National Aeronautics and Space Administration

FY23 Strategic Initiatives Research and Technology Development (SRTD)

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

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Strategic Focus Area: An Integrated Community of Practice for Scientific Understanding from Data Science

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Objective:

We aim to identify where and when specific types of seasonal frost accumulate on Mars, and from this to constrain where and how volatile transport and deposition processes are active.

We accomplish this by generating a global map of the present-day Martian seasonal frost cycle, with a high-number of ties to landform-scale (10s-meter-scale) environments. Existing spacecraft observations of a range of spectral, spatial and temporal resolutions (i.e., visible: *HiRISE*, *CTX*; NIR: *CRISM*; thermal: *THEMIS*, *MCS*) are used to identify where and when different types of frost have been detected over the past 7+ Mars years.

This project is one of two *Science Understanding through Data Science (SUDS)* trail-blazing projects that bring data science (DS) techniques into analysis of massive, information-rich archives, enabling new science.

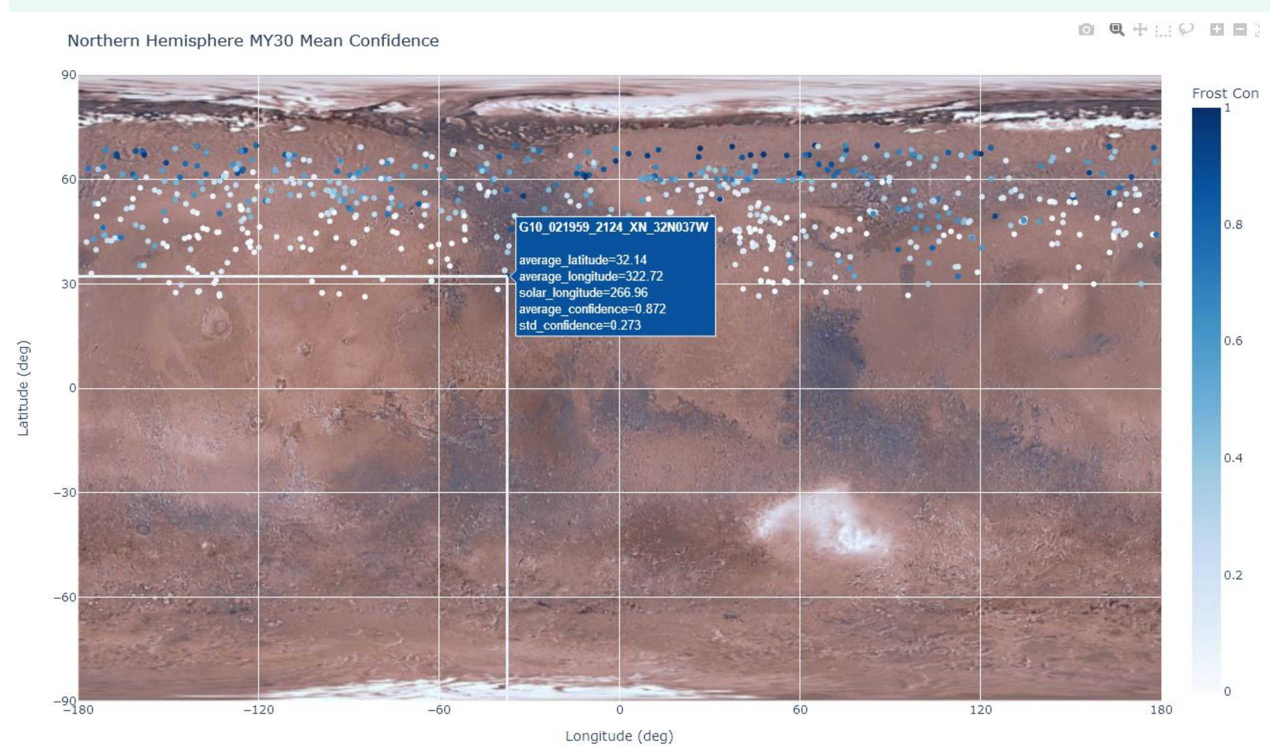

Figure 1. Map of north mid-latitude *CTX* ML frost detections from Mars Year 30. While most follow the expected trend (more frost near poles), the display tool enables searches for potential false positives and negatives.

