Investigating the Impact of Long-Range Transported Saharan Dust on Cirrus Clouds in the Arctic

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Abstract: A rare event of a long-range transport of Saharan dust happened during the HALO-(AC)^3 campaign in March/April 2022. Airborne lidar measurements were performed in the Arctic region. The dust layer could be observed with our measurements from end of March to early April 2022. We use our lidar measurements to characterize this Saharan dust long-range transport and to investigate its impact on cirrus cloud formation and cirrus properties in the Arctic region.

1. Introduction

Being a major contributor to the Earth's tropospheric aerosol load [1], Saharan dust has a large impact on the Earth's radiation budget by scattering and absorbing of solar and terrestrial radiation [2]. And Saharan dust particles have found to be effective ice nuclei [3]. Once lifted up from the ground, Saharan dust can be transported over days and thousands of kilometers, with its main transport path being over the Atlantic Ocean within the so-called Saharan Air Layer [4]. But Saharan dust can also be transported to other regions, e.g. to Europe [5], or the Mediterranean [6, 7]. In very rare events, Saharan dust can be even transported as far as into the Arctic [8].

The Arctic climate changes in an unprecedented intensity, exceeding the mean global warming at least by a factor of two (e.g. [9]). Due to this phenomenon the gradient between the Mid-latitudes and the Arctic becomes less pronounced [10], leading potentially to more frequent transport of airmasses from the Mid-latitudes into the Arctic [11]. The HALO-(AC)^3 took place in March/April 2022 out of Kiruna, Sweden. During the HALO-(AC)^3 period, one of the rare events where Saharan dust was transport into the Arctic at higher altitudes took place.

We will show airborne lidar measurements performed within HALO-(AC)^3 during the long-range transported Saharan dust event. We use the measurements to characterize Saharan dust layers in the Arctic, as well as to investigate their impact on cirrus cloud properties.

2. Method

2.1. HALO-(AC)^3

HALO-(AC)^3 aims to characterize the Arctic atmosphere and to study the impact of Cold Air Outbreaks and Warm Air Intrusions [9]. For that the German High Altitude and LOng range (HALO) aircraft was applied. HALO was equipped with a remote sensing payload acting as a flying cloud observatory [12]. HALO-(AC)^3 campaign took place in March/April 2022. A total of 17 research flights were performed out of Kiruna, Sweden.

2.2. WALES lidar system

One of the key instruments of the HALO-(AC)^3 payload is the WALES (water vapor lidar system in space) lidar system. WALES is a combined airborne high spectral resolution [13], and water vapor differential absorption lidar system [14]. It performs polarization sensitive measurements at 532 nm. Additionally, it is equipped with an HSRL channel using an iodine filter. In addition, it measures the water vapor concentration using the differential absorption lidar (DIAL) principle operating in the 935 nm wavelength range.

3. Results

3.1. Saharan dust layer

A strong Saharan dust plume was transported out of the Sahara towards Southern and Central Europe mid of March 2022. The dust layer was e.g. visible over the Munich ACTRIS (www.actris.eu) site as thick aerosol layer up to about 3 km altitude. Additionally, a thin aerosol layer could be detected in heights from about 6-8 km in the evening hours of 16 March 2022 (not shown here). A preliminary analysis using HYSPLIT [15] forward and backward trajectories indicates that this thin aerosol layer had its source in the Sahara and was further transported in eastward directions and finally into the Arctic where it was trapped in the Arctic vortex.

The long-range transported Saharan dust layer could be observed with our airborne lidar measurements over the Arctic from End of March 2022 to early April 2022.

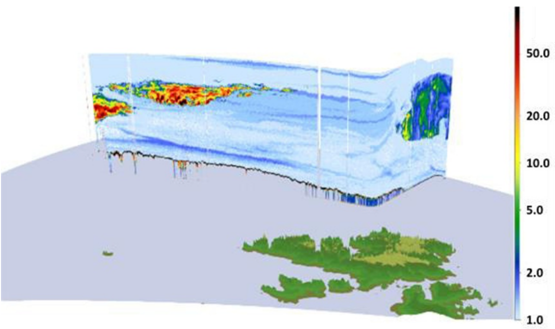

Figure 1. Backscatter ratio at 532 nm measured with the WALES lidar system north-west of Svalbard on 30 March 2022.

Figure 1 shows an example of the aerosol layer observed north-west of Svalbard at a height between about 6 and 9 km on 30 March 2022.

The aerosol layer has only low values of the extinction coefficient at 532 nm with maximum values of 0.01 km^{-1} (Figure 2). The particle linear depolarization ratio at 532 nm within this layer is 0.3 ± 0.03 (std <0.01), and the lidar ratio within this layer shows a mean value of 44 ± 8 (std ~12) sr.

