DUST DEVILS AND CONVECTIVE VORTICES DETECTED BY MSL

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Introduction:

Dust devils are small-scale whirlwinds, driven by solar insolation [*Sinclair*, 1969]. Dust devils on Mars were first imaged by the Viking orbiters [*Thomas and Gierasch*, 1985] and have since then been studied using the data measured by all successful orbiter and lander missions to Mars. It has been suggested that they maintain the background dust haze of the Martian atmosphere [*Basu et al.*, 2004; *Cantor et al.*, 2006; *Whelley and Greeley*, 2008].

In this study signatures of dust devils and dustless convective vortices were sought in the data measured by NASA's Mars Science Laboratory (MSL) rover during its first Martian year (sols 13 ... 681). MSL is the first Mars lander equipped with a high-resolution pressure sensor that has operated on the surface for longer than one Martian year. This enabled studying the annual variation in vortex activity using surface pressure measurements for the first time.

This study has been previously presented by the authors in JGR Planets [*Kahanpää et al.*, 2016].

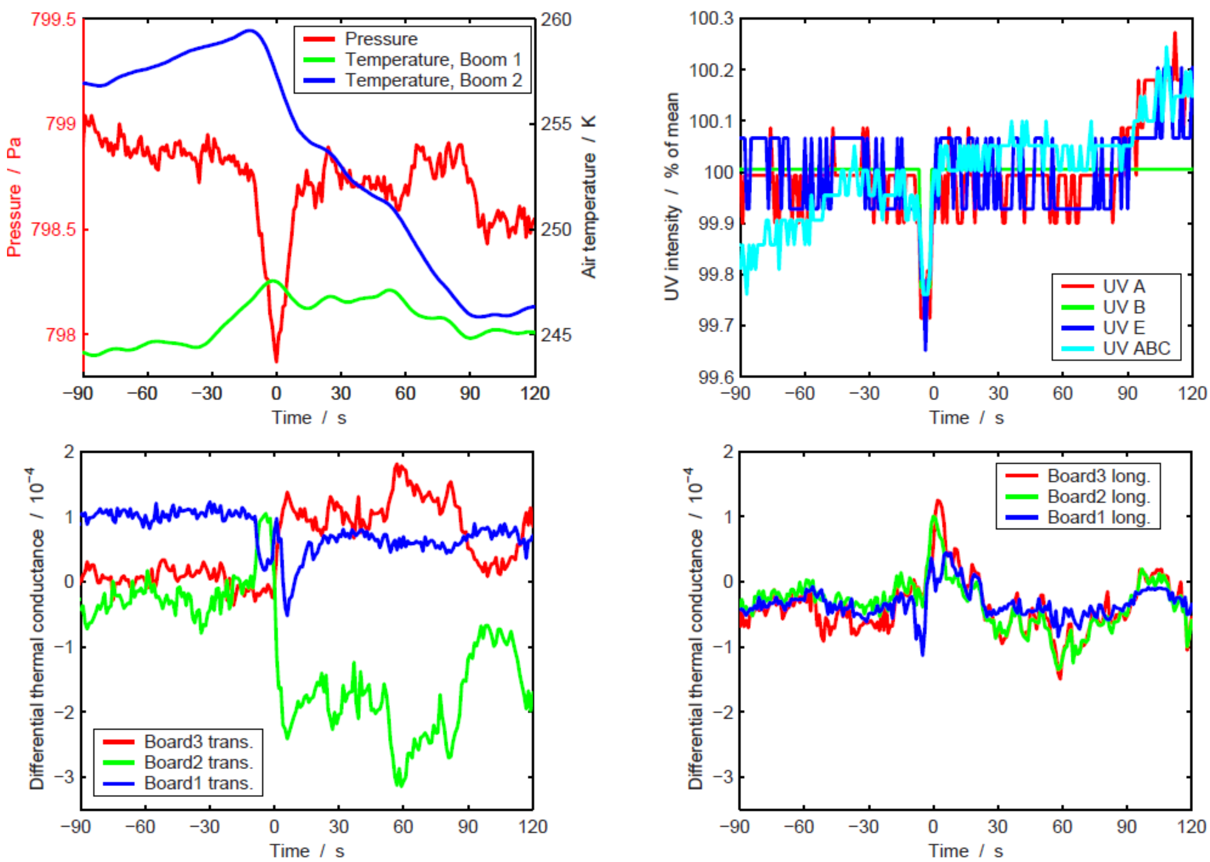

Figure 1: REMS measurements during a vortex event on MSL sol 86 at 11:02 Local Mean Solar Time. Top left: pressure and air temperature. Top right: Ultraviolet radiation intensity. Bottom left: wind sensor raw data in transversal direction. Bottom right: wind sensor raw data in longitudinal direction.

