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Interactive comment on "Aerosol profiling using the ceilometer network of the German Meteorological Service" *by* H. Flentje et al.

H. Flentje et al.

harald.flentje@dwd.de

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Authors' response to reviewer #1:

First we thank the reviewer for the detailed and constructive comments!

General reply:

The fact that the quantitative information about the ash cloud is not derived from the ceilometers, but stems from additional measurements, is indeed very important and will clarified in the text.

Additionally triggered by the Eyjafjöll eruption, the DWD ceilometer network is currently evolving from a cloud height monitoring towards a 24/7 aerosol plume alerting network. This requires simplicity and robustness and implicates parallel efforts to characterise uncertainties, limitations and integration details. This process will take several years and directly interacts with building/integrating a national respective international aerosol observation network. We consider it timely and important to highlight the potential of a ceilometer network in this context, even initially (unavoidably) with not elaborate characterisation – of course this limited scope has to be adequately claimed and the basic uncertainties and evolution paths must already now be discussed and outlined.

Our approach was initiated by urgent requests from ministries of transport, aviation advisory and environmental security centres as well as WMO (e.g. GAW office) to foster scientific discussion on ceilometers' newly recognized potential contribution to a future overarching international aerosol observation network part of which will be GALION.

Thus our revision will: - summarize and estimate the magnitude of uncertainties involved in ceilometer data evaluation at levels 0, 1,etc., based on literature, sensitivity studies and the signal/noise ratio

- clarify that the quantitative information about aerosol layers is not derived from the ceilometers, but stems from indispensable additional measurements

- focus our statements to the benefit achieved additionally by the use of ceilometers – in a network - rather than compete with lidars and drown in the complex bunch of considerations which will be discussed within the community during the next months and years.

- provide Germany-wide overview maps of backscatter intensity sections as zoomable electronic supplement files instead of stamp-size figures

- include a section on enlarging the footprint of lidar extinction profiles by use of ceilometer data for sufficiently coherent and passive plumes

Point by point:

affiliation: will be corrected

3644/4: Literally a ceilometer is a lidar but we agree that it should not be denoted as 'lidar system' as this implies complexity. For better readability, except for introduction of what a ceilometer is we will use the term ceilometer.

3644/9: good point – ok

3644/13: ok

3644/17: ok

3644/20: As our title is '...using the ceilometer network...' this paper is not only on ceilometer results but shall show what becomes possible when ceilometers are used synoptically and are added to hitherto available information/measurements. The fact that ceilometers substantially contribute to the ability to roughly estimate these quantities (at upper levels), naturally using everything what's available, is the central motivation of integrating them into aerosol plume alerting systems in the future. But we agree that it must be clearly stated already in the abstract that the quantification is a merit of the additional data, not the ceilometers. It may at this stage of uncertainty discussion by appropriate to reduce our statement in the way, that 'mass concentrations up to the order of 1mg/m^3 are estimated'.

3645/21: Bösenberg's Vichy (ILRC 2000) introduction to EARLINET will be added since Matthias et al is a good overview paper for those who want to inform about EARLINET

3645/22: ok

3645/23: We think that MPLnet should not be completely disregarded (it is only mentioned once and at this text passage) as it constitutes a relevant remote sensing effort (to our knowledge the most relevant profiling in N-America) which will have to be integrated either into the envisioned GALION or at least considered when building a global aerosol observation network. But we agree that differences in scientific goals and quality criteria between the networks should be mentioned in this context.

3646/10: ok

3646/23: ok, you are right – there are (and will be) ongoing reorganisations, replacements (of old LD-40) and additional installations but this sounds odd.

3646/24: Data coverage varied during the volcano episode (instrumental or download failures. . .). Data from about 20 remote ceilometers were not collected because they were stored very elaborately manually via USB sticks by that time. Online operation will be realised till end 2011.

3646/24: ok, will be checked

3647/6: ok, will be added

3647/15: both, depolarisation-upgraded (prototype announced by manufacturer for 2012) and field-of-view enlarged instruments will replace part of the existing network units (when mature). How many units will be exchanged has still to be decided.

3647/17: ok, will be reworded

3648/10: good point, will be added

3649/8: only few DWD sites are presently equipped with a sun photometer. Complementation will be discussed within the German Aerosol Network. The applicability of global radiation measurements to estimate AOD sufficiently accurate will be investigated (c.f. Gueymard, J. Appl. Met, 1996).

3649/12: Thin stratospheric layers as reported by Jäger et al, are at or below the sensitivity (SNR) threshold of the instruments and they may reach beyond it's vertical range. Thus without gradients it is more difficult to distinguish such signals from instrumental artefacts than with structured layers which show temporal development.

