

Subsurface Water Ice Mapping (SWIM) to Support the International Mars Ice Mapper (I-MIM) Mission. Nathaniel E. Putzig,¹ Gareth A. Morgan,¹ and the Mars SWIM Team. ¹ Planetary Science Institute, Lakewood, CO, USA and Tucson, AZ, USA. Contact: nathaniel@putzig.com.

Introduction: The Mars Subsurface Water Ice Mapping (SWIM) project supports an effort by NASA's Mars Exploration Program to assess in situ resource availability for future human missions [1–2]. We are performing global reconnaissance mapping and focused multi-dataset synergistic analysis to characterize the distribution of water ice from 60°S to 60°N (**Fig. 1**). In 2019, we produced ice consistency maps for most of the northern hemisphere (0–60°N and 0–225°E, 290–360°E). In 2020, we extended our mapping to include the southern hemisphere (0–60°S) and the previously omitted band of the northern hemisphere (225–290°E) at elevations < +1 km. In the autumn of 2021, we began a new phase to expand and improve the resolution of our geomorphological mapping which was completed at the end of 2022. Mapping results are available on the SWIM project website (<https://swim.psi.edu>).

Motivation: Mid-latitude ice, accessible within the scope of most mission architectures (upper few meters) has been discovered on Mars through remote sensing investigations. For example, fresh impacts revealing icy substrates have been reported using HiRISE and CTX data [3–4], and glacial deposits have been found in the mid-latitudes with geomorphologic and radar sounding studies [e.g. 5]. The use of water for fuel generation is a critical component in current human mission scenarios, and thus knowledge of the complete inventory of the distribution and depth range of these water-ice deposits across Mars is of enormous value to

planning such missions. It is widely acknowledged that current orbital instruments and datasets cannot resolve buried ice at the scales necessary to fully characterize them for planning extraction methods, and an effort involving multiple space agencies and other institutions is underway to develop an International Mars Ice Mapper Mission (I-MIM). SWIM results are intended to guide the design and operations of I-MIM by identifying areas of likely ice at lower latitudes on Mars and by highlighting the limitations of current datasets that could be overcome with I-MIM instruments. The SWIM results are also valuable on their own for advance planning of in situ resource utilization on human surface missions.



SWIM Project: Our primary goal is to create water-ice mapping products to inform future mission planning. Prior global studies of Martian ice deposits have largely concentrated on one or two data types, such as neutron maps [6], thermophysical data [7–8], and geomorphic surveys of periglacial features [e.g. 9]. In contrast, the SWIM project is integrating all relevant orbital datasets for a holistic assessment of accessible ice reserves. Our team includes a broad background of relevant expertise and has been leveraging existing and new techniques to generate the most up-to-date maps of Martian water ice distribution.

At the XXIII SRR Meeting, we will present a summary of the SWIM project and results after this

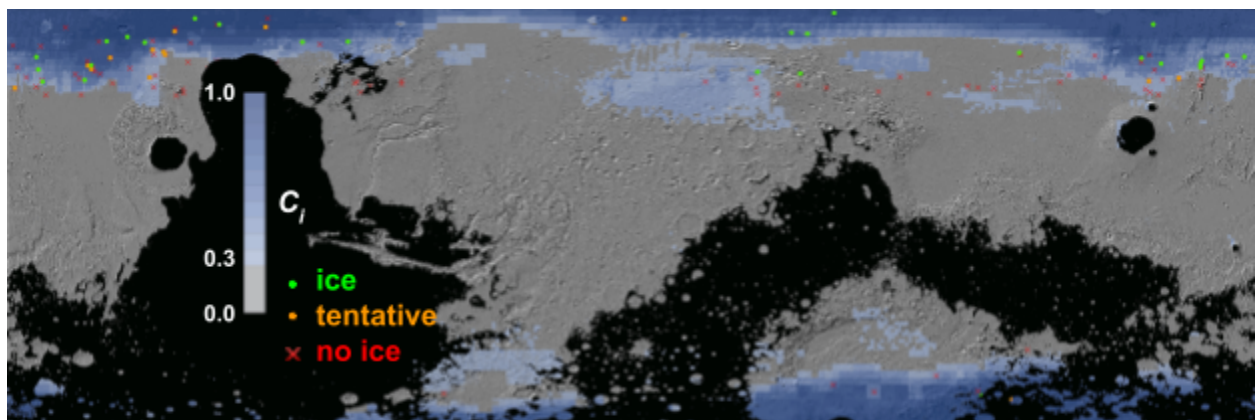


Figure 1. Map of composite water-ice consistency (C_i) in the 0-1 m depth zone in the Mars SWIM study area (180°W-180°E, 60°S-60°N) overlain on MOLA shaded relief (grayscale) and blacked out at elevations > +1 km. Colored dots represent fresh impacts, with those showing signs of ice exposure serve as ground truth.

