TRIPLE – Ice Data Hub, Model-based Mission Support and Forefield Reconnaissance System

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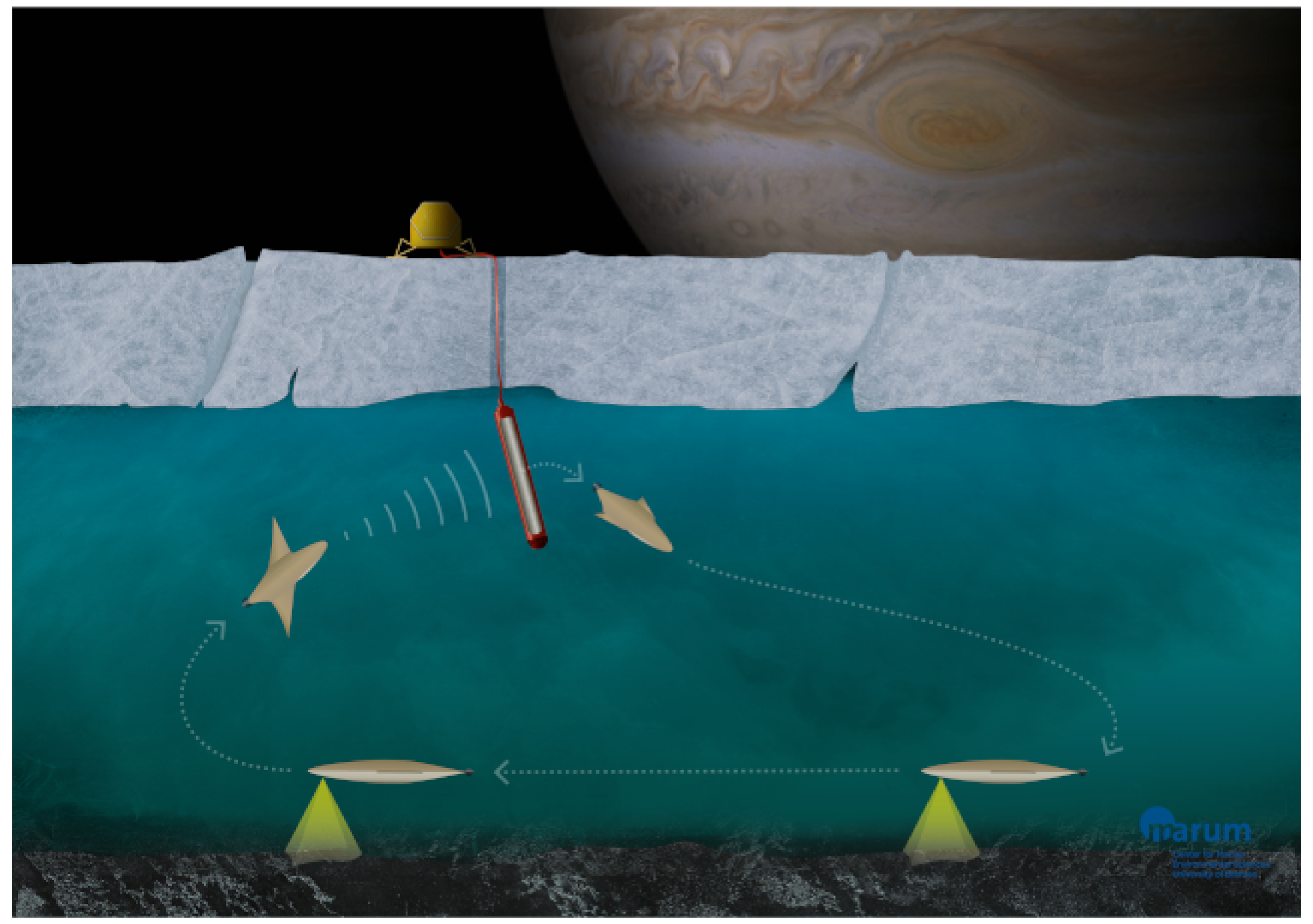
TRIPLE – Technologies for Rapid Ice Penetration and subglacial Lake Exploration



▲ **Fig. 1:** Mission concept of TRIPLE (courtesy of MARUM, Bremen)

There is evidence that some icy moons in our Solar System like the Jovian moon Europa and the Saturnian moon Enceladus have a water ocean below an icy crust. TRIPLE is an exploration concept to access subglacial lakes. It is anticipated to develop the system and test it in Antarctica while always having a future space mission to Europa in mind. More details at www.triple-project.net.

