Atmospheric aerosol depolarization ratio with Doppler lidar - A long-term perspective

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Abstract: Some HALO Photonics Doppler lidars measure the atmospheric volume depolarization ratio at a wavelength of 1565 nm. We inspected 4 years of data from 6 instruments operated in different environments across Finland with the aim of retrieving the atmospheric aerosol depolarization ratio. The long-term performance of these instruments was examined by investigating the stability of the noise floor and the amount of polarizer bleed-through. We further developed the method for correcting the background noise and constructed an algorithm distinguishing aerosol from hydrometeors. We observed that the 4-year averaged aerosol depolarization ratio varies from 0.07 at sub-arctic Sodankylä to 0.13 in the boreal forest in Hyytiälä. At all locations, the aerosol depolarization ratio peaks during spring and early summer, which we attribute to pollen. Overall, our analysis supports the long-term usage of HALO Doppler lidar depolarization ratio measurements, especially the detection of aerosols that may pose a safety risk for aviation.

1. Introduction

HALO Photonics StreamLine Doppler lidars (denoted HALO Doppler lidars hereafter) have been providing continuous profiling of the atmosphere at 1565 nm wavelength for many years in the Finnish ground-based remote sensing network [1]. Depolarization ratio, which can be obtained from these profiles, is a parameter that describes the sphericity of the backscattering particles. It can be used to distinguish non-spherical particles such as dust and volcanic ash from spherical particles such as marine aerosol. In this study, long-term performance of the HALO Photonics Doppler lidar has been assessed and an algorithm has been created to distinguish aerosol from hydrometeors without the use of other auxiliary data. The result statistics of depolarization ratio of atmospheric aerosol was obtained. These statistics can be used as a baseline for atmospheric aerosol, so that potentially hazardous layers such as smoke and volcanic ash can be detected easily. This would improve the safety of aviation and air quality.

2. Instrumentation

The HALO Doppler lidars are operating at four measurement stations across Finland (Fig. 1) with different environments, enabling comparisons between urban and rural, as well as marine, continental and sub-arctic regions.

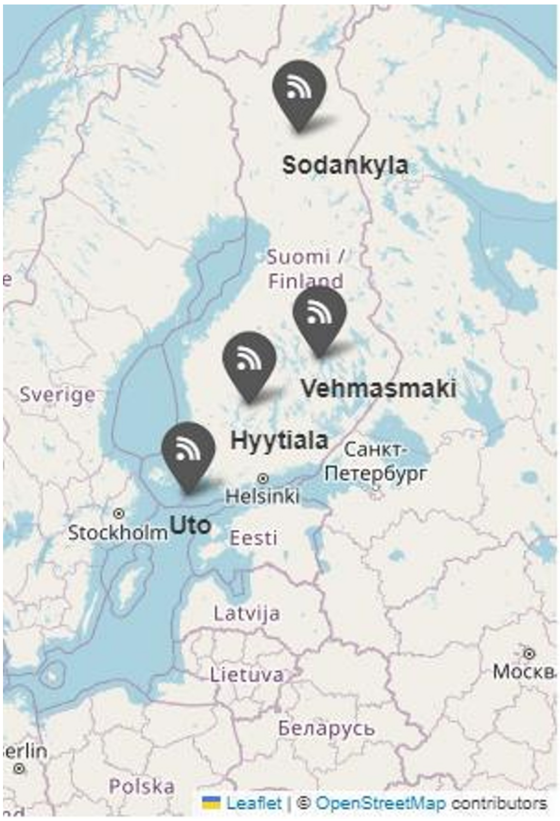

Figure 1. Map of the measurement sites.

The HALO Doppler lidars, operated by the Finnish Meteorological Institute are pulsed Doppler lidars, transmitting linearly polarized light at 1565 nm wavelength. The lidar is equipped with heterodyne detectors that can switch between recording the return in either parallel or orthogonal with respect to the transmitted polarization [2], termed co-polar (parallel) and cross-polar (orthogonal).

3. Methods

To assess the instrumental noise floor, the aerosol- and hydrometeor- free part of the SNR profiles have been manually collected every day for all the instruments.

To examine the instrumental internal polarizer, we investigate the bleed-through [3]. It is resulted from the incomplete extinction in the lidar internal polarizer, which the co-polar signal is leaking into the cross-receiver. This results in a systematic bias of depolarization ratio. Liquid cloud base is expected to have zero depolarization ratio [4], so it was used as a reference to assess the degree of the polarizer bleed through for each instrument.