Considering the aerosol classification scheme as introduced by [16] the layer can be clearly identified as Saharan dust layer. The extinction to mass conversion [17] reveals that the dust mass concentration of this layer is between about 1 μg/m^3 and 2 μg/m^3. This is about 1-2% of the value found after long-range transport over the Atlantic Ocean in the Saharan Air Layer [2].

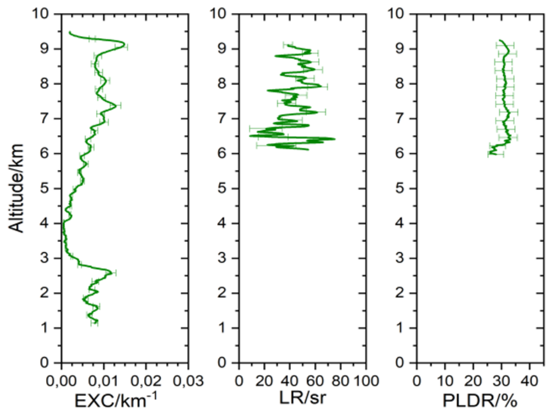

Figure 2. Profiles of the extinction coefficient, lidar ratio and particle linear depolarization ratio at 532 nm for the Saharan dust layer measured north-west of Svalbard on 30 March 2022 from about 14:00 to 15:00 UTC.

3.2. Impact on cirrus clouds

Figure 3 shows two different cirrus clouds that were measured during this flight. One was not connected to the Saharan dust layer, the other one developed within the dust layer.

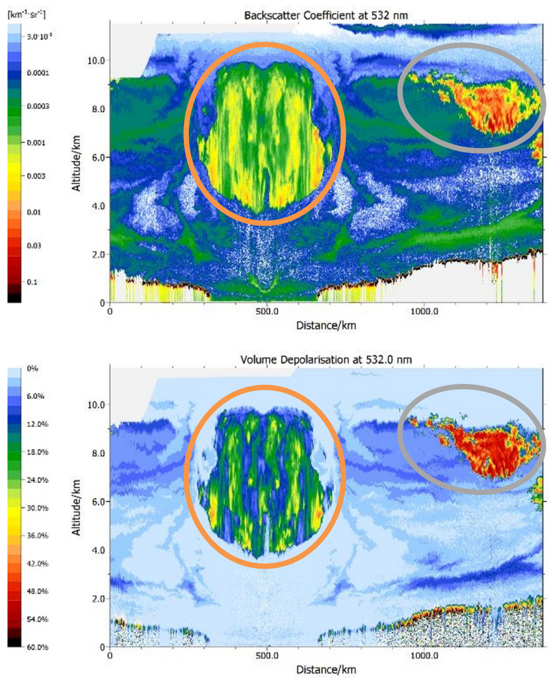

Figure 3. Time-height cross section of the backscatter coefficient (upper plot) and the volume depolarization ratio at 532 nm (lower plot) measured on 30 March 2022. The orange circle highlights the cirrus cloud that evolved in dust free airmasses, the grey circle the cirrus cloud evolved within the dust layer.

The cirrus cloud outside the Saharan dust layer showed lower values of the backscatter ratio (BSR) with corresponding lower values of the volume and particle depolarization ratio compared to the cirrus cloud formed within the Saharan dust layer.

4. Discussion

Looking at the collocated measurements of the water vapor mixing ratio in combination with temperature information from models, e.g. ECMWF analyses, the relative humidity over ice (RHi) distribution within and outside of cirrus clouds can be studied [18, 19]. The RHi distribution gives information about the stage of the cloud within its lifecycle [18, 20] as well as on the dominant freezing process [19]. The cloud evolved within the Saharan dust layer shows a lower supersaturation compared to the cloud outside the Saharan dust layer. This could be an indication of more heterogeneous freezing taking place in the formation of the cirrus, due to the presence of Saharan dust particles acting as ice nuclei.

Cloud formation due to heterogeneous freezing in the Arctic is challenging to be captured realistically in model simulations. The aerosol transport as well as the freezing processes have to be modelled correctly. Comparing our measurements with model analysis (not shown here), one finds, that the cloud formed in Arctic background conditions is well captured by the model, while the cloud within the Saharan dust layer is not present in the model.

5. Conclusion and Outlook

Saharan dust particles have a strong impact on cirrus cloud formation and properties by acting as effective ice nuclei. Cirrus clouds are important contributors for the Arctic radiative budget. Thus, it is important to investigate if and how cirrus clouds change under the influence of a possible increased transport of mid-latitude airmasses into the Arctic. With this also the transport of aerosols, e.g. dust, into the Arctic might increase. Thus, it is also crucial to investigate the long-range transport of Saharan dust and its impact on cirrus cloud formation and the cirrus clouds' optical, microphysical and thus radiative properties. We will use our combined aerosol/cloud and water vapor lidar measurements to better characterize differences of cirrus clouds formed under the impact of Saharan dust. The synergy of lidar and the simultaneous radar measurements can give further insight into the dust's impact on the cirrus cloud's microphysical properties.

6. References

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