Subsurface Water Ice Mapping (SWIM) to support the International Mars Ice Mapper (I-MIM) mission

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Mars Subsurface Water Ice Mapping (SWIM) Team Roster

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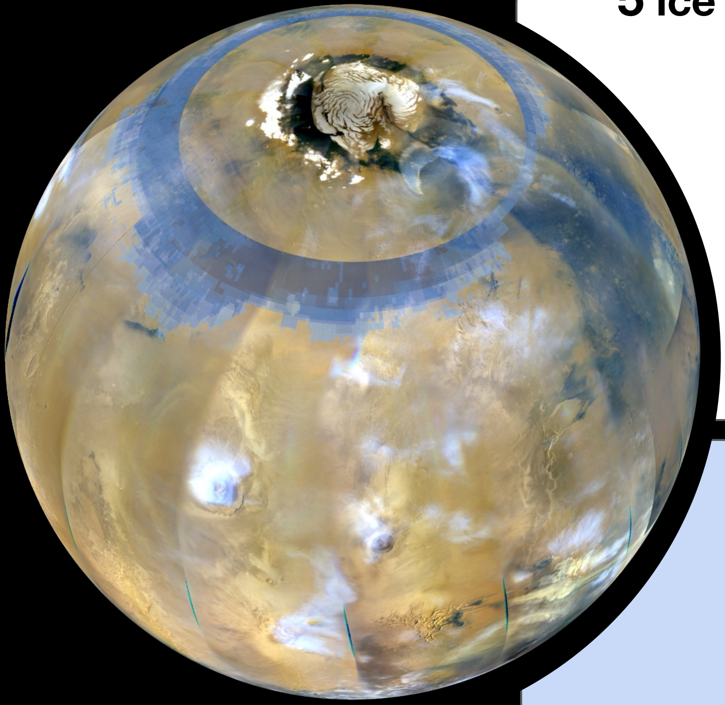
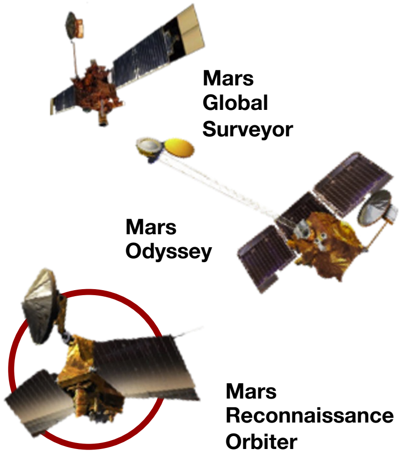
Subsurface Ice Mapping through Data Integration



5 ice characterization techniques

- Neutron - **MONS**
- Thermal - **TES/THEMIS/MCS**
- Geomorphology - **CTX/HiRISE**
- Radar Surface - **SHARAD**
- Radar Subsurface - **SHARAD**



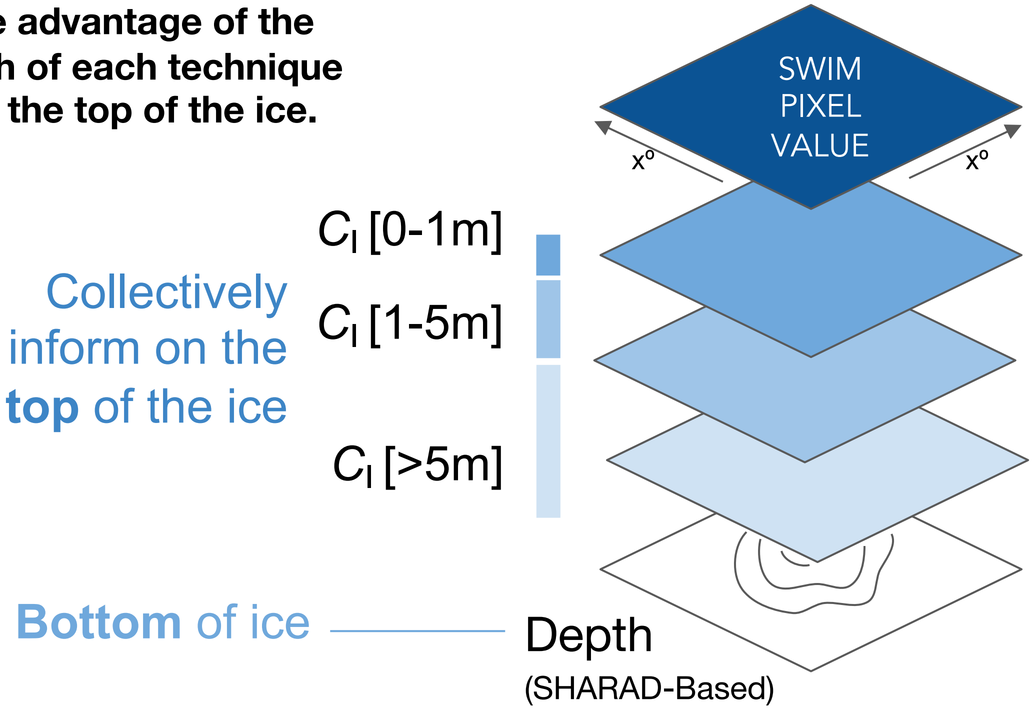
- For each technique, we isolate distinct properties of the subsurface that provide proxies for the presence (or absence) of ice.
- Termed ***ice consistency (C)***, measurements range from **-1**, meaning wholly inconsistent with ice, to **+1**, meaning

SWIM Ice Consistency Layers

Technique	Sens. Depth	Ice Consistency (C_X) Mapping	Methods
Neutrons	< 1 m	C_N -1 0 +1 Wdn 5% 10% 25%	Wdn is water-equivalent hydrogen modeled in lower of 2 layers [Pathare+18].
Thermal	< 1 m	C_T 0 +1 lo/hi *d* > 50cm < 30cm	Map TES matches to low-over-high thermal inertia layers [after Putzig+07]. Averaged with TES, MCS results of Banfield+08, Piqueux+19.
Radar Surface	< 5 m	C_{RS} -1 0 +1 P_{RS} 1σ 0.5σ -0.5σ -1σ	Surface power v. global distrib. Power values corrected for ionosphere, surface roughness, regional slope and anomalous returns.
Radar Subsurface	> 15 m	C_{RD} -1 0 +1 ε' 7 5 3	Dielectric constant ε' estimated from radar delay times Δt and thickness h from MOLA DEM of associated topographic features.
Geomorphology	variable	C_G 0 +1 Weighted 8-landform tally (**CTX**) Polygon Density (**HiRISE**)	**CTX:** Grid mapping of 8 landforms at 1°x1° (24º-38ºS), 4°x4°, and 10°x10°. Landforms weighted based on likelihood of ice and depth zone of interest. **HiRISE:** Polygon Occurrence/Images Surveyed

SWIM Ice Consistency (C_I) Process

For later phases, we take advantage of the relative penetration depth of each technique to constrain the depth to the top of the ice.



