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Directional close-contact melting in glacier ice

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The Saturnian moon Enceladus shows incidence of liquid water underneath a thick ice sheet cover and is thought to be a potential candidate for extraterrestrial life. However, direct exploration of these subglacial aquatic ecosystems is very challenging. Within the scope of the joint research project 'Enceladus Explorer' (EnEx) (consisting of FH Aachen, RWTH Aachen, Bergische Universität Wuppertal, Universität Bremen, TU Braunschweig und Bundeswehr Universität München), initiated by the German Space Agency, a maneuverable close-contact melting probe has been developed. The force-regulated and heater-controlled probe is able to melt against gravity or even on a curved trajectory. Hence, it offers additional degrees of freedom in its melting motion, e.g. for target oriented melting or obstacle avoidance strategies. General feasibility of the concept has been demonstrated in various field tests. However, in order to optimize its design and to adopt it to extraterrestrial missions a simulation model is needed, capable of determining melting velocity and efficiency at given environmental conditions and system configurations.
Within this contribution, the physical situation is abstracted into a quasi-stationary mathematical model description, and a numerical solution strategy is developed to compute melting velocity and temperature distribution within the probe and the surrounding ice. We present an inverse solution approach, in which a background velocity field of the ice mimics the melting velocity. The fundamental balance laws are solved with the corresponding melting rate. Following Newton's laws, the resulting force acting on the probe has to balance the contact force exerted by the probe and can hence be used for convergence.
We present both, analytical results to a simplified head geometry, as well as results from a simulation model implemented into the open source software Elmer for arbitrary head geometries. The latter can deal with the full 3d situation, which is demonstrated through various examples. We will conclude by discussing modeling results with respect to recent laboratory experiments and field tests conducted in Antarctica.