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# MRO-MCS observed polar warming and clouds during 2018 Martian global dust storm

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## Abstract

This study focused on the impact of most recent global dust storm (GDS) of 2018 over the north polar region of Mars using the observations from Mars Climate Sounder (MCS) onboard Mars Reconnaissance Orbiter. The MCS column integrated dust opacity shows the peak of the dust storm during $L_S$ ~195-210° ($L_S$ is the solar longitude), which is also visible over the polar region. The vertically integrated polar warming index (PWI) in the NH shows a decline during the active storm phase of GDS 2018, indicates more dust radiative heating over low-mid latitudes. Also, PWI variation suggests a delayed response (~10°$L_S$) of the polar atmosphere to the active dust lifting over northern low to southern mid-latitudes. No significant change in the cloud vertical depth is observed on the poleward side of the north polar hood. These observations indicate only an indirect (not by direct radiative forcing and associated heating) impact of global dust loading in the north polar atmosphere during the decaying phase of the 2018 GDS.

## 1 Introduction

The Martian global dust storm (GDS) is one of the most dynamical events in the solar system and can be observed from the Earth [6]. A GDS is not a single weather system and is a combination of several regional dust storms occurring simultaneously across the planet. Depending upon the availability of dust in the surface reservoirs that need few years to replenish once exhausted, the occurrence of GDS is seen typically once in three years [1]. Previous spacecraft observations showed the occurrence of GDS during 1971, 1973, 1977a, 1977b, 2001, and 2007 [13]. The most recent GDS occurred in 2018 [16] or Mars year (MY) 34 (MY convention as per [2]). Dust is a significant modulator of Martian weather and climate, including an important phenomenon, i.e., water ice cloud appearance [17, 18, 24]. The GDS may effectively alter the water vapor abundance in the lower to the middle atmosphere [15]. The atmospheric warming due to the dust radiative heating creates a moist middle atmosphere by increasing the water vapor mixing (diminishing the condensation) ratio and elevates the hygropause altitude. This may again enhance the atmospheric water vapor escape rate [15]. Moreover, the GDS can significantly impact the vertical distribution of the temperature and condensates directly or indirectly by influencing the global circulation [4]. Therefore, being the most extensively observed GDS event, several studies have been carried out to understand the dynamical and meteorological impact of the same [18 20, 21, 22]. However, no or very few studies so far have characterized the impact of 2018 GDS by focusing on the polar region. Hence, the present work used the global retrievals of dust, water ice, and temperature from the Mars Climate Sounder (MCS) onboard Mars Reconnaissance Orbiter (MRO) to understand the impact of 2018 GDS on the polar hood clouds (PHC) and temperature. Notably, this study focuses on the northern hemisphere (especially north PHC), where the concerned GDS was initiated.

## 2 Data and Methodology

MRO is a sun-synchronous and polar orbital satellite that crosses the equator around 3 AM and 3 PM local times [9]. MCS onboard MRO is a radiometer observing the limb of the Mars atmosphere since September 24, 2006 [7]. MCS provides the global profile observations of temperature (K), and extinction ($km^{-1}$) of dust (at 32 µm), and water ice (at 11.9 µm). The limb-viewing geometry of MCS precludes itself from measuring the near-surface atmosphere, though the profiles are vertically extended up to ~90 km with a resolution of ~5 km. In the extinction profile, the error lies within $10^{-5}$–$10^{-6}$ $km^{-1}$, while the altitudinal error is within ±1 km [10]. This work used the MCS derived data records (DDR version 5.3.2) provided by the NASA Planetary Data System atmospheric node. This is an interim version of v5.2 [14] that uses a 'two-dimensional retrieval algorithm' for better vertical coverage. The v5.3.2 uses a far-infrared channel for the dust retrievals that gives more vertically extended and improved observation during a dusty atmospheric condition. The present work uses the column dust map by following Montabone et al. [21]. The column integrated dust opacity is estimated by extrapolating the truncated profiles and assuming well-mixed dust below the truncation altitude [19]. The column opacity data are 'quality controlled' and uses 'iterative weighted binning' to form the gridded data [21].

The MCS temperature data is used to estimate the polar warming index (PWI) or $T_{PWI}$ in the northern hemisphere (NH). The $T_{PWI}$ [12] at a particular altitude, z is estimated by using the equation (1).

$$T_{PWI} = T_{Hemispheric\ max.} - T_{Equatorward\ minimum} \qquad (1)$$

Here, the 1st term in the right side of equation (1) is the maximum temperature in a given hemisphere at altitude z,

and the 2nd term denotes the minimum temperature between the latitude of the 1st term and the equator at the same height. It is worth noting; this study used vertically integrate $T_{PWI}$ computed for the altitudes 50-60 km from the zonal mean MCS temperature profile, as the polar warming is significant within this range [12]. Further, this study estimated the cloud vertical depth associated with the north PHC using the MCS zonal mean water ice density-scaled opacity profiles during the 2018 global dust storm. The density-scaled opacity is the extinctions scaled by the atmospheric density [17, 23]. Here, only the opacity exceeding ~$10^{-3}$ are considered. Hence, the metric can be considered as the vertical depth of the thick clouds.

