Detailed In Situ Sampling of Two Dust Devils in Morocco. J. Raack[1], D. Reiss[2], M.R. Balme[1], K. Taj-Eddine[3,4], and G.G. Ori[4,5], [1]School of Physical Science, STEM, The Open University, Milton Keynes, UK, jan.raack@open.ac.uk; [2]Institut für Planetologie, Westfälische Wilhelms-Universität, Münster, Germany; [3]Géologie et Géoinformatique, Faculté des Sciences Semlalia, Université Cadi Ayyad, Marrakech, Morocco; [4]Ibn Battuta Centre, Faculté des Sciences Semlalia, Université Cadi Ayyad, Marrakech, Morocco; [5]International Research School of Planetary Sciences, Università "G. D'Annunzio", Pescara, Italy.

Introduction: Here we report on in situ sampling of the dust load and the grain size distribution of different sample heights of two dust devils (DDs) in the Sahara Desert in southern Morocco (northwestern rim of the Erg Chegaga at 29°53'8"N, 6°19'6"W) during a field campaign in spring 2012 [1]. Former studies of in situ measurements of lifted particles in DDs were published by [2,3,4], where only [3] presented vertical grain size distributions comparable to our work.

Background: DDs are small vertical convective vortices which occur on Earth and Mars [e.g.,5,6], and are formed by insolation under clear skies [6]. On Earth they are most common during spring and summer in semi-arid to arid regions [7]. DDs consist of a low pressure region in the interior which is surrounded by tangential winds and updrafts [8,9]. These winds and updrafts lifted particles (dust and sand) which makes them visible [6,10].

Particles entrained into the atmosphere by DDs have an influence on the (terrestrial) climate, weather, human health, and biogeochemistry [6,11,12]. I.e., by scattering and absorbing the incident sunlight [13]. Lifted small aerosols (<~20-25 µm) can be entrained into the atmosphere as a suspension and probably transported across the whole globe [6,11,14]. Larger particles (sand-size) remain at lower heights and build-up the so-called “sand skirt” of the DDs [6,15], which reinforces the erosional significance of DDs. Their erosional potential can also be recognized by their ability to remove fine particles of the surface and rework the surface, which is observable in dark [16,17,18] and bright [19] dust devil tracks on Earth and, more common, on Mars [e.g.,20,21,22,23].

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, which was holding upright into the path of the DD [1]. We took samples of two active DDs: DD #1 with a diameter of ~15 m, and a sampling interval of 0.5 m between 0.1 and 4 m height; DD #2 was weaker (~4-5 m diameter) with a sampling interval of 0.25 m between heights of 0.5 and 2 m [1].

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 [24]. 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). 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 are both decreasing continuously with height (Fig. 1d). Measurements for DD #2 show comparable results with only minor variations (e.g., highest number of lifted grains around 0.75 m (~28.5%), and more variations for mean value and median of grain sizes) [1].

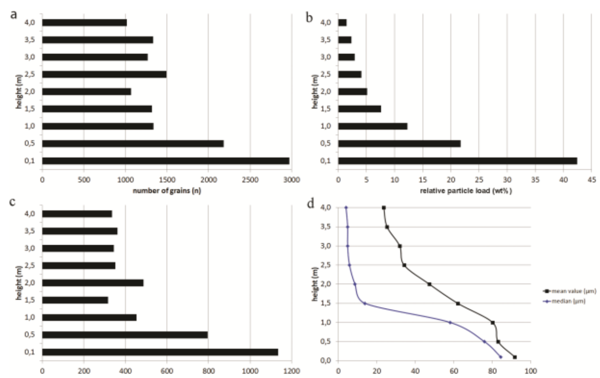

Figure 1: Measurements of DD #1. **(a)** Number of measured grains, **(b)** relative particle load (wt%), **(c)** maximum diameter of grains, and **(d)** mean value and median of the diameter vs. height. From [1].

General grain size distributions for both DDs from clay (<2 µm) to medium sand (250-<500 µm) are quite comparable with some slight variations [1]. Both DDs show a relative 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 very comparable in both sampled DDs, the detailed distribution of clay and silt varies [1].

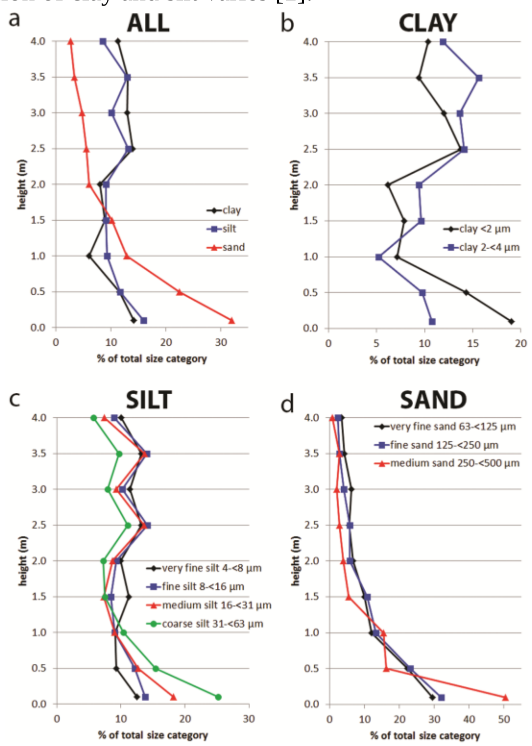

Figure 2: (a) Relative values of the total distribution of different particle sizes within DD #1. **(b-d)** Relative values of **(b)** clay, **(c)** silt, and **(d)** sand. From [1].

Discussion: 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 their 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 [25,26] 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 in situ sampling of [3] shows some striking similarities. Our measurements confirm the observations of [3] 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 [2], who presented a composition of a DD with ~42% fine sand and ~58% silt and clay, our measurements show a general lower 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 [4], and a direct evidence for the existence of a sand skirt.

[4] concluded that ~10 wt% of the total lifted material contains of grains between 0.1 and 10 µm, which will go into suspension. If we assume, that grains with a diameter <25 µm could get into suspension [6,11], our results show that only less than ~0.05-0.15 wt% could remain in the atmosphere [1], which is substantial less than [4] proposed. This discrepancy is probably caused due to different dimensions and strengths of DDs, or due to different source regions [1].

Conclusion: With our work we present the first very detailed in situ measurements of terrestrial DDs. Our comparable measurements of both different DDs imply a similar or comparable internal structure, despite their different strengths and dimensions. The vertical trend of decreasing particle size with height within DDs is confirmed and shows a nearly exponential decrease with height. With our measurements we also provided verification of the existence of sand skirts in both sampled DDs. Furthermore, althought our measurements show that only between ~0.05 to 0.15 wt% of the particle load can go into suspension, these values represent between ~58.5% and ~73.5% of all lifted particles. During our field work, each day we observed numerous larger dust devils which were up to several hundred meters tall and had diameters of several tens of meters. This implies, that a tremendous amount of small particles will lift up and stay in the atmosphere, which could have influence to the climate and the human health.

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Acknoledgements: The fieldwork was supported by Europlanet (TNA039). The author is funded by a Horizon 2020 Marie Skłodowska-Curie Individual Fellowship.