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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Radiative forcing from particle emissions by future supersonic aircraft" *by* G. Pitari et al.

G. Pitari et al.

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Detailed point-by-point reply to Anonymous Referee #2

We found the review of this referee to be constructive on some points, but not all. In other cases we think the comments are too general in their negative approach. We try, however, to clarify as much as possible all points raised by the reviewer and to modify the text where needed, following the referee suggestions.

(1) This is a general statement reflecting an opinion. We think that the goal of the paper and its contribution to the literature have been reached: to show the magnitude and uncertainties of the aerosol radiative forcing from future supersonic aircraft emissions, with an analysis of both direct and indirect forcings (the latter via heterogeneous chemistry).

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(2) This criticism may have arisen because Table 1 is positioned in the text under Section 3 (this is acknowledged at the end of the Introduction: ”a description of the emission data set is given in section three”). We agree with the referee that the discussion made in the core of the Introduction could be misleading without explicit reference to Table 1. For this reason we have included the following paragraph after line 8 at page ACPD-5093:

”As explained in Section 3 of the paper, this modeling study is based on the supersonic aircraft configurations developed by Airbus for years 2025 and 2050 during the EU-funded project SCENIC (SCENIC 2005; Grewe et al., 2007). A summary of the 2050 emission scenarios is presented in Table 1, S6 being the supersonic reference case (Mach 2.0) including also aerosol emissions: if not differently specified, in the remaining of the paper we refer to scenario S6”.

(3) We agree with the referee: the ozone response to HSCT emissions may change with flight altitude. We have modified lines 12-13 at page ACPD-5093 as follows:

”HSCT emissions can lead to an ozone column decrease as a result of NOx and sulphate aerosol emissions, depending on the altitude of the emissions (IPCC, 1999)”.

(4) A new check of English errors has been made trying to polish the text. References have been added in the introduction (Baughcum and Henderson, 1998; NASA, 1999; JPL, 2000; Wuebbles et al., 2003; Rogers et al, 2000; Rogers et al., 2002; Dessens et al., 2007; Weisenstein et al., 2006; Kinne et al., 2006; Textor et al., 2006; Textor et al., 2007), as well as in the aerosol validation part and in the atmospheric impact section (Shulz et al., 2006). The following paragraph has been added after line 24 at page ACPD-5093:

”The uncertainty range in model predictions of the atmospheric impact of future supersonic aircraft is due to several factors: altitude of the emissions, depending on the selected HSCT scenario (Baughcum and Henderson, 1998; IPCC, 1999; Grewe et al., 2007), kinetics rates of photochemical reactions that are relevant in the lower

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stratosphere (JPL, 1997; JPL, 2000; Wuebbles et al., 2003; Dessens, et al., 2007), model-dependent removal efficiency of supersonic aircraft emitted species from the emission regions and their transport on atmospheric large scales (IPCC, 1999; NASA, 1999; Rogers et al., 2000; Rogers et al., 2002)".

For what concerns IR effects affecting aerosol radiative forcing a clarification is needed. In the Introduction (lines 25-26 at page ACPD-5093) we refer to the dominant radiative effect of aviation aerosols (SW scattering and absorption) with the purpose of listing those effect that we have explicitly included (i.e. direct RF and indirect RF via heterogeneous chemistry) and those that we have not included (potential aerosol feedback on cirrus ice particle formation in the upper troposphere). The ULAQ radiative code, however, does include both SW and IR effects. The first are calculated on-line using a delta-Eddington approximation code for a multi-layer atmosphere, the second are calculated using pre-calculated fluxes of IR absorption/emission based on particle emissivity. Aviation aerosols perturb both the geometric surface area density (plume particles) and the lower stratospheric optical depth: the latter change is mainly produced by transport of aircraft emitted sulphur dioxide on large atmospheric scales. The accumulation mode of lower stratospheric aerosols is such that the particle effective radius is of the order of 0.2 μm. For these typical effective radii, the tropopause IR flux change due to lower stratospheric aerosols is much smaller than the solar flux change (Lacis et al., 1992). This is well explained in the IPCC (1999) report on aviation and the global atmosphere: "Sulphate aerosol scatters a fraction of incident solar radiation to space, thereby leading to negative direct radiative forcing. The direct RF in the longwave spectrum is likely to be negligible as a result of the size of aerosol particles and the corresponding wavelength dependence of the specific extinction coefficient (e.g., Haywood and Shine, 1997; Haywood et al., 1997). The same applies to BC aerosols". (This is an extract from the IPCC, 1999 report at pages 204-205). However, to clarify the point raised by the referee we have modified lines 25-28 at page ACPD-5093 as follows:

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”For the aerosols we have calculated both the direct forcing (i.e. scattering and absorption of incoming solar radiation and absorption/emission of longwave planetary radiation) and indirect forcing produced by changes of chemical species (i.e. O3) affected by heterogeneous chemical process on the surface of aerosol particles”.

