National Aeronautics and Space Administration

Holistic and Multi-scale Assessment of the Global Martian Frost Cycle

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Strategic Initiative Leader: Susan E Owen
Strategic Focus Area: An Integrated Community of Practice for Scientific Understanding from Data Science (SUDS)

Objectives

Construct global monthly Mars frost maps at the 10-1000 km scale using visible, thermal, and spectral data to understand:

(1) where and when different types of frosts form across Mars, and
(2) locations of landforms that can be associated (via hypothesized formation processes) with specific types of frost.

Background

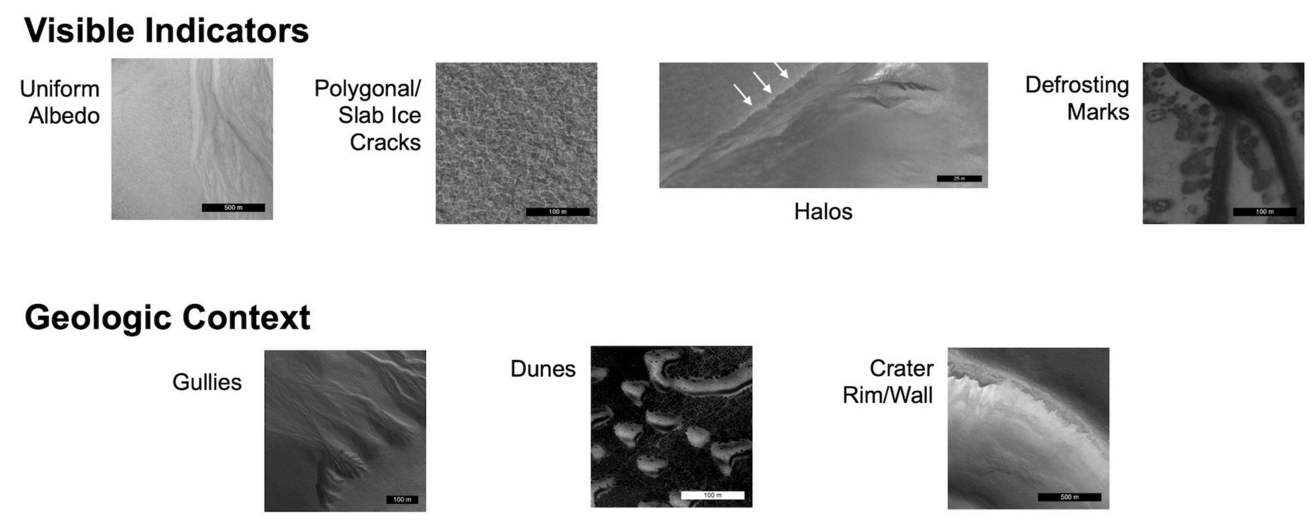
Mars' seasonal frost cycle is a critical area of planetary science study because frost is a dominant driver for Mars' climate and surface evolution through the last few billion years (i.e., the Amazonian epoch). Understanding the frost cycle will help validate models of the present-day martian volatile cycles or atmospheric systems, or connect global models with the meters-scale environments relevant for e.g., spacecraft operations, identification of low-latitude ice reservoirs, and fine-scale surface-atmosphere interaction processes.

Approach and Results

1. Create a labeled dataset of visible frost observations from the **HiRISE** instrument, along with metadata annotations to aid with interpretation and bias identification/mitigation (Figure 1).
2. Fine-tune the InceptionV3 **convolutional neural network** model to detect frost, and use augmentation to mitigate bias caused by overall illumination differences across scenes (Figure 2).
3. Deploy the model globally to over **20,000 HiRISE observations**, and compare with expected frost patterns to validate and identify problematic terrains or observing conditions (Figure 3).
4. Update and re-train the model on identified observations for which the initial model performs poorly.
5. Incorporate thermal observations from **MCS** to resolve ambiguities in visible observations.
6. Investigate terrains causing false positives in a novel VNIR **CRISM** frost detection approach (ICV).

Significance and Benefits to JPL and NASA

1. Shared lessons learned to JPL community at July SUDS Seminar
2. Guides the development of new science investigations with a unique, multiscale, and quantitative picture of volatile transport
3. Critical for future Mars mission planning and interpretation by providing more robust bounds on predicted spacecraft EDL and surface operations environments
4. Provides an important input for the design of and returned data interpretation of many ongoing and future Mars missions, particularly those focused on atmospheric circulation/climate patterns or ice distribution



Confidence Based on Strength of Indicators

Indicator	Uniform Albedo	Polygonal Cracks	Halos	Slab Ice Cracks	Defrosting Marks
Strength	Weak	Weak	Medium	Medium	Strong

Figure 1: Summary of contents from the Martian Frost Labeling Guide, showing visible frost indicators, geologic context, and confidence assessment criteria.