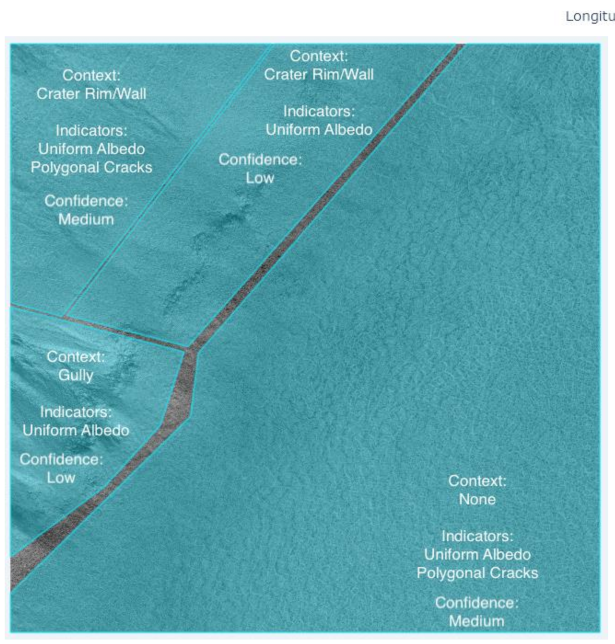

Figure 2. Portion of a *HiRISE* image that was manually labeled (via Labelbox) with respect to geologic context, presence of frost indicators, and estimated confidence of frost was presence. (*CTX* used same method.)

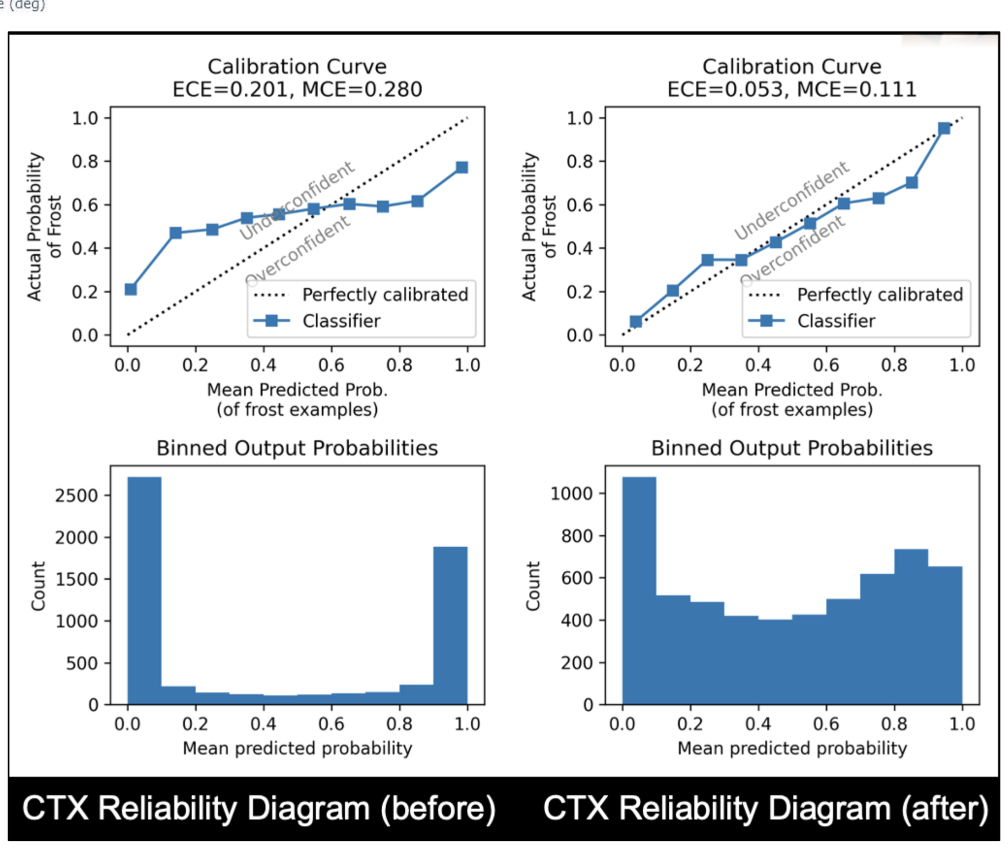

Figure 3. Reliability diagram measures how under- or over-confident predictions are on average. Prior to calibration (*left*), we are underestimating non-frost confidences and overestimating frost confidences. Calibration brings predictions in-line with the test set observations (*right*).

