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Development of a Novel Subsurface Ice Probe and Testing of the First Prototype on the Morteratsch Glacier

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We present the novel concept of a combined drilling and melting probe for subsurface ice research. This probe, named "IceMole", is currently developed, built, and tested at the FH Aachen University of Applied Sciences' Astronautical Laboratory. Here, we describe the IceMole's first prototype design and report the results of its field tests on the Morteratsch glacier in Switzerland. The current design of the IceMole is adapted to the subsurface investigation of terrestrial glaciers and ice shields, but in the long run, the probe should also be adapted to extraterrestrial ice research (e.g. on Mars' polar caps, Jupiter's moon Europa, or Saturn's moon Enceladus).

On Earth and on other planets and moons, analysis of the various mineral, gaseous, and (eventually) organic inclusions is important for understanding the conditions and processes at the formation time of the ice layers, because the ice protects them from subsequent environmental alteration. The current terrestrial method to study deep ice primarily uses the traditional drilling and ice-core-sample-return method. This method is not well suited for near- and medium-term robotic planetary exploration missions. Those missions require all scientific instruments on board of the probe, so that the ice can be analyzed in situ and only data has to be sent back. A robotic melting probe would be better suited for in-situ ice analysis.

The concept of melting probes for deep ice research is known since the 1960s, however, these probes have three main drawbacks: 1) they penetrate only vertically down and cannot change direction; 2) they cannot penetrate dust/dirt layers; 3) they cannot be recovered from greater depths (which is at least a drawback for terrestrial applications). To remedy these drawbacks, we have developed the novel concept of a combined drilling and melting probe (IceMole) that uses a hollow ice screw (as it is used in mountaineering). The IceMole design philosophy is that of rapid prototyping. The first IceMole prototype was build in 2009/10 and was tested on the Swiss Morteratsch glacier in September 2010. It has the shape of a rectangular tube (15cm x 15cm cross section) with a $\sim$3kW melting head at the tip. The required electric power is generated by a surface aggregate and transmitted via a cable that is uncoiled from the probe. Communications and data transfer to the surface is also via the power cable. The ice screw, being located at the tip of the melting head, generates a driving force that presses the melting head against the ice, thus leading to a good conductive heat transfer. The thermally isolated ice screw transfers ice into the probe, where it can be analyzed in situ. The IceMole can change direction by differential heating of the melting head (in the next prototype, also side heaters will be implemented), which generates a torque that forces the IceMole into a curve.

On the glacier, three penetration tests have been successfully performed: 1) melting 45° upwards for $\sim$1.5m, against gravity; 2) melting horizontally for $\sim$5m; 3) melting 45° downwards for $\sim$3m, thereby penetrating three obstructing non-ice layers (mud and sand found on the glacier) and driving a curve with a radius of $\sim$10m. The penetration velocity was $\sim$0.3m/h (but will be increased for the next prototype). The test results show that the IceMole concept is a viable approach to deliver scientific instruments into deep ice and to recover them afterwards. Another advantage of the IceMole with respect to drilling is that biological contamination can be minimized and the process can be made highly autonomous, so that there is no need for an operator on the surface.