DUST DEVIL ACTIVITY AT THE CURIOSITY MARS ROVER FIELD SITE.

M. T. Lemmon[1] and C. E. Newman[2], N. Renno[3], E. Mason[1], M. Battalio[1], M.I. Richardson[2], and H. Kahanpää[4].
[1]Texas A&M University (College Station, TX, 77843-3150, USA, lemmon@tamu.edu); [2]Aeolis Research; [3]Univ. Michigan; [4]Finnish Meteorological Institute.

Introduction: Vortices and dust devils are important boundary layer processes for energy transport and their contribution to the atmosphere's dust load [1,2]. They have been observed on Mars both from orbit and from landers and rovers [1,3]. While vortices have been characterized for the first Mars year of the Curiosity mission [4,5], there is only one published report of an imaged dust devil [6].

Imaging of dust devils: As of sol 1561, we have identified 19 dust devils or other dust lifting events (such as gusts) in Navcam and Mastcam images. In all cases, they were identified based on repeat images. One was identified in a Mastcam multispectral sequence on sol 1520; the remainder were identified in atmospheric monitoring movies that include the horizon. Two dust devils have been identified in 250 North-looking dust devil movie sequences (chosen to maximize areal coverage over Aeolis Palus); the remaining Navcam detections were in cloud movies that include the lower parts of Aeolis Mons. Figure 1 shows example dust devil or gust images. Generally, the dust events are not observable on unprocessed images, but show clearly in ratio images. The lifted dust clouds have contrasts of one to several percent; optical depths likely range up to 0.2 or so. Figure 2 shows the sampling of the south-looking image sequences that showed dust devils.

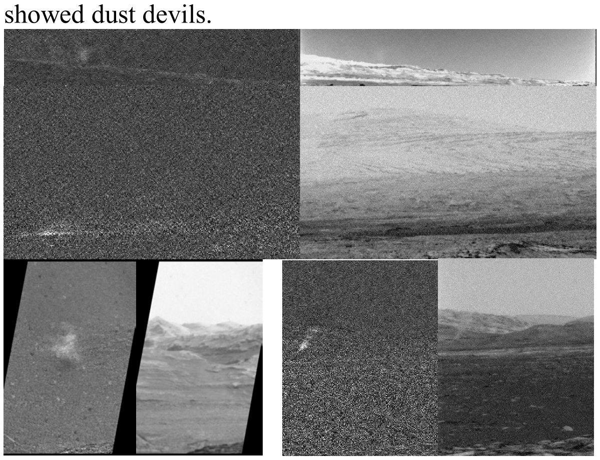

Figure 1: Images of dust devils in Gale crater. Top row: ratio image and Navcam image from sol 1304, NCAM00567 sequence; middle row: ratio and Navcam image from sol 744, NCAM00552 sequence; bottom row: ratio and Mastcam image from sol 1520, MCAM00741 sequence, and ratio and Navcam image from Sol 1545, NCAM00554.

Other dust lifting phenomena. In many images, the morphology of the dust cloud is indistinct, given the Navcam resolution. Most of the images are consistent with dust devils; some are distinctly columnar in shape; about a quarter are laterally extensive. The latter generally occur over the dune field, and may represent gust inducing dust lifting via large-scale saltation events.

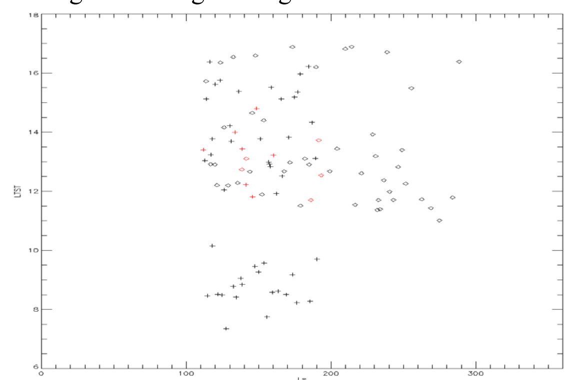

Figure 2: Temporal distribution of imaged dust lifting (red) and of other image sequences that cloud have shown dust lifting (black).

Detections of vortices: Given the rarity of dust devils in north-looking images and the much higher occurrence in images of the mound (1 per 100 sequences vs. 1 per 10 sequences), we surveyed REMS pressure and temperature data for vortices as the rover traversed closer to the mound. We used methods similar to ref. 5, looking for a pressure drop of at least 0.5 Pa, with several samples of the pressure drop, and with a person inspecting algorithmic detections to determine dust devil vs. artifact, and to determine of there was also a signal in the UV data from shadowing. We find vortices peak near noon; are more common in summer to autumn; and are more common later in the mission (Figure 3).

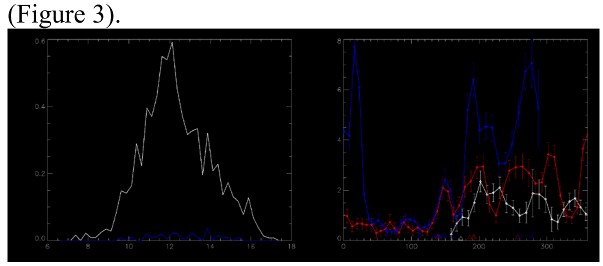

Figure 3: Left: Vortices per hour over LTST (white) and UV-shadow events (blue). Right: Vortices per sol over L_S (white=Mars year 31, red=Mars year 32, blue=Mars year 33).

