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Dust Devils and Convective Vortices on Mars

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Abstract

Dust devils are low pressure convective vortices able to lift dust from the surface of a planet. They are a common feature on Mars and they can also be found on desertic locations on Earth. On Mars they are considered an important part of the atmospheric dust cycle. Dust in Mars is an essential ingredient of the atmosphere where it affects the radiative balance of the planet. Here we review observations of these dusty vortices from orbit, from in situ measurements on the surface of Mars and some of the models developed to simulate them.

1 Introduction

Dust devils are low pressure convective vortices, with a dusty core and high rotational wind speeds, whose intensity depends on the vertical extension of the Planetary Boundary Layer (PBL) [20]. They are usual in Earth and Mars, being much more common and one order of magnitude larger in Mars [1]. When these convective vortices attain horizontal velocities large enough they are able to lift dust inside of the vortex and then they can be directly observed by high-resolution cameras on orbiters as dusty plumes. Depending on the intensity and dust amount of the dust devil, and also of the illlumination angle from the Sun, it is possible to observe its shadow on the ground, and therefore to measure its height. Images from orbit can also observe the track that dust devils leave on the ground, which can last for months.

There are now several missions that have landed on Mars. Some of these missions have carried meteorological sensors like pressure sensors and visual cameras where dust devils can also be identified. The Phoenix lander, Mars Pathfinder and Mars Science Laboratory rovers carried both kind of instruments. The close pass of a dust devil produces a short-lived pressure drop of about 1 Pa in these sensors. However, without further information it is not possible to know if the sudden pressure drop is due to a dust devil or just to a convective vortex with no dust inside. Without simultaneous wind data it is also not possible to identify how far or close the vortex passes or the maximum intensity of the pressure drop at the vortex center.

2 Visual observations from orbit

Dust devils from orbit can be directly observed in high-resolution images of the planet; or their tracks can be identified by linear structures in the ground which sometime can be observed on different days showing surface changes. Since the use of orbital images provides a nearly global coverage of the Martian surface statistical inferences of where these events are more probable can be obtained. Orbital images with dust devils large enough to be observed allow to estimate their dimensions and movement over the surface. However, only the largest events are directly observed and their observation depends on the availability of orbit images of suitable regions for dust devil formation and close to the noon when these events develop more frequently possibly due to the larger thermal differences between the hot surface and the colder air. For instance, [6] noticed that images from the Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) of some regions with extensive track formation (e.g. Casius quadrangle) showed absence of dust devils observed, due to the time at which the images were collected far from local noon.

There are several published works that have studied the dust devils tracks on the surface. [28] and after [19] present a search of these ground features using Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), Context Camera (CTX) and High Resolution Imaging Science Experiment (HiRISE) images. From these observations they inferred wind directions and dust devils formation rate from 557 dust devils traks. They also extracted an estimation of the duration of dust devils (from 10s of seconds to several minutes) from their track lengths and diameters. Vortex wind motions were measured from HiRISE images in [2] in which dust devils appear in motion revealing tangential winds of around 20 to 30m/s. An extensive survey was made by [6] using images from the MOC camera on MGS over nine regions on Mars including the Amazonis region, known as one of the most active dust devil sites on Mars. Images from the same instruments were also used by [3] to evaluate the four possible landing regions for the Phoenix Mars Lander, measuring dust devils tracks but with no evidence of active dust devils.

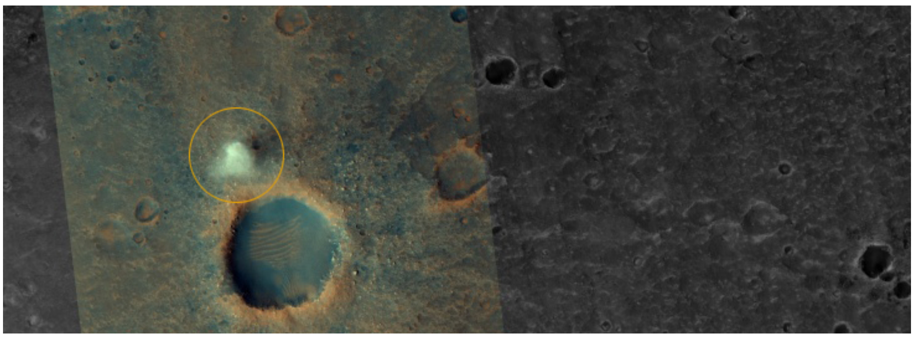

Figure 1: Dust Devil captured from orbit, inside the orange circle, in the image ESP_021925_1650 from HiRISE instrument on March 31, 2011.

Other instrument that has been used to do similar dust devil studies is the High Resolution Stereo Camera (HRSC) on board Mars Express (MEX). From these images it is possible to measure the dimensions and speed of dust devils, concluding that these dusty events move with the wind direction [23]. Analysis of dust devil tracks on MOC and HiRISE images by [24] and [25] also allow to infer surface wind directions that can be compared with results from simulations donw using General Circulation Models (GCM) [26].

