

In Situ Sampling of Terrestrial Dust Devils and Implications for Mars

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1. Introduction and Background

Here we report on in situ sampling of the relative dust load and the vertical grain size distribution at different sample heights of several dust devils (DDs). The sampling occurred during two field campaign on rippled surfaces in the Sahara Desert in southern Morocco (2012: northwestern rim of the Erg Chegaga; 2016: plains east of Erg Chebbi). We present advantages and difficulties of such in situ sampling, the first published results from our 2012 field trip [1], and some implications for Mars.

DDs are small vertical convective vortices which occur on Earth and Mars [e.g.,2,3], and are formed by insolation under clear skies [3]. DDs consist of a low pressure region in the interior which is surrounded by tangential winds and updrafts [4,5]. These winds and updrafts lift particles (dust and sand) which makes them visible [3,6].

Particles entrained into the atmosphere by DDs have an influence on the climate and environment [3,7,8]. Lifted small aerosols ($\sim <25 \mu\text{m}$ on Earth [3,7]; $\sim <20 \mu\text{m}$ on Mars [5]) can be entrained into the atmosphere in suspension and transported over long distances. Larger particles (sand-size) remain at lower heights and build-up the so-called "sand skirt" of the DDs [3,9], which reinforces their erosional ability. Their erosional potential can also be recognized by their ability to remove fine particles of the surface and rework the surface: observable as dark [e.g., 10,11] and bright [12] dust devil tracks on Earth and, more commonly, on Mars [e.g.,13,14].

2. Data and Methods

For our in situ sampling we used a 5 m high aluminium pipe with sampling areas made of removable adhesive tape on one side. This device was held upright, facing into the path of the DD [1]. After one passage of the dust devil, the sampling tape, which now had grains adhered to it, was preserved immediately on-site by sticking the sample patches onto glass slides. With this method we took samples of two DDs during the 2012 (sampling up to 2 and 4 m, sampling intervals 0.25 and 0.5 m), and six DDs during the 2016 field trip (sampling up to 5 m each, sampling intervals 0.5 m).

The maximum diameter of all particles at all sampling heights within a representative area of 0.5 cm^2 were measured using an optical microscope. Grain sizes were classified after [15].

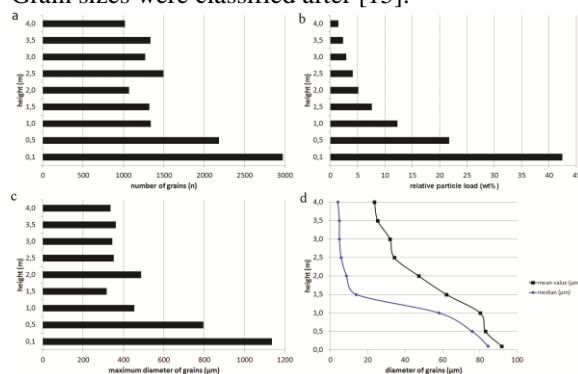


Figure 1: DD #1. (a) Number of measured grains, (b) relative particle load (wt%), (c) maximum diameter of grains, and (d) mean value and median of the diameter vs. height. From [1].

3. Results

An example of measuring results from DD #1 is presented in Fig. 1. The greatest number of particles ($\sim 36.8\%$) were sampled within the first 0.5 m (Fig. 1a). The relative particle load (wt%) shows a nearly exponential decrease of lifted particles with height (Fig. 1b). The largest grains sizes were found in the lowest 0.5 m, while above this the maximum grain sizes range between ~ 300 and $\sim 500 \mu\text{m}$ (Fig. 1c). Median and mean values both decrease with height (Fig. 1d). Measurements for DD #2 show comparable results with only minor variations [1].

General grain size distributions for both DDs from clay to medium sand are comparable with some slight variations [1]. Both DDs show a relatively high amount of clay ($\sim 31.18\%$ of lifted particles for DD #1, $\sim 35.8\%$ for DD #2), a constant decrease in abundance of silt, and an increase in abundance of sand (e.g., up to the maximum of $\sim 20.83\%$ for medium sand in DD #1) [1].

