MCS Observations of the Initiation and Development of Large Regional Dust Events on Mars

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Abstract

Why do some Martian dust storms, in some Mars years, expand to reach planet-encircling status, while the majority do not? In what ways do the largest regional events differ from those that become global? Comparisons of observations from these two categories of events may help answer these questions. The dust storm season of 2018, which included a global-scale dust event, was preceded by five successive dust storm seasons in which only regional-scale events were observed. The recent record thus presents an opportunity for making quantitative comparisons between regional-scale and global-scale dust events. Observations by the Mars Climate Sounder, on board the Mars Reconnaissance Orbiter spacecraft, provide unique 4D information on temperatures and aerosol loading of the Mars atmosphere, to altitudes of >80 km. Available MCS observations span the past eight Mars years. We have previously employed MCS observations to characterize the evolution in latitude, longitude, and altitude of atmospheric dust clouds during the initiation phase of the 2018 global event. Other atmospheric fields provide complementary information. For instance, observed changes with time in atmospheric 'dynamical heating' also help characterize the response of the Mars atmosphere to added dust loading. In this process, the atmosphere in regions far removed from the locations where dust is lifted may be warmed by adiabatic compression within the descending branches of Hadley-like meridional circulation cells. We will present and interpret MCS observations of these and other phenomena for selected large regional-scale dust events of Mars Years 29-33 (from 2009 through 2017), and draw comparisons with observations obtained during the 2018 global event. We will additionally explore the implications of the results within the context of current hypotheses for the triggering of the largest dust storms on sub-seasonal time scales.

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- **Mars Climate Sounder (MCS) observations can characterize Martian regional dust storms (Table 1) in 3 spatial dimensions and time**
- **Investigations of the initiation of the 2018 global dust event (Figure 1) provide new insights and new tools for such investigations**
- **Preliminary investigation of the 29A dust event (Figures 4-6) reveals regional storm dust lifting, lofting, and layering in unprecedented detail**

