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Interactive Comment

Interactive comment on "Simulating the global atmospheric black carbon cycle: a revisit to the contribution of aircraft emissions" *by* J. Hendricks et al.

J. Hendricks et al.

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We would like to thank the referee for the very detailed comments which helped us to achieve major improvements of the manuscript.

Reply to 'General Comments':

We agree with the reviewer that the uncertainties of the model approach should be discussed in more detail. Therefore, we changed the mauscript as documented below (Replies to 'Specific Comments').

We also agree that parts of the manuscript have to be reorganized. Especially the descriptions of the model approach seem to be quite misleading in the original manuscript. We are very sorry that the descriptions of the method were hard to un-

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derstand. We think that some points of the referees criticisms are the consequence of misunderstanding caused by the misleading description (see detailed discussions below).

To make the approach more clear, we reorganized and shortened the methodology section and included a flow chart of the method to estimate aircraft BC particle number concentrations.

Replies to 'Specific Comments':

(1)
The principal motivation to perform this study with a GCM is to obtain representative climatologies of the global BC distribution and its perturbation by aircraft. Such climatologies are required as the basis for further studies on indirect climatic effects of BC from aviation caused by BC impacts on cirrus cloud formation.

Vertical resolution:
We agree with the referee that a higher vertical resolution would be desirable. However, several studies on the impact of the vertical resolution on the transport of aircraft emissions have been previously perfomed with the ECHAM4 model (e.g., Rogers et al. 2002, Meteorologische Zeitschrift, 11, pp 151-159). These studies reveal that increasing the vertical resolution of the model would change the aircraft-induced BC perturbations simulated in the present study only slightly. Since information on the impacts of uncertainties in the BC removal on the BC distributions simulated with ECHAM were lacking, it was very important for the present study to perform the set of sensitivity tests described in the manuscript. Since a huge amount of memory and computing time is necessary to perfom these simulations, we decided for the limited vertical resolution. The sensitivity simulations demonstrated that the effects of uncertainties in aerosol-cloud interactions on the simulated aviation impacts mostly are larger than the effects of the vertical resolution revealed, for instance, by Rogers et al. (2002). Therefore we think that our decision was reasonable.

Nevertheless, we think that the criticism of the referee is justified. We therefore comment on the potential impacts of an increased vertical resolution in the revised manuscript (3rd to last paragraph of Sect. 3.2.4).

General transport features:
We agree with the referee that tracer transport in GCMs can have uncertainties. We therefore included discussions on the uncertainty due to transport schemes in global models into the paper (revised manuscript, Sect. 3.2.3, paragraph 3; Sect. 3.2.4, paragraph 7).

Subgrid-scale microphysics:
The parameterization of Kärcher and Meilinger (1998) used here is designed to parameterize aerosol-aerosol interactions in aircraft plumes. The parameterization is based on simulations performed with a detailed plume process model. The application of this parameterization on the transformation of emitted BC particles in the plume revealed that two processes dominate the transformation of BC: i) The coagulation with small liquid particles which results in liquid coating of the BC particles. ii) The scavenging of BC by large liquid background aerosols. The efficiency of the self coagulation of BC is too small to have a significant impact. Process i will not change the number concentration of the particles containing BC from aviation. In contrast, process ii has the potential to reduce this number concentration since several BC particles can be scavenged by the same background particle. Since aircraft BC ageing is identified here with reductions of the BC number-to-mass ratio, only process ii is relevant here. Process ii is therefore parameterized by Eq. 2. (Eq. 2, revised manuscript; Eq. A1, original manuscript) following the approach of Kärcher and Meilinger (1998).

We try to make this more clear in the new version of the model description which also includes a discussion on the potential effects of BC interactions with contrail ice particles.

(2) We included a dicscussion on how our results compare to the Koehler et al. results

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(revised manuscript, end of Sect. 3.2.4). We want to avoid a discussion on our results in the introduction.

(3) We agree with the referees criticism of cross-references between the appendix and the main part of the text. To make the methods more clear, we reorganized and shortened the methodology section, especially the description of the maximum and minimum estimates of aircraft BC particle number. We skipped the appendix. We reduced the information formerly given in the appendix to the most essential points and integrated them into the main text. Additionally, we included a flow chart of the method to estimate aircraft BC particle number concentrations.