SWIM Equations

SWIM Phase 1 used unweighted averaging:

$$C_I = \frac{C_N + C_T + C_{RS} + C_{RD} + C_G}{5}$$

Later SWIM phases use weighted averaging:

$$C_I = \frac{s_N C_N + s_T C_T + s_{RS} C_{RS} + s_{RD} C_{RD} + C_G}{s_N + s_T + s_{RS} + s_{RD} + 1}$$

Depth zone	s_N	s_T	s_{RS}	s_{RD}
0-1 m	1	1	0.2	0
1-5 m	0	0	1	0.3
> 5 m	0	0	0	1

Notes:

- *Weighting values are shallowness of method X:* $s_X = \frac{\text{depth of interest}}{\text{depth of penetration}}$
- *Landforms feeding into the geomorphic C_G term have different sensing depths and are weighted separately for different depth zones.*

Morgan et al. [2021] *Nature Astronomy*.

Putzig & Morgan et al. [2023] Ch. 16 in *Handbook for Space Resources*

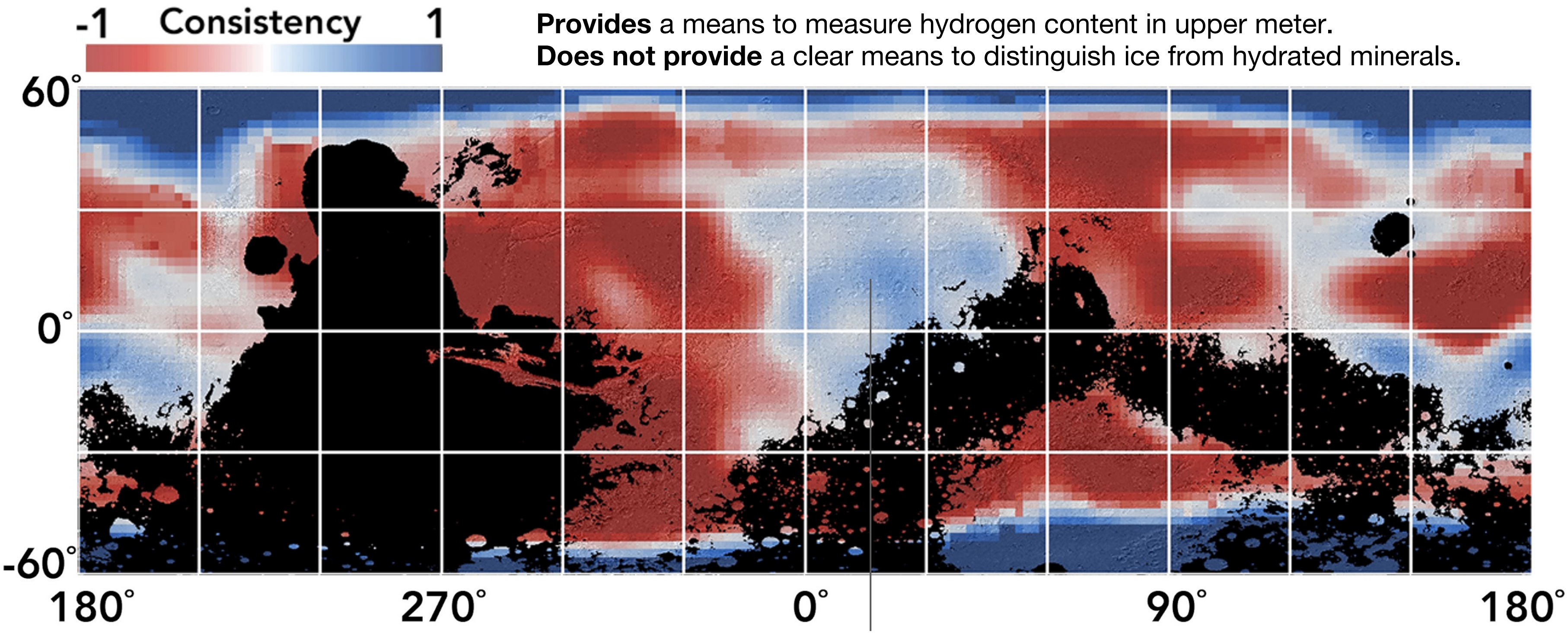
https://swim.psi.edu/

Technique-specific Ice Consistency Maps

Neutron SWIM Layer

Computed from **Pathare et al [2018]** map of lower-layer water-equivalent hydrogen (Wdn).

Provides a means to measure hydrogen content in upper meter.
Does not provide a clear means to distinguish ice from hydrated minerals.