3 Visual observations from rovers

First direct observations of dust devils from Mars surface were obtained by the cameras on the Mars Pathfinder (MPF) rover. Dust devils were not obvious in the images obtained by MPF but at least five dust plumes could be identified removing the contribution of the dust haze and using spectral differencing techniques [13]. New events were detected by [5] varying the contrast range of the frames, and correcting them with a flat field to eliminate the signal of the background dust haze. More solid results were obtained by the Spirit mission in the Gusev crater which identified 533 dust devils observed from Ls 137 to 339 covering a full dust devil season in the sourthern hermisphere [8].

Figure 2: Dust Devils observed on Sol 616 of Spirit's mission in Gusev Crater at approximately 1 PM Mars Local Solar Time. NASA/JPL.

Data from the Phoenix lander were analyzed in [4] resulting in 37 unique dust devils in images provided by the Surface Stereo Imager (SSI) instrument. However sizes and distances to these dust devils were difficult to analyze. The last visual detection of dust devils was reported by [14] with images from the Navigation Cameras (Navcam) of MSL. Currently this is the only visual detection of a dust devil by MSL but this detection is controversial due to the low contrast of the dust devil that requires very strong image processing techniques to make it visible.

4 Detections from pressure drops

Sudden pressure drops in the pressure signal of a variety of meterorological instruments on Mars surface have been used as the basis to characterize statistically the abundance of dust devils of many Martian landing sites. Typical dust devils and warm vortices produce local pressure drops of 0.5 Pa or larger with a variable duration of a few to some 10s of seconds.

A systematic search with the Mars Pathfinder surface pressure data were published by [15], with 79 detections of sudden pressure drops observed during a period of 83 sols centered at Ls 163 (North late summer). [4] published a detailed analysis of pressure data from the Phoenix Mission with 197 vortices found in a period of 150 sols centered at Ls 113 (North early summer). Systematic studies of Dust Devils with REMS data have been published recently: [14] found 149 vortices during the first 360 sols of the mission; [10] and [27] found 245 and 252 events during 707 and 681 sols respectively. Similar methodology was used in [16] to evaluate the pressure data from REMS instrument during the first two Martian years of MSL on Mars, with 694 sudden pressure drops found. The larger amount of data examined in this last work allowed to characterize seasonal changes in the abundance of warm vortices at Gale crater, observe interannual variability with more pressure drops in the second martian year than in the first, and characterize the dayly variation of warm vortices activity.

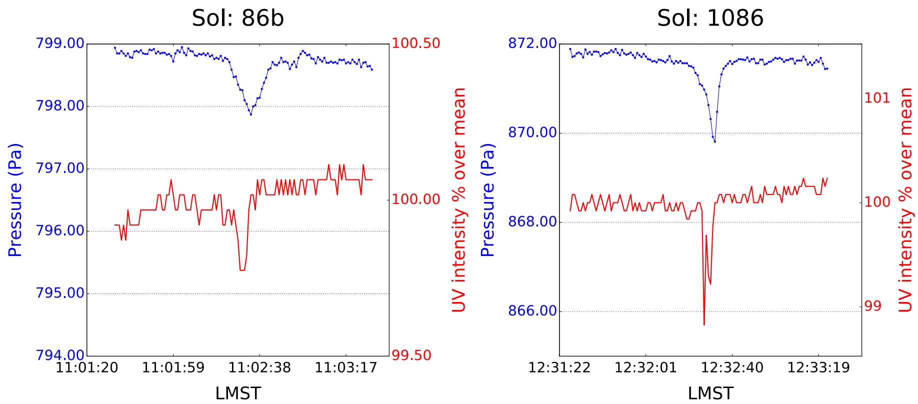

Figure 3: Pressure drops captured during sol 86 (Ls=200°) and sol 1086 (Ls=32°), with an almost simultaneous small drop of UV signal (0.3% and 1.2% of UV intensity respectively). The geometry discards any shadow cast from the masthead or REMS booms.

In order to find if these vortices correspond to dust devils able to lift dust from the surface one possible strategy is to examine variations in the signal from the REMS UV sensors at the same time or close to sudden pressure drops. This UV light variations could be caused by the partial shadowing of sunlight from the dust in the dust devil. One of these events was found in [10] with a UV drop of 0.3% and a second one on [16] with a more intense decrease of the UV signal on the order of 1.2 %. Both events are shown in Figure 3.

5 Dust devil models: From data analysis to Large-Eddy Simulations

Phenomenological models able to provide more information on the vortex characteristics from the pressure signal they produce [11] and from pressure and simultaneous wind data have been presented in [12]. Simple analytical models have been developed to understand the basic physics governing dust devils on Mars [20, 9]. General Circulation Models (GCM) can also be used to investigate the conditions in which these vortices can develop ([17, 18]). Advanced Large-Eddy Simulations (LES) solving the equations of atmospheric fluid dynamics with enough spatial resolution to simulate convective vortices have been applied to the study of Martian dust devils. LES provide an excellent tool to understand the conditions of the formation of dust devils [22]. From these simulations the convective vortices show velocities up to around 10 m/s, tangential velocities from 10 to 20 m/s and a pressure drop in the center of the vortex of about 2 Pa, similar to large events in the in situ measurements from different spacecrafts. LES show a strong correlation between the intensity of convective motions with surface pressure that is more noticeable when the pressure is lower [21]. According to several simulations, the wind conditions affect also to the formation of convective vortices which are less probable in windy conditions [7].