Development of day-time turbulence. We surveyed all REMS data to characterize pressure variability. Over 10-minute intervals, we determined RMS variation of pressure with respect to a cubic-polynomial fit (Fig. 4). During daytime, a quiescent transition period ($\Delta P<0.1$ Pa) is observed before the onset of a convectively active period ($\Delta P>0.1$ Pa). The active period starts earlier and ends later during summer than in other seasons. During sols ~1000 to ~1100 and 1400 to the end of the survey, we see enhanced activity that does not fit the other two Mars years for the same season. The earlier episode marks the traverse over Marias pass; the latter represents the transition onto and through Murray Buttes.

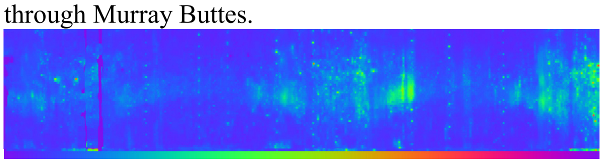

Figure 4: Convective activity over time. RMS pressure variation over ~10 minute intervals is shown, averaged over ~1 hour and ~ 28 sols. Color bar is 0.04-0.26 Pa. Sol range, horizontal, is 1-1551; LTST range, vertical, is 6-18 hours.

Modeling the distribution of dust devils: Renno et al. [7] provided a theory for dust devils based on treating them as convective heat engines. The 'dust devil activity' is defined as the surface sensible heat flux multiplied by the vertical thermodynamic efficiency (which increases with the thickness of the Planetary Boundary Layer [PBL]). This theory can be combined with the output from Mars atmosphere models to predict the amount of vortex activity and dust devil-produced dust lifting [4,8,9].

Figure 5 shows the predicted dust devil activity in Gale Crater, based upon output from a nested mesoscale (~500m resolution) model simulation using the MarsWRF model [10]. The top row shows the surface sensible heat flux, which depends on the surface-to-air temperature difference and the surface wind stress, and shows clear dominance of the upper slopes of Aeolis Mons in the NW quadrant of the crater where MSL landed, peaking in the noon plot.

The second row shows thermodynamic efficiency, which has far more variability in terms of spatial pattern with time of sol and shows peak values on the northern rim in the noon and 3pm plots.

Overall, however, the spatial variation in dust devil activity - shown in the bottom row - is dominated by the larger spatial variation in surface sensible heat flux, and largely follows that pattern, with peak dust devil activity predicted on the slopes of Aeolis Mons to the S and SE of MSL's current position.

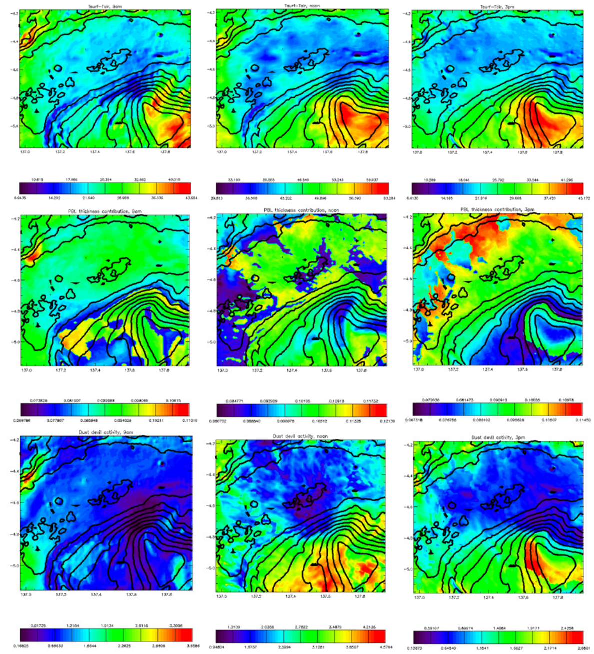

Figure 5: Spatial distribution of sensible heat flux (top), thermodynamic efficiency (middle), and dust devil activity (bottom) at 9 AM (left), noon (middle), and 3 PM (right).

Conclusion: We have analyzed systematic imaging surveys and meteorological data over the first 2.3 Mars years of the MSL mission. Dust devils are more common than previously thought. During mid-day times, dust devils appear in over 10% of surveyed image sequences. Detected dust devils are associated with the lower foothills of Aeolis Mons, out to the nearby dunes. Vortices are more common after the first Mars year. While the distribution of vortex strength has not changed, the larger number of vortices results in a larger number of strong vortices and a larger number of dust-containing vortices. We are investigating the spatial and temporal distribution of dust devils with mesoscale models. Our results suggest that local heating and winds are more important than boundary layer thickness for explaining the observed results.

References: 1. Fenton et al. 2016, Space Science Rev. 203, 82-142.. 2. Klose et al. 2016 Space Science Rev., 203, 377-426. 3. Murphy et al. 2016, Space Science Rev., 203, 39-87. 4. Kahanpaa et al. 2016, J. Geophys. Res. 121, 1514-1549. 5. Steakley and Murphy 2016, Icarus 278, 180-193. 6. Moores et al., 2015, Icarus 249, 129-142. 7. Renno et al. 1998, J. Atmos. Sci., 55, 3244–3252. 8. Newman et al. 2002, J. Geophys. Res. 107 (E12), No. 5123. 9. Kahre et al. 2006, J. Geophys. Res., 111, E06008. 10. Newman et al. 2017, Icarus, in press.