# MARS SUBSURFACE WATER ICE MAPPING (SWIM): THE SWIM EQUATION AND PROJECT INFRASTRUCTURE.

M. R. Perry[1], Z. M. Bain[1], N. E. Putzig[1], G. A. Morgan[1], A. M. Bramson[2], E. I. Petersen[2], M. Mastrogiuseppe[3], D. M. H. Baker[4], R. H. Hoover[5], H. G. Sizemore[1], I. B. Smith[1], B. A. Campbell[6]. [1]Planetary Science Institute (mperry@psi.edu), [2]Lunar and Planetary Laboratory, University of Arizona, [3]California Institute of Technology, [4]NASA Goddard Space Flight Center, [5]Southwest Research Institute, [6]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 four longitude bands: "Arcadia" (150–225ºE, which contains our pilot-study region), "Acidalia" (290–360ºE), "Onilus" (0–70ºE, which covers Deuteronilus and Protonilus Mensae), and "Utopia" (70–150ºE). Our maps are being made 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 the summer or fall of 2019. Follow us on Twitter @RedPlanetSWIM for project news and product release information.

**The SWIM Datasets:** To search for and assess the presence of shallow ice across our study regions, we are integrating multiple datasets to provide a holistic view of the upper 10s of m of the Martian subsurface. We divide the datasets into two regimes: shallow (< 5 m depth) and deep (> 5 m depth). The individual datasets we consider include neutron-detected hydrogen maps (MONS), thermal behavior (both TES and THEMIS), multiscale geomorphology (HiRISE, CTX, HRSC and MOLA), and SHARAD radar surface and subsurface echos [1,2,3,4,5,6,7,8]. Additional datasets are under consideration, but have yet to be implemented at this time.

It is important to note that this study does not intend to identify all existing ice, since currently available data sets impose limits on lateral and vertical resolutions as well as the sensing depth (Figure 1). In broad terms, the available datasets examine four zones:

1. The surface itself: image and elevation data.
2. Depths to ~1 m: thermal and neutron spectrometers.
3. Depths to ~5 meters: radar surface reflections.
4. Depths of ~20 to >100 m: radar reflections from subsurface interfaces.

**The SWIM Equation:** Interpreting the presence of ice from these datasets is to a degree subjective and does not lend itself to precise calculations of probabilities. However, some quantification of our confidence in our identification and mapping of ice is warranted and is highly desirable for planning future landing sites that rely on the presence of ice for resources or scientific studies. To that end, we have developed the SWIM Equation, produced in the spirit of the famous Drake Equation [9] for conceptualizing the number of civilizations in our galaxy. In the case of the SWIM equation, each of our terms is based on actual measurements and thus we argue that the derived output is a tangible representation of the likelihood of shallow ice.

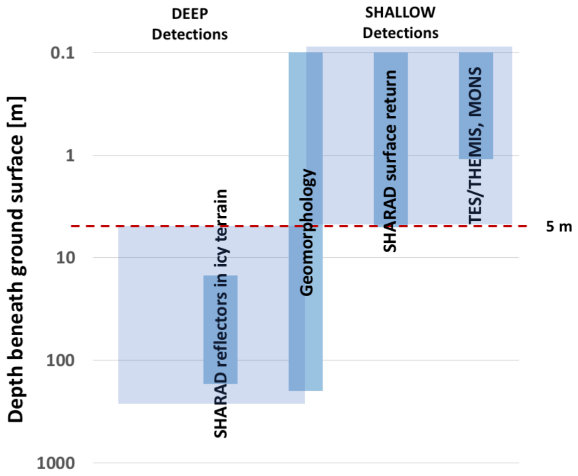

***Figure 1:*** *Various sensing depths of the datasets currently in use by the SWIM Team.*

We begin by defining for each dataset consistency values that range from -1 to +1, where -1 indicates that a given measurement is inconsistent with the presence of ice. In contrast a +1 indicates that the measurement is consistent with the presence of ice. A value of 0 means the data is inconclusive. We divide the equation into two terms, one for shallow ice (< 5 m depth) and one for deep ice (> 5 m depth). **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:**

$$C_I = (C_{IS} + C_{ID})/2$$

$$C_{IS} = (C_N + C_{TES} + C_{THM} + C_{GS} + C_{RS})/5$$

$$C_{ID} = (C_{GD} + C_{RDR} + C_{RDE})/3$$

Where each C term is **consistency** of a given data set with shallow (*S* subscript) or deep (*D* subscript) ice (Table 1).