To study the seasonal pattern of the depolarization ratio of aerosol, we developed the Aerosol Identification algorithm to distinguish aerosol from clouds and precipitation using only data from the Doppler lidar. The algorithm utilized data in both the time and height domain for distinguishing aerosol from larger hydrometeors.

To minimize random noise and extract weak aerosol signal, 1-hour averaged of depolarization ratio was calculated. However, despite the data has been processed with the background correction algorithm by [5], a second-order polynomial component persists and greatly affect the depolarization ratio of aerosol. We developed an automated fitting of the second-order polynomial to the data to further improve the depolarization ratio measurement.

4. Results

Figure 2 shows the noise floor level for each instrument. It is calculated as the standard deviation of the co-polar signal-to-noise ratio normalized by the number of pulses in each integration time of each instrument ($\sigma_{\mathrm{SNR}} \times \sqrt{N}$) in the aerosol- and hydrometeor-free region.

Overall, most instruments are stable during the study period. Some fluctuations were observed in Utö-32, but the noise floor level itself is low, and visual inspection indicate no issues in the data quality.

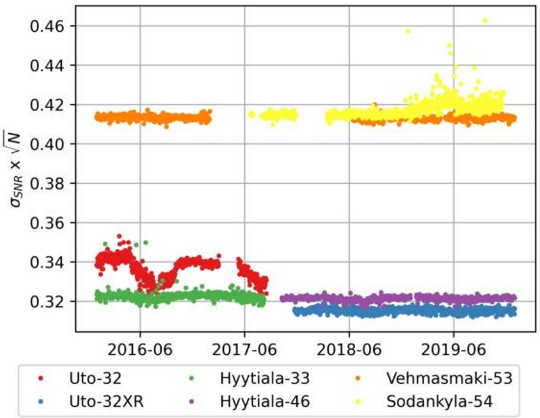

Figure 2. Noise floor of all the instruments.

Table 1 displays the estimate of the bleed-through in the instrumental internal polarizers. Overall, the values of the estimated bleed-through in this study are smaller than the previous short case studies such as 0.011 ± 0.007 in Limassol [3] or 0.016 ± 0.009 and 0.013 ± 0.006 in Vehmasmäki [3, 6]

Table 1. Bleed-through of all the instruments.

Instrument	Estimated of bleed-through
Utö-32	0.011 ± 0.007
Utö-32XR	0.004 ± 0.004
Hyytiälä-33	0.005 ± 0.005
Hyytiälä-46	0.008 ± 0.008
Vehmasmäki-53	0.007 ± 0.007
Sodankylä-54	0.005 ± 0.005

The aerosol identification algorithm developed here was compared with Cloudnet classification algorithm [7-8] as seen in Fig. 3. There are some differences in these algorithms stemming from different goal and instruments. Cloudnet's goal is to provide observations of cloud properties for forecast and climate model [7]. Additionally, Cloudnet also utilizes data from cloud radar and other instruments. Meanwhile, the aerosol identification algorithm focuses on aerosol signal, especially in capturing weak signal.

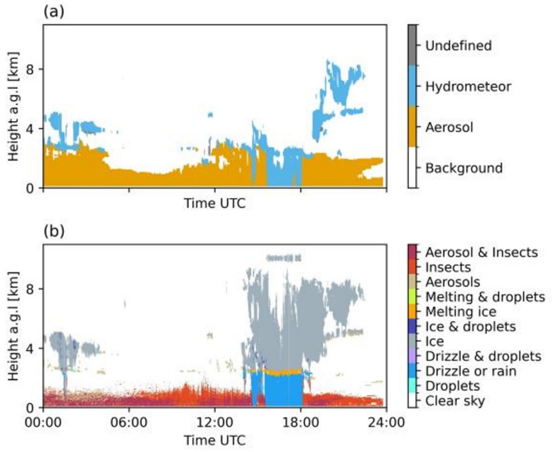

Figure 3. a) The aerosol identification algorithm, b) Cloudnet classification algorithm

After comparing all the data in Hyytiälä, we found that only 7.7% of the aerosol data points from the aerosol identification algorithm are classified as hydrometeor in the Cloudnet algorithm. Given the large amount of data, we are confident that this algorithm is capable of extracting the overall statistics of the aerosol depolarization ratio.

