DUST DEVIL POPULATIONS : COMPARING IN-SITU MEASUREMENTS WITH IMAGING AND TRACKS

R. D. Lorenz, *JHU Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, USA (Ralph.lorenz@jhuapl.edu),*

Introduction:

Dust devils have been studied in two principal ways - by remote observation and by in-situ measurements. Here I attempt to reconcile these very different kinds of data.

Optical Surveys:

Various widely-discrepant optical surveys have been reported in the literature, from Sinclair's work in the 1960s to observations from Mars rovers and orbiters. Lorenz (2009) showed that surveys to date all fell on a line of N~50/A, where N is the occurrence rate in devils/km2/day ; a more recent evaluation including additional surveys (Lorenz, 2013) supports that relation, but notes that a particularly active Chilean site, and Mars orbital observations (perhaps made more efficient by looking from above, where the slender aspect ratio of optically-thin dust devils means their optical contrast and thus detection efficiency may be higher) may be more accurately described by N~1000/A.

This perhaps surprising reciprocal relationship results from a roughly fixed angular size threshold for detection of devils, such that when a large area is observed from a fixed station, only the less abundant large devils are seen. The distance at which a devil occurs, varies as √A and thus the solid angle subtended (total pixels) varies as 1/A. The cumulative number of devils above a given diameter varies as ~1/d.

Lorenz (2013) also noted a correlation of dust devil longevity with diameter, of roughly $T \sim 40d^{0.66}$ where T is the duration in seconds and d the diameter in meters.

In-Situ Surveys:

Dust devils (and indeed vortices more generally) are detected in meteorology data most reliably by a drop in pressure and/or a rotation in wind direction. Windspeed and temperature changes are sometimes, but less reliably, detected. Although various signatures have been measured by vehicle (or foot-borne) penetrations of devils, for unbiased population surveys, long time series data from fixed stations is needed, much as such data have been acquired at Mars.

Lorenz (2012a) evaluate the pressure drops ΔP_x recorded in the two Mars (Pathfinder and Phoenix – by Murphy and Nelli, 2002 and Ellehoj et al., 2010, respectively) surveys and one terrestrial one (Lambeth, 1966), with numbers N of vortex detections of ~80,~450 and ~19 respectively. The Mars data indicate a differential power law (-2) of observed pressure drop. New terrestrial data (N>100, Lorenz, in preparation) acquired with long-duration 'expendable' data loggers (Lorenz, 2012b) also support this relationship, which can be expressed as $N(>=\Delta P_x) \sim 1/=\Delta P_x$. It is important to recognize, however, that the sensed pressure drop at a fixed station depends on the miss distance x and diameter d of the vortex, as well as its central pressure drop ΔP_o.

Comparing in-situ with imaging:

A key point here is to assume a typical translation velocity of dust devils. Fortunately, this is generally very close to the ambient wind speed, and dust devils tend only to form when windspeed u is in the range 1.5<u<7.5 m/s. Thus to within a factor of two or so for Earth we can assume u~3 m/s.

Oke et al (2007) report in the most active bare ground sites initiated ~40 devils per km^2 in a 20-day period, forming ~30km of track per km^2 (a rate quite consistent, given the survey area A=35 km^2, with 50/A devils/km^2/day). Thus to a first order, there were two devils formed per km^2 per day, and each devil produced a track of ~750m, and thus lasted about 4 minutes.

If one imposes a periodic boundary condition on a square 1km domain, then if 40 devils had 1km tracks, and one would expect one to pass within 25m of a fixed station. Roughly speaking, with 750m tracks, perhaps ~40m would be the expected minimum distance.

The pressure drop and windspeed have traditionally been modeled with the classic 1880s Rankine vortex model, which captures the overall structure well. However, it introduces an undifferentiable singularity in the radial profiles which in real vortices is smoothed out by friction. A less peaked windspeed, and a slower fall-off with radial distance, that reproduces field data better is described by the formalisms of Burgers, Rott, and most succinctly by Vatistas et al. (1991).

If a 'typical' dust devil (a somewhat meaningless term) has a diameter of ~15m, and has a central pressure drop of ~1mbar, then the observed pressure drop can be calculated from Vatistas' formula (slightly re-expressed)

$$\Delta P_{obs}=\Delta P_o,\{1- (2/\pi) \arctan ([2x/d]^2)\}$$

Which yields an unobservable 0.03mbar. This calculation underscores the inadequacy of considering 'typical' values, since it is known that fixed station observations are of the order of ~1/day for a 0.3mbar threshold. To made a useful evaluation we must integrate over the population - for example, not only does a larger dust devil have a lower proportional decrease in pressure drop for a given miss distance (i.e. for fixed x, arctan ($[2x/d]^2$) is much larger for larger d, but as we noted earlier a larger dust devil tends to last longer, and thus is more likely to make a close encounter of a given station.