In the SWIM Equation, we calculate an overall "ice consistency value" for each pixel (1/20°) of our map by summing each individual consistency value and normalizing by the number of datasets.

**Project Infrastructure:** Since the SWIM team has investigators located throughout North America, we developed a project infrastructure to facilitate information sharing, ease of access, and consistency of projects throughout the duration of the SWIM project. For example, the subsurface radar mapping incorporates ~6000 individual radargrams. Such a large undertaking requires standardization of procedures and workflows, readily available data sets necessary for proper interpretation of the radargrams, and built-in fail safes in the event of catastrophic systems failure of either the equipment or the investigator.

*Table 1: SWIM Equation Terms*

| *Term* | *Data Sets* | *Ice Depth (m)* |
|---|---|---|
| $C_{I}$ | All | < 5 and > 5 |
| $C_{IS}$ | Shallowly sensing data sets | < 5 |
| $C_{ID}$ | Deeply sensing data sets | > 5 |
| $C_{N}$ | Neutron-detected hydrogen in form of ice | < 1 |
| $C_{TES}$ | Thermal behavior (TES) | < 1 |
| $C_{THM}$ | Thermal behavior (THEMIS) | < 1 |
| $C_{GS}$ | Small-scale ice-related geomorphology | < 5 |
| $C_{RS}$ | Radar surface returns with ice-like low power | < 5 |
| $C_{GD}$ | Large-scale ice-related geomorphology | > 5 |
| $C_{RDR}$ | Radar subsurface returns with ice-like low permittivity | > 5* |
| $C_{RDE}$ | Radar subsurface dielectric constant estimations | > 5* |

A shared file system ("Pool") was established to decentralize the individual SeisWare projects to allow users to work on multiple projects in different locations. Dynamic files (i.e. horizons, dielectric estimation locations, session files) and static files (i.e. raster images, projection files, basemaps, clutter simulations and US SHARAD PDS browse products ["radargrams"]) for each SeisWare project are stored and saved in the Pool. To enable and standardize subsurface radar analysis, we purchased two high-performance computer workstations optimized for SeisWare, a commercial seismic data analysis program that has proved very efficient for analyzing radar data [e.g., 10, 11], and we identically set-up each SeisWare project on both systems. These two workstations, along with two previously existing workstations in Colorado and Ontario, were integrated via the Pool. The Pool also houses TES and THEMIS analysis data, geomorphological data and regions of interest, resources and references for investigators, and preliminary results used in the overall consistency maps. For more information regarding each component of the SWIM project and its various techniques and datasets, see the other SWIM Project presentations at this LPSC: Morgan at al. (overview), Bramson et al. (radar), Hoover et al. (thermal), Bain et al. (surface reflectivity), and Putzig et al. (geomorphology).

To facilitate the public dissemination of project information and final products, we developed a website (https://swim.psi.edu). These public deliverables include, but are not limited to: presentations and publications, individual dataset results and consistency maps, and composite consistency maps developed according to the SWIM Equation. The website also features a secure area for team members that facilitates communication within the team. This secure area provides useful resources for team members such as tools for requesting and delivering super-resolution and coherently summed radargrams.

**Preliminary Results:** Preliminary results for the Arcadia Pilot Study and SWIM: Mars Northern Hemisphere project are available through a number of abstracts for the 50th LPSC: Morgan at al. (overview), Hoover et al. (thermal analysis), Bramson et al. (radar analysis), Bain et al. (surface reflectivity), and Putzig et al. (geomorphology).

**Acknowledgments:** 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] Pathare, A. V. et al. (2018) *Icarus*, 301: 97-116 [2] Christensen, P.R. et al. (2001) *JGR: Planets.* 106.E10: 23823-23871 [3] Christensen, P. R. et al. (2001) *Space Sci. Rev.* 110, 1-2: 85-130 [5] Malin, M. C. et al. (2007) *JGR: Planets.* 112.E5 [6] Jaumann, R. et al. (2007) *Planet. Space Sci.* 55.7-8: 928-952 [7] Zuber, M. T. et al. (1992) *JGR: Planets* 97:E5: 7781-7797 [8] Seu et al. (2004) *Planet. Space Sci.* 52. 1-3: 157-166 [9] F. Drake, D. A. Vakoch, and M. F. Dowd. (2015) *The Drake Equation: Estimating the Prevalence of Extraterrestrial Life through the Ages*, Cambridge University Press. [10] Putzig et al. (2009) *Icarus.* 204.2: 443-457 [11] Putzig et al. (2014) *JGR: Planets* 119.8: 1936-1949 [12]