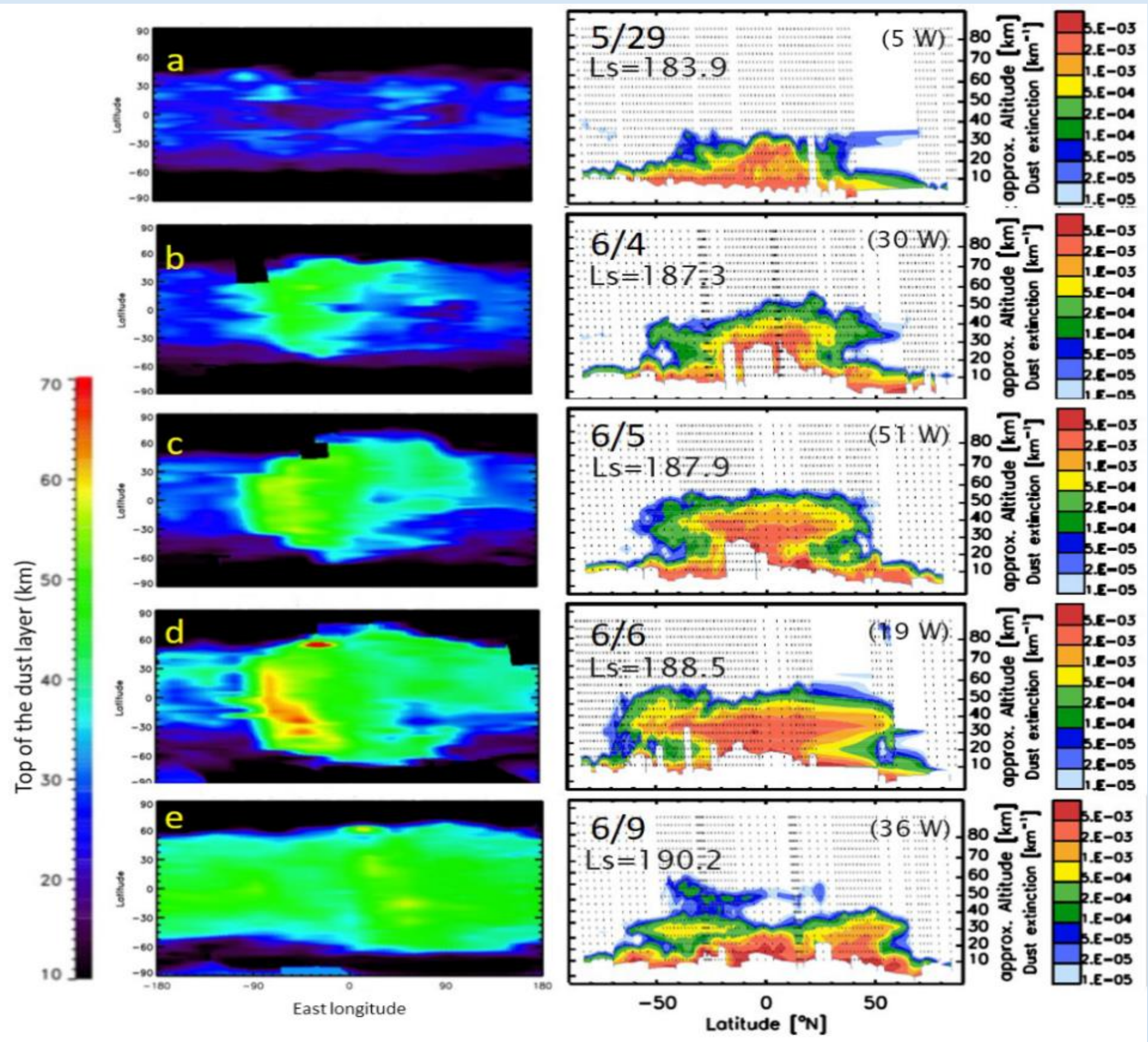


Figure 1. Lateral and vertical evolution versus time of atmospheric dust loading during the initial growth phase of the 2018 Global Dust Event, from Shirley et al., *GRL*, 2019 (10.1029/2019GL084317). Left column: Maps of the altitude of the top of the dust layer (km), defined as the altitude where extinction drops below 10^{-4} km^{-1}. Right column: Atmospheric dust extinction cross-sections. Equator-crossing longitudes for the cross sections are indicated at upper right. Hash marks indicate the latitudes and altitudes of MCS retrievals. Panel a illustrates pre-storm conditions; panels b-e illustrate rapid expansion and decay of a regional Hadley circulation above the Acidalia storm track.

Quantitative Metrics for Regional Storm Characterization and Comparison:

The investigation will track vertical, areal, and temporal variability of the following quantities, for each regional storm investigated:

- Dust extinction
- Dust column opacity (Fig. 5b)
- Dust layer peak altitude (Fig. 5a)
- Dust terminal (sedimentation) velocity
- Adiabatic ("dynamical") heating (Fig. 5c)
- Direct dust heating (Fig. 5d)
- Storm areas
- Storm directions and velocities

Bonus Topic: Orbit-spin Coupling and the 29A Storm

Advance forecasts of a GDE during the 2018 dust season appeared in Shirley (2015) and Mischna & Shirley (2017)

The MY 34 GDE and the 29A storm each began near times when orbit-spin coupling torques on the Mars atmosphere were changing most rapidly (Fig. 2)