Methods:

When a convective vortex passes by a fixed meteorological station, a transient pressure drop is detected as the pressure is lower at the vortex center [*Ringrose et al.*, 2007]. Such abrupt pressure drops were identified automatically in the pressure record measured by the Rover Environmental Monitoring Station (REMS) instrument onboard MSL [*Gómez-Elvira et al.*, 2012]. The used identification algorithm searches for 20 s intervals that fulfill the following criteria:

– Mean pressure > 0.1 Pa lower than mean of previous and next 20 s intervals
– Minimum pressure > 0.3 Pa lower than mean of previous and next 20 s intervals.

The same algorithm has been previously used in the study on the Phoenix data by *Ellehoj et al.*, [2010].

All pressure events identified by the algorithm were gone through by hand and classified as "true", "potentially true" or "false". Only events classified as “true” and with magnitude > 0.5 Pa were used in this study.

Results:

– 252 transient pressure drops were identified.
– These events resembled the vortex signatures detected by the previous Mars landers Pathfinder and Phoenix [*Murphy and Nelli*, 2002; *Ellehoj et al.*, 2010]; however, the MSL observations contained fewer pressure drops greater than 1.5 Pa and none greater than 3.0 Pa.
– Coincident wind variation was detected in 87 % of the events, providing further evidence of vortex passage.
– A clear, coincident minimum in UV radiation flux was detected in only one event (Figure 1). This drop in UV intensity was probably caused by dust lifted by the vortex and obscuring sunlight. The non-detections of clear UV dips in all other events indicates that these vortices were generally not lifting dust. This observation fits very well with the result that only one probable dust devil has been observed visually by MSL [*Moores et al.*, 2015]
– Coincident variations in air temperature readings proved to be hard to interpret, as the REMS air temperature sensors are affected by heat generated by the rover [*Gómez-Elvira et al.*, 2014].
– Dimensions of the vortices were evaluated by multiplying durations of pressure drops with background wind velocities. The resulting "encounter lengths" ranged from 2.3 m to 755 m, with small vortices more common.
– The vortex detections occurred between 9:02 and 15:56 Local True Solar Time and their occurrence rate peaked in the noon hours.
– During the most favorable season (L_S 112.5° to 247.5°) the noontime occurrence frequency was practically the same as that observed by Phoenix [*Ellehoj et al.*, 2010] and about 2/3 of that detected by Pathfinder [*Murphy and Nelli*, 2002].