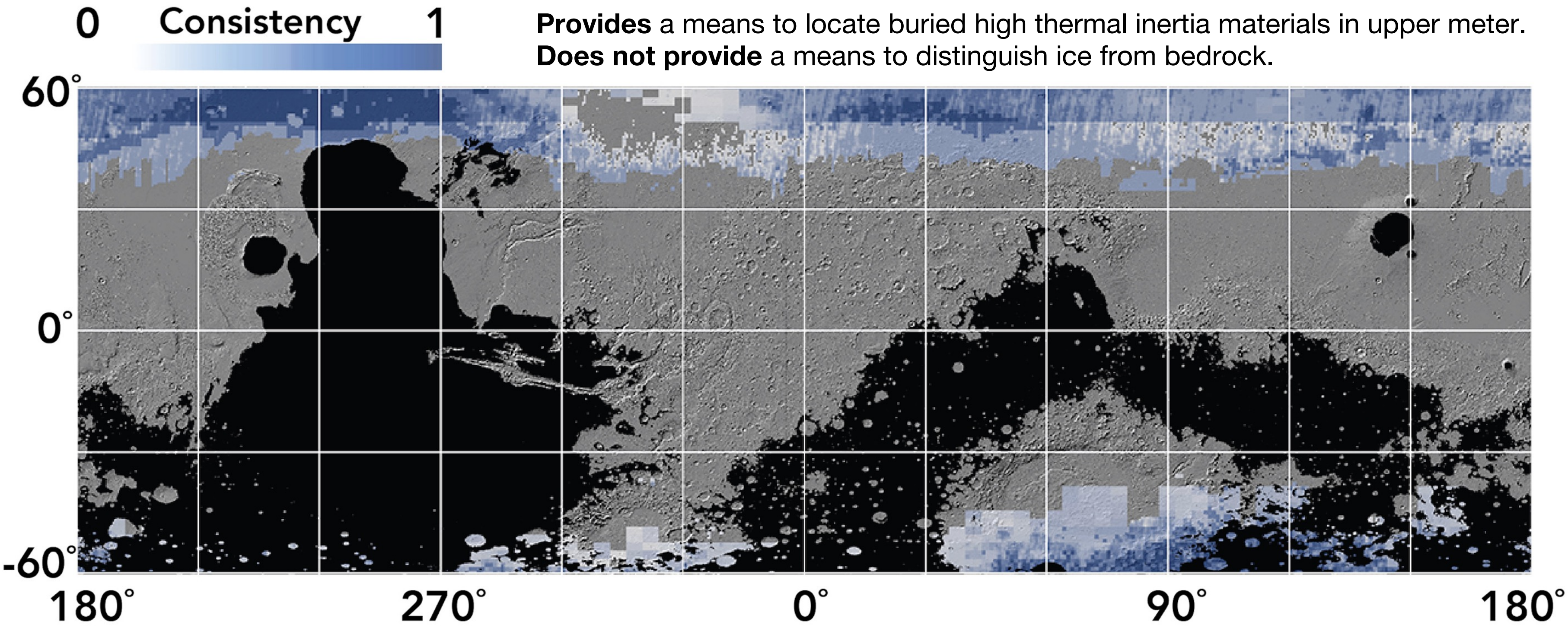


Equatorial positive values are possible hydrated minerals

Thermal SWIM Layer

Combined results from **SWIM 2.0**, **Bandfield & Feldman [2008]**, and **Piqueux et al [2019]** for models with ice at 50 cm or shallower.

Provides a means to locate buried high thermal inertia materials in upper meter.
Does not provide a means to distinguish ice from bedrock.

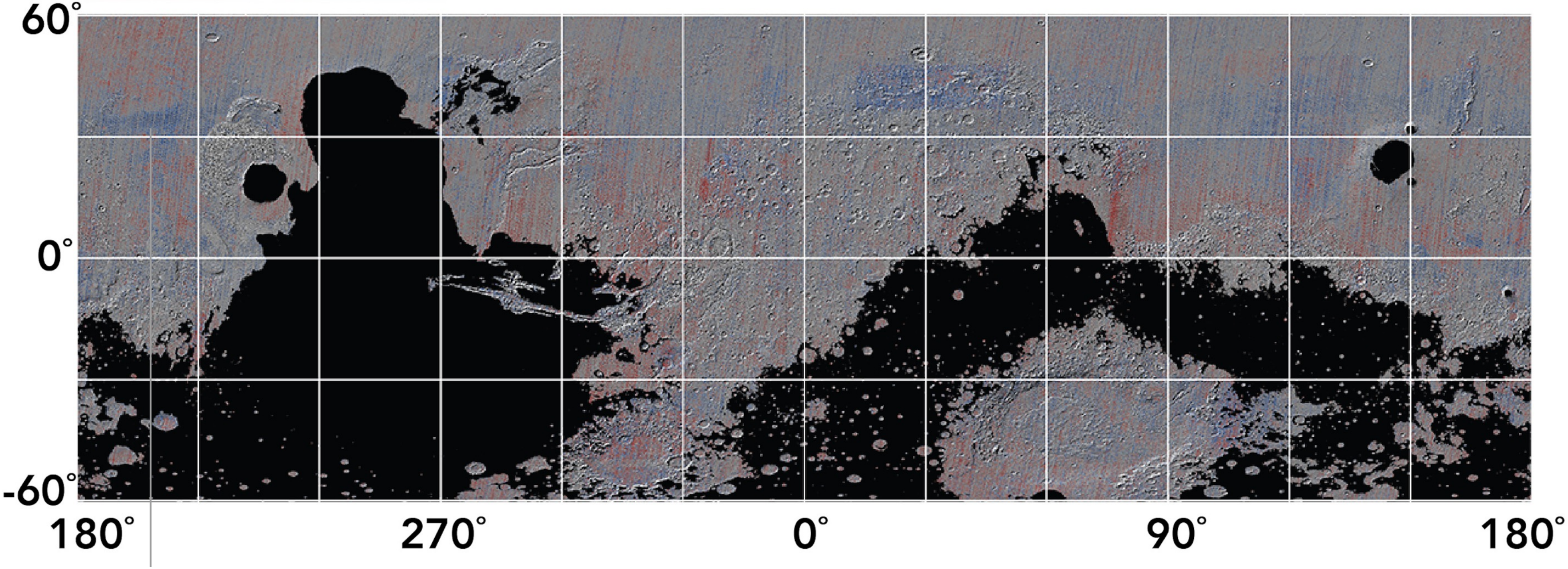


Thermal ice consistency relies on detecting a lower layer with high thermal inertia. Bedrock may result in false positives.

Radar Surface Power SWIM Layer

Computed from SHARAD data

Provides a means to identify low-density materials in the upper 5 meters.
Does not provide a means to distinguish ice from dust, low-density ash, etc.

