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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Spatial variation of aerosol optical properties around the high-alpine site Jungfraujoch (3580 m a.s.l.)" *by* P. Zieger et al.

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We thank the 1st reviewer for his or her useful and productive comments, which helped to improve the clarity and quality of the manuscript.

Reviewer 1: The paper reports on a closure experiment in a high-alpine region by using in-situ instrumentation as well as lidar and passive remote sensors. The in-situ instruments were placed at the research station Jungfraujoch whereas the lidar was located about 2000 m below and could scan towards the Jungfraujoch. Therefore, all systems could practically sense the same air masses. Thus local closure studies could be performed and are well justified. The paper is well written and logically structured. The instrumentation is introduced in necessary

detail. The results are carefully discussed considering meteorological conditions and measurement errors. Some minor issues, which should be considered in the revision of the paper, are listed below.

Introduction, last paragraph: References should be added for more recent aerosol closure studies.

Reply: A list of references for recent closure studies has been given in the second part of the introduction, where it better suits the structure of the manuscript. In addition, we have added the reference of Hoffmann et al., 2010, who present the results of a very recent airborne and ground-based closure study in the Arctic and the overview paper of Ansmann et al., 2011, who show a nice overview on closure studies with a focus on mineral dust. We have modified this paragraph:
"Closure studies have been proposed (see e.g. Ogren, 1995; Penner et al., 1994) and initiated to assess the consistency of aerosol properties measured with various techniques from different platforms. For example, closure studies between LIDAR (Light Detection And Ranging) and in-situ measured aerosol size distribution, scattering and absorption coefficients (often together with Mie theory) have been performed in several studies (see e.g. Hoffmann et al., 2012; Zieger et al., 2011; Fierz-Schmidhauser et al., 2010; Schmid et al., 2003; Gobbi et al., 2003; Fiebig et al., 2002; Wex et al., 2002; Russell and Heintzenberg, 2000; Hoff et al., 1996, and references therein). An overview on closure studies with a focus on mineral dust is given in a recent publication by Ansmann et al. (2011)."

Reviewer 1: Page 11110, line 17: explain FUBISS (seems to be the place of first appearance here)

Reply: Yes. We have changed the sentence to:
"During this time also columnar aerosol optical properties were measured from the KLS with the FUBISS instrumentation (Free University Berlin Integrated Spectrographic System, see Sect. 2.3.2)."

Reviewer 1: Page 11114-11115, eq. (3) and (4): use of indices is somewhat strange, what is the physical meaning of index ep (extinction by particles) for the backscatter coefficient? Why do you switch to aer for L?

Reply: We agree, that the current abbreviations are not fully consistent. We removed the subscript 'aer' for the lidar ratio and the backscatter coefficient to be consistent with the current literature. The subscript for the molecular part is kept with 'm'. We prefer keeping 'ep' (extinction by particles) as a subscript for the aerosol extinction coefficient similar to the aerosol scattering coefficient 'sp' (scattering by particles), which is used in all of our previous publications and in the literature that deal with in-situ measurements of aerosol optical properties (especially in the nephelometer community, see e.g. Anderson and Ogren, 1996).

Reviewer 1: Page 11115, line 13: aerosol size -> particle size (the term aerosol usually describes a suspension of particles in air)

Reply: Changed accordingly.

Reviewer 1: Page 11115, line 20: lidar inversion is usually performed following Fernald (1984)?

Reply: We have followed the detailed description in Kovalev and Eichinger (2004), who describe and discuss various different inversion techniques (including the limitations of the earlier published method by Fernald, 1984). We therefore keep the reference of Kovalev and Eichinger (2004) and refer the reader to this comprehensive book. To be consitent, we have removed the Klett reference, since it is also described and discussed in Kovalev and Eichinger (2004).

Reviewer 1: Page 11116, eq. (6): this equation is incorrect; the depolarization ratio can only be determined by considering a calibration factor. Please describe how the calibration is performed and whether you mean volume or particle depolarization.

Reply: Yes, we agree. We have changed the sentence:
"The linear volume depolarization ratio δ is defined as ..."
and following Eq.6:
"... where the the signal ratio is evaluated using the manufacturer supplied instrumental calibration factor."

Reviewer 1: Page 11116, line 5: "The lidar was measured. . ."?

Reply: Sentenced changed to:
"The LIDAR was tilted at a zenith angle ..."

Reviewer 1: Page 11117, eq. (7): avoid to mix up abbreviations (here AOD) and variable names (here tau) in equations

Reply: Yes, we agree. We have changed AOD in the equation to τ_a to be consistent with the other optical depth variables. We have also added τ_a in the corresponding figures. In the text we have decided to keep the abbreviation AOD which is more common and simplifies the reading of the article.