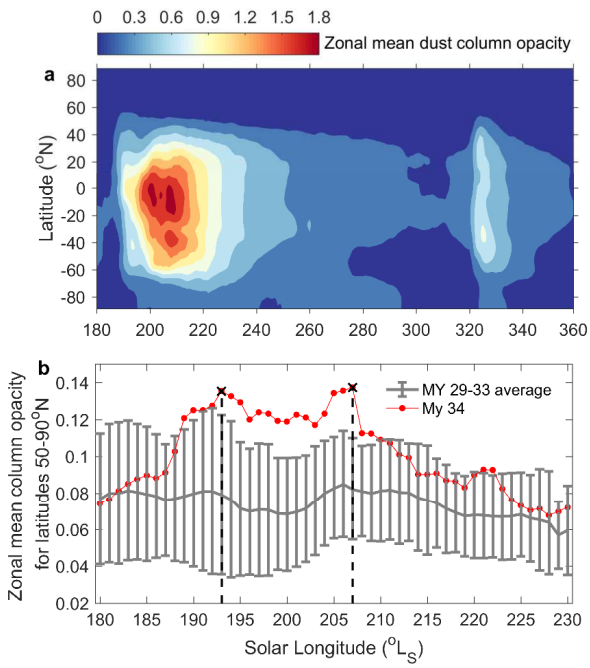


**Figure 1.** Variation of the MCS column dust opacity during (a) entire perihelion ($L_S$ = 180 – 360°) and (b) Mars Year (MY) 34 (2018) global dust storm (GDS) period.

## 3 Results and Discussions

The zonally averaged column integrated dust opacity is used to observe the latitudinal and temporal distribution of the 2018 GDS. The distribution of the column dust opacity typically provides the general understanding of the storm onset, growth, and decay phase, which can be useful for studying further the meteorological conditions modulated by the GDS [5]. The column dust opacity starts increasing (become ~0.6 to ~0.3) over latitudes -60 – 60°N from $L_S$ ~190°, indicating the onset of 2018 GDS (Figure 1a). The column opacity exceeded 1.0 after $L_S$ ~200°. The opacity maximum is visible within the tropics and southern sub-tropics during $L_S$ ~200-210°. After that, the dustiness starts decreasing and drops significantly after $L_S$ ~220°. The background opacity touched the typical seasonal value around $L_S$ 250°. It indicates a faster decay phase of 2018 GDS compared to the 2001 or 2007 storm [22]. The noticeable column dust opacity (~0.6) is again seen around $L_S$ 260°, but it is a separate dust event related to the summer-time cap edge storms [3]. The occurrence of 2018 GDS also influences the atmospheric dust abundance over the northern polar latitudes (Figure 1b), where (~50-90°N) the PHC is observed [11]. The above-average dust opacity is marked in Figure 1b during $L_S$ ~193-209°, indicating the possible atmospheric impact over these regions, and can be considered for analyzing further.

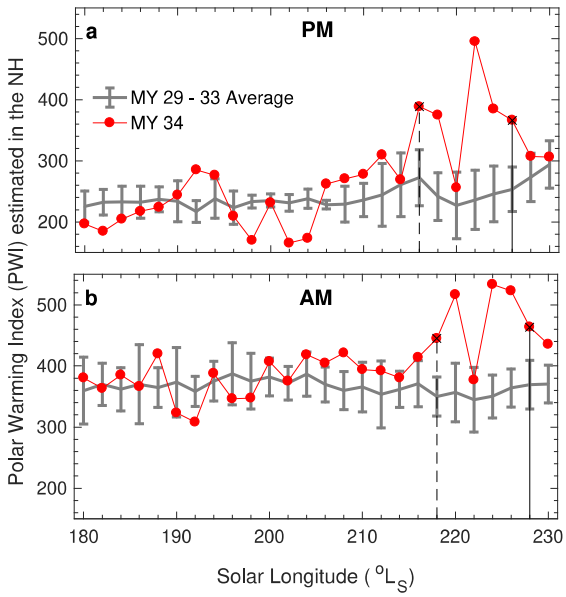


**Figure 2.** Comparison of polar warming index (estimated from MCS temperature observation) between 2018 GDS period and MY 29-33 average for (a) daytime (~3 PM) and (b) nighttime (~3 AM).

