EPSC Abstracts
Vol. 11, EPSC2017-294, 2017
European Planetary Science Congress 2017

Meteorological properties of Martian Dust Devils as observed by MSL

H. Kahanpää (1,2), M. T. Lemmon (3), E. Mason (3) and M. Battalio (3)
(1) Finnish Meteorological Institute, Helsinki, Finland (henrik.kahanpaa@fmi.fi), (2) Aalto University / School of Electrical Engineering, Espoo, Finland, (3) Texas A&M University / Department of Atmospheric Sciences, Texas, USA

Abstract

The Mars Science Laboratory rover (MSL) has observed dust devils simultaneously by imaging and by meteorological measurements. We use this data to determine central pressure drops and maximum wind speeds inside these Martian dust devils.

1. Introduction

Dust devils on Mars were first detected in images taken by the Viking orbiters [14]. Since then dust devils have been imaged by several Mars orbiters and landers (reviews of these observations are given in [2] and [10]). In addition, Mars landers with meteorological instrumentation have detected abrupt changes in wind direction and transient pressure dips interpreted as being caused by passing convective vortices [1][5][9][11][12][13]. However, the connection between the vortices detected in the wind and pressure data and the optically detected dust devils and has remained unclear. For example, it has not been known if the vortices detected by meteorological means lifted dust or not. As a consequence, the meteorological properties of Martian dust lifting vortices have been poorly constrained. The reason for this is that dust devils have not been observed simultaneously by both imaging and by meteorological measurements, until now.

2. Methods

2.1 Instrumentation

The MSL rover Curiosity [4] carries a suite of environmental sensors called REMS (Rover Environmental Monitoring Station) [3]. REMS includes sensors for measuring atmospheric pressure, wind speed and direction, air temperature, ground temperature, relative humidity and UV radiation flux. Nominally REMS performs 5-minute long measurement sessions with 1 Hz sampling rate, starting on every Martian hour. Furthermore, one hour long "extended measurement sessions" are performed by REMS at varying times of the sol. MSL is also equipped with cameras capable of filming atmospheric "movies", i.e. sequences of images aimed to survey varying atmospheric phenomena.

2.2 Measurement strategy

A campaign of imaging Dust Devil Search Movies was initiated soon after Curiosity landed in Gale crater on August 6, 2012 [8]. These movies consist of 4 to 24 frames pointed towards North. 249 such movies had been taken up till sol 1520 but only two dust devil had been detected in them [6][8]. However, a dust devil was identified in South/South-West direction in a multispectral sequence taken by Curiosity's Mast Camera (Mastcam) on sol 1520 [6]. Since then Navcam dust devil surveys have been performed in all directions. In these surveys two images are taken in each direction to identify moving features. In addition, "movies" with durations up till 30 minutes, comprising of 21 to 45 frames, have been taken by Navcam in directions where dust devils have been detected in the surveys. REMS extended measurement sessions have been scheduled to cover these movies whenever possible.

2.3 Determining the central pressure drops of imaged vortices

We analyze the REMS atmospheric pressure data measured during Navcam movies that contain identified dust devils. If a pressure dip is detected concurrently with the passing of a dust devil, then we model the pressure field of the dust devil by the

Lorentzian vortex model [1][5][7]. In this model, the pressure p at distance d from vortex center is given by

$$p(d) = p_\infty - \frac{\Delta p_{centre}}{(2d/D)^2 + 1}, \qquad (1)$$

where p_∞ is the background pressure level, D is the half-maximum diameter of the pressure depression of the vortex and Δp_{centre} is the magnitude of the pressure depression at the center of the vortex. The pressure curve detected by a stationary measurement station, as a function of time t, can be calculated from eq. 1 by assuming that the vortex moves along a straight line and passes by the measurement station at distance $d_{\min}$ at time point t_0 [1]:

$$p_{obs}(t) = p_\infty - \frac{\Delta p_{obs}}{(2(t-t_0)/\Gamma)^2 + 1}, \qquad (2)$$

where Γ is the half-maximum duration of the detected pressure dip and Δp_{obs} is the magnitude of the detected pressure drop at time point t_0. The ratio of the detected pressure drop Δp_{obs} and the central pressure drop Δp_{centre} can be solved from geometry:

$$\frac{\Delta p_{centre}}{\Delta p_{obs}} = \frac{(\Gamma U)^2}{(\Gamma U)^2 - 4d_{\min}^2}, \qquad (3)$$

where U is the translation velocity of the vortex. We use eq. 3 to determine the central pressure drops of dust devils detected simultaneously in the movies and pressure data. The detected pressure drop duration Γ and the detected pressure drop magnitude Δp_{obs} are solved from the pressure data, and the distance of the closest encounter $d_{\min}$ with the dust devil and its translation velocity U are determined from the images, leaving Δp_{centre} the only unknown factor in eq. 3. Further, when the central pressure drop of a dust devil has been solved, then the maximum tangential wind velocity of the dust devil can be solved by assuming that the vortex is in cyclostrophic balance. We estimate the maximum wind velocities inside the dust devils by summing the calculated maximum tangential wind velocities and the observed translation velocities.