The system is divided into three main components:

1) **Melting Probe:** The melting probe serves as a carrier system for the nanoAUV through the ice to the subglacial water reservoir and back. For a safe arrival at the subglacial lake, it is mandatory to have a powerful trajectory planning and forefield reconnaissance system.

2) **nanoAUV:** A small autonomous underwater vehicle designed to explore the subglacial lake. Samples should be taken at predefined points of interest.

3) **AstroBioLab:** Instruments for analyzing samples taken by the nanoAUV.

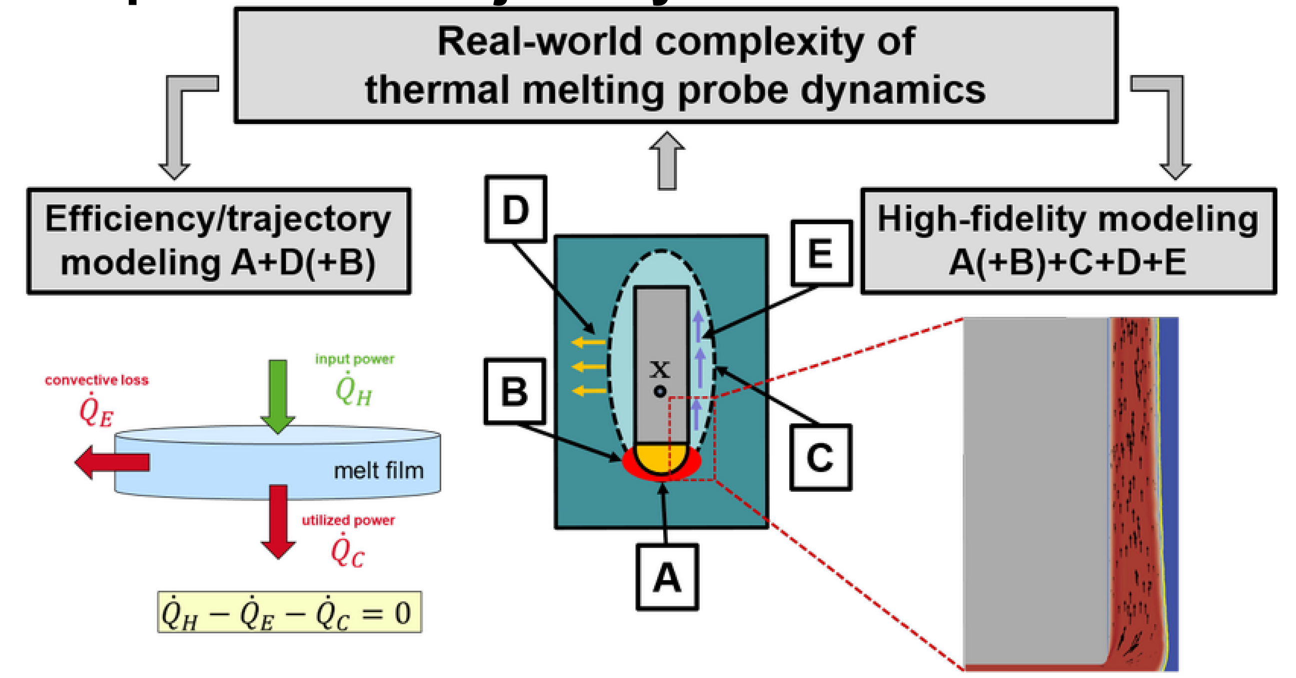
Data Management with the Ice Data Hub

Some selected main features of the Ice Data Hub (soon available via GitHub):

- ✔ Python library to handle data in simulation software
- ✔ Export methods and interfaces to different simulation environments (e.g., trajectory modeling or wave propagation simulation)
- ✔ Plain human-readable YAML files are used to store data (including figures)
- ✔ GUI (browser-based app) to view, manipulate, add, plot and map data sets

