REPORT FROM THE MARS SUBSURFACE WATER ICE MAPPING (SWIM) PROJECT.

N. E. Putzig,[1] G. A. Morgan,[1] H. G. Sizemore,[1] D. M. H. Baker,[2] A. M. Bramson,[3] Z. M. Bain,[1] E. I. Petersen,[3] R. H. Hoover,[4] M. R. Perry,[1] M. Mastrogiuseppe,[5] A. Pathare,[1] C. Dundas,[6] I. B. Smith,[1,7] B. A. Campbell.[8] [1]Planetary Science Institute (than@psi.edu), [2]NASA Goddard Space Flight Center, [3]University of Arizona Lunar and Planetary Laboratory, [4]Southwest Research Institute, [5]California Institute of Technology, [7]York University, [8]Smithsonian Institution.

Introduction: The Subsurface Water Ice Mapping (SWIM) in the Northern Hemisphere of Mars project supports an effort by NASA's Mars Exploration Program to determine *in situ* resource availability. We are performing global reconnaissance mapping as well as focused multi-dataset mapping to characterize the distribution of water ice from 0º to 60ºN in all longitudes outside of 225–290ºE (the high-standing Tharsis region). Our maps are available to the community on the SWIM Project website (https://swim.psi.edu) and we intend to present final results at the next Human Landing Site Selection workshop, expected in November of 2019. Follow us on Twitter @RedPlanetSWIM for project news and product release information.

Background: There are numerous challenges associated with delivering humans to the surface of Mars and returning them safely to Earth. With current propulsion technology, mass remains the ultimate premium, and thus leveraging all available in situ resources at Mars will be essential. The most valuable resource for "living off the land" is water, which together with the atmospheric carbon dioxide offers fuel to sustain an outpost and for the return to Earth. Of course water is also a critical ingredient of life support, and local sources are needed for sustaining a long-term outpost.

Surface ice exists on Mars in plentiful volumes. The planet hosts two multi-kilometer-thick ice caps in the form of the north and south polar layered deposits. Unfortunately, these sources of water are not viable due to their high latitude. Living off the land also means that other considerations—such as a reliable source of solar energy and relatively moderate ambient thermal conditions—become critical. The higher solar radiation and manageable length of night offered by the lower latitudes are indispensable to mission success. For the return trip to Earth, a low-latitude location is also key for reducing the energy requirements needed for exiting the Martian gravity well. Thus, future mission planning must isolate regions of Mars that optimize both water sources and energy supplies.

Ice Resources on Mars: Non-polar ice, accessible within the scope of most mission architectures (upper few meters) has been discovered on Mars through remote sensing investigations. For example, imaging of fresh impacts reveals an icy substrate in many locations [1-2] and glacial deposits have been found within the mid-latitudes through a combination of geomorphologic and radar sounding studies (e.g., [3]). Knowledge of the complete inventory of the distribution and depth range of these water ice deposits across Mars is thus of enormous value to human missions.

Methods: The primary goal of this project is to generate ice mapping products that enable planning for future human missions. Prior global studies of Martian ice deposits have largely concentrated on one or two data types, such as neutron-spectrometer mapping [4] and geomorphological surveys of periglacial features (e.g., [5]).

The SWIM project is unique in that it has integrated all appropriate, available orbital datasets to provide an holistic assessment of accessible Martian ice reserves. By employing a team with a diverse background of relevant expertise and by leveraging new data processing techniques, the SWIM Project has generated the most up-to-date maps of Martian water ice distribution for the northern mid-latitudes.

We have carried out global reconnaissance mapping with thermal and radar data as well as focused multi-dataset mapping between from 0º and 60ºN within four study regions to characterize the distribution of water ice (Fig 1). The current focus on the northern hemisphere is driven by the preferred landing conditions at lower elevations (i.e., higher atmospheric density) relative to the south.

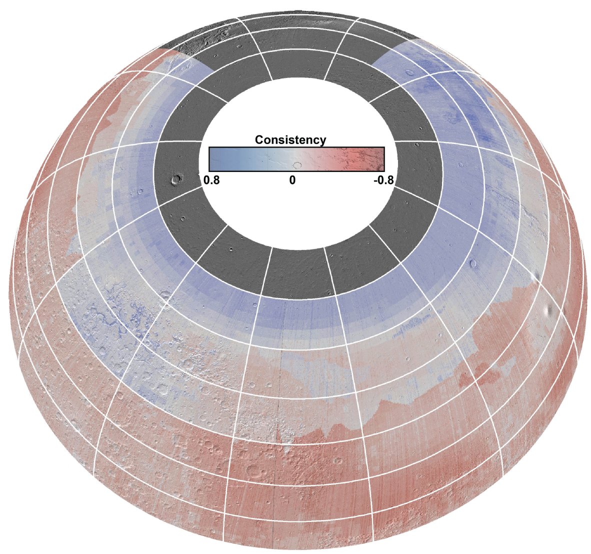

Figure 1. *Map of multi-dataset consistency with the presence of near-surface ice in the northern hemisphere of Mars (0 to 60°N, centered at 75°E) [9].*