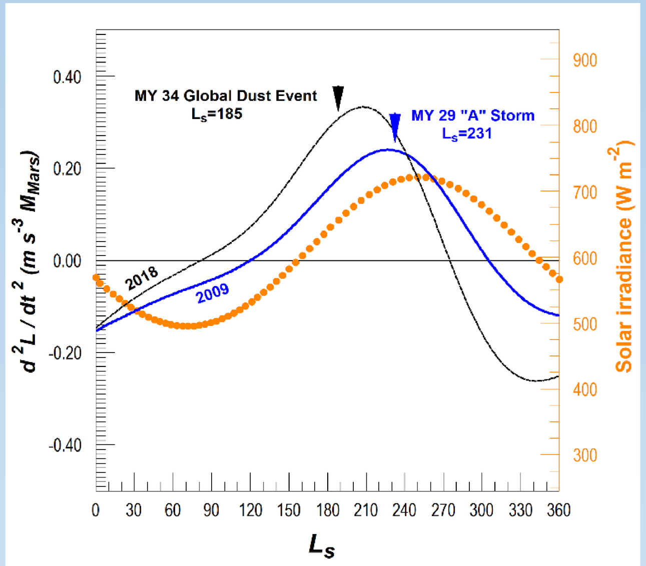
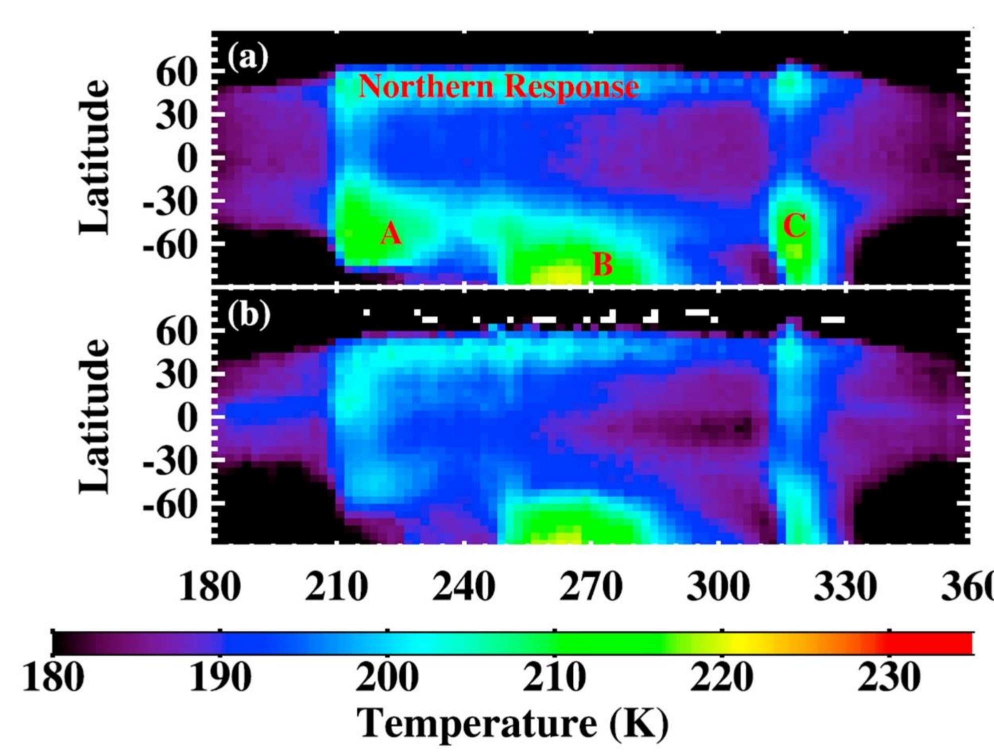


Figure 2. The d^2L/dt^2 waveforms for Mars Years 29 and 34. Orange dots indicate the solar irradiance as a function of time within the Mars year (scale at right). Arrowhead symbols denote the inception dates for the MY 29 A storm and the MY 34 GDE.

- Large regional dust storms during the MRO Mission



Events		Start (L_s)	Peak (L_s)	End (L_s)	Rise Time (DL_s)	Duration (DL_s)	Peak T (K)
MY 29							
	Storm A	231.3	241.0	265.9	9.7	34.6	224.5
	Storm B	260.0	275.0	293.1	15	33.1	212.9
	Storm C	311.5	317.0	323.6	5.5	12.1	215.8
MY 30							
	Storm A	234.8	247.0	250.8	12.2	16	213.9
	Storm B	257.2	269.0	292.9	11.8	35.7	216.7
	Storm C	316.8	323.0	329.6	6.2	12.8	199.0
MY 31							
	Storm A	209.1	213.0	237.0	3.9	27.9	217.7
	Storm B	248.5	263.0	287.4	14.5	38.9	220.3
	Storm C	312.0	319.0	325.1	7	13.1	218.7
MY 32							
	Storm A	218.4	227.0	247.0	8.6	28.6	223.0
	Storm B	254.9	263.0	292.6	8.1	37.7	219.5
	Storm C	311.3	313.0	326.3	1.7	15	208.9
MY 33							
	Storm A	217.8	223.0	239.0	5.2	21.2	217.0
	Storm B	249.9	269.0	291.7	19.1	41.8	220.1
	Storm C	324.1	327.0	341.9	2.9	17.8	212.4
MY34							
	Storm C	320.6	325.0	336.5	4.4	15.9	221.0

Figure 3. The zonal mean temperature structure at 50 Pa (~25 km) highlights the A, B, and C regional storms of MY 31. (a): Daytime temperatures; labels indicate the A, B, and C storms. (b) nighttime temperatures. (Kass et al., 2016).

