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, [2]University of Arizona Lunar and Planetary Laboratory (bramson@LPL.arizona.edu), [3]California Institute of Technology, [4]NASA Goddard Space Flight Center, [5]Southwest Research Institute, [6]Smithsonian Institute

What is SWIM?

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 for future human missions. Using several techniques and instruments, we are performing global reconnaissance mapping as well as focused multi-dataset mapping from 0º to 60ºN. We present the project datasets and infrastructures as well as the SWIM Equation and the results of combining all datasets used in the current SWIM Northern Hemisphere study.

For results from the other datasets, see the other SWIM Project posters at this LPSC:
Bramson et al. [1] (subsurface reflectors) Hoover et al. [2] (thermal analysis)
Bain et al. [3] (surface reflectivity) Putzig et al. [4] (geomorphology)
as well as the talk by Morgan at al. [5] (overview) at 9:45 AM on Friday morning

Final results will be presented at the next Human Landing Site Selection workshop.
Our maps are being made available to the community on the SWIM Project website.
Follow us on Twitter for project news and product release information.

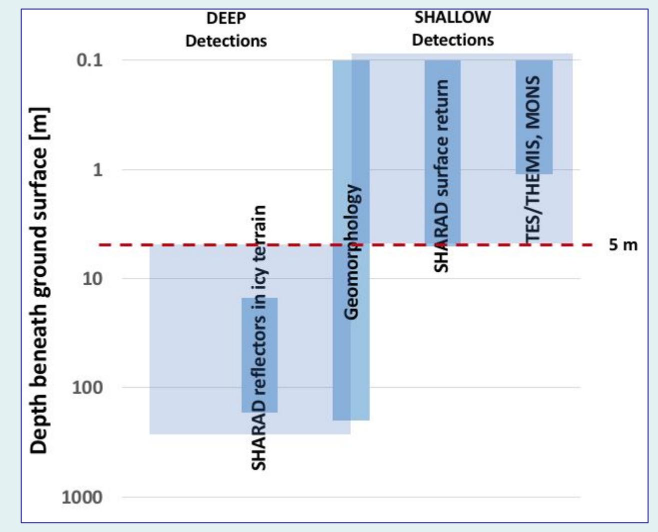
https://swim.psi.edu/ @RedPlanetSWIM

Extension Activities

- Add additional study regions
- In-depth analyses for regions of interest
- Incorporate ice-exposing impact locations to the SWIM Equation
- Advanced data analysis techniques. See other SWIM posters for data-set specific extension activities

Data Sets and Techniques

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 meters of the Martian subsurface.



Right: Various depth resolutions of the data sets and surface features used in the SWIM project to search for ice within the Martian subsurface.

Infrastructure

- We developed a project infrastructure to facilitate information sharing, ease of access, and consistency of projects.
- The subsurface radar mapping incorporates ~6000 individual SHARAD [6] radargrams.
- A shared file system ("Pool") was established to decentralize the individual SeisWare projects (used for radargram interpretation work [e.g., 7,8]) to allow users to work on multiple projects in different locations. Dynamic files (i.e. horizons, dielectric estimation locations, session files), 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.
- The Pool also houses TES [9] and THEMIS [10] analysis data, geomorphological data and regions of interest, resources and references for investigators, and preliminary results used in the overall consistency maps.

The SWIM Equation

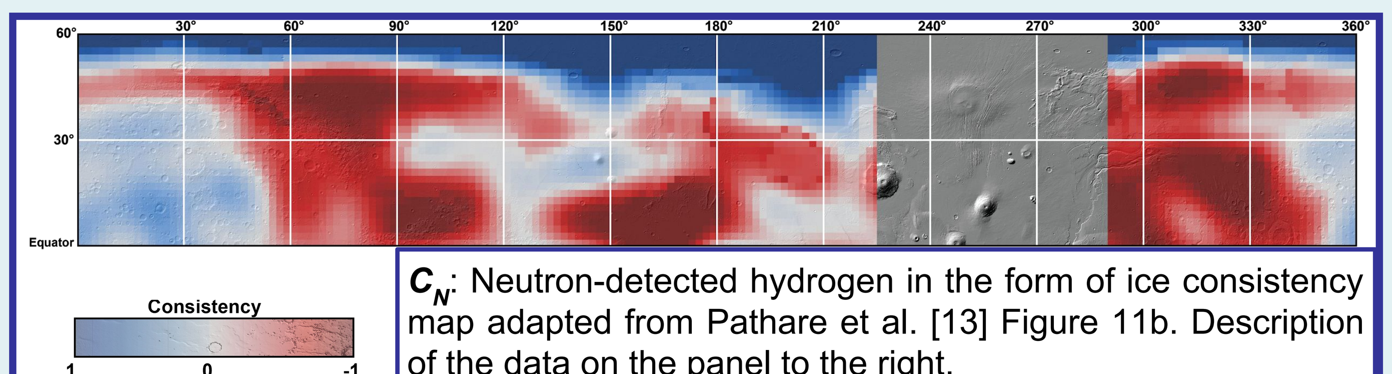
$$C_I = (C_N + C_T + C_G + C_{RS} + C_{RD}) / 5$$

