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Liquid water and resurfacing of Enceladus' south polar terrain

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Earth, Jupiter's moon Io and Saturn's tiny moon Enceladus are the only solid objects in the Solar System to be sufficiently geologically active for their internal heat to be detected by remote sensing. Interestingly, the endogenic activity on Enceladus is only located on a specific region at the south pole, from which jets of water vapor and ice particles have been observed ([1], [2]). The current polar location of the thermal anomaly can possibly be explained by diapir-induced reorientation of the satellite [3], but the triggering of the thermal anomaly and the heat power required to sustain it over geologic timescales remain problematic. Using a three-dimensional viscoelastic numerical model simulating the response of Enceladus to tidal forcing, we have demonstrated in a previous recent study [4] that only interior models with a liquid water layer at depth can explain the observed magnitude of dissipation and its particular location at the south pole (Fig. 1). Moreover, as tidally-induced heat must be generated over a relatively broad region in the southern hemisphere to explain the observed thermal emission, we proposed that this heat is then transferred toward the south polar terrain where it could be episodically released during relatively short resurfacing events.

In the present study, we investigate the thermal stability of localized liquid water reservoir at the rock-ice interface by performing simulations of thermal convection in three-dimensional spherical geometry with the numerical tool OEDIPUS ([5],[6]) and by computing the corresponding dissipation pattern using the method developped in [4]. Where liquid water is present, a constant temperature equal to the melting temperature of water ice is prescribed at the base of the ice shell. Outside this region, a constant heat flux owing to the radiogenic power coming out of the silicate core is prescribed. Figure 2 illustrates the temperature field obtained for varying size of the liquid reservoir (ranging from 60^o to 120^o). These preliminary results indicate that a total power of 2.4 GW is required to sustain a liquid zone of 60^o in width, 5 GW for a liquid zone of 120^o, and 8 GW for a liquid zone of 180^o. This is comparable to the typical tidal dissipation value expected in the south polar region ([1], [4]). We are currently coupling our 3D viscoelastic tidal dissipation model to the 3D thermal convection code in order to precisely determine the tidal dissipation pattern resulting from the viscosity field and its effect on the 3D thermal structure.

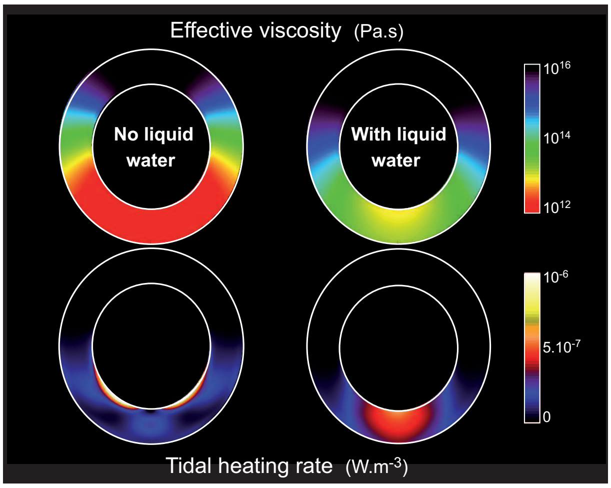

Figure 1: *Spatial distribution of tidal heating rate within the ice shell. Contour plots display an arbitrary viscosity structure of the ice shell (top) and the corresponding generated volumetric heating rate (bottom) as a function of radius and latitude at zero longitude for model without (left) and with (right) liquid layer at the base of the ice shell. When a decoupling layer is present, the maximal dissipation rate is obtained at the center of the viscous anomaly and covers a major portion of the ice shell in the south polar region, whereas in absence of a decoupling layer, it occurs at the edge of the viscous anomaly and only at the base of the ice shell.*

In parallel, we investigate the likelihood of short resurfacing events by incorporating a self-lubricating, simple-damage rheology adapted from [7] in our models in order to simulate the fracturation of the cold icy crust. As the 3D spherical simulations are extremely time-consuming, we perform this series of simulation using a 2D cartesian version of the code [8]. Two different evolution scenario are tested: a first one where the reservoir of liquid water is sufficiently large to be sustained during the entire duration of the simulation, a second one where the liquid water just disappeared at the beginning of the simulation. In the two

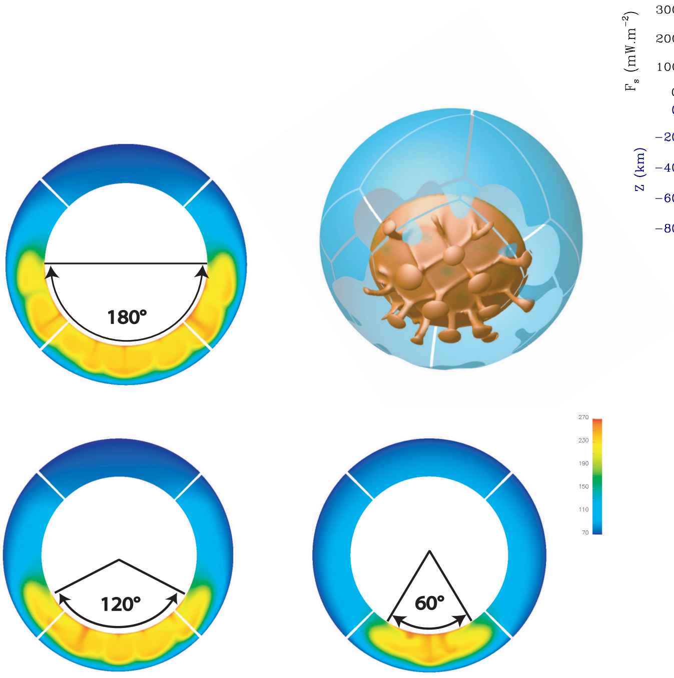

Figure 2: *Temperature field in Enceladus' ice mantle obtained for different sizes of the internal liquid reservoir using the 3D spherical numerical tool OEDIPUS. A linearized exponential law (Frank-Kamenetskii approximation) is assumed to describe the temperature dependence of viscosity, with a viscosity value of 10^{14} Pa.s at the melting point and an activation energy of 50 kJ.mol^{-1}.*

scenarios, a rupture of the lithosphere is observed owing to stress accumulation near the surface. This leads to a short and huge release of heat. The preliminary simulation presented on Figure 3 indicates that heat flux of the order of 200 mW.m^{-2}, comparable to the values observed over the south pole, are obtained during a relatively short period of time (< 500 kyr). This simulation shows that even if the liquid zone totally disappears and that tidal dissipation strongly decreases, a resurfacing event can still occur. However, the internal cooling associated with such an event is so large that only an initially large reservoir of liquids can survive. We are currently investigating the conditions in which a localized water sea can persist beneath the south pole on geologic timescales.

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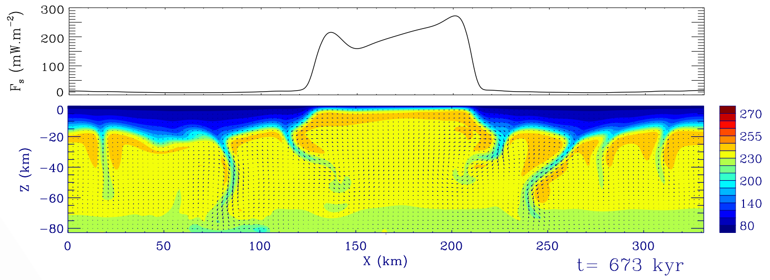

Figure 3: *Temperature field after rupture of the lithosphere and corresponding surface heat flux. In this simulation, the liquid water reservoir totally disappears before the lithosphere rupture occurs.*

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