6 Conclusions

Dust devils are a common feature on Mars and Earth surfaces. On Mars they are larger, more frequent and have a larger overall impact than on Earth. The study of dust devils involves different methodologies from image analysis to meteorological measurements at Mars surface and numerical simulations. Comparison with results from GCMs and LES can be used as one of the tests to validate these models. In spite of their frequency and intensity, their overall effect in the dust cycle on Mars atmosphere is yet to be assesed.

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References

[1] Balme, M., & Greeley, R. (2006). Reviews of Geophysics, 44(3), RG3003.

[2] Choi, D. S., & Dundas, C. M. (2011). Geophysical Research Letters, 38(November), 15.

[3] Drake, N. B., Tamppari, L. K., Baker, R. D., Cantor, B. a., & Hale, A. S. (2006). Geophysical Research Letters, 33(19), 25.

[4] Ellehoj, M. D., Gunnlaugsson, H. P., Taylor, P. a., Kahanp, H., Bean, K. M., Cantor, B. a., Whiteway, J. (2010). Journal of Geophysical Research, 115, E00E16.

[5] Ferri, F., Smith, P. H., Lemmon, M., & Renn, N. O. (2003). Journal of Geophysical Research: Planets, 108(E12).

[6] Fisher, J. A., Richardson, M. I., Newman, C. E., Szwast, M. A., Graf, C., Basu, S., Wilson, R. J. (2005). Journal of Geophysical Research: Planets, 110(E3).

[7] Gheynani, B. T., & Taylor, P. A. (2010). Boundary-Layer Meteorology, 137(2), 223235.

[8] Greeley, R., Whelley, P. L., Arvidson, R. E., Cabrol, N. a., Foley, D. J., Franklin, B. J., Thompson, S. D. (2006). Journal of Geophysical Research, 111(E12), E12S09.

[9] Horton, W.; Miura, H.; Onishchenko, O.; Couedel, L.; Arnas, C.; Escarguel, A.; Benkadda, S.; Fedun, V. (2016). Journal of Geophysical Research: Atmospheres, 121, 7197-7214.

[10] Kahanpää, H., Newman, C., Moores, J., Zorzano, M.-P., Martn-Torres, J., Navarro, S., Schmidt, W. (2016). Journal of Geophysical Research: Planets, 121(8), 15141549.

[11] Lorenz, R. D. (2013). Planetary and Space Science, 76(1), 96103.

[12] Lorenz, R. D. (2016). Icarus, 271, 326337.

[13] Metzger, S. M., Carr, J. R., Johnson, J. R., Parker, T. J., & Lemmon, M. T. (1999). Geophysical Research Letters, 26(18), 2781.

[14] Moores, J. E., Lemmon, M. T., Kahanp, H., Rafkin, S. C. R., Francis, R., Pla-Garcia, J., McCullough, E. (2015). Icarus, 249, 129142.

[15] Murphy, J. R., & Nelli, S. (2002). Geophysical Research Letters, 29(23), 2103.

[16] Ordonez-Etxeberria I., Hueso R., Snchez-Lavega A., 2016 (submitted).

[17] Pla-Garcia, J., et al. (2016). Icarus, 280, 103-113.

[18] Rafkin, S.C.R., et al. (2016). Icarus, 280, 114-138.

[19] Reiss, D., & Lorenz, R. D. (2016). Icarus, 266, 315330.

[20] Rennó, N. O., Burkett, M. L., & Larkin, M. P. (1998). Journal of the Atmospheric Sciences, 55(21), 32443252.

[21] Spiga, A.,& Lewis, S. R. (2010). The Mars Journal, 5, 146158.

[22] Spiga, A., Barth, E., Gu, Z., Hoffmann, F., Ito, J., Jemmett-Smith, B., Wei, W. (2016). Space Science Reviews, 131.

[23] Stanzel, C., Pätzold, M., Williams, D. a., Whelley, P. L., Greeley, R., Neukum, G., and the HRSC Co-Investigator Team. (2008). Icarus, 197, 3951.

[24] Statella, T., Pina, P.,& da Silva, E. A. (2012). Planetary and Space Science, 70(1), 4658.

[25] Statella, T., Pina, P., & da Silva, E. A. (2014). Advances in Space Research, 53, 18221833.

[26] Statella, T., Pina, P., Silva, E. A., Nervis Frigeri, A. V., & Neto, F. G. (2016). Planetary and Space Science, 110.

[27] Steakley, K., & Murphy, J. (2016). Icarus, 278, 180193.

[28] Reiss, D., Spiga, A., & Erkeling, G. (2014). Icarus, 227(E12), 820.