We have developed the SWIM Equation, produced in the spirit of the famous Drake Equation [11] 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. 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.

Term	*Data Sets*	*Sensing Depth (m)*
C_I	All	< 5 and > 5
C_N	Neutron-detected WEH (Water-equivalent hydrogen)	< 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

Above: Explanation of SWIM Equation Terms and Sensing Depths

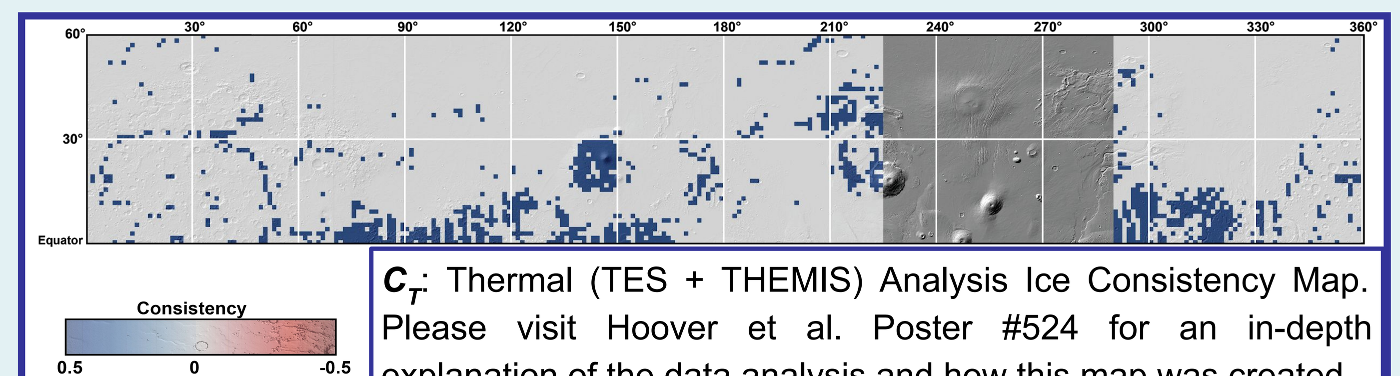
Results & Products



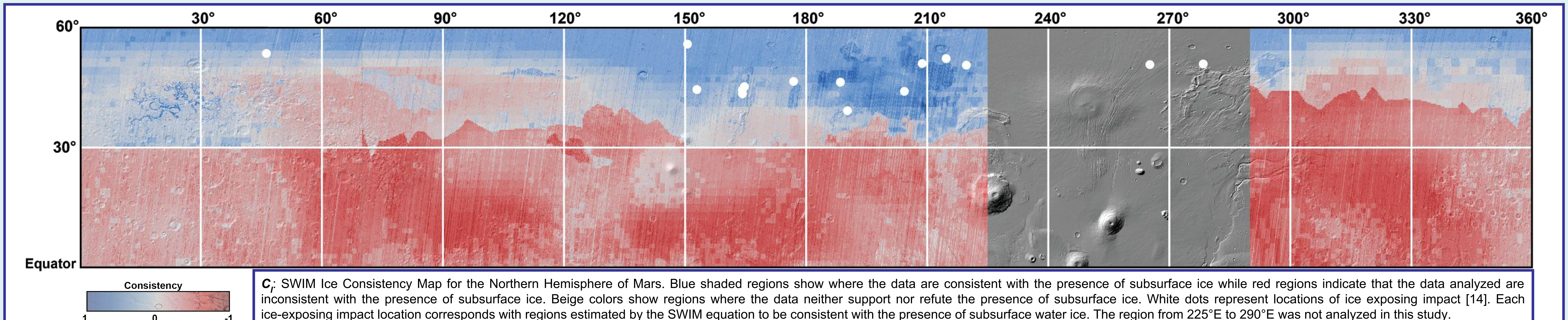
C_N: Neutron-detected hydrogen in the form of ice consistency map adapted from Pathare et al. [13] Figure 11b. Description of the data on the panel to the right.

