CHANGES IN SURFACE ALBEDO INDUCED BY DUST DEVILS AND THE MY 36 L_S155 DUST STORM AT JEZERO CRATER

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Introduction:

Since February 2021, the environmental conditions at Jezero Crater have been monitorized by MEDA, the suite of meteorological sensors onboard the Mars 2020 Perseverance rover [1]. Simultaneous measurements from the Thermal and Infrared Sensor (TIRS), the Radiation and Dust Sensor (RDS), the Pressure Sensor and the Wind Sensor allow studying dust lifting at the Martian surface by analyzing an unprecedented set of magnitudes, including high frequency measurements (1 – 2 Hz) of surface broadband albedo and temperature, wind speed and direction, and pressure. In addition, Mastcam-Z and Navcam images [2,3] provide additional context and support albedo variations detected by MEDA by showing changes in the surface caused by dust lifting and sand transport.

Jezero Crater was affected by a dust storm between sols 313 and 318 of the mission (L_s ~155º), which caused a significant change in environmental conditions. We have classified the albedo changes in two categories: rapid variations that occurred during typical relatively quiescent conditions, and changes induced by the dust storm [4].

Instrument description and methodology: TIRS [5] comprises five channels which measure downward (IR1) and upward (IR4) longwave (6.5 – 30 µm) radiation, atmosphere temperature (IR2), reflected shortwave (0.3 – 3 µm) radiation (IR3), and surface temperature (IR5). Channels IR3, IR4 and IR5 cover an area of about 3 m^2 located at less than 4 meters from the RTG [1]. The RDS has two sets of photodiodes. One of them points towards the zenith and includes a detector (TOP7) with a hemispheric field of view that measures between 190 and 1100 nm [1]. We use the ratio between TIRS IR3 and RDS TOP7 measurements as a proxy for surface albedo (note that the values do not correspond to the actual albedo because TIRS and RDS measure in different spectral bands, but it is valid for our purpose of analyzing changes). The wind sensor consists of two booms at above 1.5 m above the ground, separated by 120º in azimuth to mitigate hardware wind interferences [1].

Albedo changes induced by dust devils:

MEDA measurements show the passage of numerous convective vortices close to the rover, which are detected as pressure drops [6]. Some of these drops are accompanied by a decrease in shortwave radiation, indicating that there was dust lifting by the convective vortex.

Simultaneous measurements of radiation and wind measurements suggest that some of the dust devils passed over the rover [7]. Here we have analyzed these measurements to identify the dust devils that are more likely to have affect the closest surroundings of the rover and we have analyzed the albedo in the surface portion covered by TIRS before and after the passage of the dust devil.

We have identified more than 40 dust devils that could have potentially altered the surface albedo during the first 350 sols of the Mars 2020 mission. We have observed that these dust devils cause a transient decrease in the surface temperature measured by TIRS [8]. The analysis of the events with a larger effect on surface temperature reveals that the decrease in temperature is not always accompanied by a change in surface albedo. This highlights the importance of dust availability and mobility at the surface.

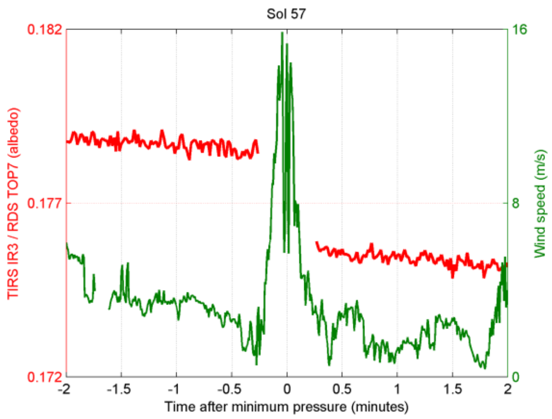

Figure 1. Change in surface albedo (red) and wind speed (green) caused by the passage of a dust devil on sol 57 of the Mars 2020 mission.

Figure 1 shows the change in surface albedo caused by a dust devil that affected Perseverance's location at 11:16 LMST on sol 57. In this case, the albedo decreased by around 1.5%.

Wind speeds and terrain properties. Determining a wind speed threshold for dust lifting or sand transport is a challenging task: first, it depends on particle availability and mobility at the surface, which depends on the rover location; and second, wind speeds are not measured at the exact region where observed dust lifting occurs; in this regard, the analysis of dust lifting and sand transport through surface albedo changes with MEDA minimizes potential uncertainties due to the small distance between the wind sensor booms and the TIRS target.

Despite these difficulties, it is possible to estimate an upper bound for which we observe dust lifting and a subsequent albedo change under favorable conditions. The most significant albedo changes occurred with peak wind speeds above 15 m/s, but it is not possible to discard dust lifting with lower wind speeds.

It is important to notice, however, that strong winds associated with some intense dust devils have not altered the surface. As an example, an intense dust devil on sol 173 caused winds at the rover's location above 20 m/s, but it did not cause detectable changes in surface albedo.