Table 1. Large Regional-Scale Dust Storms, MY 29 – MY 34. After D. M. Kass et al. 2016, Interannual similarity in the Martian atmosphere during the dust storm season, GRL 43, 6111, (10.1002/2016GL068978).

- A snapshot of the "29A" Regional dust storm

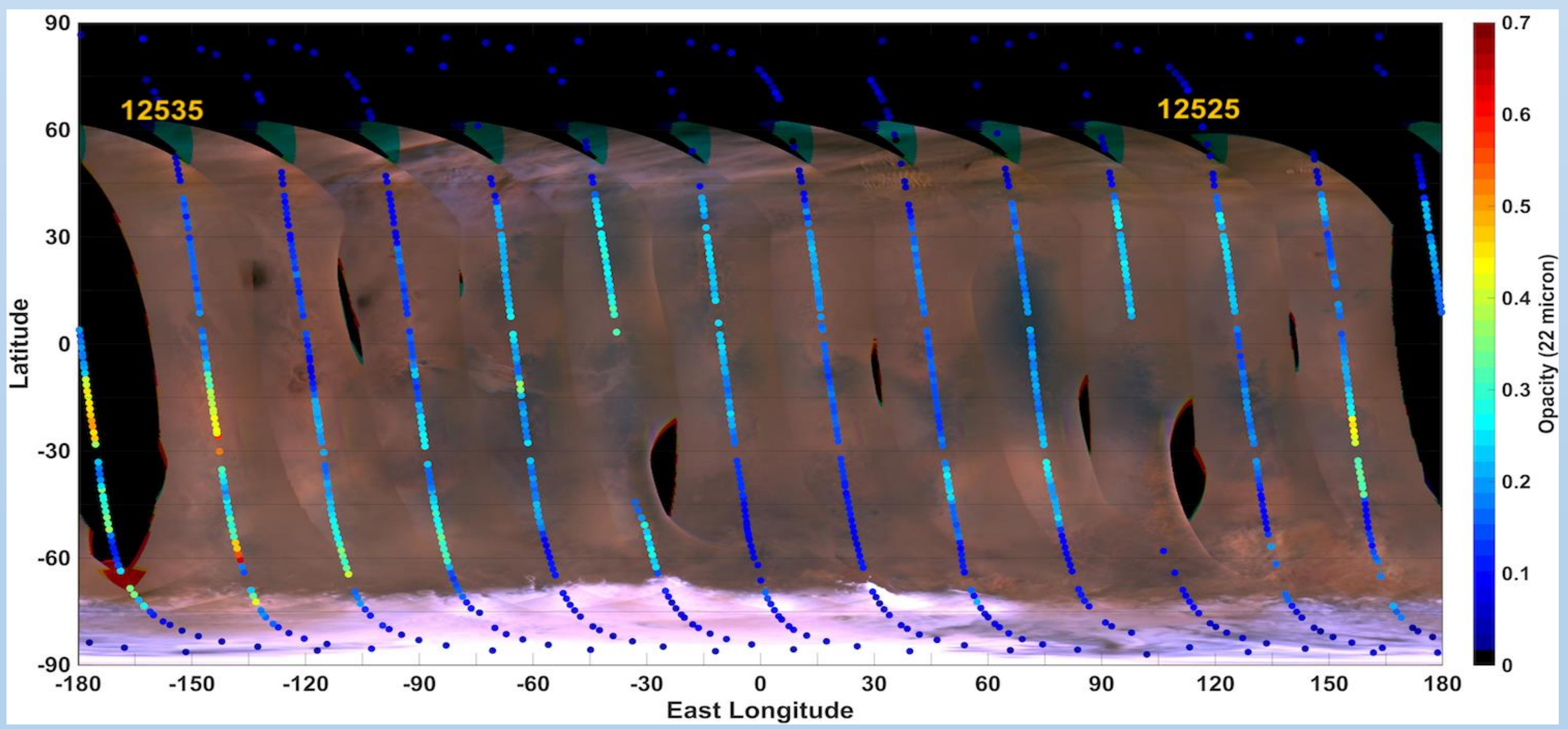


Figure 4. The Mars Daily Global Map for 29 May 2009 (L_s=236°), during the mature phase of the MY 29A storm. Dots identify MRO orbit tracks and the locations of individual MCS profiles, with color coding corresponding to the MCS dust column opacity at 22 µm. Cross sections for Orbits 12525 and 12535 are shown at right. Image courtesy of J. M. Battalio. The MARCI Mars Daily Global Map archive resides on the Planetary Data System (PDS).