▲ **Fig. 2:** Graphical User Interface (GUI) of the Ice Data Hub

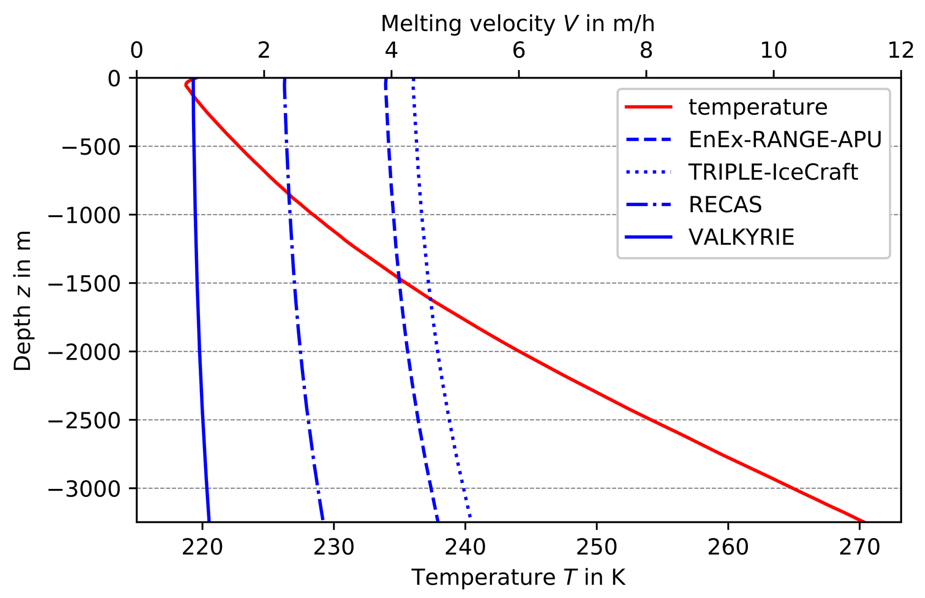
Computational Trajectory Prediction



▲ **Fig. 3:** The dynamic behavior of a thermo-electric melting probe depends on the complex interplay of various thermofluidmechanical processes like contact phase-change at the probe's hot point (A), (potentially) liquid-vapor phase-change (B), liquid-solid phase-change at the channel's lateral sides (C), heat conduction into the ice (D), and convection of melt water in the channel (E).

While design optimization tasks ideally require a high-fidelity model of the fully coupled process around the probe, model-based decision requires information on overall transit time and power consumption, which can already be well approximated by efficiency / trajectory modeling (including A, B and D).