Albedo changes induced by the dust storm:

Between sols 313 and 318 of the mission, Jezero crater was affected by a dust storm. During this storm, dust opacities measured by Mastcam-Z increased from less than 0.4 on sol 312 to almost 1.4 on sol 316, decreasing again to 0.4 on sol 319 (see Figure 2). Perseverance remained at the same location between sols 287 and 328, providing a unique opportunity to track surface albedo changes during 40 sols, including those before, during and after the storm.

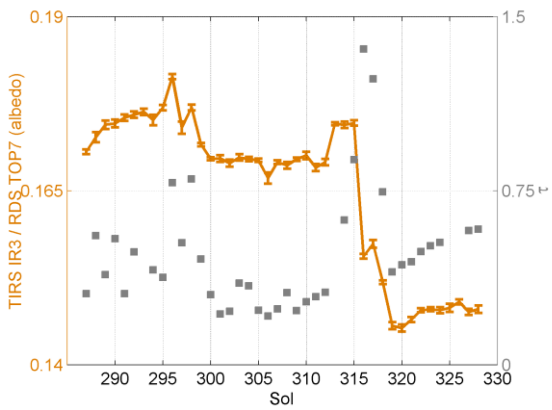

Figure 2. Change in surface albedo at 13 LMST (dark orange) and dust opacity (gray) between sols 287 and 328.

Figure 2 shows the temporal evolution of the surface albedo between sols 287 and 328 at 13 LMST (a similar behavior is observed at other times). The most remarkable feature shown in this figure is the strong darkening of the surface induced by the dust storm: there was a 17% decrease in surface albedo between sols 315 and 319; the largest sol-to-sol variation occurred between sols 315 and 316, when the albedo decreased by around 11%. In contrast, the albedo remained stable both before and after the storm. There are two secondary variations in surface albedo, which are associated with two enhanced opacity events on sols 296 and 298.

Analysis of the albedo changes. In this section, we use Mastcam-Z images of the surface observed by TIRS to further assess the changes induced by the dust storm.

Figure 3 shows a comparison of images of the portion of the surface observed by TIRS before (top) and after (bottom) the dust storm. One of the most apparent changes can be found in the wheel tracks. When rover wheels press on the soil as the wheels roll along, they mold the soil into track impressions. This molding process destroys any light surface cohesion/crust while reconfiguring the grains into molds to closely match the intricate shape of the wheel tread. The composition of the molded track material remains virtually unaltered, but original appearance is replaced by a sort of very light artificial cohesion. These tracks appear to be fainter in the lower panel, suggesting that all of the fines (dust, silt, sand) making up the molded tracks were mobilized.

Figure 3. Comparison of portions of Mastcam-Z projections corresponding to the TIRS field of view before (top) and after (bottom) the dust storm.

In addition, there appears to be an overall darkening, which is particularly notorious at regions showing a higher albedo contrast with the sand. Variations in sand and dust cover of the bright rock in the field of view could also have contributed to the observed decrease in albedo.

Effect of the albedo change on surface temperatures. TIRS measures surface temperature at the same portion of the surface where the albedo changes are detected. This fact provides a unique opportunity to study potential effects in surface temperature of the observed change in albedo.

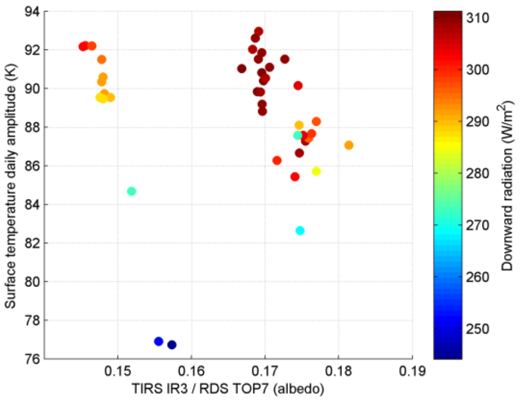

Figure 4. Diurnal amplitude of surface temperature as a function of surface albedo between sols 287 and 328 of the mission. Colors represent the downward radiation at 13 LMST.

Figure 4 shows the daily amplitude of the surface temperature measured by TIRS as a function of the surface albedo and incoming shortwave radiation measured by RDS. The lowest diurnal amplitudes occurred during sols 316 and 317, when opacity was high and caused a significant decrease in downward shortwave radiation (dark blue markers). When comparing sols with similar insolation (around 290 – 300 W/m^2), the diurnal amplitudes increased from 86 – 88 K before the storm to 90-92 K after the storm. This is consistent with a decrease in surface albedo: for a given downward shortwave radiation, the darkened surface would absorb a larger fraction of incoming radiation, which could cause an additional heating of the surface. The change in albedo could modify the differences between surface and air temperatures, affecting atmospheric thermodynamical processes.

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