According to this, we have also changed lines 19-20 at page ACPD-5103 as follows:

”A δ-Eddington approximation is used for evaluating solar radiation scattering/absorption in a multi-layer atmosphere; for the longwave spectrum, pre-calculated IR fluxes based on particle emissivity are used. A validation of the ULAQ model calculations of aerosol radiative forcing has been made in the framework of the AeroCom project (Shulz et al., 2006)”.

(5) Txx is the usual method for defining the resolution of a global scale numerical model. It means ”geographical resolution equivalent to a xx-wave spectral triangular truncation”. The SLIMCAT model may change the resolution (depending from the application) from xx=10 to xx=170, i.e. from T10 to T170. Several tests have been made to insure proper representation of the large-scale accumulation of aircraft emissions (NOx, H2O, HC) using T15 (see references in the text). The choice would have been different in case of upper tropospheric studies. In the SCENIC project one of the perturbation scenarios was to study the change of model resolution (scenario P1). The results are shown and discussed in the project final report (chapter WP5-D5.3, Fig. 18) (SCENIC, 2005). Only SLIMCAT has done this calculation using T42 (2.5x2.5) resolution, instead of T15. The conclusion was that the results of the supersonic emission impact were not highly sensitive to the model resolution. Some differences were found in the transport of NOy within the stratosphere, but with no big impact on the ozone column. Due to computing time resources and storage availability and in order to be able to calculate all the SCENIC scenarios (2025, 2050+ perturbations) a practical decision was taken to run the model at T15 for all the simulations. The acronym SCENIC is now explained at the beginning of the Introduction (see point (2) above, as well as in the abstract).

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(6) The comment on wide use of grey literature is only partially acceptable. It is true that we cite the final report of the EU-funded project SCENIC, but since we are aware of possible difficulties in having access to this, we also cite the ACP-2007 paper of Grewe et al. "Climate impact of supersonic air traffic: an approach to optimize a potential future supersonic fleet results from the EU-project SCENIC" (ACP, 7, 5129-5145, 2007). A summary of the emission scenarios is given in the Grewe et al (2007) paper: this is not grey literature. In our present paper we also include a Table (Table 1) which is even more complete that the one in Grewe et al. (2007). The referee did not give enough attention to this table, since information on Mach number and cruise altitude are there.

(7) The referee here has two major criticisms: (a) aerosols are studied only with the ULAQ model; (b) validation plots are not shown in the paper. Here we go to the overall strategy of this paper. The idea (and this is stated both in the abstract and Introduction) is to use a model including microphysics and transport of aerosols to calculate the aviation impact on several aerosol-related quantities: geometric surface area density (SSA-SAD), mass density, extinction profile, optical depth. This model performs the radiative calculation to have an estimate of the direct RF. However, since sulphuric acid aerosols may feedback on chemistry through NOx and Cl/Br heterogeneous reactions in the stratosphere, we try to assess the O3 related perturbation due to these aerosols by passing the ULAQ model calculated SSA-SAD perturbation to other three ACMs (other than ULAQ). The purpose is to better bound the resulting O3 change (due to aviation emissions of NOx, H2O and sulphuric acid aerosols) and the associated UV+IR radiative forcing. This work was conducted under the EU-project SCENIC, where the ULAQ model was the only one designed to have full interaction between aircraft emissions and the population and size distribution of lower stratospheric aerosols. To make this overall assumption clearer to readers, we have changed lines 4-5 in the Introduction at page ACPD-5094 as follows:

"In section four we present results for black carbon (BC) and sulphate (SO4) aerosols

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as simulated in the University of LAquila CTM (ULAQ-CTM), with appropriate model validation (Weisenstein et al., 2006; Kinne et al., 2006; Textor et al., 2006; Textor et al., 2007). The ULAQ-CTM is the only SCENIC model including an aerosol microphysics code on-line with chemistry: the purpose is to calculate the impact of supersonic aircraft on the geometric surface area density and then pass to the other ACMs the calculated surface area density fields for the chemistry-transport calculations (section five)".