A more detailed view of the grain size distribution of DD #1 for every sample height separated in clay, silt, and sand is shown in Fig. 2. While the general distribution of sand is comparable in both DDs, the detailed distribution of clay and silt varies [1].

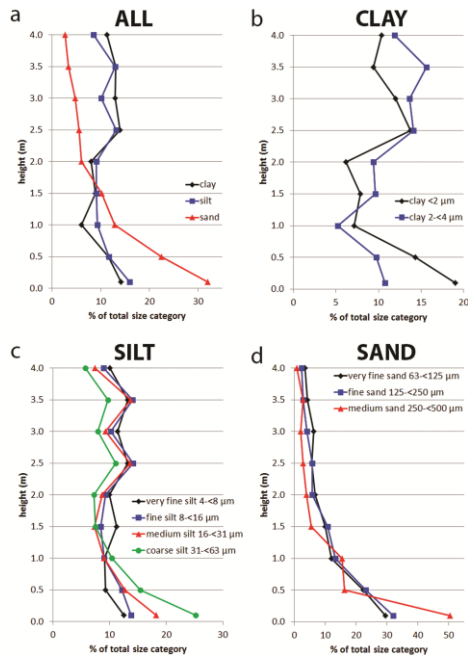


Figure 2: (a) Relative values of the total distribution of different particle sizes within DD #1. (b-d) Relative values of (b) clay, (c) silt, and (d) sand. From [1].

4. Discussion

The method used to sample active dust devils turned out to be very effective. With this method, even the smallest entrained particles (clay) of the dust devil will be preserved and are clearly visible on the non-textured bright adhesive tape under the microscope. Furthermore, the method allows a quick installation on-site and is transportable, which is important due to the fact that DDs can appear suddenly (giving a short reaction time for the sampler) and can move quickly over the surface.

Our measurements show that both DDs are comparable in their grain size distributions and their trends of mean values and medians. This is probably caused due to the same soil grain size distribution from which both DDs eroded material but also interesting in that both DDs had different sizes and intensities [1]. This is an indirect confirmation of simulations of [16-18] which showed that the dust flux of DDs are linked to their strength of pressure drops in their core, and not to their sizes.

Our measurements confirm observations from [19], that the majority (~65-80%) of lifted particles within a DD were smaller than 63 μm , and that only 1% of grains were relatively large (200-600 μm). In our experiments only ~1.8% for DD #1 and ~0.6% for DD #2 have sizes of 250 to <500 μm [1].

In contrast to [20], who presented a composition of a DD with ~42% fine sand and ~58% silt and clay, our

measurements show a general smaller amount of lifted sand. Furthermore, our results show that between ~77 and ~89 wt% of the total particle load were lifted only within the first meter of the DDs, which is in good agreement with [21], and a direct evidence for the existence of a sand skirt. [21] concluded that ~10 wt% of the total lifted material contains grains between 0.1 and 10 μm , which will go into suspension. If we assume, that grains with a diameter <31 μm could go into suspension [1,3,7], our results show that only less than ~0.05-0.15 wt% can be entrained into the atmosphere [1], which is substantial less than proposed by [21]. However, these values represent between ~58.5% and ~73.5% of all lifted particles [1], because of the huge amount of entrained small particles. On Mars, the amount of lifted particles will be general higher as the surficial dust coverage is larger [22,23], although the atmosphere can only suspend smaller grain sizes (~<20 μm) [5] compared to Earth.

5. Conclusions

(I) Our measurements of DDs imply a similar or comparable internal structure, despite their different strengths and dimensions. (II) The vertical trend of decreasing particle size with height within DDs is confirmed and shows a nearly exponential decrease with height. (III) The existence of sand skirts in both DDs was directly verified. (IV) Our measurements show that only a small amount of the particle load can go into suspension, but these values represent between ~60% and ~70% of all lifted particles. We observed numerous larger dust devils each day (several hundred meters tall), which implies a much higher input of material into the atmosphere. (V) The size distribution within DDs probably represents the surficial grain size distribution they move over.

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