THE IMPACT OF THE MY34/2018 GLOBAL DUST STORM ON THE NEAR-SURFACE ATMOSPHERE IN GALE CRATER, MARS

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Abstract

The Rover Environmental Monitoring Station (REMS) instrument is onboard NASA's Mars Science Laboratory (MSL) Curiosity rover. REMS has been measuring surface pressure, air and ground brightness temperature, relative humidity, and UV irradiance since MSL's landing in 2012. In Mars Year (MY) 34 (2018) a global dust storm reached Gale Crater at Ls ~190°. REMS offers a unique opportunity to better understand the impact of a global dust storm on local environmental conditions, which complements previous observations by the Viking landers and Mars Exploration Rovers.

1. Introduction

The Martian dust cycle greatly impacts atmospheric and surface temperatures and hence the circulation, since the atmospheric dust abundance and distribution strongly affects the solar and thermal radiation absorbed and scattered in the atmosphere and hence also the radiation received at the surface (e.g. [1-3]). The role of dust in the modern climate and weather of Mars therefore also has major implications for the design and safety of future human missions.

Local and regional dust storms are ubiquitous on Mars, particularly between areocentric solar longitudes (Ls) 180 - 360º. Every few years, however, regional storms grow and merge to become a global dust storm (GDS). However, due to the rarity of such events, the evolution of the near-surface atmospheric thermal state and circulation during the onset, expansion/mature, and decay phases of a GDS have rarely been studied at the surface.

The Rover Environmental Monitoring Station (REMS) on the Mars Science Laboratory (MSL) Curiosity rover [4,5] was able to measure surface pressure, air and ground brightness temperature, relative humidity (RH), and UV irradiance in six spectral bands. These atmospheric variables reveal how the atmospheric thermal balance and large-scale structure were affected, and may also be compared to numerical model simulations to help understand how the atmospheric circulation and near-surface winds were likely impacted at each stage of the storm.

In May 2018, after more than ten years without a GDS, orbiters observed precursor storms that grew until becoming global in mid-June. The effects of this MY34 GDS reached Gale Crater in early June, when the atmospheric opacity increased by a factor of 8 in comparison to typical values for this season, reaching an optical depth of ~8.5 at 880 nm as measured by Mastcam [6]. MSL instruments were able to measure the onset, expansion/mature, and decay phases of this storm in unprecedented detail, from inside a crater, including providing the first measurements of how relative humidity and ultraviolet irradiation in different spectral bands varied during the GDS.

2. General effects of the global dust storm

The most dramatic effect was seen in the surface radiative environment (Fig. 1), with a measured attenuation in UV fluxes (represented here by the UV-ABC channel, which ranges from 200 to 380 nm) of ~95% between L_s ~190° and 195.5° (sols 2075-2085), as a result of the rise in the amount of suspended dust. The abrupt decrease in surface solar radiation only caused a moderate decrease in the daily mean surface and air temperatures. The diurnal-average air temperature was ~231 K prior to the dust storm but fell by only ~4K to ~227 K during the highly dusty phase. The impact on the diurnal range of air temperatures was far more dramatic, however, with the diurnal range decreasing ~35K between the start of the onset and highly dusty phases. Maximum temperatures decreased from ~276 K to ~249 K and minimum temperatures increased from ~202 K to ~209 K over the same period, as atmospheric opacity decreased rapidly. Similar to air temperature, the diurnal-average ground temperature decreased by only ~2K, but showed a far bigger change in the diurnal range, which decreased ~56K during the onset phase of the storm.

The daily maximum RH abruptly decreased from ~29% prior to the dust storm to less than 5% during the highly dusty phase, returning to climatological values of ~10% at L_s ~ 250° as the storm abated. As this measurement is highly influenced by the air temperature, it is better to look at the inferred volume mixing ratio (VMR). This may be calculated using contemporaneous REMS measurements of RH, air temperature, and atmospheric pressure. A strong increase in VMR was seen during the onset phase until sol 2085, from mean values of ~86 ppm, to values exceeding 150 ppm. This could be the result of reduced water adsorption by the regolith at night, due to the warmer nighttime temperatures, resulting in an increase in the atmospheric water vapor, and is consistent with previous studies suggesting this process for exchanging water between the regolith and the atmosphere [7,8]. However, the large uncertainties in the inferred mixing ratios mean that these results should be considered with care.

