THE FIRST FROST DETECTION CAMPAIGN BY THE MARS 2020 PERSEVERANCE ROVER: IMPLEMENTATION AND RESULTS.
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Introduction: Here we describe the first campaign launched by the Perseverance rover to detect frost during the first Martian year of operations (669 sols as of Jan 5, 2023). This campaign was conceived, developed and executed following lessons learnt from the Mars Science Laboratory Mission, where frost was likely detected [1].

Between sols 546 and 548 during northern winter (Ls ~297°), measurements of ground temperature and relative humidity by the Mars Environmental Dynamics Analyzer (MEDA, [2]) were used to predict frost formation, while SuperCam laser-induced breakdown spectroscopy (LIBS) and Raman spectrometer measurements [3,4] were used to detect frost formation on a target informally called Snowy Mountain. While the measured ground temperature fell below the estimated frost point, and therefore frost was predicted by MEDA, neither H enrichment in LIBS measurements nor Raman peaks associated with water ice were detected by SuperCam.

Environmental Context: Fig. 1 (top) shows that frost formation has been predicted over the first Martian year of operations on a few sols (magenta arrows), when the ground temperature (T_g) dropped below the frost point (T_f). Before sol 548, frost predictions were made on fine-grained terrains with relatively low thermal inertia, and thus cold nighttime temperatures. As temperatures were dropping and RH values were rising during the northern winter (Fig. 1), the mission decided to launch a frost campaign between sols 546 and 548.

Location and Target Selection: Fig. 2 (top) shows the rover trajectory through sol 667, with the location of the frost campaign marked by a black arrow. Zooming in, Fig. 2 (bottom) shows the field of view of MEDA's ground temperature sensor on sols 543-548, when the rover was parked (green shade). As in previous frost predictions, the terrain consisted of fine-grained regolith with an estimated thermal inertia of 250 SI units [5].

Campaign Implementation: SuperCam can search for frost by detecting the signature of hydrogen at 656.5 nm using LIBS, and by identifying Raman shifts from water ice around 3200 cm^{-1}.

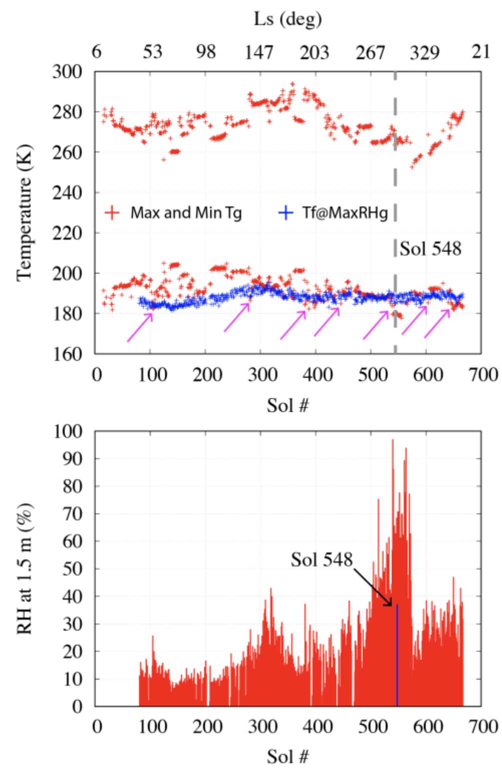

Figure 1. ***(Top)*** *Daily maximum and minimum T_g (red) and T_f at the ground (blue) obtained when T_g is minimum. Magenta arrows indicate predicted frost events ($T_g < T_f$). Because MEDA only measures RH at 1.5 m, we estimate T_f at the ground assuming a constant water vapor profile in the first 1.5 m. The dashed gray line marks sol 548, when SuperCam observations were performed.* ***(Bottom)*** *Daily maximum local RH at 1.5 m. The blue bar indicates local RH on sol 548.*

On sol 548 between 06:47 and 07:16 LMST, SuperCam performed a raster of 10 active LIBS on Snowy Mountain (Fig. 2, bottom), using Raman on every other point. In order to establish a "dry baseline" for comparisons, the same observation was performed on sol 546 at 12:40 LMST on Red Mountain, a nearby target just 2.5 cm away. During both periods, MEDA was operating continuously at 1 Hz and with the RH sensor in 'High-Resolution Interval Mode', when the sensor is powered on only for 10 s and then powered off for a few minutes to avoid self-heating.