At the Space Resources Roundtable, we will provide an overview of the entire project and present the results of our ice mapping efforts. These new mapping products represent valuable tools for mission planning activities, and they will directly support the next Mars Human Landing Site Studies Workshop. Beyond mission planning, the SWIM analysis will also highlight limitations of our previous and current orbital assets, providing a framework to advise the next generation of robotic missions.

The SWIM Datasets: To search for and assess the presence of shallow ice across our study region, the SWIM project uses the following techniques and datasets: neutron-detected hydrogen (MONS), thermal behavior (both TES and THEMIS), multi-scale geomorphology (HiRISE, CTX, HRSC and MOLA), and SHARAD radar surface and subsurface echoes (Fig 2). To extract the maximum amount of information from the datasets, we are employing multiple new techniques, including: SHARAD super-resolution and coherent summing processing for enhanced range resolution and SNR [6], corrected SHARAD surface reflectivity [7] and refined thermal modeling [8]. So, how do we derive values for ice content from these diverse datasets?

Consistency Mapping: To enable a quantitative assessment of how consistent (or inconsistent) each of the various remote sensing datasets is with the presence of buried water ice across these regions (Fig 2), we introduced the SWIM Equation. Our consistency values range between +1 and -1, where +1 means that the data are 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 inconsistent with the presence of ice. In the SWIM Equation, we calculate an overall "ice consistency value" for each pixel of our map by summing each individual consistency value and normalizing by the number of datasets. **Further revision of this equation may occur (e.g., normalizing divisors may be adjusted to account for data nulls), but presently we have the following terms:**

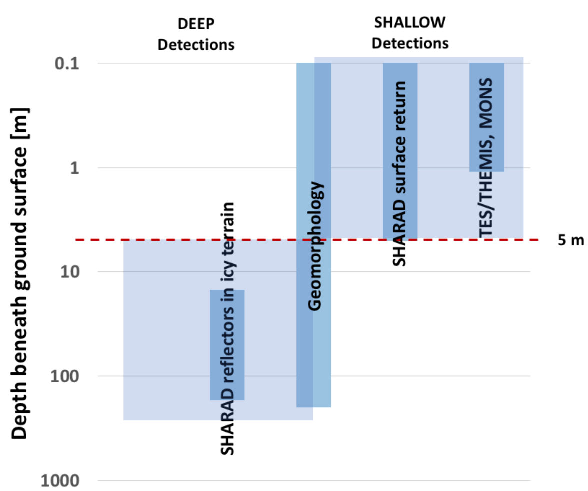

Figure 2. Range in sensing depths of various data sets used to search for ice. Our composite ice consistency map assesses the presence of ice within the entire section. Note log scale for depth.

$$C_I = (C_N + C_T + C_G + C_{RS} + C_{RD})/5$$

Where each C term is **consistency** of a given data set with the presence of subsurface ice (Table 1). Figure 1 presents a map of C_I, our composite consistency for all data sets.

Table 1: SWIM Equation Terms and Sensing Depths

Term	*Data Sets*	*Ice Depth (m)*
C_I	All	all
C_N	Neutron-detected hydrogen in form of ice	< 1
C_T	Thermal behavior (TES and THEMIS)	< 1
C_G	Ice-related geomorphology	all
C_{RS}	Radar surface returns with ice-like low power	< 5
C_{RD}	Radar subsurface dielectric constant estimations	> 5

Acknowledgements: The SWIM project is supported by NASA through JPL Subcontract 1611855. We are grateful to SeisWare International Inc. for academic licensing of their Geophysics software used in our radar analysis.

References: [1] Byrne S. et al. (2009) Science 325, 1674-1676. [2] Dundas C.M. et al. (2014) Geophys. Res. Lett. 119, 109-127. [3] Holt, J. Science, 322, 1235-1238. [4] Feldman, W. C., Science, 297, 75-78. [5] Head, J. et al., Nature, 426, 797 - 802. [6] Mastrogiuseppe et al. (2019) LPSC. [7] Bain et al. (2019) LPSC abs. 2726. [8] Hoover et al. (2019) LPSC abs. 1679. [9] Morgan et al. (2019) LPSC abs. 2918.