How Do Martian Dust Devils Vary Throughout the Sol?

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1. Abstract
Expectations of Martian dust devil timings have been based upon the measured diurnal maximum thermal contrast at the planet’s surface and observations of terrestrial dust devils, which peak in number in the afternoon[1-3, 5, 6]. In this work we show that the form of dust devil parameterisation in use within most Mars Global Circulation Models produces an unanticipated level of dust devil activity during morning hours, with many locations experiencing a peak in dust devil activity before mid-sol.

We propose the generally accepted understanding of dust devil behaviour on Mars is incomplete and that dust devil activity during morning hours would be expected based solely on insolation-driven near-surface thermal contrast. Our results display a good match with a number of sites; the Pathfinder site is shown in Figure 6. In our results, local sites exhibit a variation in the timing of dust devil lifting between sols.

2. Martian Dust Devils
Dust devils are near-surface atmospheric vortices made visible by the particles they lift from the ground and entrain in a vertical, upwardly-spailing column of air. Dust devils have been identified in many orbital images of Mars[6, 7] (Figure 1) as well as in images returned from rovers on the surface[8, 9] (Figure 2).

Dust within the Martian atmosphere absorbs incident radiation and re-radiates at infrared wavelengths, heating the immediate surroundings[10]; this heating influences local winds, affecting the transport of dust throughout the atmosphere. Changes in wind patterns and dust distribution affect surface geological processes as well as modifying the planet’s climate. Understanding how dust is injected into the atmosphere is key to understanding the Martian climate.

3. Modelling the Martian Atmosphere
The Mars Global Circulation Model (MGCMM) is a global, three-dimensional model of the Martian atmosphere. Large-scale dynamic simulations and physical processes are modelled explicitly, while smaller scale processes are simulated through parameterisation. The MGCMM dust devil parameterisation[11] models dust devils as convective heat engines[12, 13]. The flux of surface dust lifted by dust devils is calculated using the sensible heat flux at the planet’s surface and the dust devil thermodynamic efficiency. The sensible heat flux represents the energy available to drive the dust devil. It is found from the surface-to-atmosphere temperature difference, the near-surface atmospheric density and the horizontal wind speed. The dust devil thermodynamic efficiency depends primarily on the depth of the planetary convective boundary layer.

Similar dust devil parameterisations are currently implemented in most other Mars GCMMs[11, 14].

4. Results
A. Global Diurnal Dust Devil Activity
We plotted the time-of-sol at which dust devil activity peaked across the Martian surface (Fig. 3, Fig. 4). Many regions show a range in the timing of dust devil activity, including unanticipated early peaks in activity (Fig. 5).

Figure 3. Surface plot, colour scale denotes diurnal timing of peak dust devil lifting. Gridboxes in yellow, orange or red identify afternoon peaks in dust devil lifting; blue gridboxes identify morning peaks. (Display data averaged across Ls = 0-30°. White gridboxes indicate zero or near-zero lifting.)

Figure 4. Histogram of the data displayed in Fig. 3, showing (a) the anticipated curve in gridboxes exhibiting peak dust devil lifting during the afternoon and (b) the unanticipated, smaller curve in gridboxes exhibiting peak dust devil lifting during the morning.

Figure 5. Dust devil lifting within example gridboxes through Ls = 120-150°. Each line corresponds to data from one sol (60 sols total). The plots show varying diurnal timings of dust devil lifting: a) morning-only lifting, b) afternoon-only lifting, c) through-sol lifting.

Within the MGCMM parameterisation, the timing of the diurnal peak of dust devil lifting is not determined solely by heating due to insolation (Fig. 7). While the predictable diurnal variation of atmospheric density and surface-to-atmosphere temperature difference provides the environment within which dust devils can form, precisely when they form is governed by local wind speeds, which vary strongly and less predictably. Higher wind speeds result in higher levels of dust devil lifting.

B. Comparison with Surface Observations
Observations made by Mars landers identify more dust devil activity during morning hours than would be expected based solely on insolation-driven near-surface thermal contrast. Our results display a good match with a number of sites; the Pathfinder site is shown in Figure 6. In our results, local sites exhibit a variation in the timing of dust devil lifting between sols.

Figure 6. Dust devil activity in the vicinity of the NASA Mars Pathfinder levels of dust devil activity are shown for the modelled mass of surface dust lifted in each hour (left axis) is marked against the solar heating encompassing the range of results obtained through Ls = 140-190°. Dashed bars identify the number of atmospheric vortices (right axis) recorded by the lander[15, 16].

C. Wind Speeds Govern Dust Devil Diurnal Variation
In the ‘heat engine’ model, the energy that drives dust devil formation is provided by the sensible heat flux at the planet’s surface: F = F_s = C_o U T_{surf} - T_{atm}

References

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5. Conclusions
- Modelled dust devil activity displays a wider diurnal range than was expected from insolation-driven thermal contrast.
- In the MGCMM, diurnal variability of dust devil activity is governed by local wind speeds. Higher wind speeds generate higher levels of dust devil activity.
- Our results show a good match with a number of surface observations of Martian dust devils, in which landers have observed a range of dust devil lifting diurnal distributions.
- Theories of terrestrial dust devil formation may need to be further developed, or tailored specifically, to better fit the Martian environment.
- This work should be published in Jouran in 2017: Diurnal Variation in Martian Dust Devil Activity (Chapman et al.).