FY24 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: Integrated Community of Practice for Scientific Understanding from Data Science (SUDS)
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We aim to understand where specific types of seasonal frost accumulate on Mars and, from this, to constrain where and how volatile transport and deposition processes are active on Mars, via a global mapping of the present-day Martian seasonal frost cycle with a high-number of ties to landform-scale (10s-meter-scale) environments. This helps to answer: *How does seasonal frost distribution vary between years? Where are low-latitude 'frosty' microclimates creating geomorphic or geochemical changes, potentially creating habitable areas or useful human resources?*

To achieve these aims, **we constructed 36 maps (Figure 1) showing the CO_2 frost distribution through a full Mars year**, based on a compilation of spacecraft observations with a range of spectral, spatial and temporal resolutions (Figure 2), identifying 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) [1] trail-blazing projects that bring data science techniques into projects with information-rich archives to enable new science. As outlined below and shown in Figure 2, numerous data science techniques have been utilized in this project.

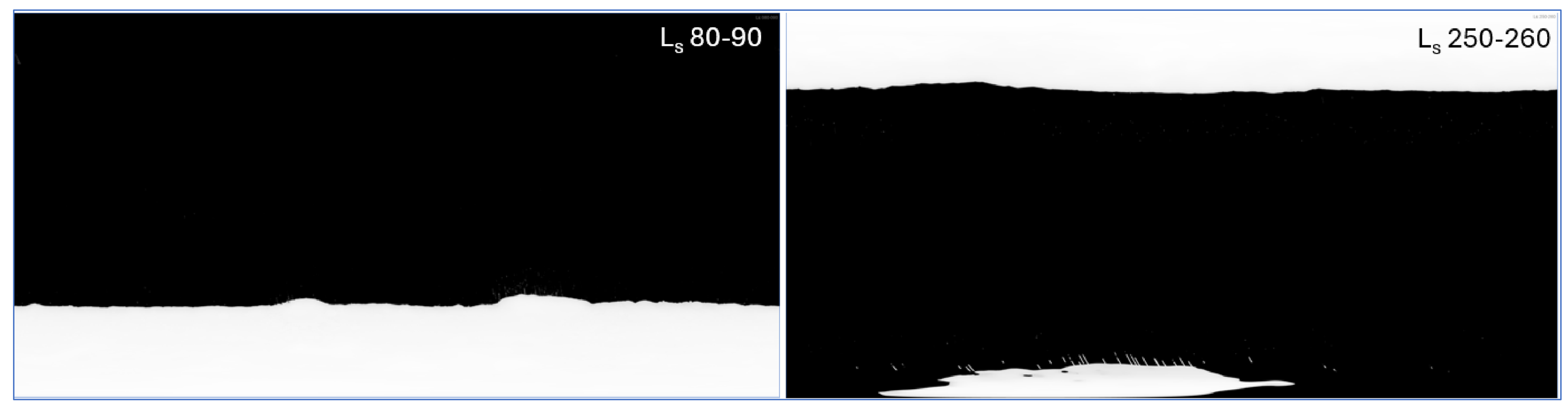

Figure 1. The integrated CO_2 frost map for temporal bin L_s 80-90° (left) and L_s 250-260° (right). White shows the extent of the seasonal frost; e.g., the retained, asymmetric south polar cap is shown in the right. Frost detections were combined using on a rule-based overlay, in order based on reliability: thermal, spectral, HiRISE, CTX. This map captures the general progression/ recession of the contiguous cap as well as smaller-scale, patchy frost in lower latitudes.