Significance/Benefits to JPL and NASA:

Our description of the present-day global seasonal frost cycle will improve interpretation of data returned by ongoing and future Mars missions – in particular those focused on atmospheric circulation/climate patterns or ice distribution. Furthermore, the detailed picture of Mars's present-day volatile transport patterns will provide more robust bounds on predicted spacecraft EDL and surface operations environments.

Background:

To date, model validation of volatile transport and surface-atmosphere interactions has been limited to using observations that are either global, but at coarse-spatial scale (>kms/pixel), or higher resolution but at a single specific study site. This is because observation-based Mars frost cycle studies rely on humans to manually parse large amounts of data to identify, measure, and analyze frost or frost-driven surface changes (e.g., *HiRISE*, covering ~3% of Mars' surface, has a data volume of 112.5 TB; *CTX*, covering the globe, is 12.8 TB).

Such manual efforts cannot scale to larger areas with finer scales, are subject to human error and repeatability issues, and require scientists to divert the majority of their attention towards manual data review rather than analysis and interpretation. Our work mitigates all of these limitations as modern DS techniques offer a way to bridge scales and datasets, enabling a more holistic characterization of the full natural system over a range of relevant spatial and temporal scales.

Approach and Results:

To create our CO_2 frost map, we are generating frost detection maps of individual datasets:

- *Visible*: We applied a visible frost detection convolutional neural networks (CNN) model to, separately, >23k *HiRISE* and >31k *CTX* images (Figure 1). Training, validation, and testing of each model were based on a small set of images that were manually labeled with frost indicators and geologic context (Figure 2). After validating the machine learning (ML) model on different terrain types and frost indicators, the model was deployed on both image archives. The frost confidence estimates were calibrated (Figure 3), then the broad ML results were spot checked (Figure 1).
- *Thermal*: Kriging was used to interpolate a global temperature map based on *MCS* and *THEMIS* data, with consideration of variance/uncertainty due to natural gradients and instrument noise. Kriging models the temperature fluctuations relative to a seasonal and latitudinal trend using the empirical correlation structure between observations within and across instruments.
- *Spectral*: A frost map based on compilation of frost detections generated by the *CRISM* team.

In early FY23, we completed generation of the first thermal- and visible-data based CO_2 frost map, using only *HiRISE* and *MCS*, and presented it at DPS [A] and LPSC [C]. We confirmed that visible false positives are removed after comparison with the coarser-resolution thermal data. We are now augmenting that map with the *CTX*-based frost map and *THEMIS*-based temperatures, then writing the paper.

In doing this work, we have defined and refined a DS pipeline that can be applied to other Earth and Planetary Science mapping efforts. For example, development of an automated ML model evaluation pipeline enabled us to more efficiently and quickly assess performance, subpopulation bias, and probability scores.

Publications: **[A]** Diniega, S. et al., "Mapping martian frost over multiple scales, based on visible and thermal frost detections," presentation at *DPS*, October 2022, Ab. 507.02. **[B]** Wronkiewicz, M. et al., "How to build ML-ready data sets: Recent research from NASA JPL on Martian Frost," invited presentation at *Labelbox Accelerate Conference*, November 2022. **[C]** Diniega, S. et al., "Generating a global, multiscale map of martian CO_2 frost from visible and thermal detections," presentation at *LPSC*, March 2023, Ab. 1829. **[D]** Wronkiewicz, M. et al., "Toward a Holistic Map of Martian CO_2 Frost," presentation at the *JPL Mars Forum*, April 2023. **[E]** Ankireddy, S., Doran, G., et al., "Building ML-Ready Data Sets for Martian Frost Detection," presentation at *6th Planetary Data Workshop*, June 2023. **[F]** Rupireddy, P., Doran, G., et al., "Characterizing false positives in CRISM VNIR frost detections," presentation at *6th Planetary Data Workshop*, June 2023. **[G]** Wronkiewicz, M. et al., "ML-Ready annotated dataset of HiRISE images," posted to *JPL Dataverse*, doi:10.48577/jpl.QJ9PYA. **[H]** Wronkiewicz, M. et al., "Using Labelbox on the SUDS Martian Frost Mapping Project," presentation to *JPL Data Science Working Group*, August 2023.

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Clearance Number: CL#00-0000
Poster Number: RPC#184