(4) Our model approach is designed for providing maximum/minimum estimates of the aircraft-induced perturbations of BC particle number concentrations. In the view of lacking information on a large number of processes and parameters relevant for BC microphysics in the UTLS, we avoided to attempt a detailed quantification of the BC particle number concentrations based on aerosol microphysics. Therefore, we did not try to simulate the micriohysical and chemical properties of particles containing aged BC from aviation. We hope that this is clearly described in the revised version of the approach.

(5) The description of the approach was reorganised (see also point 3).

(6) This is described clearly in the revised description of the approach.

(7,8) The measurements by Blake and Kato (1995) systematically underestimate the BC concentration. This was demonstrated in the publication by Strawa et al. (1999) (referenced in the manuscript). Since a corrected data set was not provided, we used the data just to compare the qualitative features of the geographical distribution of the BC concentrations with the model results. A quantitative comparison was performed only with the BEA03 data. These data suggest that the BASE simulation performes best with respect to UTLS BC concentrations. This is described in detail in Sect. 3.2.2 (revised manuscript).

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We agree that the observational data on UTLS BC currently available is too sparse to evaluate the quality of simulated global BC distributions. Therefore, we discuss this critical point several times (Introduction; beginning of Sect. 3.2.2; Sect. 3.2.3; item 1 of Conclusions).

(9) A large amount of fuel is consumed in the lower and middle troposphere over North America which results in high mass concentrations of BC in the lower and middle troposphere. These particles can be transported into the upper troposphere over the North Atlantic. We tried to explain this more clearly in the revised manuscript (Sect. 3.2.4, 1st paragraph).

(10) In this discussion, our results on the contribution of aviation to the BC mass loading are compared to the results of similar previous studies. The impact of aviation on UTLS BC mass concentration is evaluated based on the information available from the different studies. We reorganized this discussion and explained the focus more clearly in the revised manuscript (end of Sect. 3.2.4).

The Danilin et al. study is described in the Introduction (Sect. 1). Therefore, a cross-reference in Sect. 3.2.4 points to Sect. 1.

(11) The description of the approach was reorganized (see 3). Therefore, the discussion mentioned by the referee was removed.

(12) The coagulation coefficient is valid for the coagulation of aerosols in the size range of BC from aviation and accumulation mode background aerosols. This is discussed in Sect. 2.5.3 (revised manuscript). For the consideration of plume effects, see (1).

Background aerosols are omnipresent in the UTLS. This is shown by a huge number of observations (e.g. Petzold et al. 2002, Minikin et al. 2003; referenced in the manuscript). If there were no background aerosols (Nl=0), scavenging of BC by background aerosols would not be a relevant process. In this case, it would have no impact on the simulation.

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(13) The relevant ageing processes of aircraft BC potentially changing the BC number-to-mass ratio are BC scavenging by background aerosols and processing of BC by clouds. Both processes are taken into account. The processes consistently impact BC mass and number. This is explained in detail in Sects. 2.5.3 and 2.5.4 (revised manuscript).

(14) Observational data reveal that aircaft-generated BC particles are smaller compared to BC from most of the surface sources (e.g. diesel automobiles, biomass burning). This is probably due to a very efficient combustion in aircraft engines. We included a discussion on this point into the manuscript (Sect. 2.3, 3rd paragraph).

The aerosol mass and number concentrations in the model are consistent with the particle size distributions. This is explained clearly in the revised model description.

(15) This discussion was skipped to make the approach more clear.

(16,17) The discussion was replaced by a more general comment on the comparison of the simulations with observational data (revised manuscript, Sect. 2.5.3, end of 3rd paragraph).

(18) A large number of measurements document scavenging of BC by clouds (see, e.g., Hitzenberger et al. 2001 and references therein, the paper is referenced in our manuscript). Since many details of BC-cloud interactions are uncertain, especially in the case of ice clouds, we did not simulate these interactions in detail. We just consider BC particles as 'aged' as soon as significant cloud activity occurs (see revised manuscript, Sect. 2.5.3).

The maximum and minimum estimates performed here are exactly the sensitivity studies suggested by the referee. This is described more clearly in the revised manuscript.

(19) see (4), (18), and the revised model description.

(20) We skipped the word 'delimit' which seems to be rather misleading.

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