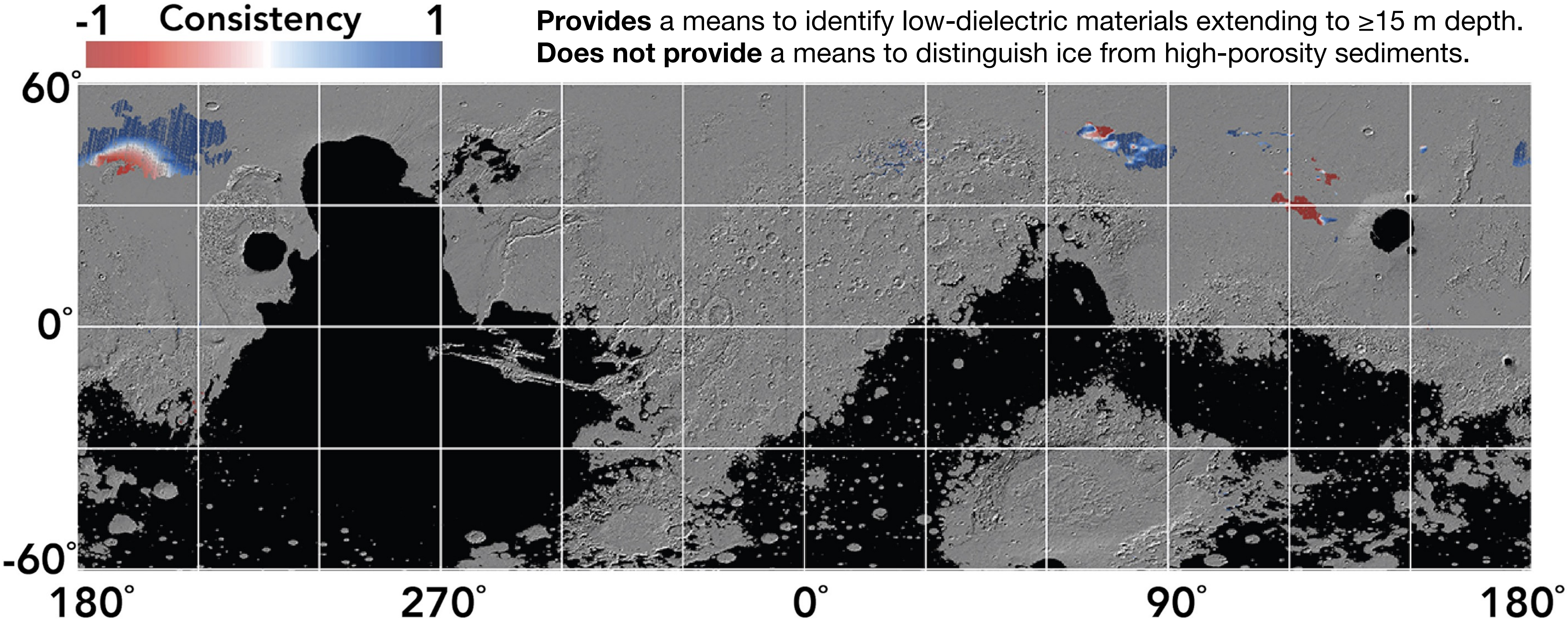


Dusty regions represent a potential false positive

Radar Subsurface Dielectric
SWIM Layer

Mapping of confirmed basal detections where deriving dielectric properties was possible with elevation constraints.

Provides a means to identify low-dielectric materials extending to ≥15 m depth.
Does not provide a means to distinguish ice from high-porosity sediments.

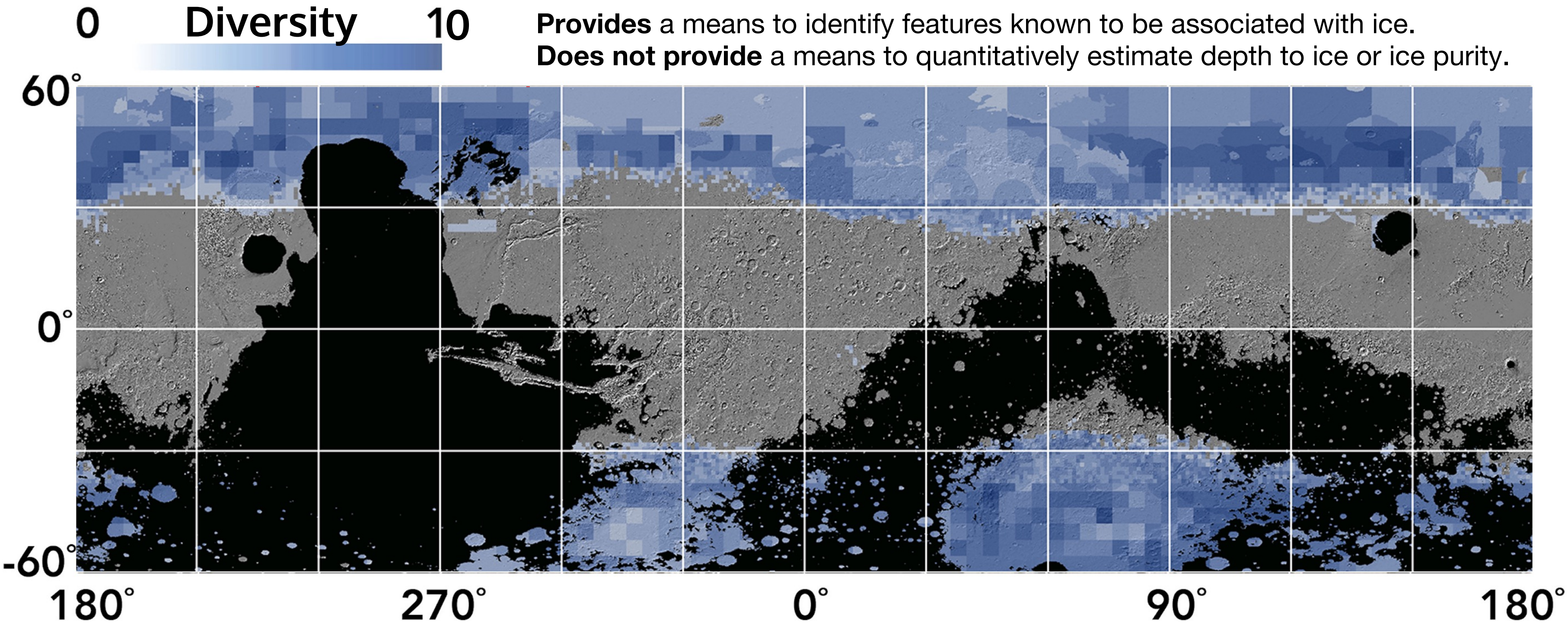


Dielectric and thus ice estimates are dependent on adequate elevation constraints, which are not ubiquitous. Many smaller-scale detections, including in southern hemisphere, are difficult to see in this global view.