latest phase of our ice mapping efforts. These new mapping products will provide valuable tools for mission planning activities, and our analysis will highlight limitations of previous and current orbital assets at Mars to advise the next generation of orbital and landed robotic missions that will be needed to fully assess water-ice resources.

The SWIM Datasets: To search for and assess the presence of shallow ice across our study regions, we combine multiple techniques and datasets: hydrogen detected by a neutron spectrometer (MONS), shallow layering modeled use thermal spectrometers (TES, THEMIS, and MCS), multiscale geomorphology (HiRISE, CTX, HRSC, and MOLA), and surface and subsurface radar echoes (SHARAD) (Fig. 2). To maximize information extracted from the data, we developed new techniques to better delineate water ice within 5 m of the surface through the use of refined thermal and radar modeling [10–11].

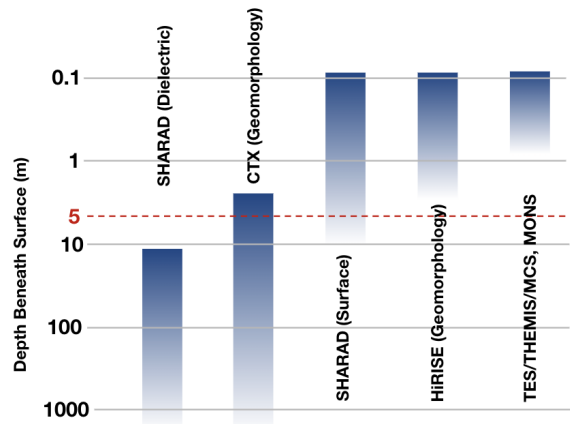


Figure 2. Ranges of approximate resolution depths for SWIM ice-detection techniques. Geomorphology spans the gap in resolution depths between radar sounding and other geophysical methods.

Consistency Mapping: To enable a quantitative assessment of how consistent (or inconsistent) the various datasets are with the presence of buried water ice across our study regions, we introduced the SWIM Equation. For each dataset, we assign consistency values between +1 and -1, where +1 means that the data are wholly consistent with the presence of ice, 0 means that the data give no indications of the presence or absence of ice, and -1 means that the data are wholly inconsistent with the presence of ice. We then calculate an overall value of ice consistency for each map pixel by summing the individual consistency values and normalizing by the number of datasets. In the 2019 study, we chose to

apply equal weighting to each input dataset. For the 2020 work, we subdivided consistency mapping into three depth zones of interest: 0–1 m, 1–5 m, and > 5 m, applying weightings to each dataset based on their nominal sensing depths. We also explored the use of Bayesian statistical analysis in an effort to assign more formal probability assessments, and while this approach is promising, the gap in sensing depths (Fig. 2) and differences in lateral resolutions of the geophysical data makes such a treatment challenging. At SRR, we will present new water-ice mapping products derived from our latest thinking on how best to integrate all of the datasets, and we will discuss their implications for planning future human and robotic missions, including I-MIM.

Study Results: Figure 1 presents our latest map of composite ice consistency at 0–1 m depths, which spans terrains $\pm 60^\circ\text{N}$ at $< +1$ km elevation. The highest consistency values, which are indicative of multiple individual datasets reporting signatures of buried ice, typically occur poleward of $\sim 40^\circ$ latitude—notably in Arcadia Planitia, where previous work found indications of widespread ground ice [12], as well as on the eastern Hellas rim and in Deuteronilus Mensae, where others have mapped extensive debris-covered glaciers [5, 13]. However, positive consistency values extend to as low as $\sim 20^\circ$ latitude in other maps for the deeper detection zones.

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