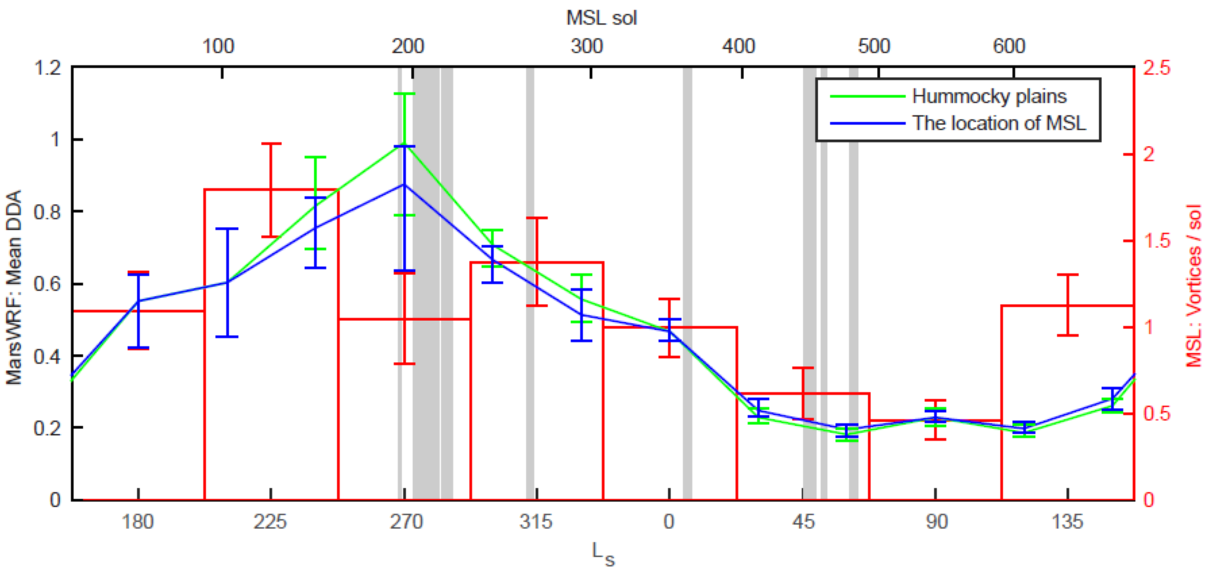

Figure 2: Mean daytime Dust Devil Activity (DDA) determined by MarsWRF, compared to the estimated number of vortices with magnitude > 0.5 Pa passing over MSL per sol, as a function of solar longitude L_S. The green line shows the DDA at grid point 137.4438 °E, 4.6049 °S, close to the MSL landing site, and the blue line the DDA at the closest grid point belonging to the same geologic unit with the location of MSL at each season. The light grey bars in the background show data gaps, i.e. periods with no REMS data.

- The occurrence frequency of vortex encounters can be converted into areal density of vortices by taking into account that their temporal coverage equals their spatial coverage [*Moores et al.*, 2015]. By using this relationship and the evaluated distribution of vortex diameters we calculated that the observed mean noontime occurrence frequency correspond to 1 vortex with central pressure depression > 0.5 Pa per 2 square kilometers.
- Vortices were detected in all seasons of the Martian year. However, there was a circa 4-fold seasonal variation in their occurrence frequency.
- The detected annual variation in the number of convective vortices followed approximately the variation in Dust Devil Activity (DDA) predicted by the MarsWRF numerical climate model [*Richardson et al.*, 2007] (Figure 2). DDA is a measure of the flux of energy available to drive dust devils, derived from the "heat engine" model [*Rennó et al.*, 1998; 2000]
- A sudden increase in vortex activity was detected on MSL sol 664. A survey of MARCI images revealed that this vortex activity was related to a passing dust storm front.

Conclusions:

We have observed that the annual variation in the occurrence rate of convective vortices on Mars follows DDA predicted by a numerical climate model. This result does not prove, however, that the amount of dust lifted by dust devils would depend linearly on DDA, as is assumed in the dust lifting parametrizations of several numerical models of the Martian atmosphere [e.g. *Newman et al.*, 2002; *Basu et al.*, 2004, *Kahre et al.*, 2006; *Newman and Richardson*, 2015]. According to our observations, the vortices on the MSL landing area lift almost no dust, even if DDA differs from zero during every sol of the Martian year. The situation is different than on the landing sites of Pathfinder and Phoenix where numerous dust devils were imaged. [*Metzger et al.*, 1999; *Ferri et al.*, 2003; *Ellehoj et al.*, 2010]. The obvious explanation for this is the smaller proportion of strong vortices with large central pressure drops. This implies that solar forcing affects the number of dust devils on Mars in two ways: by modulating the number of all vortices and by modulating the proportion of vortices stronger than the dust lifting threshold.

The modulation of the vortex pressure drop distribution explains why the number of dust devils imaged by Mars orbiters and landers varies both spatially and seasonally more than the DDA [*Kahre et al.*, 2006]. Even if DDA differs from zero during noontime almost everywhere on Mars, in all seasons, no visually detectable dust devils form if all vortices are too weak to lift dust. A more realistic dust lifting parametrization would thus require a theory where the energy available to drive vortex activity and the pressure drop distribution of the vortices were modeled separately.

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