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3650/4; ok will be done

3650/4: ok

3650/13: the citation is correct but the figure and those overview plots of the other days as well will be provided as online available zoomable electronic supplement file on order to be more useful for the reader. This will answer many questions, e.g. about which layers were detected by the ceilometers etc.

3650/26: yes

3650/26: AOD ~0.15 was measured by a collocated PFR filter radiometer (extrapolated to 1064 nm)

3650/28: ok, indeed MULIS is meant

3651/26: ok, this is misleading. Instead of giving the range of extinction coefficients within the inhomogeneous layer (optically thinnest – optically thickest regions) only the maximum values in its densest areas shall be provided. The dust layer will be outlined in the plot.

3652/15: will be done. As above, the overview plots will be provided as electronic supplementary files.

3652/21: The analysis of the fire case ceilometer data will be shown explicitly. Contributions of different error sources to the uncertainty will be estimated and the sensitivity of the extinction coefficient to the measured AOD, the assumed overlap function, the reference value and the lidar ratio will be discussed.

3652/23: The backscatter coefficient of about 2 x 10-7 sr-1 m-1 was estimated for the fire smoke layer in about 4 km altitude for averaging period 6:00-8:00 local time, based on the measured AOD (0.18+/-0.05 @ 1020 nm, MICROTOPS) and a lidar ratio of 40-60. The overlap was corrected from 1200m down to 600m with an overlap function provided by JENOPTIK, below 600 m to the ground the extinction coefficient was as-

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sumed as constant. The resulting backscatter coefficient in the PBL 4+/-1 x 10-6 sr-1 m-1 (uncertainty based on that of LR, and AOD) roughly agreed to the value measured by an integrating nephelometer at the surface 4+/-0.3 x 10-6 sr-1 m-1.

3653/1: This is a bit casual and misleading in the text: it is necessary to distinguish between the optically dominant aerosol (here the PBL) and the particle layer of interest (here the fire smoke layer). Generally, absorption increases the lidar ratio. Mattis et al, 2004 inferred somewhat lower LR at 1064 nm for free tropospheric particles in general (∼45) but for fire smoke even report increasing LR with wavelength based on EARLINET-AERONET comparisons. This agrees in part to numerical studies of Ackermann, 1998, however there it is also shown, that the behaviour of the LR is complex, e.g. depending on relative humidity and mixing state of the aerosol even if it is of the same type. The statement will be clarified.

3653:15: Yes. The different contributions to the overall uncertainty will be discussed with the above mentioned error analysis. If the LR of the aerosols within the profile differ, this translates to corresponding relative shifts in the extinction profile.

3654/8: this means only the troposphere above the layer – will be reworded

3654/11: ok this cannot directly be seen in Fig 4 – ref will be removed.

3654/19-20: Only AOD measurements are presently available at few other stations (e.g. Lindenberg, Hamburg). Some more will be upgraded. Nephelometers will be available in the vicinity of ceilometers only by chance if a corresponding research facility is nearby. A discussion like this will be added: The interpolation of profiles from lidar anchor stations with ceilometers will be feasible for aerosol plumes which are coherent on scales of the ceilometer network mesh-width. During the Eyjafjöll event (and in other cases as well) we recognized even details of the primary ash layer subsequently at different stations when crossing Germany. This means that the ceilometers are (at least in this case) close enough to each other to track internal changes of plumes and enable to link ceilometer and lidar observations. However, a thorough synopsis is a

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complex (kind of assimilation) issue which requires specialist efforts, planned e.g. for the upcoming German aerosol observation network. First steps are ongoing but not yet mature enough to be reported. For example simple interpolation between ceilometer and lidar stations is largely complicated or even useless in presence of clouds or relevant mixing/stirring. Against this, the footprint of precise extinction profiles measured by lidars may be enlarged significantly if a layer is as coherent as the volcanic ash on April 16/17, 2010 (c.f. corresponding figures which will also be supplied as zoomable electronic supplementary files to provide reasonable detailed overview maps). In Germany, Raman lidars are operated in the north, west, east and south such that interjacent ceilometer profiles allow to follow the identity of individual layers/plumes between a pair of lidar stations regardless of the transport pattern (if no substantial changes occur). More anchoring observations are available Europe-wide and are foreseen in specific occasions by means of aircraft-, drone, balloon- or dropsonde-borne in-situ instruments. The following topic then will be the user/application-oriented data processing and visualisation – i.e. a volcanic ash advisory centre needs information in a different way and at different accuraqcy than an environmental agency willing to subtract Saharan dust contribution from EU-legislated PM10 exceedances.