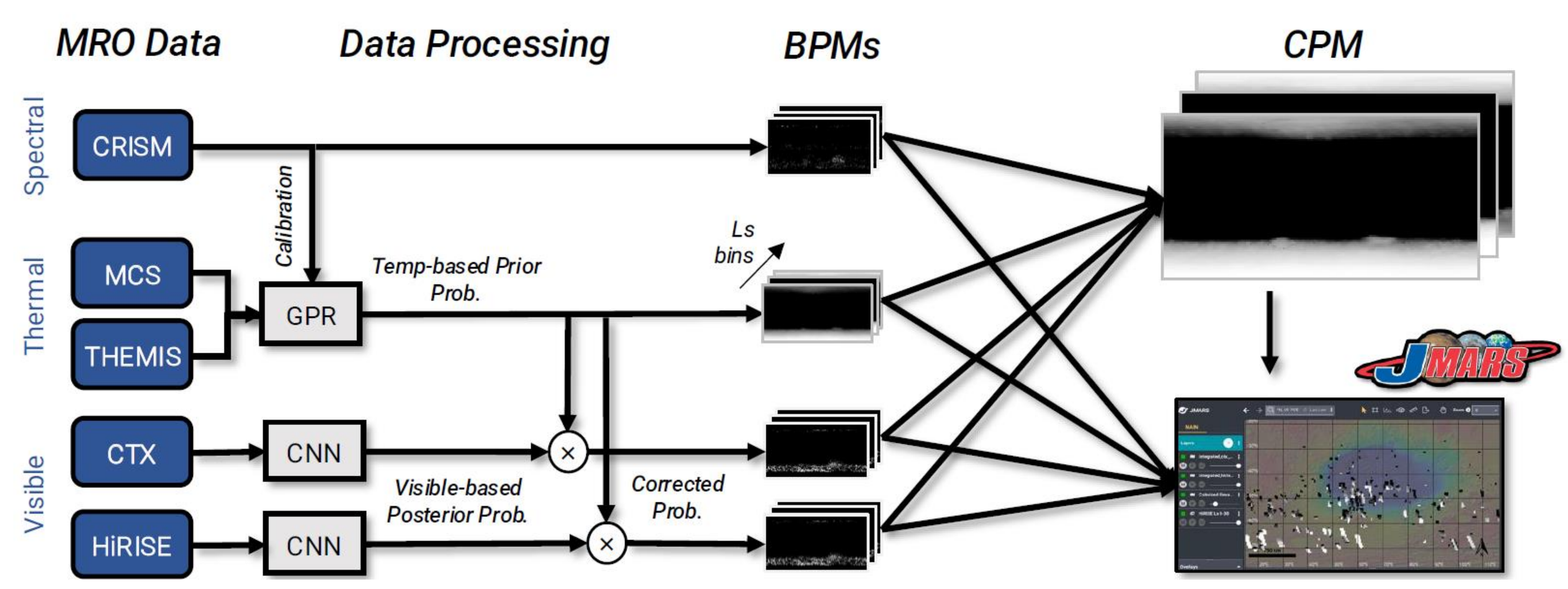

Figure 2. Conceptual overview of input data, data processing, and map products. (*Left*) Five data sources (blue boxes) provide different information about the presence of frost. (*Middle Left*) Data science techniques were applied to each data source to derive frost likelihoods (gray boxes). (*Middle Right*) Each dataset was compiled into 36 BPMs spanning the average Mars Year, with resolution 64 points-per-degree. (*Right*) These maps, along with the CPM representing the weighted average across the BPMs of frost probabilities, are uploaded to JMARS for public use.

To create our CO_2 frost map, we first generated frost detection maps of individual datasets (Figure 2):

- **Visible**: We applied convolutional neural networks (CNN) models to >23k HiRISE images and >31k CTX images. Training, validation, and testing of each were based on a small set of images that were manually labeled with frost indicators and geologic context, and checks were done to validate model results on different terrains and frost indicators. The frost likelihood estimates were calibrated and adjusted based on thermal data to remove false positives (i.e., dust).
- **Thermal**: Kriging was used to interpolate a global temperature map based on MCS/THEMIS data, with consideration of natural gradients and instrument noise. Kriging models the temperature fluctuations relative to a seasonal and latitudinal trend using the empirical correlation structure between observations. *This work has generated an interpolated temperature map (@4pm LST) for any location, any time of year.* These temperature estimates were compared with spectral data-based frost detections, which enabled a calibrated relation to frost likelihood.
- **Spectral**: Frost detections generated by the CRISM team [2] were compiled into a map in a format compatible with our visible and thermal data-based results. Although no new analysis was needed, reformatting and reprojecting this dense data required a few iterations and careful validation.

In total, *~7 billion frost detections* were generated from the above datasets. For all these individual datasets, we validated our results via comparison to prior studies (e.g., [3]) and created Base Probability Maps (BPMs) at 64ppd spatial resolution, 10-L_s bin that average across all Mars years [A]. We also finished developing our integration strategy for the individual datasets and generated Composite Probability Maps (CPMs) [B]. Our integration strategy aimed to incorporate the intuitive reliability and specific characteristics of the different datasets, yielding a detailed global picture of Mars' CO_2 frost cycle.

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References: [1] Owen, S. et al., 2021, "Scientific Understanding from Data Science (SUDS) Council Report: Phase 1 – Assessment & Recommendations." [2] Seelos, et al., 2023, "The CRISM investigation in Mars orbit: Overview, history, and delivered data products," Icarus, 419, 115612, doi:10.1016/j.icarus.2023.115612. [3] Piqueux, S. et al., 2015, "Variability of the martian seasonal CO2 cap extent over eight Mars Years," Icarus, 251, 164-180, doi:10.1016/j.icarus.2014.10.045.

Publications: [A] Diniega et al., *in revisions*, "Holistic Mapping of the Present-day Martian Seasonal CO_2 Frost: Part 1, Frost Detection within Global Visible, Thermal, and Spectral Datasets," *Planetary Science Journal (PSJ)*. [B] Diniega et al., *in prep*, "Holistic Mapping of the Present-day Martian Seasonal CO_2 Frost: Part 2, Integration of Visible, Thermal, and Spectral-based Frost Detections," submitted to *PSJ*.

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