yield a representative value of the Martian surface heat flux.

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