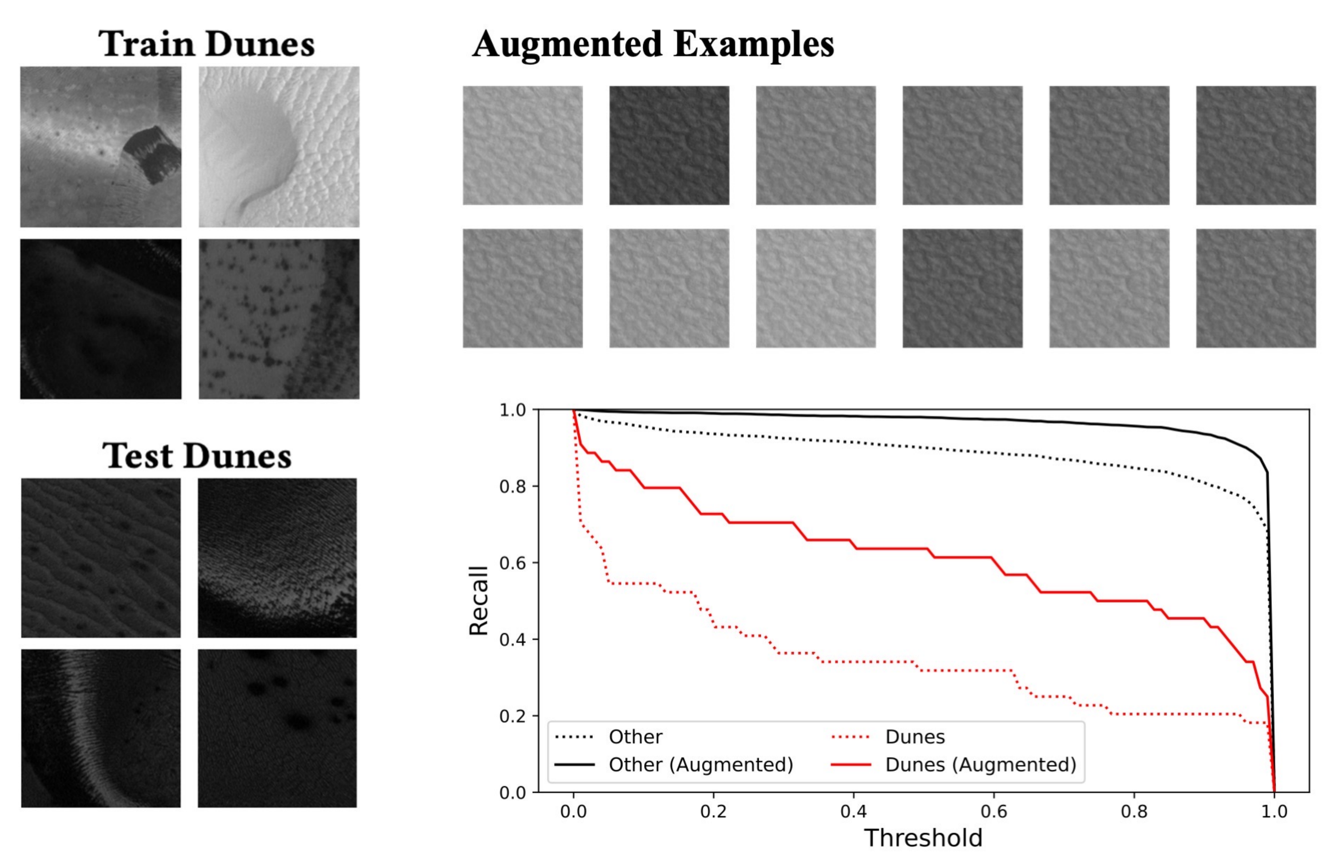


Figure 2: (Left) Representative examples of frosted dunes from the training and testing sets. An overall shift in illumination produces a bias in the model's performance on this terrain type. (Right) Example of augmented image tiles produced by adjusting overall illumination and contrast, resulting in increased frost detection recall on this terrain.