Geomorphology SWIM Layer*

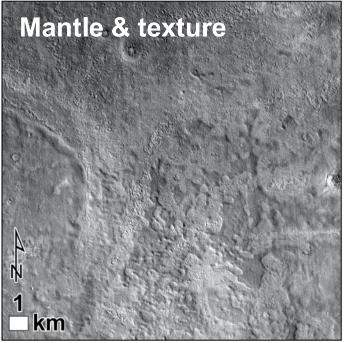
Grid mapping of eight landforms using the CTX global mosaic at 4ºx4º and 1ºx1º (equatorward zones) modified with HiRISE polygon density (10º circles). "Diversity" represents landform counts.

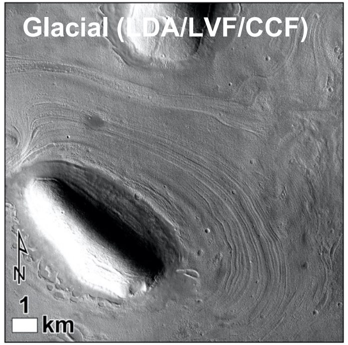
Provides a means to identify features known to be associated with ice.
Does not provide a means to quantitatively estimate depth to ice or ice purity.

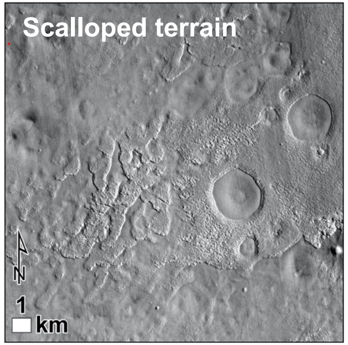


* *Depth-dependent weighting of landforms not included is applied when producing composite ice consistency maps.*

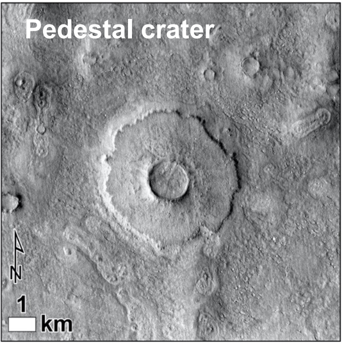
Surveyed Periglacial Features

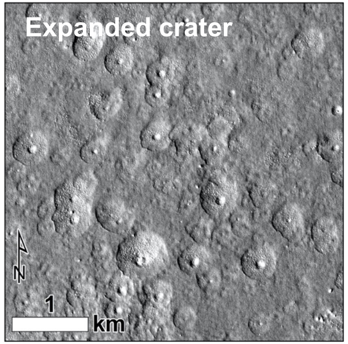


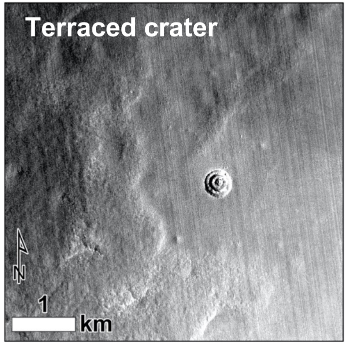


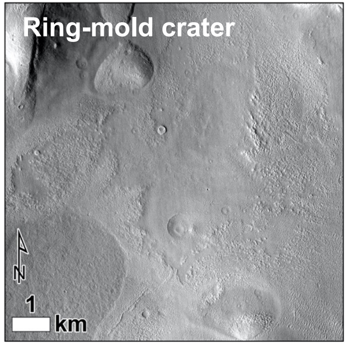


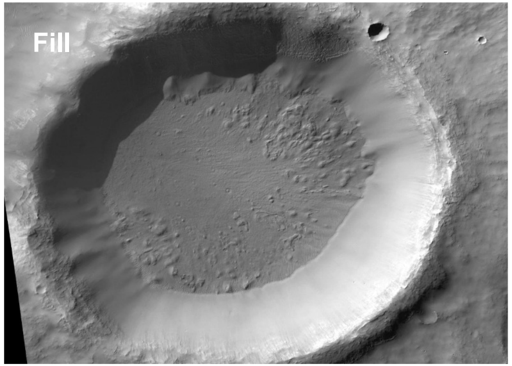
The location of **nine landforms** were mapped (though do to the uncertainty in their origin, “**Fill**” were excluded from the final SWIM maps











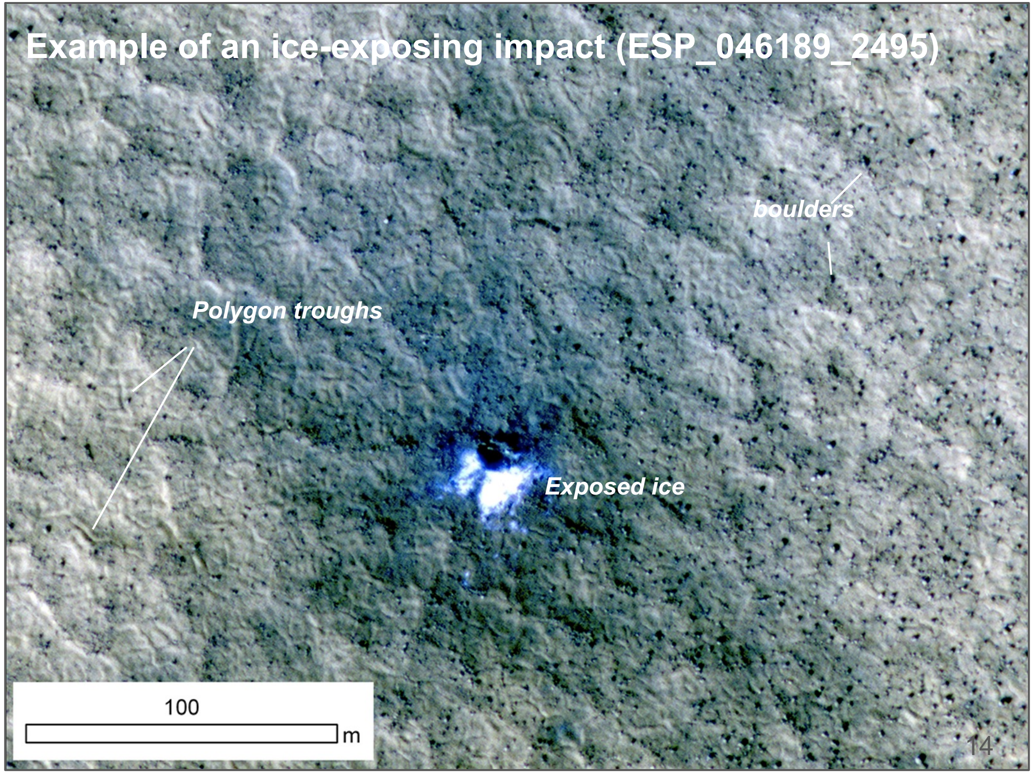
Taking a modified grid-mapping approach developed by Ramsdale et al [2017], we logged the occurrence of each periglacial features using the **CTX global mosaic** [Dickson et al., 2018].