Figure 4 shows a study case of elevated dust transported to Finland. The depolarization ratio shows a contrast difference in this layer comparing to aerosol in the boundary layer closer to the ground (Fig. 4c). The values of depolarization ratio of this layer are at around 0.22 to 0.27. This is slightly lower than the value of 0.30 reported earlier by [3].

Figure 5 displays the dust aerosol optical depth from the CAMS forecast of the same dust event. This dust layer spans across the southern part of Finland, covering both Utö and Hyytiälä station.

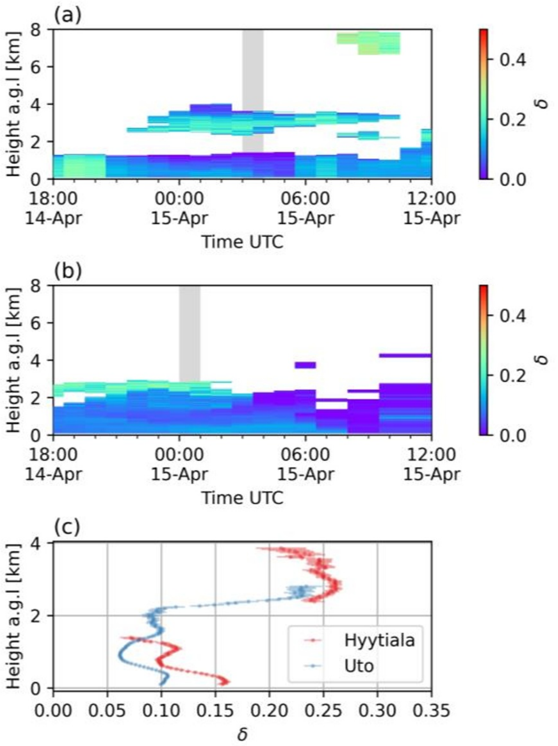

Figure 4. Depolarization ratio in a) Hyytiala. b) Uto and c) averaged in shaded area.

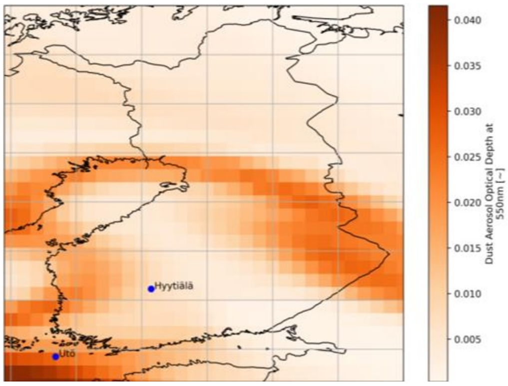

Figure 5. Dust aerosol optical depth from CAMS forecast at 2018-04-15 03:00.

Figure 6 and Table 2 show the result of the long-term analysis of aerosol depolarization ratio. Overall, the average aerosol depolarization ratio is higher in the boreal forest sites of Hyytiälä and Vehmasmäki. This stems from the abundance of pollen with irregular shape (i.e high depolarization ratio), especially during the pollen season in the summer. In Sodankylä, which located in a clean rural sub-arctic environment, the aerosol depolarization ratio is at the lowest. During the winter from October to March, the aerosol depolarization ratio remains low across all the sites.

Our observations show a base line of aerosol depolarization ratio in Finland. This in turn would support the long-term usage of HALO Doppler lidar depolarization ratio measurements, especially the detection of aerosols that may pose a safety risk for air quality and aviation.

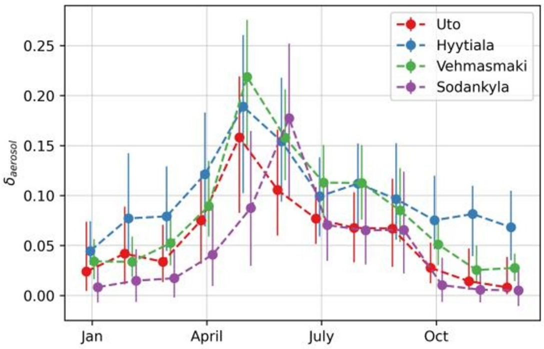

Figure 6. Monthly median of aerosol depolarization ratio across all the sites; the error bars show the 25th and 75th quantile.

Table 2. Overall depolarization ratio

Sites	Mean	Standard deviation
Utö	0.09	0.07
Hyytiälä	0.13	0.08
Vehmasmäki	0.11	0.07
Sodankylä	0.07	0.08

5. References

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