The mean pressure varies according to the usual seasonal cycle due to the sublimation of the Martian polar caps and was barely affected by the storm.

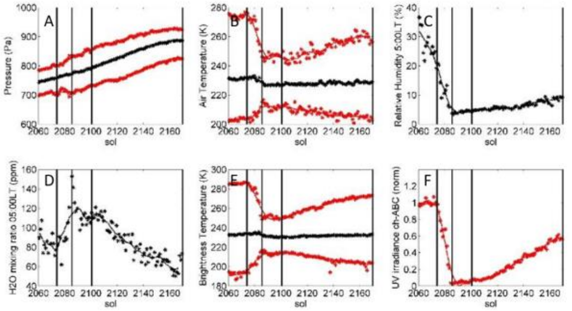

***Figure 1**: Evolution of REMS variables (sols 2060-2170) for the period encompassing the onset (sols 2075-2084), highly dusty (sols 2085-2100) and decay phases of the GDS. Daily mean, maximum, and minimum values are shown for pressure (A) and temperatures (B and E), while the relative humidity (C) and water mixing ratio (D) values correspond to values where the RH reaches its maximum (between 4:00-6:00 LTST) and their uncertainty is lower. Finally, the daily maximum UV irradiance (F) is shown normalized to the value on sol 2070. Vertical lines show the start times of the GDS onset (sol 2075), highly dusty (sol 2085) and decay (sol 2100) phases in Gale Crater.*

3. Effects on the diurnal cycle

The diurnal pressure amplitude varies during the storm, increasing from ~84 Pa prior to the storm to ~124 Pa on average during sols 2090 – 2100, with a far clearer two-peak structure. The frequency-domain behavior of the diurnal cycle shows a strong increase in the semidiurnal and terdiurnal modes. Overall, the pressure tides began to respond to the storm well before opacity showed any significant increase. However, the peak in semi-diurnal and terdiurnal tide amplitudes occurred about 20 sols after the peak in opacity. Given that optical depth measurements are *local* measurements inside Gale, and that the pressure tides respond to the larger-scale atmospheric dust abundance, the offsets in timing of the pressure tides response and opacity suggests different dust abundances inside the crater versus the regional-to-global dust distribution.

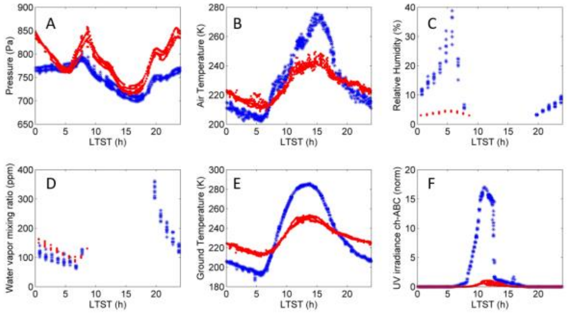

***Figure 2**: Comparison between the nominal diurnal cycle (blue asterisks) just prior to storm onset (sols 2060-2070) and the dusty diurnal cycle (red dots) within the highly dusty phase of the GDS (sols 2085-2095). The values for very low RH (<3%) are considered unreliable and therefore are not shown. The UV radiance after noon in the nominal case is affected by shadows in all sols.*

The VMR had its maximum at some time during the day and decreased from at least 19:30 LTST onwards (at least in the nominal case), reaching its minimum value shortly after sunrise, while RH was still very high. This is consistent with model analyses of the atmospheric water vapor abundance decreasing as the regolith cools and water is adsorbed into the regolith [7,9]. The daily range in air and ground temperature were reduced by ~35 K and 56 K respectively. Both followed closely the temporal evolution of the growth and decay in opacity seen at Gale. Maximum ground temperatures decreased, by about 35 K, only when the increase in local opacity occurred over Gale during the growth phase of the GDS, while the minimum ground temperatures increased by some 20 K as a consequence of the more opaque and hence warmer atmospheric layers above the rover preventing more nighttime IR radiative cooling of the surface. The ground temperature remained warmer than the near-surface air temperature during the nighttime, and therefore the typical nighttime inversion layer was absent near the surface, due to the greater coupling between the surface and atmosphere in the more opaque conditions. Consequently, the nighttime near-surface atmosphere stability was significantly reduced, allowing enhanced convection during the nighttime.

4. References

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