Unidentified crater fill material is morphologically similar to CCF, but lacks lineations and appears deflated - thus ice content is unclear

Polygon Mapping - HiRISE based Survey

SWIM 2.0 funded HiRISE studies of icy-impact sites (i.e., sites KNOWN to host ice) found polygons to be a common, small-scale feature (not resolved in CTX mosaic).

Polygons therefore provide a proxy for shallow ice. The lowest latitude ice is likely to be sporadic in extent. The higher granularity provided by using HiRISE data relative to CTX grid mapping therefore helps to better trace out the extent of low-latitude ice.

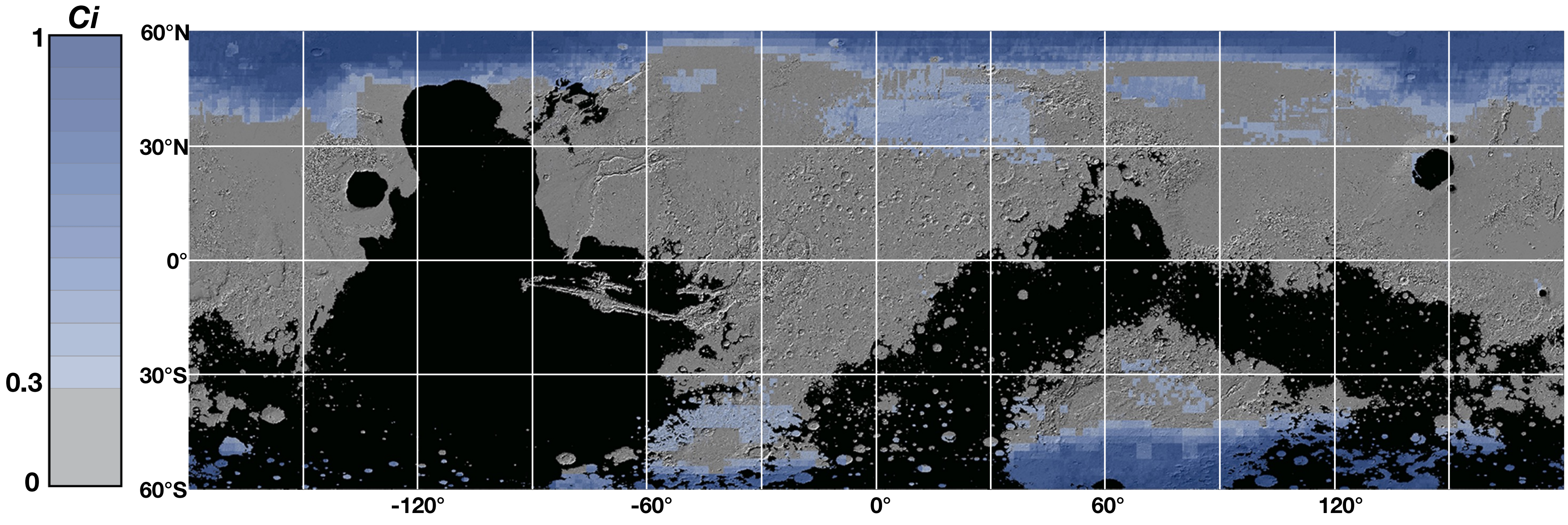


Correlation between **ice-exposing impacts** and **polygons** suggests polygons can be used to trace out shallow ice.

Composite
Ice Consistency Maps

SWIM results - *Surface layer 0-1m*

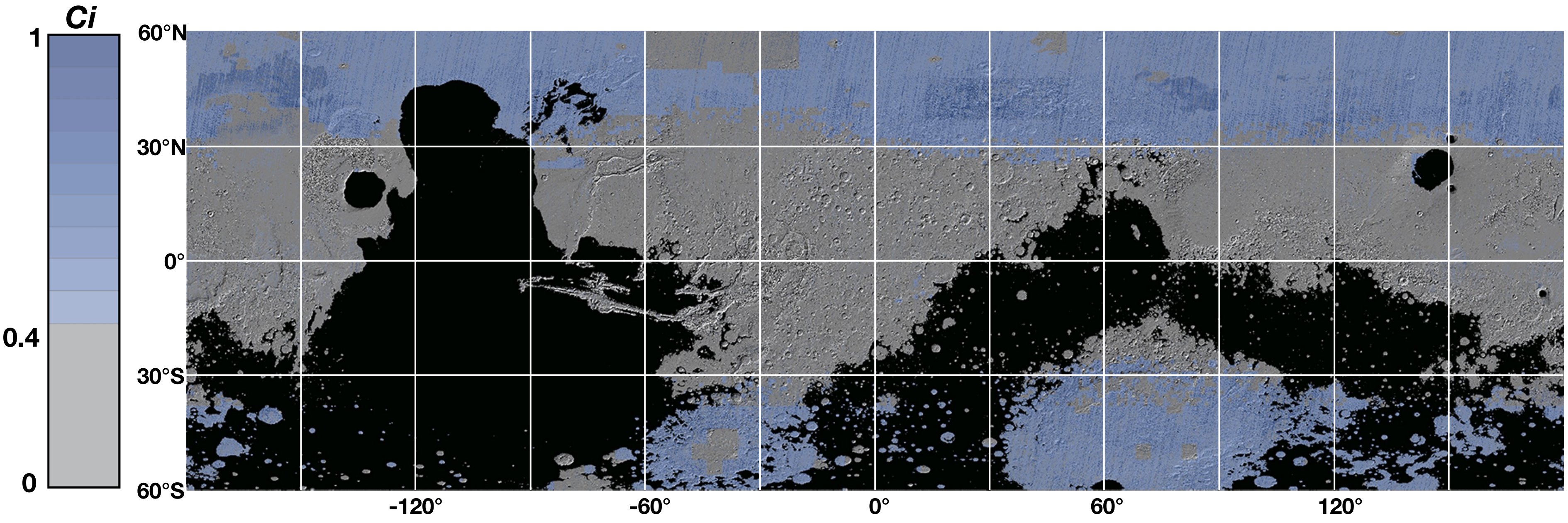
Ice Consistency: $C_I = (C_N + C_T + C_{GS} + 0.2 \cdot C_{RS}) \div 3.2$



Map threshold set to equivalent value where one term is wholly consistent with ice while others are zero.