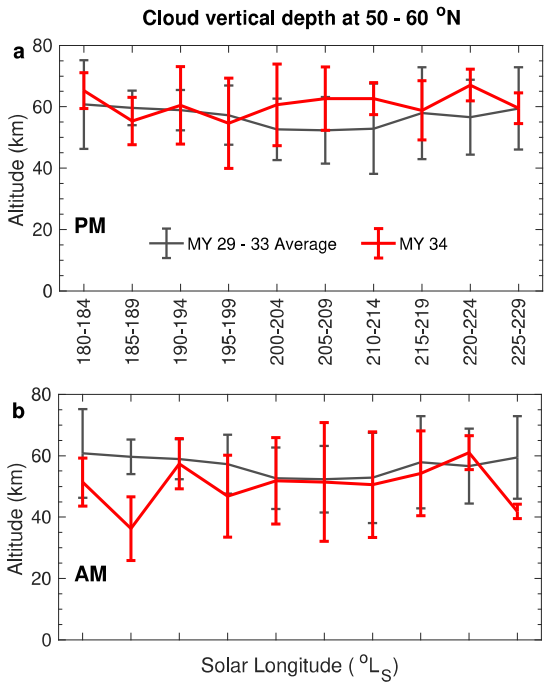


**Figure 3.** Evolution of zonal mean cloud vertical depth (estimated from the MCS IR extinction for water ice) for latitudes 50-60°N during the occurrence period of 2018 GDS for (a) daytime (~3 PM) and (b) nighttime (~3 AM).

This study estimates the vertically integrated PWI in the NH during the occurrence period of 2018 GDS (Figure 2). The daytime PWI shows a dip during the active storm phase (i.e., $L_S$ ~195-205°). It indicates the increased temperature caused by the dust radiative heating over low and mid-latitudes compared to the North Polar Region. Surprisingly, the PWI shows noticeable higher values in the daytime during $L_S$ ~216-226° (Figure 2a), which is $L_S$ ~218-228° for the night (Figure 2b). It indicates a delayed response (~10°$L_S$) of the polar atmosphere to the active dust lifting over northern low to southern mid-latitudes. The atmospheric warming reduced the vertical depth of North PHC only in the equatorward branch of it, mainly during the daytime after $L_S$ ~205° (Figure 3). However, no significant change in the vertical depth is observed on the poleward side of the PHC (Figure 4).

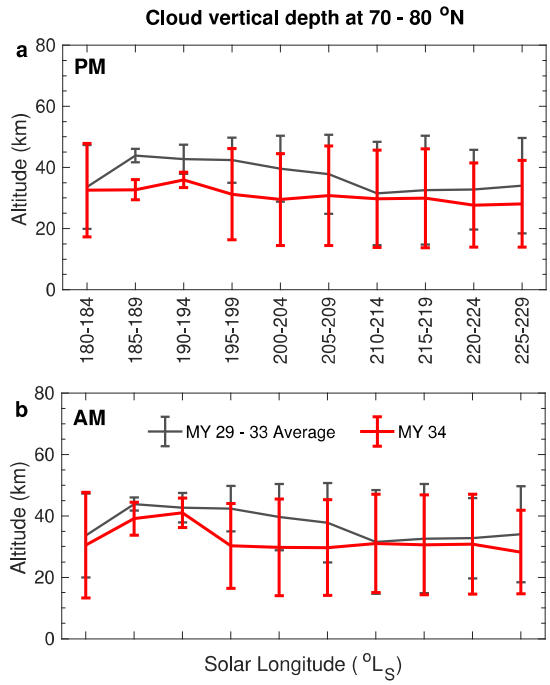


**Figure 4.** Same as figure 3, but for latitudes 70-80°N.

These observations indicate only an indirect impact of global dust loading in the north polar atmosphere. Here, the direct radiative forcing and associated heating are not much significant. Instead, the warming is induced in the descending branch of the principal meridional overturning cell (PMOC) caused by adiabatic heating [8]. The PWI shows a noticeable change only after the significant global dust loading that indicates the response of PMOC in the decaying phase of the 2018 GDS, and the mechanism may be valid at least for the northern high-latitudes.

## 4 Conclusion

The present work utilized the global observation of MRO-MCS to study the impact of GDS 2018 over the north polar region of Mars. The key findings could be summarized as follows:

- Column integrated opacity derived from the MCS IR dust extinction shows the GDS peak during $L_S$ ~195-210°, which is also noticeable over the polar region.
- The vertically integrated PWI over the NH shows a dip during the active storm phase of GDS 2018, indicating a significant dust radiative heating and associated atmospheric warming over low-mid latitudes.
- The PWI suggests a delayed response (~10°$L_S$) of the polar atmosphere to the active dust lifting over northern low to southern mid-latitudes.
- An insignificant change in the cloud vertical depth on the poleward side of the Northern PHC indicates only an indirect impact (by adiabatic heating in the downwelling branch of the PMOC) in the 'north polar atmosphere' during the decaying phase of the 2018 GDS.

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