Model-based Mission Support

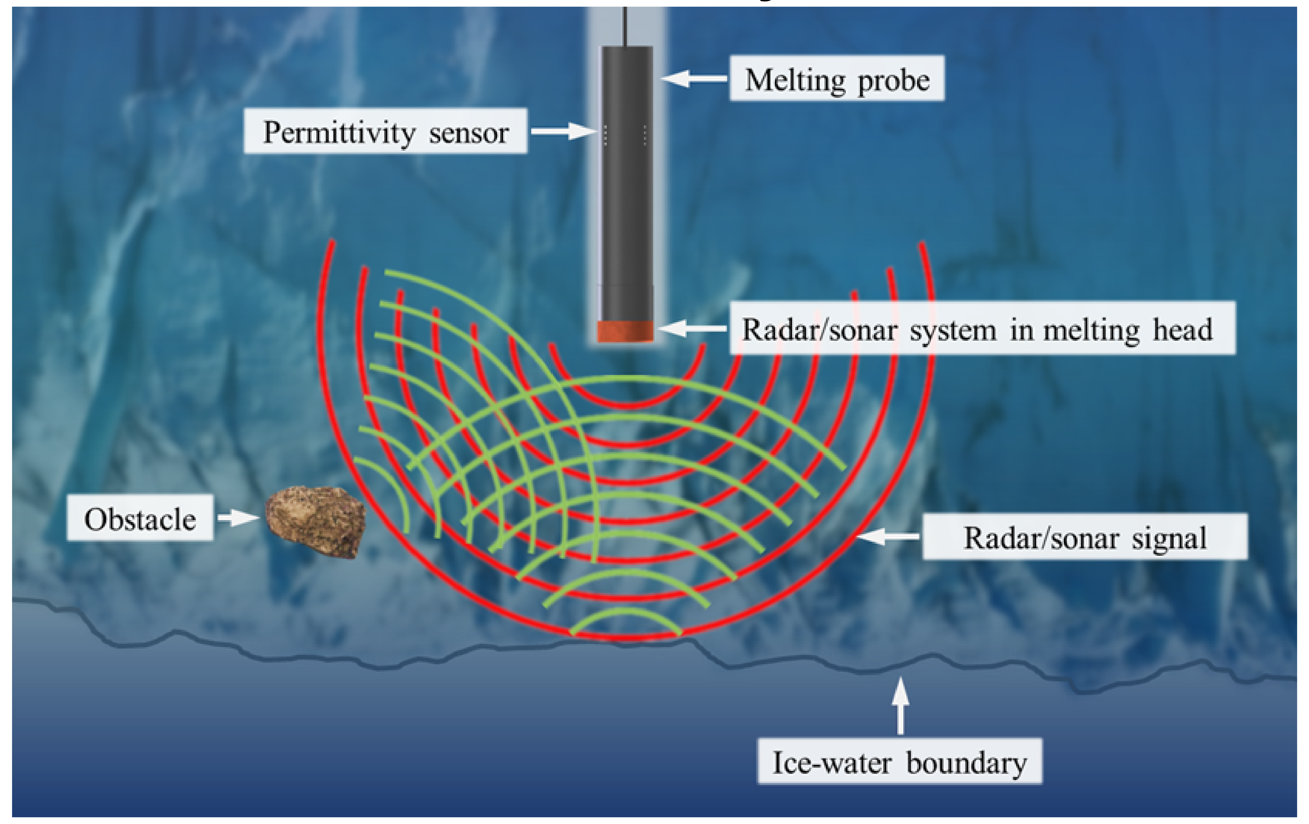


◀ **Fig. 4:** Trajectory curves for a scenario at Dome C, Antarctica. Plotted are temperature of the ice and the trajectory curves for different melting probes versus depth.

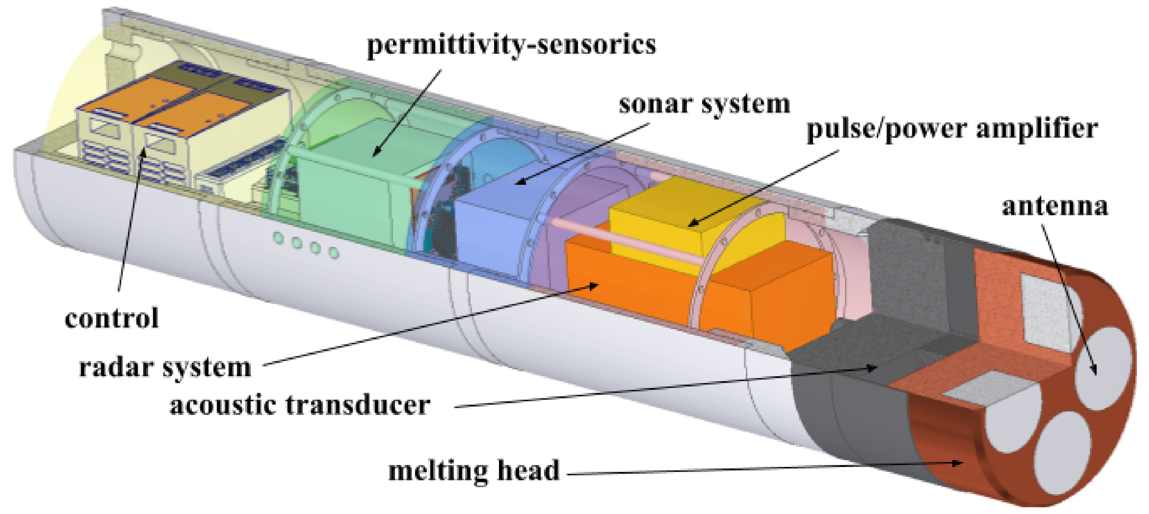
▼ **Tab. 1:** Important mission parameters as result of the trajectory modeling.

Dome C Antarctica	Transit time in d	Total required energy in MWh	Average energy required per meter of ice in kWh/m
EnEx-RANGE APU	32.3	2.230	0.686
RECAS	53.5	6.425	1.978
TRIPLE-IceCraft	29.1	13.944	4.293
VALKYRIE	139.6	16.749	5.157

Forefield Reconnaissance System



▲ **Fig. 5:** To ensure the success of a TRIPLE mission, the melting probe needs a reliable system for the exploration of its forefield as it is mandatory to avoid obstacles in the trajectory and to detect the ice-water boundary at the bottom of the icy crust. A Forefield Reconnaissance System (FRS) based on a radar/sonar combination will be developed and tested in a terrestrial analog scenario in the Alps.

