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[1,2,3]. 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 theories of dust devil formation may need to be modified specifically for the Martian environment.

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-spiraling column of air. Dust devils have been identified in many orbital images of Mars[4-7] (Fig. 1) as well as in images returned from rovers on the surface[8-10] (Fig. 2).

Dust within the Martian atmosphere absorbs incident radiation and re-radiates it at infrared wavelengths, heating the immediate surroundings[11]; 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 (MGCM)[12] is a global, three-dimensional model of the Martian atmosphere that captures large-scale dynamic circulations and physical processes are modelled explicitly, while smaller scale processes are simulated through parameterisation.

The MGCM dust devil parameterisation[13] models dust devils as convective heat engines[14]. 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 local 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 MGCMs[12,15].

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).

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 near-surface thermal contrast. Our results display a good match with a number of sites; the Pathfinder site is shown in Fig. 6. In our results, local sites exhibit a variation in the timing of dust devil lifting between sols.

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:

\[ q_{\text{heat}} = C_p \rho \frac{dT}{dt} \]

Within the MGCM 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.

5. Conclusions
- Modelled dust devil activity displays a wider diurnal range than was expected from insolation-driven thermal contrast.
- In the MGCM, 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 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 Icarus in 2017: Diurnal Variation in Martian Dust Devil Activity (Chapman et al.).

References

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