Simultaneously, the DWD (like other European) ceilometer network will be extended and upgraded. The manufacturer envisions the development of a depolarisation channel. If available, part of the network instruments will be equipped with it. For part of the instruments the optics module may be exchanged (already available) in order to reduce the overlap distance from about 1200 m to 150 m. At present, AOD measurements are available at only few stations (e.g. Hohenpeißenberg, Lindenberg, Hamburg). Several more will be upgraded and global radiation measurements will be investigated for their applicability (c.f. Gueymard, J. Appl. Met, 1996).

3645/23: particle radius – will be added

3655/8: ok

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3655/17: will be reworded -> . . .by both instruments. Then a nearly particle free layer follows, before from 6.5 to 11 km. . .

3655/20: will be added (DREAM – Dust REgional Aerosol Model, Nickovik et al, JGR, 2001)

3655/24: Indeed. This is a sanity check of the profile rather than a validation of the absolute extinction integral. The AOD from the sun photometer (SP) has been used to find the right backscatter reference value so that the integrated extinction = AOD of the ceilometer fits the SPs AOD. Then it was compared to the lidars backscatter profile.

3656/2: The value from the last measurements of the evening before and on the following morning were used. Now the level 2 AERONET data are available and were used for a new calculation: The corrected AOD value interpolated to 1064 nm is 0.097. (14.04.2009) and 0.116 (15.05.2009) resulting in an interpolated value at the time of the ceilometer measurement of AOD = 0.11, the same value as for level 1.5.

3656/20: Indeed this is an important issue that needs to be better explained: The ash layer was entrained into the PBL from 17 April noon onward as was indicated by surface SO2 observations and the concentration increase of super-micron particles at ground. But only on 18 April in the afternoon (after temporary rainout) and 19 April till noon of 20 April large particles (in part ash) were dominant in the PBL as seen by visual inspection. The Angstrom coefficient measured by an integrating nephelometer (using 450nm and 700nm) at the surface was highest (up to 0.69) on 19 April till noon of 20 April, indicating the optical dominance of the large (ash + maybe contributions of Saharan dust) particles and the main period of the event, relevant for extraction of the extinction-to-mass ratio. Taking into account that the ash was also mixed with smaller particles (increasing the bulk specific extinction) and the literature values reported for the specific extinction of Saharan dust are only little smaller (0.65 e.g. Gerasopulos et al, Ann. Geophys, 2009 – and comparably few) we use the lowest observed value of 0.8+/-0.2 m^2/g as specific extinction coefficient whereby the error interval is estimated from its temporal variability range and small contributions of other particle types.

3657/3: we cannot be sure about that but the correspondence of the particle size spectrum (which is the critical parameter) at the surface and that measured at higher altitudes in-situ by aircraft (DLR) and at Jungfraujoch gives trust in the representativeness of our PBL measurements for the elevated layer. But you are right that this impedes an additional error source that we should estimate and compare to the results of other groups.

3657/5: we estimated some variability of the main ash layer over Germany which is reflected by this different interval. But these values are based on AODs reported by other groups not involved in this paper, thus this numbers should be the same as in sect 4.1, only referring to Hohenpeißenberg

3657/22: ok

3658/10ff: we agree what concerns the in-situ measurements 'validation'. We will also follow your advise to clearly state that the estimation of the ash's mass concentrations is the merit of the AOD and in-situ measurements rather than the ceilometers. But we think that it is important and relevant information to the community that, given all this additional information is availably (which is the case at several European ceilometer stations), it is possible to estimate a mass concentration which is of the order of up to 1 mg/m^3 which is not in contradiction to the values observed by the lidars. Of course a rigid error consideration has to be developed before such combination of instrumentation can be effectively contribute to (inter)national aviation advisory systems. This, however, we see as our future task, based on this start we made.

3663: will be improved

3664: as above, we will provide those 'maps' as electronic supplementary files and only show the southern German region of fig 2 (like in Fig 8) as illustration, enlarging the individual backscatter sections.

3666: yes, this must changed. Labels will be enlarged. The peak is part of the cloud occurring after 10 UTC which is visible also in the overlap range. BSR is backscatter ratio and will be explained.

3667: The profile is an average of the whole day and also includes the afternoon clouds. It shall help to visualize the ash layer to the reader. We will think about changes, maybe averaging only the cloud free regions.

3668: will be changed accordingly

3669: ok

3670: two or three stations will be extracted as agreed above

3671: labels will be enlarged

3673: ok

Interactive comment on Atmos. Meas. Tech. Discuss., 3, 3643, 2010.