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### Global characterization of the Martian global dust optical depth with 2.7 $\mu\text{m}$ observations by OMEGA/MEx

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**Introduction:** Dust is a key parameter of the Martian atmosphere, controlling its heating through direct absorption of solar radiation. The quality of dust is not constant in time and space, and dust storms explain part of this variability. Local dust storms, occurring at scales below  $1.6 \times 10^6 \text{ km}^2$ , have been suggested to develop into vertical dust transport movements that reach high altitudes, such as rocket dust storms [1,2]. Local dust storms can also coalesce and develop into regional dust storms [3,4,5,6]. Dust storms, notably regional dust storms larger than  $1.6 \times 10^6 \text{ km}^2$  have been frequently investigated by visible observations from orbiters [6,7]. However, spectroscopic observations of dust storms, notably local dust storms, are more limited, and no statistical studies have been conducted on such datasets yet. We successfully retrieved dust optical depth and statistically detected local dust storms using observation data from the Mars Express during Martian years (MY) 27-29, which was equipped with the high-resolution Near-Infrared Spectrometer OMEGA. We then conducted a statistical analysis of local dust storms over three Martian years, including MY28 when a global dust storm occurred, investigating their occurrence locations and frequencies.

**Method:** In this analysis, we developed a new method to retrieve the dust optical depth using the atmospheric 2.77  $\mu\text{m}$  CO<sub>2</sub> absorption band. Typically, this band saturates during nadir observations when surface pressures is greater than approximately 400 Pa in the Martian environments, resulting in almost zero observed radiance under low dust conditions. However, when the aerosols are lifted into the atmosphere, reflected sunlight by aerosols can be detected in nadir-observations. We utilized this technique to retrieve dust optical depth in the atmosphere using the L-channel of OMEGA at 2.77  $\mu\text{m}$  used here. For the retrievals of the dust optical depth, we employed a Look-up-table method [8,9] that calculates many synthetic spectra at 2.77  $\mu\text{m}$  in advance for tabulated grid values of physical parameters (such as dust opacity, observing geometry, atmospheric temperature, etc) by DISORT radiative transfer module [10] implemented in the ARS code [11]. With this method, an instantaneous retrieval of dust optical depth is possible by comparing them with observed spectra.

The validity of this method was evaluated by comparing it with two previous studies: (1) retrieval of dust optical depth from the 2.0  $\mu\text{m}$  CO<sub>2</sub> absorption band [12] and (2) retrieval of dust optical depth from the reflectance level of the continuum [13]. In regions or seasons with high dust conditions ( $\tau$  at 2.77  $\mu\text{m}$  in this study greater than 0.1, which roughly corresponds to visible optical depths greater than 0.5 – 1.0), the dust optical depth by our method aligned within the error range with the other two studies. However, in regions or seasons with low dust content ( $\tau$  at 2.77  $\mu\text{m}$   $\leq 0.1$ ), inconsistencies are sometimes observed when other methods detect large values of dust optical depth. These discrepancies may be due to differences in altitude sensitivity observed by different wavelengths. While the retrieval using the 2.77  $\mu\text{m}$  band is sensitive to altitudes of approximately 30 km, 2.0  $\mu\text{m}$  is sensitive to altitudes of around 20 km (Figure 1). Therefore, the differences observed between the two retrieval methods could be explained by the presence of dust confined below 30 km. This also suggests a possible method for estimating dust altitude by combining two or more wavelengths with different CO<sub>2</sub> absorption characteristics.

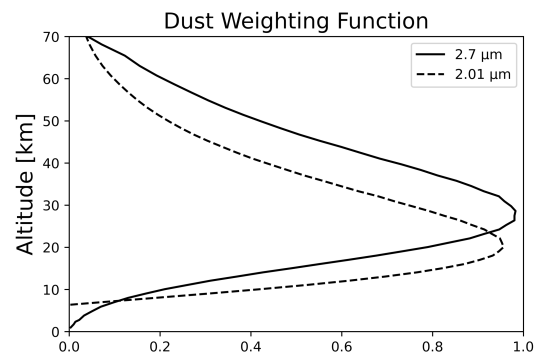


Figure 1. The altitude sensitivity of the radiances was calculated using DISORT at 2.7  $\mu\text{m}$  and 2.0  $\mu\text{m}$  in Nadir viewing for total dust optical depth.