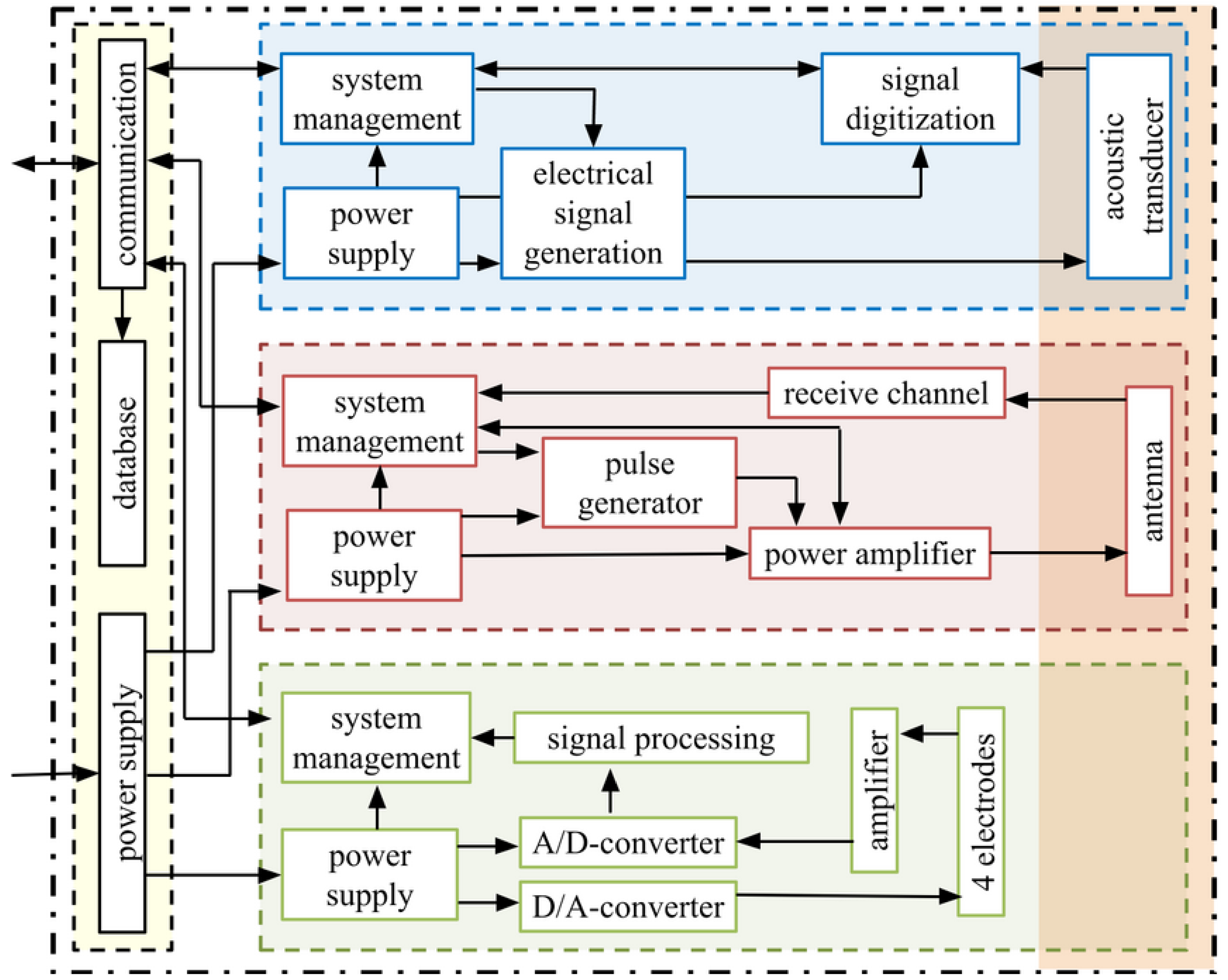


▲ **Fig. 6:** Conceptual model for a melting probe equipped with FRS

Radar System: A sequential sampling radar with a specialized pulse amplifier will be implemented for high range while maintaining high resolution. Multiple Rx-Channels and an antenna array in the melting head allow for digital beamforming techniques for enhanced angular resolution.

Sonar System: The melting head serves as head mass for a tonpilz transducer with a piezoelectric driving stack. Runtime measurements will enable the extraction of the position of possible obstacles in the ice shield. In addition, the sonar can support the navigation of the AUV in the subglacial water reservoir.

Permittivity Sensor: An in-situ permittivity sensor will be developed to measure the electrical properties of the ice within the electromagnetic near field. With this approach, the varying propagation speed of electromagnetic waves in the surrounding ice can be compensated for.



▲ **Fig. 7:** Block diagram of the FRS system with its main components and the relevant subsystems (Sonar, Radar, Permittivity).

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