Left: Pathare et al. [12] produced the most definitive global maps to date of near-surface water-equivalent hydrogen (WEH) in an upper layer (W_{up}), lower layer (W_{dn}), and depth (D) to the lower layer. They refined the cross-over technique developed by Feldman et al. [13] to produce the first maps of self-consistent (i.e., derived entirely from MONS neutron data) W_{up} , W_{dn} , and D. These W_{dn} results (expressed in terms of WEH as percentages) were then scaled to fit into the SWIM equation using the following:

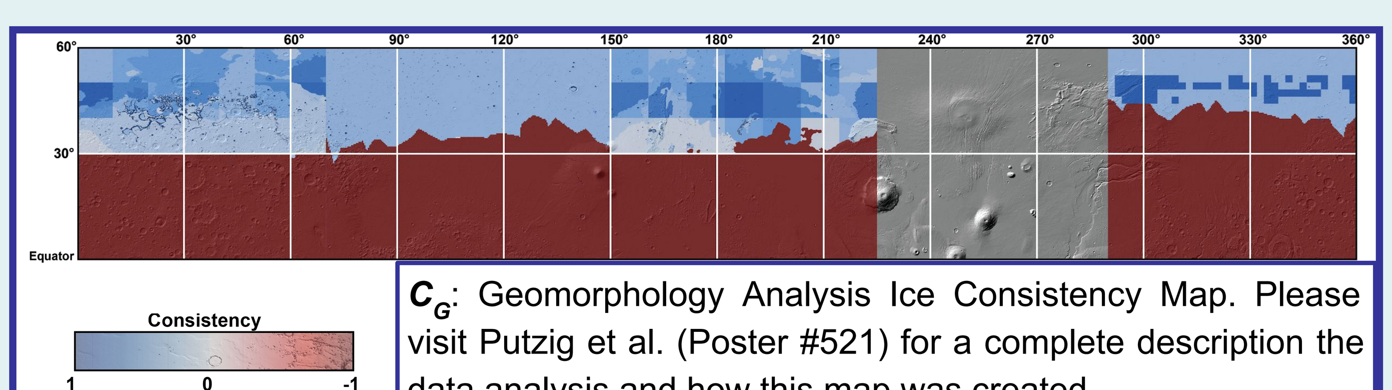
$W_{dn} \geq 25\%$	Consistent with ice
$10\% < W_{dn} < 25\%$	Scaled between 0 and 1
$5\% < W_{dn} \leq 10\%$	Scaled between -1 and 0
$W_{dn} < 5\%$	Inconsistent with ice



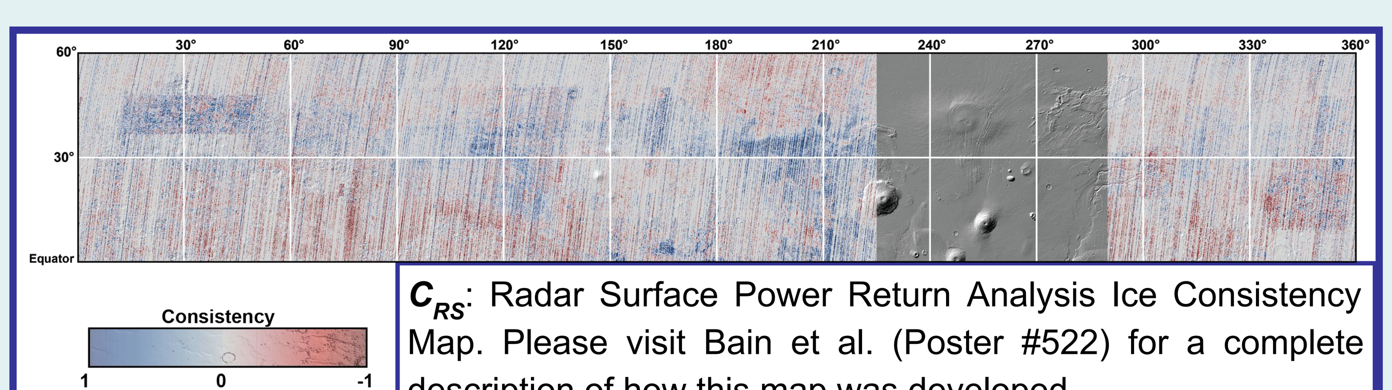
C_T: Thermal (TES + THEMIS) Analysis Ice Consistency Map. Please visit Hoover et al. Poster #524 for an in-depth explanation of the data analysis and how this map was created.