**Result:** We applied our method to the entire observational of OMEGA during MY27-29, comprising approximately 8300 orbits, to derive seasonal variation of dust optical depth (Figure 2). This analysis focused on observations at low solar zenith angles (below 60°). Ice clouds, which cannot be distinguished from dust, were detected using the ratio of 3.4  $\mu\text{m}$  to 3.5  $\mu\text{m}$ , and data containing ice clouds were excluded [14]. The

result including the global dust storm in MY28, is consistent with previous studies [12,15].

In addition, utilizing our retrieved dust optical depth, we statistically analyzed the occurrence of local dust storms. The dust optical depth exceeding 0.2 in regions ranging from  $1.0 \times 10^4 \text{ km}^2$  to  $1.0 \times 10^6 \text{ km}^2$  is defined as a local dust storm in this study. According to these criteria, a total of 137 local dust storms were detected from MY27 to MY29. When focusing on solar longitude (Ls), local dust storms are observed to occur predominantly between Ls  $250^\circ$  and  $280^\circ$  (Figure 3). This trend is consistent with previous studies from visible imaging observations [6,7]. It is attributed to increased solar radiation and atmospheric temperature due to approaching perihelion, leading to enhanced dust activity. Therefore, like regional dust storms, the primary driver of local dust storms is believed to be atmospheric heating.

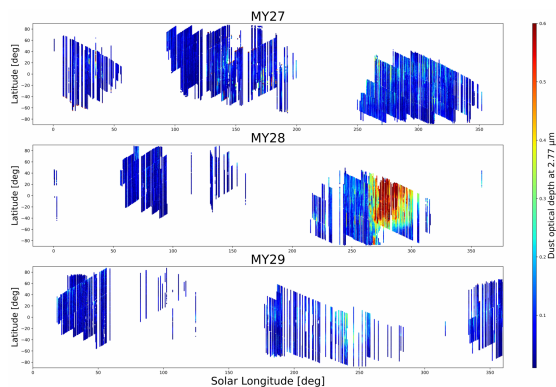


Figure 2. Seasonal variation of the dust optical depth retrieved from 2.77  $\mu\text{m}$  in MY27-29.

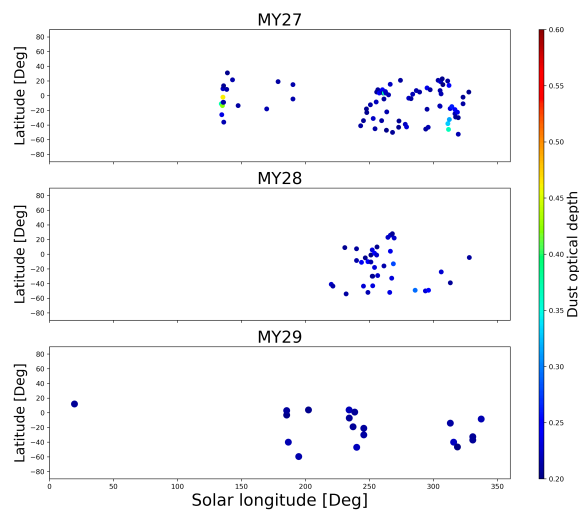


Figure 3. Maps of detected local dust storm events in MY27-29. The colors on the map of local dust storms indicate dust optical depth as measured by the 2.7  $\mu\text{m}$  wavelength.

**Discussion:** Two interesting features are observed in the detected local dust storms.

The first is that characteristic local dust storms are those that occur frequently between Ls  $130\text{--}150^\circ$  of MY27. A comparison of these results with the visible observations indicates that they occur in similar areas. The detected local dust storms include a previously detected storm that may be representative of the “rocket dust storm” phenomena, possibly suggesting strong dust vertical transport [1,2]. This season is typically a calm period for dust activity, with large dust storms being rare. Therefore, with low dust content in the atmosphere during this time, local dust storms in specific regions may develop into rocket dust storms when atmospheric temperatures rise due to certain factors. Another interesting aspect is that such a series of strong local dust storms are detected only in MY27, which might be due to the local time of the observations (MY27:  $\sim 14\text{h}$ , MY28:  $\sim 10\text{h}$ , MY29:  $\sim 8\text{h}$ ) or interannual variation.

The second characteristic is related to global dust storms in MY28. At Ls  $=269^\circ$ , a global dust storm has occurred. At Ls  $=267^\circ$  just before the global dust storm started, we detected a strong local dust storm on the eastern side of the Hellas Basin, with a trend like that of previously detected a rocket dust storm [1,2]. It is suggested that this strong dust storm could be related to the development of the global dust storm.

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