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Dust-Raising and Power Law Statistics of Dust Devils

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Abstract

Are Martian dust devils really larger than Earth's? What is the dust injection rate into the atmosphere? These important questions cannot be answered without a rigorous discussion of the observed size population, and consideration of the size-dependent efficiency of detection of the relevant observations. There is some evidence in both optical diameters, and in-situ meteorological measurements, that Martian dust devils follow a power-law diameter distribution. Remarkably, terrestrial data is often too poorly-binned to permit meaningful comparison with Mars. Requirements for future field data are identified: better-determined diameter measurements, and statistically-significant populations of unbiased in-situ measurements from fixed stations or arrays.

1. Introduction

Dust devils are widely-observed on Mars and in terrestrial arid regions. As with other phenomena, there are many more small ones than there are big ones - the size distribution is strongly skewed.

Dust devils are likely a major agent of injection of climatically-important dust into the Martian atmosphere, and yet estimates of this process often rely on naïve multiplication of the area of a 'typical' dust devil by a 'typical' dust flux and the number density of dust devils. Yet estimates of this latter quantity, on both Earth and Mars, differ by some 4 orders of magnitude [1]. Furthermore, the skew of the distribution means that the mean size of a devil does not accurately indicate the population-integrated dust-raising effect, since dust-raising is nonlinearly dependent on diameter (likely at least ~d^2 given the area of a devil, possibly a higher power if velocity or dust-loading are diameter-dependent). Thus large devils may dominate the effects of smaller ones.

A power law appears to be indicated in the best-sampled diameter dataset, that from the Mars Exploration Rover Spirit, at Gusev [1]. Some terrestrial datasets have been argued to be more accurately represented by an exponential function [2]. However, these datasets are too coarsely-binned to permit a statistically-robust discrimination of fitting function [3] (apart from that of Ryan and Carroll [4] - see figure 1), especially when the truncation of the distribution at a minimum (and/or maximum) size is considered. The determination of these limits observationally is usually confounded by low detection efficiency at small sizes (a sensor resolution limit) or poor statistics at large sizes (a time-area product limit in the observation [3]).

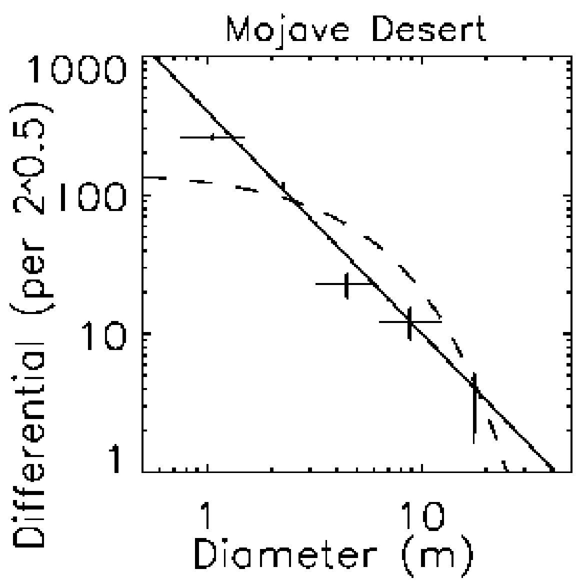

Figure 1. Ryan and Carroll's Dust devil diameter data, binned appropriately, with power-law fit (solid line) and exponential function (dashed line).

A power-law diameter function, for which some theoretical justifications can be offered [3], can be readily used to explain, with a fixed angular detection threshold, the discrepancy of observed dust devil densities, since observed densities appear to be inversely related to the study area as would be expected for such a threshold and a -2 power law [1]. It should furthermore be obvious that assertions that Mars dust devils are larger than those on Earth is contingent upon assessing the relevant detection efficiency functions, such that the true populations, and uncertainties thereon, can be estimated from the observed populations. It seems plausible that the true Mars dust devil population has a larger mean (or median, or mode, or maximum size) but this has not in fact been robustly demonstrated as yet since merely quoting averages of observed populations takes no account of detection efficiencies.

2. In-Situ Observations

Power law statistics appear to be evident in in-situ data too [5] - the pressure drops reported at Mars Pathfinder [6] follow a power law distribution (figure 2), as do those from the Phoenix lander [5,7].

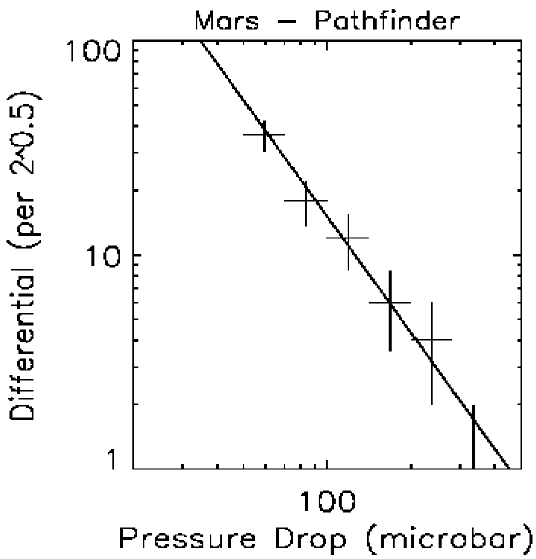

Figure 2. Binned statistics (crosses denote error bars and bin width) of the Mars Pathfinder dust devil/convective vortex pressure drop from Murphy and Nelli [6]. A power law fit is shown as a solid line.

Remarkably, there is not an adequate dataset for Earth with which to compare, although it should not be difficult to acquire such data : some 80 devils encountered by a fixed station in the Mojave in 30 days [4], although pressure drop data were not obtained. A simple datalogging package with pressure and other sensors (but perhaps not a conventional mast-mounted anemometer) could be left unattended in the field for a month or two to obtain data adequate for comparison with Mars.

3. Future Terrestrial Data Needs

The upcoming Mars Science Laboratory, which carries a capable meteorology package suitable for studying dust devils, makes the need for terrestrial analog data even more acute. As discussed in [3], the binning of terrestrial dust devil observations has been a significant limitation, and unattended timelapse imaging may be an efficient way to obtain a dataset whose biases are if not smaller, then at least more readily-quantifiable than conventional field observations. Similarly, one or more long-term fixed stations with suitable cadence (enabled by new memory technology in dataloggers) should be able to obtain data that robustly allow correlations between meteorological variables and identification of population functions.

Acknowledgements

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