Reviewer 3

We would like to thank the reviewer for taking the time to evaluate our manuscript and provide valuable feedback. We have modified the manuscript with the proposed changes along with step-by-step answers to the suggestions. Please note that changes have been highlighted in the manuscript and the corresponding answers to the reviewer by text below. The original comments are presented in black.

The paper by Filioglou presents studies of the depolarization ratio of smoke (fresh and long-range transported) and volcanic ash at 1565 nm. Adding measurements of the depolarization ratio at a longer wavelength is in general of high interest and importance. The paper is well written and has a clear structure. This is way I recommend publication after addressing this general comment:

Giving the significance depolarization measurements at a longer wavelength can have, the authors should add some more details on the system specification and the data processing should be given. The authors refer to former publications on that, but a minimum of information should at least been given here. Furthermore, it would be good to get at least a rough error estimation.

Thank you for your comment. We have expanded Sect. 2.1 to give a more detailed description of the HALO Doppler lidars and the post-processing we applied. We have also added the uncertainty of δ_{1565} in Fig. 3.

Sect. 2.1 of the revised manuscript reads now:

Halo Photonics StreamLine lidars are commercially available pulsed Doppler lidars that operate at 1565 nm wavelength (Pearson et al., 2009). Due to the high pulse-repetition rates and low pulse energies they are eye-safe, enabling continuous long-term operation. Here, we use Halo Doppler lidars that are equipped with a cross-polar receiver channel, which enables consecutive measurement of co- and cross-polar signals and subsequent retrieval of particle linear depolarization ratio Vakkari et al., (2021). The cross-polar channel is implemented through a fibre-optic switch between the normal receiver path and the path with a fibre-optic polarizer. The lidars were configured with 30 m vertical resolution and focus was set to 2000 m; first 90 m were excluded due to effects from the outgoing pulse. Other technical specifications can be found in Table 1.

At Kumpula (FI) and Welgegund (SA), the Halo Doppler lidars used were capable of full hemispheric scanning (i.e., model StreamLine). At Kiviniemi (FI), the version with limited scanning (i.e. StreamLine Pro) was used. In this study, we utilize only the vertically-pointing measurements. At Kiviniemi (FI), the vertically-pointing integration time was set to 7 s per ray and 13 min out of every 15 min was vertically-pointing measurement. At Kumpula (FI), the vertically-pointing integration time was set to 3.5 s per ray and 8 min out of every 15 min was vertically-pointing measurement. At Welgegund (SA), the vertically-pointing integration time was set to 7 s per ray and 6 min out of every 15 min was vertically-pointing measurement.

For each Halo Doppler lidar the data was post-processed following Vakkari et al., (2019). The post-processing is based on hourly background checks carried out automatically by the lidar. Quantifying the non-polynomial component in the instrument noise floor, denoted P_{amp} by Vakkari et al., (2019), requires an extended data set of background checks and internal temperature. We used background checks from the full 11-month campaign at Welgegund (SA), and 12 months centered at the case study for the two other lidars, respectively. We determined also the internal temperature dependency of P_{amp}, though it has only a very minor effect. For each measured profile, we used the aerosol- and cloud-free parts of the profile to fit the linear and parabolic components of the instrumental noise floor. These fits and the instrument and campaign specific P_{amp} were then used to process the corrected co- and cross-polar signal-to-noise ratio (SNR) and attenuated backscatter profiles following Vakkari et al., (2019).

Bleed-through, i.e. the incomplete extinction in the lidar internal polarizer where co-polarized signal is leaking into cross-receiver due to imperfect polarization separation in the instrument, was determined from liquid cloud base observations similar to Le et al., (2024). For Kiviniemi (FI), a bleed-through of 0.0165 ± 0.010 was determined. For Kumpula (FI), bleed-through was determined as 0.00715 ± 0.0028. For Welgegund (SA), bleed-through was determined as 0.0085 ± 0.007. These values are in good agreement with the long-term statistics in Le et al., (2024).

At 1565 nm wavelength, the molecular backscatter contribution is about 2 orders of magnitude lower than at 532 nm, being approximately 1.9×10^{-8} m^{-1} sr^{-1} at standard pressure and temperature (Bucholtz et al., 1995) which is considered negligible. In addition, no evidence of multiple scattering was observed under the prevailing measurement conditions. Therefore, δ_{1565} as derived directly from the instrument after correcting for the bleed-through, can be regarded as a reasonable approximation of the particle linear depolarization ratio, obtained without applying a correction for the molecular scattering contribution, especially during high aerosol load conditions. The associated uncertainty, $\sigma_{\delta_{1565}}$, is estimated according to Vakkari et al., (2021) taking into consideration the instrumental noise and the uncertainty in bleed-through. In the absence of hydrometeors, the atmospheric transmittance is very close to unity therefore, the attenuated backscatter coefficient, hereafter ATB_{1565}, can be used as a proxy for the particle backscatter coefficient, hereafter β_{1565}. This assumption is valid provided that extinction within the sampled aerosol layer remains sufficiently small. Attenuation in dense aerosol layers can lead to an underestimation of the true β_{1565}. For the exceptionally fresh smoke case at Kiviniemi (FI), β_{1565} retrieved using the forward Klett method (Wiegner and Geiß, 2012) was used to estimate the smoke mass concentration, as this quantitative parameter requires an accurate measure of backscatter intensity and could therefore be biased by substantial departures of atmospheric transmittance from unity observed during periods of high plume density. A Lidar Ratio (LR) of 51 sr was used in Klett inversion according to Mie calculations (see Sect. 2.4)

To determine the upper boundary of the smoke layer in the lidar observations at Kiviniemi, we first identified the maximum of the ATB_{1565} profile within the lowest 500 m. The layer top was then defined as the first altitude above this maximum at which the δ_{1565} exceeded 0.1. If no such threshold was reached, the layer top was instead assigned to the altitude corresponding to the maximum of the ATB_{1565} profile. For the Welgegund case, the maximum of the δ_{1565} profile was first located between 2 and 4 km and then the base and top boundaries were determined using the second derivative of ATB_{1565}. For the Kumpula case, ATB_{1565} observations with values lower than 0.2 Mm^{-1} sr^{-1} or higher than 2 Mm^{-1} sr^{-1} were excluded. The remaining observations were subsequently used to define the boundaries of the smoke layer. In all cases, cloud-free layers were considered only.