In Situ Sampling of Terrestrial Dust Devils and Implications for Mars.

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Introduction: Here we report on in situ sampling of the dust load and the 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 and Lac Dayet Srij). We present advantages and difficulties of such in situ sampling, the first published results from our 2012 field trip, and some implications for Mars [1].

Background: 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, weather, human health, and biogeochemistry [3,7,8]. Lifted small aerosols (~<25 µm on Earth [3,7]; ~<20 µm 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].

Data and Methods: For our in situ sampling we used a 4 m high aluminum 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 dust and sand grains adherend to it, was preserved immediately on-site by sticking the sample patches onto glass slides. With this method we took samples of two DDs (first: diameter ~15 m, sampling interval 0.5 m between 0.1-4 m height; second: ~4-5 m diameter, sampling interval 0.25 m between 0.5-2 m [1]) during the 2012 field campaign, and six DDs of various dimensions (sampling interval 0.5 m between 0.1-5 m height each) during the 2016 field campaign. To date, only data from the 2012 fieldtrip has been analysed.

The maximum diameter of all particles at all sampling heigths within a representative area of 0.5 cm^2 were measured using an optical microscope. Grain sizes were classified after [15]. Estimations of percentage weights (wt%) of lifted particles were calculated under the assumption of being perfectly rounded, which is an overestimation and give the maximum volumes [1].

Results: An example of measuring results from DD #1 is presented in Fig. 1. Here, the greatest number of particles (~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 ~500 µm (Fig. 1c). Median and mean values both decrease with height (Fig. 1d). Measurements for DD #2 show comparable results with only minor variations [1].

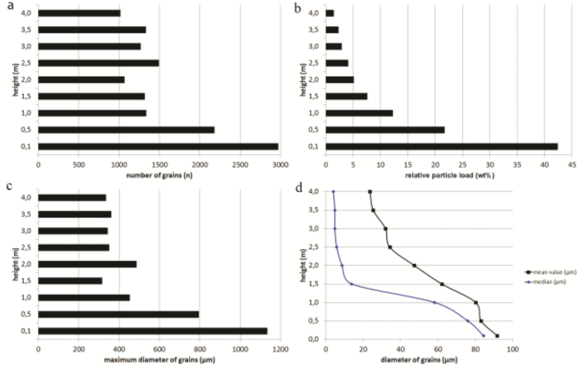

Figure 1: Measurements of DD #1. **(a)** Number of measured grains, **(b)** relative particle load (wt%), **(c)** maximum diameter of grains, and **(d)** mean value and median of the diameter vs. height. From [1].

General grain size distributions for both DDs from clay (<2 µm) to medium sand (250-<500 µm) are comparable with some slight variations [1]. Both DDs show a relatively high amount of clay (~31.18% of lifted particles for DD #1, ~35.8% for DD #2), a constant decrease in abundance of silt, and a increase in abundance of sand (e.g., up to the maximum of ~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 (Fig.2a,b), silt (Fig.2a,c), and sand (Fig.2a,d) is shown in Fig. 2. While the general distribution of sand is comparable in both sampled DDs, the detailed distribution of clay and silt varies [1].

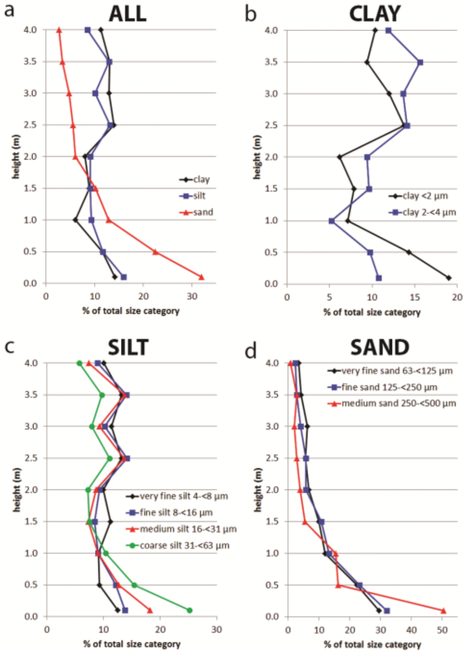

Figure 2: (a) Relative values of the total distribution of different particle sizes within DD #1. **(b-d)** Relative values of **(b)** clay, **(c)** silt, and **(d)** sand. From [1].

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 (coarse grained rippled surface ~100 m distant from a dune field), but also interesting is 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.

Comparison with terrestrial in situ sampling of [19] shows some similarities. Our measurements confirm their observations 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.

Conclusion: (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)** Although our measurements show that only a small amount of the particle load can go into suspension, these values represent between ~60% and ~70% of all lifted particles. During our field works we observed numerous larger dust devils each day which were up to several hundred meters tall and had diameters of several tens of meters. This implies a much higher input of fine grained material into the atmosphere than the relative small dust devils which were sampled in our 2012 study [1]. **(V)** The size distribution within DDs probably represents the surficial grain size distribution they move over.

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