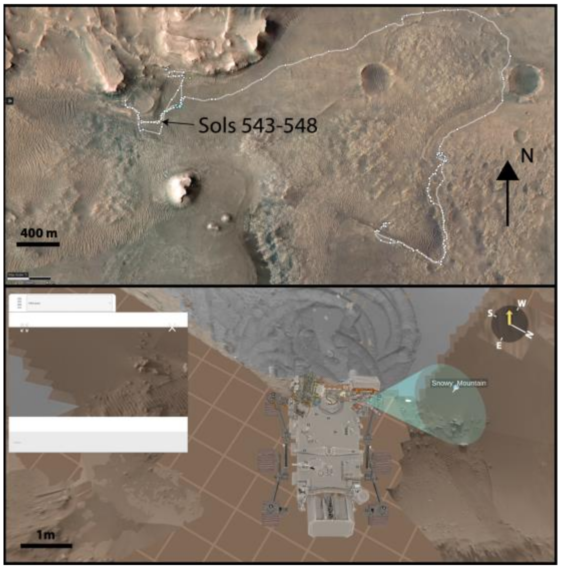

Figure 2. (***Top***) *HiRISE map showing the trajectory of Perseverance during the first 667 sols of the mission. The blue and green dots indicate the position of the rover and Ingenuity on sol 667.* (***Bottom***) *Field of view of the ground temperature sensor (shaded green area) on sols 543-548, which included the SuperCam target called Snowy Mountain. A zoomed-in view of the field of view is shown on the top left insert.*

Results: Fig. 3 shows MEDA observations during sol 548, when frost formation was predicted between 04:00 and 08:00. However, Fig. 4 shows no significant H enrichment in LIBS between Red Mountain (left) and Snowy Mountain (right). Although not shown, Raman spectra on 'Snowy Mountain' did not contain water ice signatures (Raman shift around 3200 cm^{-1}) either. Therefore, SuperCam did not detect frost.

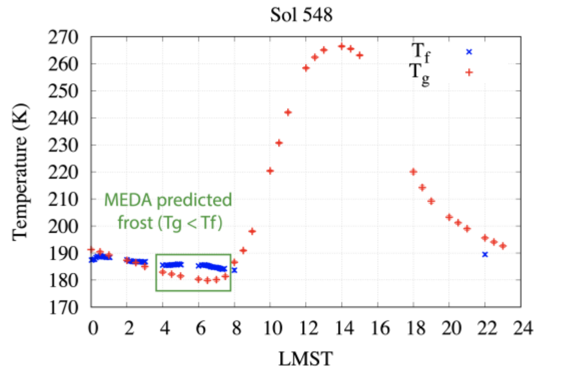

Figure 3. *Ground temperature (red) and estimated frost point (blue) as a function of LMST on sol 548. Frost was predicted between 04:00 and 08:00 (green rectangle).*

Discussion: Potential causes explaining discrepancies between MEDA and SuperCam include the assumption that water vapor content is constant in the first 1.5 m. If water adsorption is occurring at night, then the frost point at the ground would be lower than at 1.5 m, and therefore the condition $T_g < T_f$ might not hold. Thus, we need to better understand penetration depths of adsorption. In a future frost campaign, we plan to choose a target in permanent shadow and with finer grain than on sol 548, where pebbles were mm sized. Additionally, we plan to use SuperCam VISIR techniques, which were not used in this campaign but that are sensitive to the presence of -OH and H_2O.

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References: [1] Martínez G. et al. (2022) *VII MAMO*, Paris, France. (p. 3501). [2] Rodríguez-Manfredi J. A. et al. (2021) *Spa. Science Rev.* 217.3. [3] Wiens R. et al. (2021) *Spa. Sci. Rev.* 217.1. [4] Maurice S. et al. (2021) *Spa. Sci. Rev.* 217.3. [5] Martínez G. et al. (2023) *JGR:Planets* (in press).

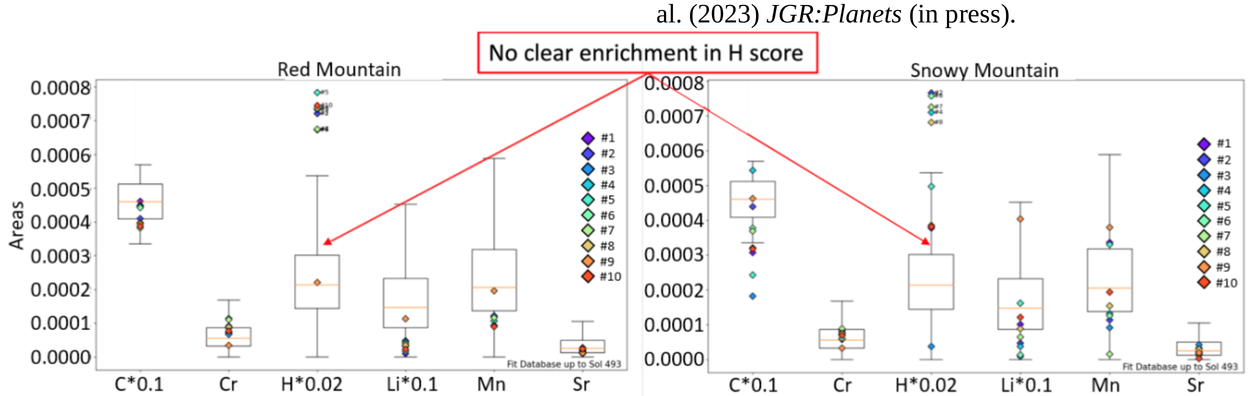

Figure 4. *Results of LIBS raster on 'Red Mountain' (left) and 'Snowy Mountain' (right), showing no clear enrichment in H content (red arrows). Colored diamonds represent results from each of the 10 shots, while boxes and error bars represent averages from all SuperCam targets up to sol 548.*