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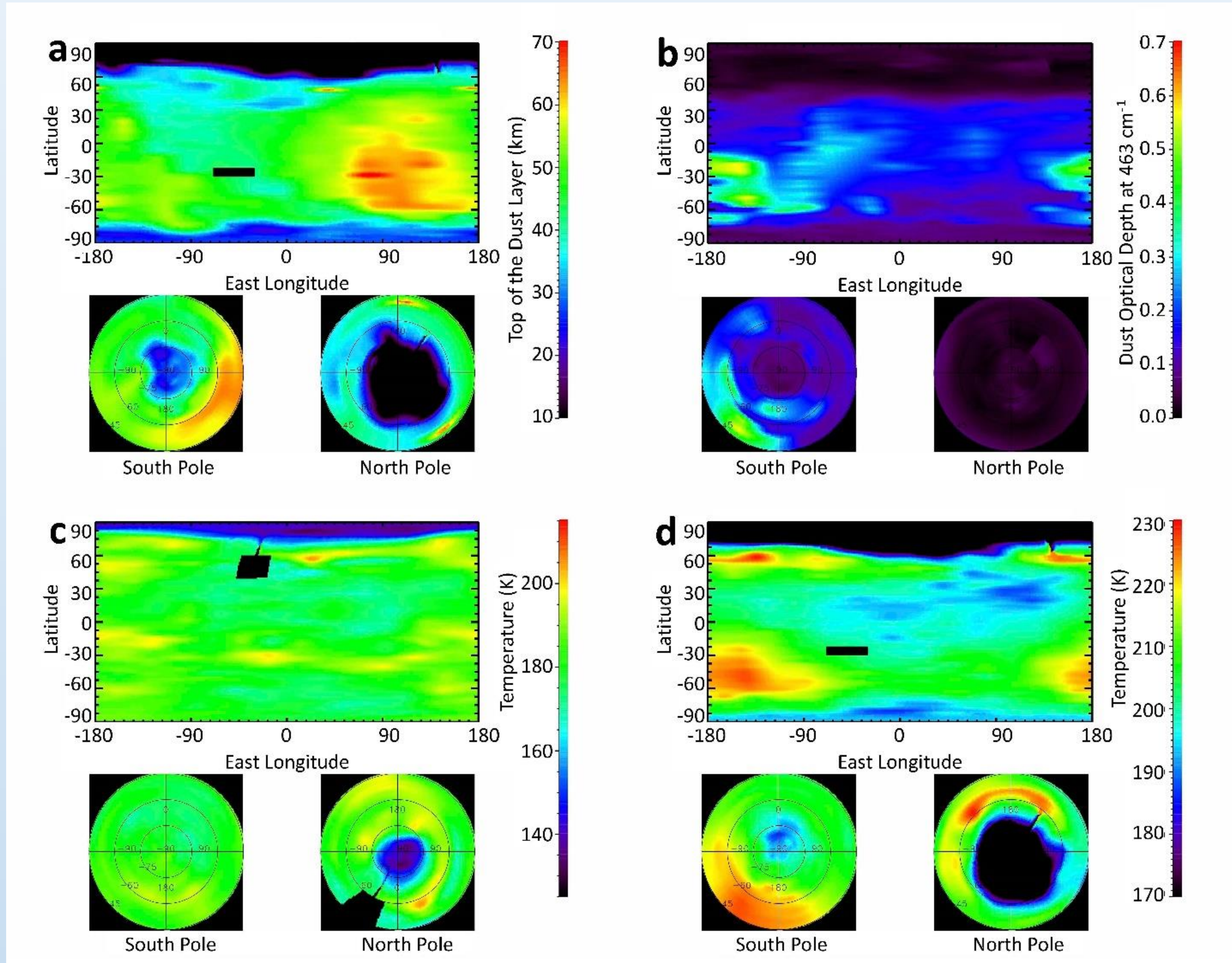