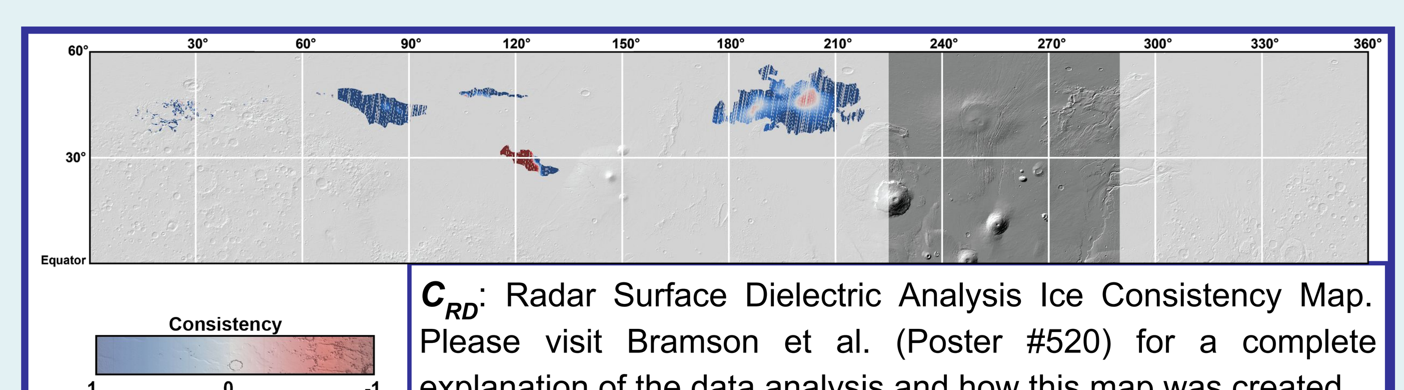
C_I: SWIM Ice Consistency Map for the Northern Hemisphere of Mars. Blue shaded regions show where the data are consistent with the presence of subsurface ice while red regions indicate that the data analyzed are inconsistent with the presence of subsurface ice. Beige colors show regions where the data neither support nor refute the presence of subsurface ice. White dots represent locations of ice exposing impact [14]. Each ice-exposing impact location corresponds with regions estimated by the SWIM equation to be consistent with the presence of subsurface water ice. The region from 225°E to 290°E was not analyzed in this study.



C_G: Geomorphology Analysis Ice Consistency Map. Please visit Putzig et al. (Poster #521) for a complete description the data analysis and how this map was created.



C_{RS}: Radar Surface Power Return Analysis Ice Consistency Map. Please visit Bain et al. (Poster #522) for a complete description of how this map was developed.



C_{RD}: Radar Surface Dielectric Analysis Ice Consistency Map. Please visit Bramson et al. (Poster #520) for a complete explanation of the data analysis and how this map was created.

REFERENCES: [1] Bramson et al. (2019), LPSC Abstract #2069; [2] Hoover et al. (2019), LPSC Abstract #1679; [3] Bain et al. (2019), LPSC Abstract #2726; [4] Putzig et al. (2019), LPSC Abstract #2087; [5] Morgan et al. (2019), LPSC Abstract #2918; [6] Seu et al. (2004), Planet. Space Sci. 52. 1-3; [7] Putzig et al. (2009), *Icarus* 204.2; [8] Putzig et al. (2014), *JGR: Planets* 119.8; [9] Christensen et al. (2001) *JGR: Planets.* 106.E10: 23823-23871; [10] Christensen et al. (2001) *Space Sci. Rev.* 110, 1-2: 85-130; [11] 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. [12] Pathare et al. (2018), *Icarus* 301: 97-116 [13] Feldman et al. (2011), *JGR: Planets* 116.E11 [14] Dundas et al. (2014), *JGR: Planets* 119.1 109-127; We are grateful for SeisWare, Inc. for access to the interpretation software used for the radar subsurface reflector analysis.