Such an evaluation is best performed by numerical simulation, and our model is named VEMOOSE (Vortex Evolution Model with Observation Operations Simulated Explicitly). A population of dust devils is introduced into a 1km square grid; they have a -2 power law central pressure drop (CPD). The pressure drops observed by a fixed station are shown in figure 1, under two different assumptions. First is that the CPD and the diameter are independent (but both have -2 power laws). If this is the case, then the observed distribution has a similar shape (dashed line). On the other hand, it could be that larger dust devils are more intense – in this (dotted line) case, the diameter is assumed to be proportional to the CPD. In that instance, the pressure drops observed have a much shallower fall-off : a large central pressure is associated with a large diameter, and thus a smaller decline with distance. Hence the observation efficiency of the larger devils is greater.

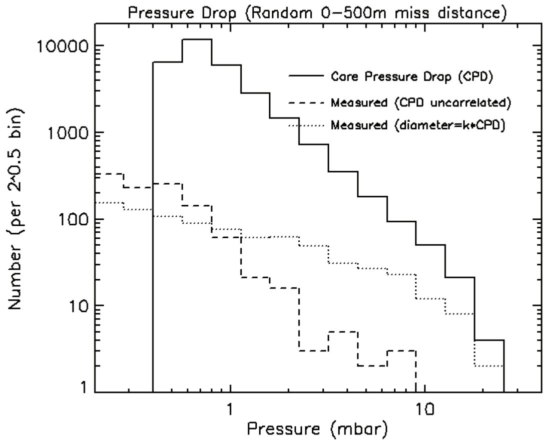

Figure 1. Observed pressure drops for a station at the center of a 1km grid for uncorrelated (dashed) and correlated (dotted) diameters and central pressure drops, assuming the Vastitas et al. (2013)

It is because these various variables are correlated that the notion of an 'average' dust devil is so problematic. For a given observing technique, the 'average' of what shows up may be quite different from the average indicated in another dataset. Thus the population parameters and correlations (e.g. longevity vs diameter) must be considered in evaluating the overall dust lifting potential, and in comparing different datasets.

Dust Devil Tracks

Another window on Mars into dust devil behavior is the (usually-dark) tracks formed by them (figure 2). These have been used to estimate total dust devil activity over long periods, and to estimate the duration of individual dust devils. However, their interpretation requires some care, as it is known (e.g. Verba et al., 2012 – see figure 3) that the size distributions of tracks and of dust devils are different.

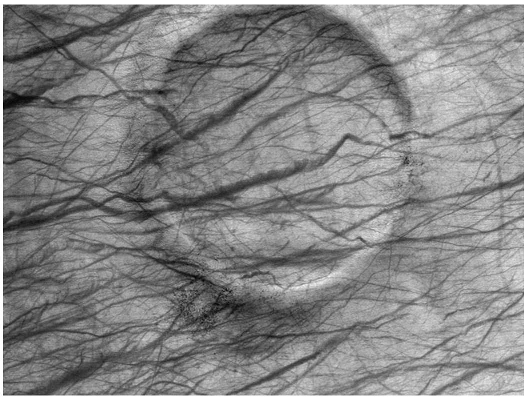

Figure 2. Abundant trails on the Martian surface are a convenient record of dust devil activity, providing information on their size evolution, the tortuosity of their paths, and their longevity.

Such a difference can arise naturally if larger dust devils are more intense (i.e. higher windspeeds, which will be associated with higher CPD) and therefore are more likely to etch visible tracks by dust-lifting. This is consistent with the most frequently-observed track diameter being larger than the most frequently-observed dust devils. Note that the fall-off of track numbers at widths <30m is not obviously a resolution effect, as the HiRISE imaging resolution is only 0.5m.

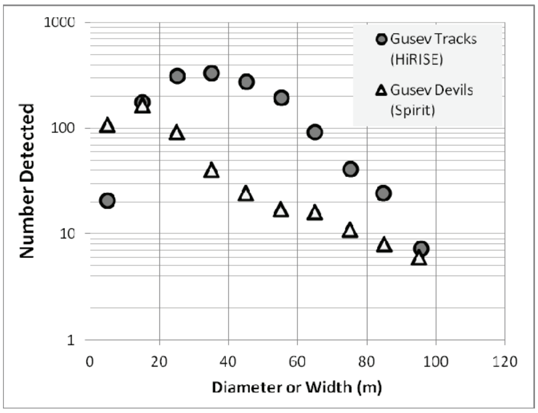

Figure 3. Data from Verba (2012) showing the observed relative abundances of dust devil tracks seen from orbit against dust devils observed in-situ by the

Reconciling the track and diameter characteristics with in-situ measurements will be a next step in this work. If CPD is correlated with diameter (as perhaps the track data suggests) then it may be that the CPD population is actually a much steeper fall-off than the -2 power law indicated by the in-situ observed pressure drops.

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