3. Results

We have identified 214 unique dust devils in the dust devil surveys and movies imaged over sols 1545 through 1660. The great majority of these dust devils have been detected in the foothills of Aeolis Mons, the central mountain of Gale crater. Apparently the explanation why only two dust devils were detected in the original Dust Devil Search Movies is that these movies faced North, i.e. towards the plains on the crater floor and away from the central mountain [6]. The REMS instrument recorded environmental variables, including atmospheric pressure, concurrently with 56% of the images in Navcam dust devil surveys and movies. We are currently investigating the dust devils detected in these images using the methods described in section 2. First results of the inferred central pressure drops and maximum wind speeds inside these Martian dust devils will be shown in this presentation.

4. Summary and Conclusions

This is the first study where central pressure drops of Martian dust devils are determined using in situ data. The results will be used to constrain the threshold pressure drop and/or threshold wind velocity required for dust lifting in a Martian convective vortex. Knowledge on these threshold values helps in parametrizing the amount of dust lifted by dust devils in numerical models of the Martian atmosphere.

Acknowledgements

The contribution of H. Kahanpää in this study was funded by The Finnish Cultural Foundation (grant number 00170395), and the travel expenses of H. Kahanpää were granted by the Emil Aaltonen foundation.

References

[1] Ellehoj, M. D. et al.: Convective vortices and dust devils at the Phoenix Mars mission landing site, J. Geophys. Res., Vol. 115, E00E16, 2010.

[2] Fenton, L. et al.: Orbital Observations of Dust Lofted by Daytime Convective Turbulence, Space Sci. Rev., Vol. 203(1), pp. 89-142, 2016.

[3] Gómez-Elvira, J. et al.: REMS: The Environmental Sensor Suite for the Mars Science Laboratory Rover, Space Sci Rev, Vol. 170, pp. 583-640, 2012.

[4] Grotzinger, J. P. et al.: Mars Science Laboratory mission and science investigation, Space Sci. Rev., Vol. 170, pp. 5-56, 2012.

[5] Kahanpää, H. et al.: Convective vortices and dust devils at the MSL landing site: Annual variability, J. Geophys. Res. Planets, Vol. 121(8), pp. 1514-1549, 2016.

[6] Lemmon, M. T., Newman, C. E., Renno, N., Mason, E., Battalio, M., Richardson, M. I., and Kahanpää, H.: Dust devil activity at the Curiosity Mars rover field site, 48th Lunar and Planetary Science Conference, 20–24 March 2017, The Woodlands, Texas, USA, 2017.

[7] Lorenz, R. D.: Heuristic estimation of dust devil vortex parameters and trajectories from single-station meteorological observations: Application to InSight at Mars, Icarus, Vol. 271, pp. 326-337, 2016.

[8] Moores, J. E. et al.: Observational evidence of a suppressed planetary boundary layer in northern Gale Crater, Mars as seen by the Navcam instrument onboard the Mars Science Laboratory rover, Icarus, Vol. 249(15), pp. 129-142, 2015.

[9] Murphy, J., and Nelli, S.: Mars Pathfinder convective vortices: Frequency of occurrence, Geophys. Res. Lett., Vol. 29(23), pp. 2103, 2002.

[10] Murphy, J. et al.: Field Measurements of Terrestrial and Martian Dust Devils, Space Sci. Rev., Vol. 203(1), pp. 39-87, 2016.

[11] Ringrose, T. J., Towner, M. C., and Zarnecki, J. C.: Convective vortices on Mars: A reanalysis of Viking Lander 2 meteorological data, sols 1–60, Icarus, Vol. 163(1), pp. 78-87, 2003.

[12] Ryan, J. A., and Lucich, R. D.: Possible dust devils, vortices on Mars, J. Geophys. Res., Vol. 88(C15), pp. 11005-11011, 1983.

[13] Steakley, K., and Murphy, J.: A year of convective vortex activity at Gale crater, Icarus, Vol. 278, pp. 180-193, 2016.

[14] Thomas, P., and Gierasch, P. J.: Dust devils on Mars, Science, Vol. 230(4722), pp. 175-177, 1985.