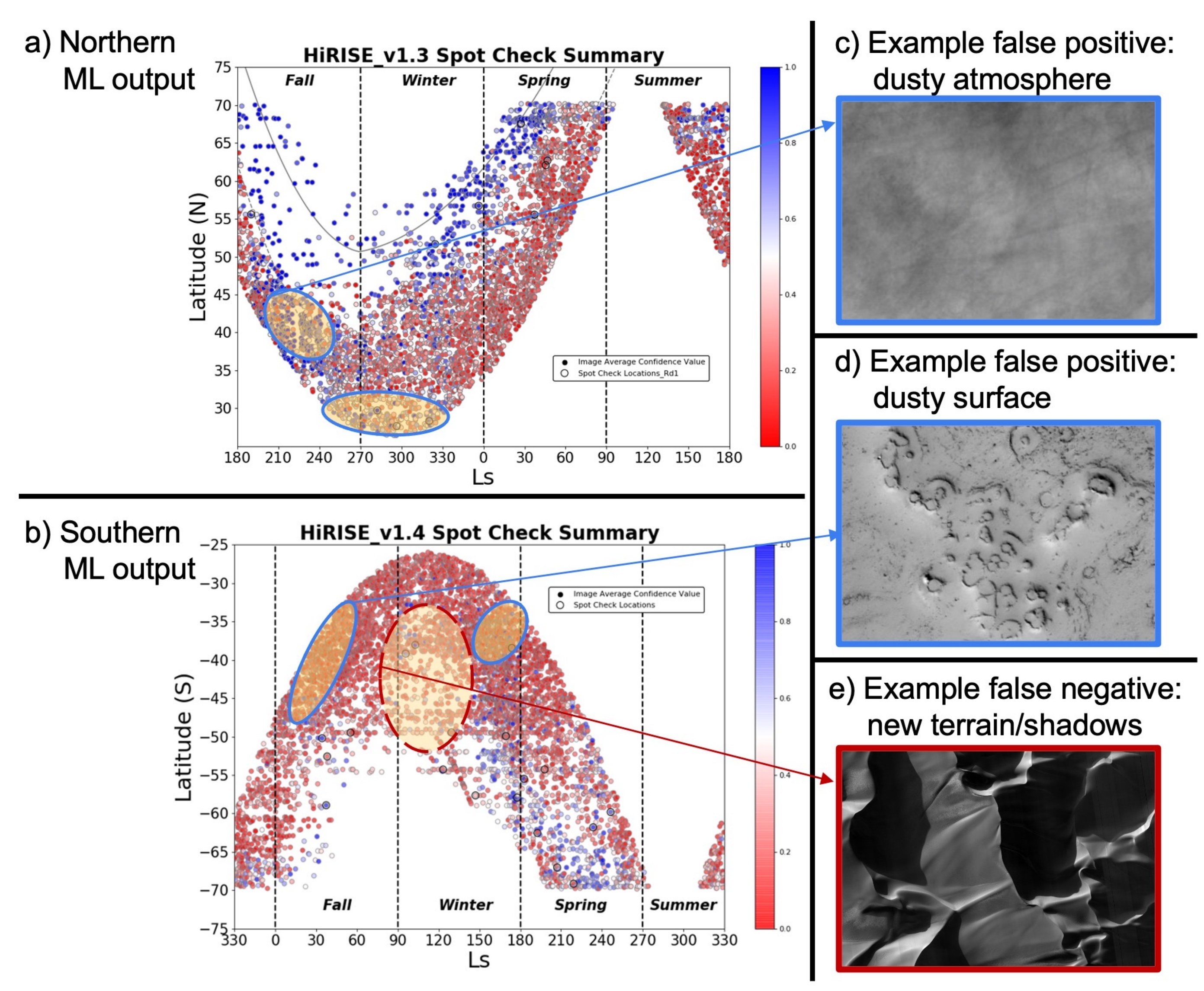


Figure 3: HiRISE frost detections in the northern (a) and southern (b) hemispheres, based on the ML model: blue point = high confidence that frost is present and red = low confidence that frost is present. Generally, frost/blue should concentrate towards the inside portions of these curves. Some areas with many false negatives (red outline as points show as red when they are expected to be blue) and false positives (blue outline), with typical reasons for the misidentification shown in (c-e).

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Publications:

[A] S. Diniega, G. Doran, S. Lu, K. L. Wagstaff, J. Widmer, and M. Wronkiewicz. "Martian Frost in HiRISE Observations of Northern Mid-Latitude Craters (1.1.0) [Data set]," Zenodo, 2022. https://doi.org/10.5281/zenodo.6561242
[B] G. Doran, S. Diniega, K. L. Wagstaff, M. Wronkiewicz, Steven Lu, and Jake Widmer. "Building Machine-Learning-Ready Data Sets for Martian Frost Detection" PSIDA, Madrid, Spain, 2022.
[C] G. Doran, S. Diniega, S. Lu, M. Wronkiewicz, K. L. Wagstaff, and J. Widmer. "Evaluating Terrain-Dependent Performance for Martian Frost Detection in Visible Satellite Observations," 3rd ACM SIGKDD Workshop on Deep Learning for Spatiotemporal Data, Applications, and Systems, Washington DC, USA, 2022.

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