SWIM results - *Near-surface layer 1-5m*

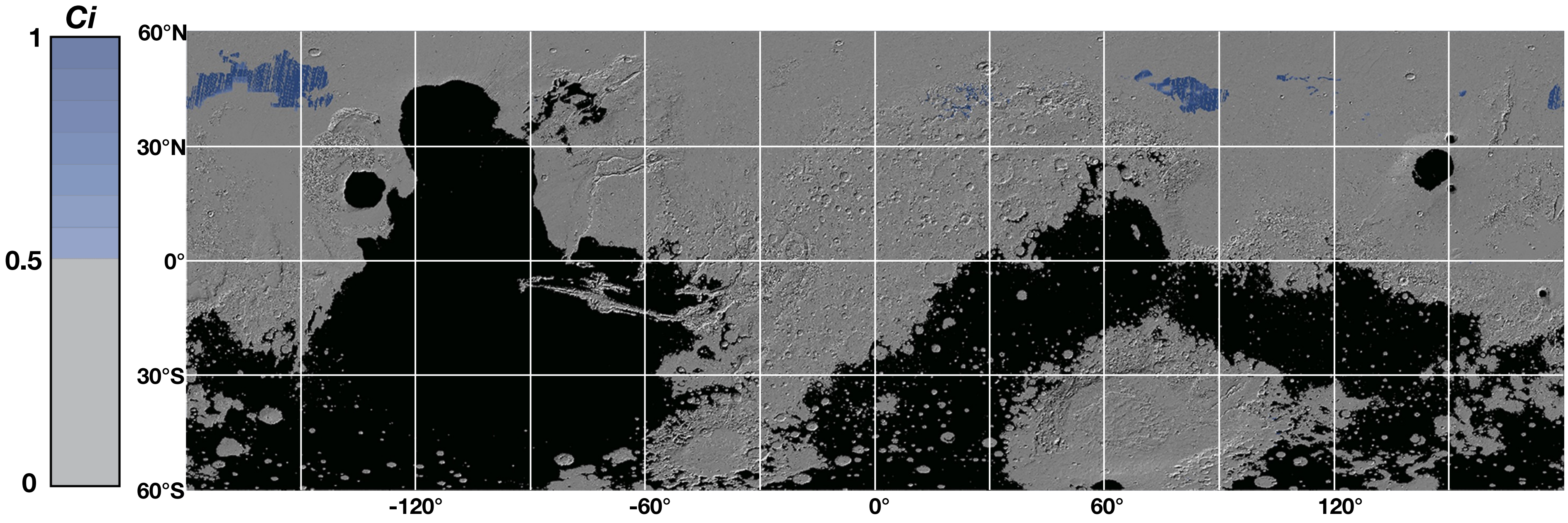
Ice Consistency: $C_I = (C_{RS} + C_{GM} + 0.3 \cdot C_{RD}) \div 2.3$



Map threshold set to equivalent value where one term is wholly consistent with ice while others are zero.

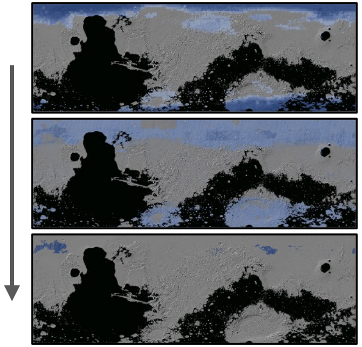
SWIM results - *Deeper subsurface >5m*

Ice Consistency: $C_I = (C_{RD} + C_{GD}) \div 2$

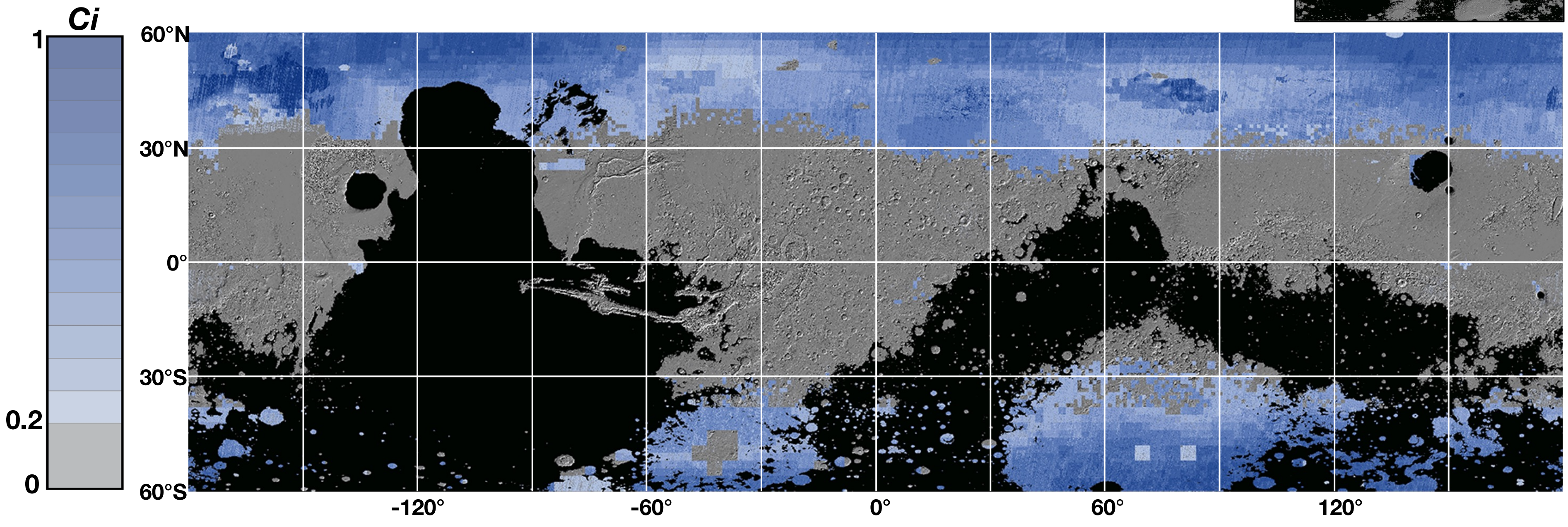


Map threshold set to equivalent value where one term is wholly consistent with ice while others are zero.