Reviewer 1: Page 11118, line 14/15: "It allows to estimate the observed aerosol type, . . ." What does aerosol type mean in this context? As the Angström exponent also aui should primarily depend on particle size.

Reply: The measured aui depends on the forward scattering region of the aerosol phase function. The aerosol phase function not only depends on the particle size distribution, but (among others) also on the complex refractive index of the aerosols. The aureole index therefore holds additional information on the chemical composition or - more broadly formulated - it gives information on the aerosol type, which show different forward scattering properties. This has been shown in Zieger et al.(2007) using Mie calculations for different aerosol types like sea salt, urban aerosol or desert dust. However, the aui does not reflect a direct

quantitative value and is being used as an indicator in addition to other measured parameters. We have modified the second sentence in the last paragraph of Sect. 2.3.2:
"It allows to estimate the observed aerosol type, if e.g. compared to values computed by Mie calculations for different aerosol types like sea salt, desert dust or urban aerosol (see Zieger et al.,2007)."

Reviewer 1: Page 11123, line 20: refractive index of dust taken from Hess et al. (1998) – there should be better values available meanwhile (check, e.g., Kandler et al., Tellus 61B, 32-50, 2009)

Reply: The refractive index at λ=550 nm is given by OPAC of Hess et al.(1998) to be at 1.53+0.0055i. Kandler et al.(2009) give values for the refractive index of different mineral dust components (like hematite or quartz) as well as average values. These values all lie within the range of the OPAC derived value (e.g., Kandler et al.(2009) state at $\lambda = 530$ nm a value of (1.564$\pm$0.008)+(0.0035$\pm$0.0005)i which can be considered close to the OPAC derived value). Since we have no information on the specific chemical composition of the measured Saharan dust, we have to rely on a mean value. We also have to keep in mind, that we have measured long-range transported Saharan dust at Jungfraujoch, whose refractive index might differ from the values measured directly at the source.

Reviewer 1: Page 11124, first paragraph, discussion of Fig. 3: There is not only a discrepancy for the blue curve, but also for the red one (no Saharan dust). Could you discuss the reasons?

Reply: The points in the scatter plot were grouped according to the Ångström exponent of the single scattering albedo, which is used to discriminate the Saharan dust from other aerosol present at Jungfraujoch. The Saharan dust influenced points and the not influenced points were separately fitted with a linear regression. Remaining differences from the linear regression are due to the simplified

assumptions for the Mie calculations (spherical particles, refractive index, measured size), which is described in the following sentences. For clarification, we have added and modified the following sentences:
"The points in Fig. 3 were grouped for values α_{ω_0} <0 (Saharan dust influenced) and α_{ω_0} >0 (not Saharan dust influenced) and a weighted linear least squares regression was applied for each group. The slopes of the regression lines in Fig. 3 are clearly different for the two different aerosol types predominant at the JFJ. Remaining differences from the individual regression lines are due to the simplified assumptions for the Mie calculations (spherical particles, fixed refractive indices) and the measured aerosol size distribution. Moreover, this example shows that the calculation of the optical properties during the SDE are highly uncertain due to the dominance of non-spherical particles, where Mie theory is not applicable Nousiainen (2009)."

Reviewer 1: Page 11126, line 14: wind direction - only horizontally or also vertically (up-wind/downwind)?

Reply: The horizontal wind direction was clearly different above KLS compared to JFJ. The vertical wind direction was measured by second instrument, but its data was strongly influenced by the position of the instrument close to the building. The vertical wind direction was therefore not considered for further analysis. We have modified this sentence:
"Clear differences in the horizontal wind direction were observed by measurements of the wind profiler at the KLS and an anemometer at the JFJ ..."

Reviewer 1: Page 11130, line 21: measures -> measure?

Reply: Yes. Changed accordingly.
"... while MODIS is installed on two polar orbiting satellites (Terra and Aqua) which measure twice a day at mid-latitudes."

Reviewer 1: Page 11131, line 11: values smoothly increases and recovers -> values smoothly increase and recover

Reply: Changed accordingly.

Reviewer 1: Page 11131, line 24: allows to determine -> allow the determination of

Reply: Changed accordingly.

Reviewer 1: Page 11132, line 10: where -> were

Reply: Changed accordingly.

Reviewer 1: Page 11145, Fig. 4: units for LR are missing

Reply: Units for LR were added in Fig. 4 and Fig. 6.

Comment: Page 11146, Fig. 5: I cannot distinguish the different symbols/colors (especially in panels a and e). Can this plot be improved? In panel a, are these red bullets (caption) or crosses (legend)?

Reply: The figure has been improved. The ambient and dry in-situ measurements are now both shown as solid squares.

Reviewer 1: Page 11147, Fig. 6: LR = 65 sr (legend) or 75 sr (caption)?

Reply: It should be LR=75 sr. Changed accordingly.

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