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## Integrated Study of Martian Dust: Detection of Local Dust Storms, Estimation of Vertical Distribution, and Surface Pressure Analysis Using OMEGA Observations

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Understanding the Martian dust cycle is essential for clarifying the atmospheric circulation and meteorological phenomena. Unlike Earth, Mars has a thin atmosphere primarily composed of CO<sub>2</sub>, where atmospheric dust plays a dominant role in regulating the energy balance and driving atmospheric motion. Among various dust-related phenomena, Local Dust Storms (LDS), defined as storms that span less than  $1.6 \times 10^6$  km<sup>2</sup> or last fewer than three Martian days (Cantor et al., 2001), are particularly important for studying localized dust lifting and its potential connection to regional or global dust events (Martin and Zurek, 1993; Cantor et al., 2001; Hinson and Wang, 2010; Wang and Richardson, 2015). However, due to their limited spatial extent and short lifetimes, LDS have remained challenging to detect and characterize comprehensively.

In this study, we developed a method for identifying LDS using data from the OMEGA (Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité) imaging spectrometer onboard Mars Express (Bibring et al., 2004). Specifically, we used the strong CO<sub>2</sub> absorption band at 2.77 μm to retrieve dust optical depth. This band is sensitive to altitudes around 20–30 km and offers the critical advantage of being largely insensitive to surface reflectance properties. Applying this retrieval method to data from Martian Years (MY) 27 through 29, we detected 146 LDS events. Our statistical analysis revealed clear seasonal and diurnal patterns. LDS occurrences were most frequent during southern summer (Ls = 270°–360°), consistent with past findings that identify this season as conducive to dust activity (e.g., Smith, 2004; Montabone et al., 2015). However, we also observed an anomalously high frequency of LDS during northern summer in MY27 (Ls = 130°–150°), a period not typically associated with elevated dust activity. Furthermore, a noticeable increase in LDS activity was detected just before the onset of the Global Dust Storm (GDS) in MY28. Diurnally, LDS were most often observed near noon, implying that storm initiation may begin in the morning hours. Their spatial distribution varied significantly with season. During Ls = 0°–180°, LDS tended to be confined to specific regions such as Chryse Planitia and southern Acidalia. In contrast, during Ls = 180°–360°, LDS appeared more widely across mid-latitudes, with a notable absence in the northern

high-latitude region (above 40°N). These results offer new insight into the role of LDS in the broader Martian dust cycle, particularly their potential influence on triggering regional or global events.

Building on these findings, we are working on two additional research directions. The first involves estimating the vertical structure of dust by multiple spectral bands with different CO<sub>2</sub> absorption strengths. For example, the 2.01 μm band is sensitive to lower altitudes than the 2.77 μm. By comparing dust optical depth values retrieved from the 2.01 μm (Leseigneur and Vincendon, 2023) and the 2.77 μm (Kazama et al., under review), we aim to characterize whether the dust is well-mixed throughout the column or exists as a detached layer. Preliminary results have demonstrated the feasibility of this technique in distinguishing between detached and uniform dust layers, suggesting the potential for more detailed three-dimensional analyses of dust transport.

The second one concerns the retrieval of surface pressure, which is typically retrieved from the 2.01 μm CO<sub>2</sub> absorption feature (Forget et al., 2007). However, this approach is strongly influenced by dust conditions, which introduces systematic uncertainties under dusty conditions. By incorporating independently retrieved dust optical depth from the 2.77 μm band as a fixed input, we can better decouple atmospheric and surface effects. This improvement may help us better explore potential interactions between dust storms and surface pressure variations, including possible pressure drops or wave-like features linked to thermal tides and gravity waves.

We plan to extend these techniques to data from upcoming Mars missions, including the Martian Moons eXploration (MMX) mission, set to launch in 2026. The MIRS (MMX InfraRed Spectrometer) instrument onboard MMX features high spatial resolution and broad coverage, making it well-suited for continuous monitoring of atmospheric dust and surface pressure at global scales (Barucci et al., 2021; Ogohara et al., 2022; Kuramoto et al., 2022). We aim to investigate seasonal and interannual variability in Martian dust activity from a long-term perspective using MIRS data.

In conclusion, this work integrates high-resolution imaging spectroscopy, retrieval techniques, and statistical analysis to provide a multi-scale understanding of Martian dust dynamics.