Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2020-1281-RC2, 2021

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Lidar Depolarization Ratio of Atmospheric Pollen at Multiple Wavelengths" *by* Stephanie Bohlmann et al.

Anonymous Referee #2

Received and published: 26 January 2021

Lidar observations of pollen in the atmosphere receive interest by the community as pollen are not yet as well characterized as other aerosol types. The authors contribute to the characterization effort by extending the wavelength range from 355 and 532 nm towards 1565 nm and by presenting measurements of birch-spruce pollen mixtures. Especially, the spruce pollen turns out to be strongly depolarizing. Especially the spectral dependence of the depolarization ratio is of great value. The figures of the manuscript are in an excellent shape. However, I have two major concerns which should be addressed before publication. In the following, I'll provide my comments to improve the manuscript.

My major concerns:

1. Presenting a particle linear depolarization ratio (PLDR) of a birch-spruce pollen

mixture (44% at 532 nm and 16% at 355 nm) has not so much use to the community. We need to have the same mixture of birch and spruce pollen to measure the same PLDR. The PLDR of pure birch and pure spruce pollen is needed to apply the findings to future measurements.

Under the assumption that the mixing ratio measured by the in-situ pollen sampler is valid for the whole boundary layer, the PLDR of each pure type could be calculated. This assumption is already made throughout the paper (line 143, Fig. 7+8), but contains some uncertainties which should be addressed.

Furthermore, Shang et al. (2020) already reported PLDR for pure birch pollen. This open another way to address the PLDR of pure spruce pollen. Reporting a value for the PLDR of pure spruce pollen will enhance the impact of this manuscript.

2. The calibration of the PLDR is not touched in the manuscript sufficiently. This is an essential part for a paper focusing on PLDR values. Otherwise the PLDR values cannot be trusted. Two lidars are involved which have to be calibrated. The short period of time (4 days) allows to give more detail about the calibration measurements of the PollyXT and the Halo Doppler lidar during this specific period.

Using the depolarization ratio measurements of a Halo Doppler lidar is something new. The paper by Vakkari et al. (2020) describing the depolarization calibration is still under review and needs to be accepted before acceptance of the present manuscript is possible. Nevertheless, some more details about the depolarization calibration of the Halo Doppler lidar during the pollen campaign are necessary for this paper.

The PLDR at 532 nm decreases with height for all days whereas the depolarization ratio at 1565 nm stays vertically almost constant (Fig. 3). Why? This is not satisfactorily explained (line 176/177) and could lead to the impression that something is wrong with the depolarization ratio of the Doppler lidar.

My main comments:

3. A subsection describing the birch and spruce pollen is missing. Fig. 4 and the describing text in Sect. 3.2 occur somewhere in the description of the lidar measurements and should be moved to the beginning of the paper.

4. Do you mainly observe whole pollen grains or fragments?

A spruce pollen with 100 μm in size is large compared to all wavelengths used in your study and so no spectral behavior is expected. The strong difference in PLDR between 355 and 532 nm could not be explained with such large pollen grains. Your optical particle sizer (OPS) counts only up to 10 μm, which is even too small for birch pollen (20 – 30 μm in diameter). Do you have any indication about the strength of the fragmentation process? Is it related to temperature, RH, wind speed or age of the pollen grain?

5. Do the depolarization ratios reported by Cao et al. (2010) correspond to whole pollen grains or fragments?

6. Does the microscopic analysis of the Hirst sampler count only whole pollen grains or does it include fragments as well? Maybe the large spruce pollen grains are more likely fragmented. This could explain their high PLDR as you discuss in lines 330-333. Please extend the discussion and collect further information on fragmented pollen grains. Maybe on the tape of the Hirst sampler?

7. Please improve your discussion of the spectral dependence of the PLDR and motivate, why it is important to measure the depolarization ratio at several wavelengths. The spectral dependence of the PLDR was studied previously for different aerosol types. A similar behavior with a maximum at 532 nm and a decrease towards the ultraviolet and the near infrared was observed for mineral dust (Burton et al., 2015, Haarig et al., 2017). The optical properties of mineral dust are dominated by the large particles (>1 μm) as well. Whereas small smoke particles in the stratosphere (< 1μm) show a completely different behavior with a strong decrease of the PLDR with increasing wavelength (Haarig et al., 2018, Hu et al., 2019).

8. The depolarization ratio at 1565 nm is consequently not called particle depolarization ratio (PDR), but just depolarization ratio (DR). This might confuse some readers. In fact, you measure the volume depolarization ratio at 1565 nm. However, the molecular influence is negligible at such long wavelengths and the volume depolarization ratio is equal to the particle depolarization ratio. Can you calculate once the molecular influence at 1565 nm? Are gas absorption lines expect at this wavelength which could interfere with your results? With this low number you can argue, that you measure the PDR.

9. You are arguing that the pollen grains are large compared to the wavelength (355 and 532 nm), so the BAE = 0. But how do you explain the large difference in the PLDR between 355 and 532 nm?

Minor comments

10. Ice nuclei (e.g., L.43) should be called “ice nucleating particles” (INP) to follow the convention of Vali et al., 2015. Please consider this throughout the manuscript.

11. L.39/40 “Airborne measurements revealed the presence of pollen up to 4 km above ground with a considerable amount of pollen still observed at 2 km” Where did they measure? Please include the region at this point.

12. L.45 The phrase “increase the cloud albedo and cloud lifetime and reduce precipitation” goes beyond the scope of your article and would need further references.

13. L.88 Did you merge the signals or the products? Please be more specific.

14. L.116 “was processed similar to Vakkari et al. (2020)” Where is the difference to Vakkari or is it just the different bleed-through? When did you perform the calibration at liquid cloud base?

15. L.148 The VDR in the UV is strongly influenced by the molecular scattering and therefore the effect of the particles is smaller compared to larger wavelengths.

16. L.155 Find a better title for the subsection. Something like “Case study with highly depolarizing aerosol”.

17. Section 2.1, 3.1 and 3.2 needs some more structure, e.g., Section 2.1 starts and ends with depolarization. Better separate the discussion about the negative BAE from the spectral dependence of PLDR in Section 3.1. In Section 3.2 move the pollen description to a separate (sub)section at an earlier position in the paper.

18. Which trees are surrounding your measurement site? Do they contribute to the pollen load?

19. L.288 “It must be noted, that the Ångström exponent also depends on the background aerosols and its use to characterize pollen needs to be considered carefully”. It is mentioned very late in the manuscript. At the beginning you should make clear, that BAE and PLDR are always a mixture of pollen and background aerosol. Already there, you can mention that you will later use the method of Shang et al. (2020) to separate the background and the pollen influence.

20. Fig. 3(e) Consider adjusting the x-axis to a maximum value of 2 to be comparable to the other backscatter coefficient profiles and enlarge the profiles for 16 – 18 May.

21. Fig. 4 Add the year to the dates in the caption.

22. Fig. 10 + 11 Please add the threshold (-0.4) to the figures.

23. The text should be improved in terms of spelling and unusual expressions, e.g.,

L.242 relationship, no plural.

L.293 “Estimation of the pollen depolarization ratio”

L.296 “of total particles” – find a better expression.

L.302 “are related to PDR larger than”

L.329 has –> have

L.350 affect the detected depolarization ratio as well.

24. Avoid long sentences, better split them, e.g., L.85-88; 93-95 (using . . . using)

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Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-1281, 2020.