Tidally heated convection and the occurrence of melting in icy satellites: application to Europa

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Observations of icy satellites have revealed widespread marks of cryovolcanism. Because aqueous cryomagmas are negatively buoyant, two processes are required to explain these observations: one mechanism to generate melt close enough to the surface, and another one to transport this melt to the surface. Here, we investigate the generation of melting in a systematic way, using a set of 85 numerical simulations where we vary the viscosity contrast, Rayleigh number, and tidal heating rate. Applied to Europa, and considering a hydrosphere composed of pure water, our simulations suggest that isolated melt pockets can be generated close to the surface (≈5 km) as long as the ice layer thickness (d*) remains modest (15<d*<35 km). However, the generation of melting becomes increasingly difficult as the amount of anti-freeze compounds in the subsurface ocean increases. Furthermore, the proportion of melting increases very sharply with increasing tidal heating rate. In particular, when the tidal heating rate exceeds a threshold, an asymptotic regime is reached where the surface heat flux remains constant, i.e., the tidal heat generated above this threshold is only used for melting the ice shell. In that regime, we found a direct relationship between the surface heat flux and d*. Finally, we provide a new assessment of Europa's thermal state. Using available constraints, we propose that the ice shell thickness should exceed 25 km. However, d*≈25-35 km implies a tidal power (>3 TW) much larger than expected. An extrapolation of the trends suggested by our results indicates that a more reasonable tidal power (<1 TW) would involve d*≈ 80-100 km.

Keywords: Europa, Icy Satellites, Thermal convection, Melting, Cryovolcanism, Tidal Heating