SWIM results - *composite of all layers*



Simple average of the 0-1m, 1-5m and >5m depth-zone maps



Map threshold set to equivalent value where one term is wholly consistent with ice while others are zero.

Ground Truth

Ice Exposing Impacts

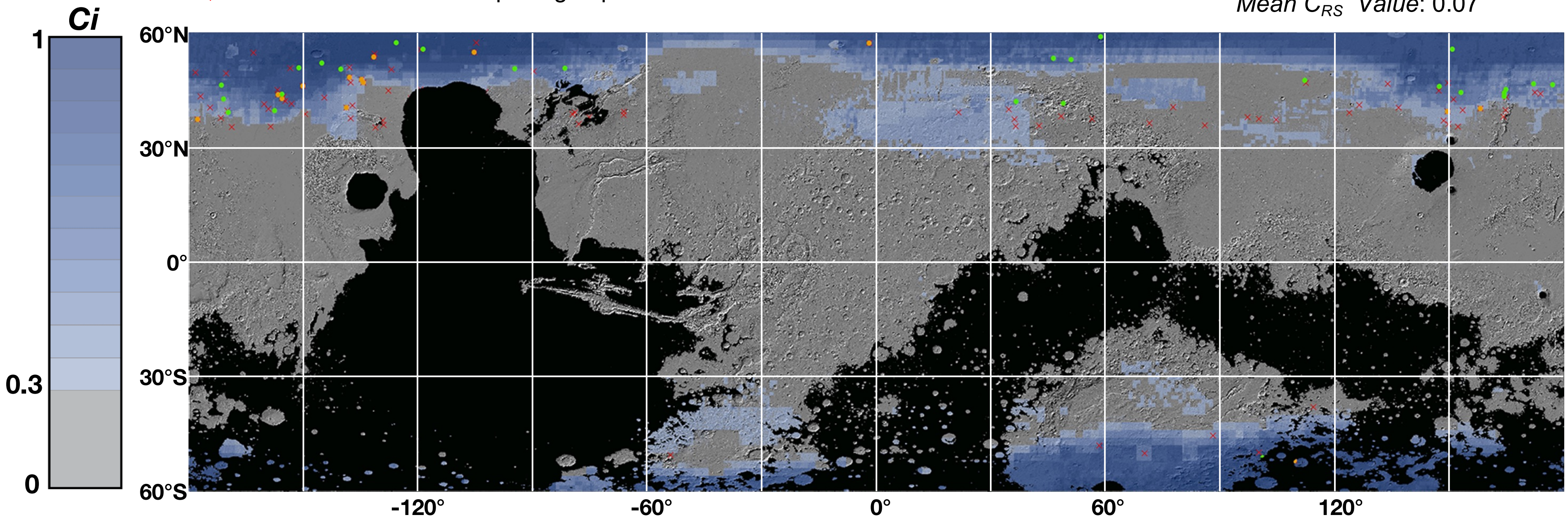
SUBSURFACE WATER ICE MAPPING
RED PLANET

SWIM results - *Surface layer 0-1m*

Location of Ice Exposing Impacts
Location of **POSSIBLE** Ice Exposing Impacts
Location of **NON**-Ice Exposing Impacts

Exposing Impacts Ci Values:

Mean Ci *Value*: **0.5**
Mean C_N *Value*: 0.42
Mean C_T *Value*: 0.42
Mean C_G *Value*: 0.76
Mean C_{RS} *Value*: 0.07



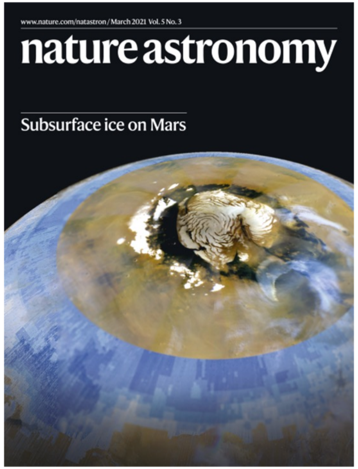
Comparing to 0-1m map because most fresh impacts only excavate materials within the upper meter.

Publications and Products

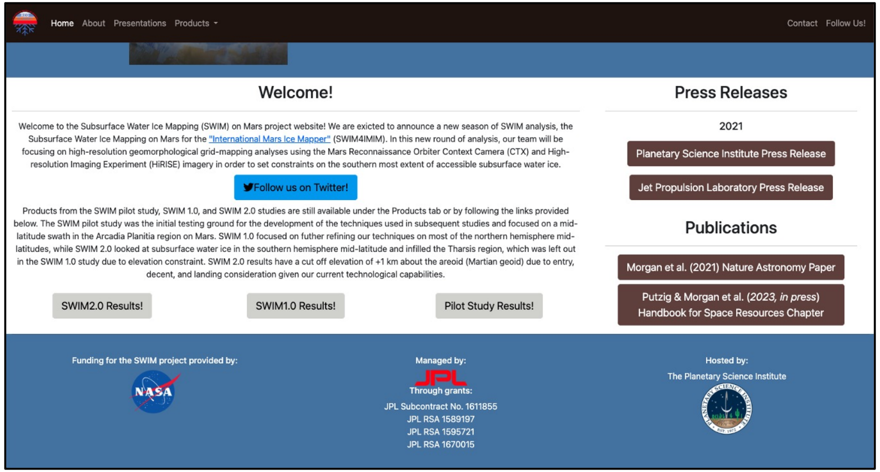
Morgan G.A., et al, 2021. Availability of subsurface water-ice resources in the northern mid-latitudes of Mars. Nature Astronomy 5, 230-236.

Putzig, N.E., Morgan, G.A., et al., 2023. Ice Resource Mapping on Mars. Ch. 16 in Badescu, V., Zacny, K., Bar-Cohen, Y. (Eds.), Handbook of Space Resources, Springer, Cham, pp. 583-616.

Additional publications in preparation.



Mapping products are available at swim.psi.edu.



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