Figure 5. Cylindrical and polar map views of MCS data products to be employed in the proposed analysis. All views are for 29 March 2009, during the mature phase of the MY29A LRDS (Ls=236.5). The altitude of the top of the atmospheric dust layer (km) is shown in (**a**). MCS dust column opacity is shown in (**b**). Nighttime atmospheric temperatures at ~45 km altitude (6.8 Pa pressure level), illustrating dynamical (or adiabatic) heating, are provided in (**c**). Day side atmospheric temperatures at ~25 km altitude (50 Pa), are shown in (**d**).

- **MCS cross–sections of temperature and dust extinction on 29 March reveal longitudinal variability of vertical structures in atmospheric temperatures and dust loading above two lifting centers on this date**

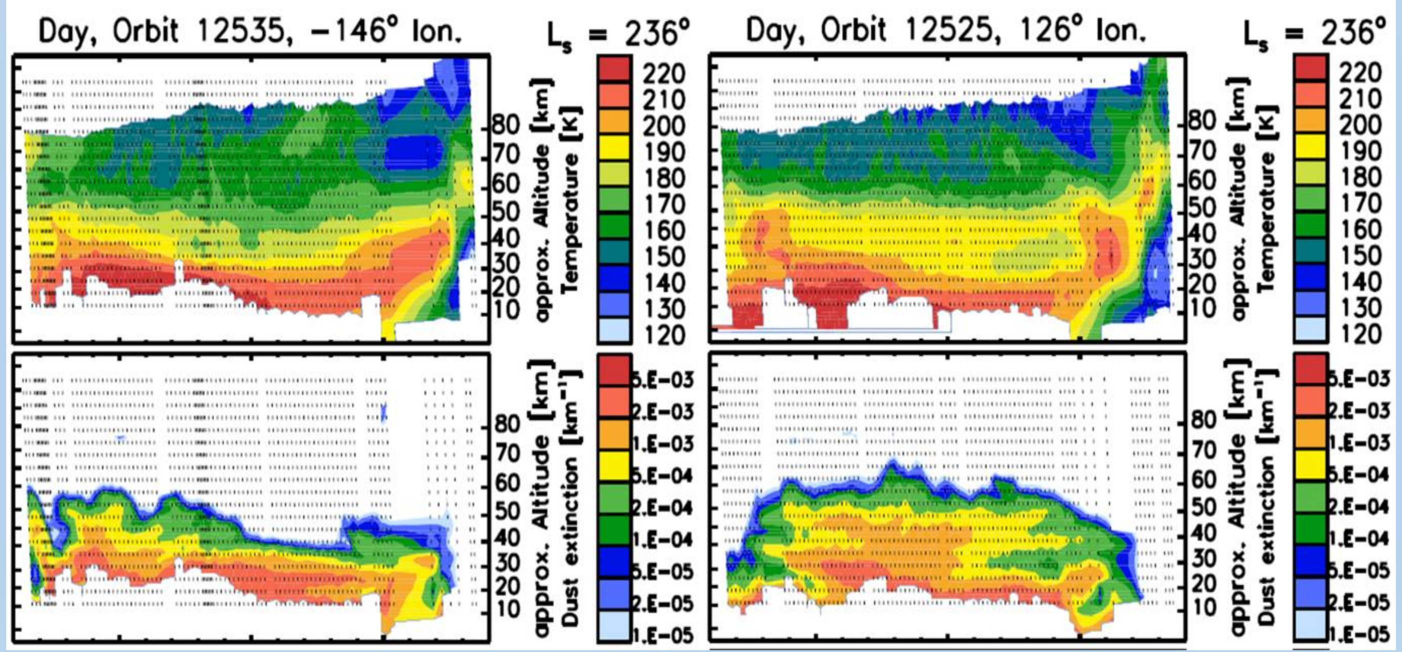

Figure 6. Cross-sections of MCS dayside temperatures (top) and dust extinctions (bottom) from MRO orbits 12535 (left) and 12525 (right).

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