For what concerns the model validation, we thought that the usual approach to rely on previously published papers and scientific assessments could be used in our case, as well. We see, however, that the referee has probably skipped the citation to the Weisenstein et al (2006) work (i.e. Chapter 6 of the SPARC assessment on stratospheric aerosols, where the ULAQ model gave an extensive contribution). Anyhow, since the reviewer explicitly asks for graphics in the manuscript to explain the comparisons with SAGE II and HALOE we have added three new figures (new Figures 2-3-4: see below). We hope this may help us to believe, instead of being "unbelievable" For introducing these figures we have modified lines 16-22 at page ACPD-5101 as follows:

"Extinction profiles calculated in the model for several wavelengths are compared in Fig. 2 and 3 to SAGE II and HALOE data, respectively (see also Weisenstein et al., 2006). In the stratosphere the model shows good agreement at wavelengths in the visible and near infrared, whereas an underestimation, of about a factor of 3, is present at λ=5.26 μm above 30 km. The good model performance is confirmed by the comparison of annually and zonally averaged field of sulphate aerosol surface area density (SAD) calculated by the model with the SAGE II derived values (Fig. 4). Model values are obtained from the calculated sulphate aerosol size distribution for particles larger then 0.05 μm, in order to include only the contribution of optically active aerosols in the geometric surface area density. The model is able to reproduce the SAD maximum (about 2×10^{8} cm^{1}) in the layer between 10 and 13 km poleward of 40$\circ$ of both hemispheres, resulting from large-scale transport accumulation (Brewer-Dobson stratospheric circulation)".

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Lines 13-15 at page ACPD-5101 and 2-3 at page ACPD-5102 have been modified to: (a) include a reference to the AeroCom validation of model calculated tropospheric aerosol optical depth and (b) specify that we are talking here of high latitude horizontal gradients. ACPD-5101 lines 13-15:

”probably due to an unrealistic abundance of dust aerosols coming from the Sahara region. A validation of the ULAQ model calculations of tropospheric aerosol optical depth has been made in the framework of the AeroCom project (Kinne et al., 2006)”.

ACPD-5102 lines 2-3: ” âd’166;and for a too flat high-latitude horizontal gradient above 25 km”.

(8) A discussion of RF calculations and comparison between DLR E39/C and ULAQ results for water vapour is made in the Grewe et al. (2007) paper. These are the only two models coupling chemistry with a radiative transfer code; SLIMCAT and OsloCTM2 models are pure CTMs (chemistry-transport models). It is important to point out here that predicted chemical changes from ALL four models are taken into account with both the E39/C and ULAQ model (i.e. ULAQ radiation code and ULAQ perturbation pattern, ULAQ radiation code and SLIMCAT perturbation pattern etc.).

(9) The oldest reference is unnecessary in this contest and has been deleted from the text (lines 13-14 at page ACPD-5104), since it refers to tropospheric water vapour, which does not have a role in radiative forcing and even more in a study focusing on stratospheric chemical perturbations. The longwave fluxes and absorptance of water vapour in the stratosphere are calculated using the Ramanathan (1983) method. This is a ”classic” radiation transfer code and we believe is unfair to criticize this choice just in terms of ”age”. A validation of the results coming from this code is made using the IPCC (1999) results of Forster and Haywood on one side and Ponater and Sausen on the other, after stratospheric temperature adjustment. The net H2O-RF in the baseline case is 28 mW/m^2 with the ULAQ model, for a total of 44 Tg/yr of fuel consumption from supersonic aircraft. The IPCC (1999) calculation were made with the HSCT NASA

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scenario (fuel consumption: 70 Tg/yr). Scaling the ULAQ results to 70/44 we get 44.5 mW/m^2, that fit well in the range of the IPCC (1999) reference numbers of 68 mW/m^2 and 34 mW/m^2, from the calculations of Forster-Haywood and Ponater-Sausen, respectively. In order to clarify this point, we have modified the text at page ACPD-5104 line 13-14 as follows:

"The longwave flux and absorptance for H2O are evaluated following Ramanathan et al. (1983). A validation of the RF results coming from this code is made using the IPCC (1999) results of Forster-Haywood on one side and Ponater-Sausen on the other, after stratospheric temperature adjustment. The net H2O-RF in the SCENIC baseline case is 28 mW/m2 with the ULAQ model, for a total of 44 Tg/yr of fuel consumption from 2050 supersonic aircraft in scenario S6. The IPCC (1999) calculation were made with the HSCT NASA scenario (fuel consumption: 70 Tg/yr). Scaling the ULAQ results to 70/44 we get 44.5 mW/m^2, that fit well in the range of the IPCC (1999) reference numbers of 68 mW/m2 and 34 mW/m^2, from the calculations of Forster-Haywood and Ponater-Sausen, respectively".

Tables are normally used to summarize radiative forcing calculations, in order to show differences between sensitivity studies and a reference case (S6-S4 in our case). However, we agree with the reviewer that some of these tables may be unnecessary. For this reason we have deleted from the text Tables 4a (CO2 and H2O) and 4d (total). On the other hand, we keep Tables 4b and 4c (to be renamed 4a and 4b) since they provide information on ozone and aerosol column changes in different sensitivity scenarios that are needed to complete the picture given in Fig. 4.

(10) There is an error in the caption of Figure 7: only the H2O RF was calculated with the DLR E39/C radiative code. We agree with the reviewer that this may generate confusion since all other RF calculations were made with the ULAQ model. For this reason, we have changed the legend of Figure 7 and the RF bar for H2O, adopting the ULAQ model RF results (see point (9) above). The paper of Grewe et al. (2007) compares the H2O-RF values between the two models as follows:

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”Previous studies showed that the uncertainty in the calculation of the radiative forcing is less than 10% except for water vapour (Forster et al., 2001) âđ166;. For water vapour, the ULAQ radiation scheme shows higher values than the DLR E39 model, employing the same water vapour perturbation and background field. These results are consistent with previous findings (IPCC, 1999), which showed an uncertainty of a factor of two in the calculation of the water vapour related RF, with lower values derived with the DLR E39 model, compared to a narrow band model (Forster and Shine, 1997).”

This means that the ULAQ model H2O-RF calculations (after stratospheric temperature adjustment) are closer to the Forster and Shine (1997) results with respect to DLR E39C, that is another reason for including the ULAQ H2O-RF results in Figure 7, other that clarity and consistency with other RFs. In the caption of Figure 7 we specify what model got what result for H2O and O3. The new caption is as follows:

”Fig. 7. Summary of (S6-S4) RF in year 2050 per component (mW/m^2), calculated with the ULAQ-GCM radiative code. The uncertainty bar on O3 and H2O forcings is obtained using in the ULAQ-GCM radiative code with the O3 and H2O distributions from the four independent models (SLIMCAT, ULAQ-CTM, E39/C, OsloCTM2). The single RF values obtained with O3 and H2O changes from these models, in the order above, are: -4.3, -3.2, -2.0, -0.3 mW/m^2 (O3) and: 63.6, 28.0, 40.7, 31.4 mW/m^2 (H2O)”.

(11) We disagree with the reviewer. The way we present the chemical intercomparison is complete and rich of details. In summary, what we have done in the paper is the following: use Fig. 8 as validation of baseline model chemical predictions, Fig. 9 and 10 to prove that the predicted changes of ozone precursors are consistent in the models and Fig. 12 to prove that the ozone loss rates for the different catalytic cycles are very similar in the HSCT emission region. The reason for the model-dependent response in the ozone profile and column (Fig. 11) has to be found in the different efficiency of the model large scale transport in exporting the aircraft emissions (NOx, H2O and particles) out of the emission region (NH lower stratospheric mid-latitudes)

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towards the tropics and then upwards in the tropical pipe. Several citations are made to a specific paper that discusses this transport issue in detail: Rogers et al., 2002: Model intercomparison of the transport of aircraft-like emissions from sub- and supersonic aircraft (ACPD-5115 lines 18-20).

(12) The four models have been compared in detail for what concerns the stratospheric chemistry related to ozone (Section 5.2), using the aerosol predictions made in the ULAQ model. This is clearly stated in the Introduction (ACPD-5094 lines 2-10). The radiative forcings have been calculated with the ULAQ-GCM radiative code, using the O3, H2O changes from the four independent models (we agree with the reviewer that the original Fig. 7 could originate some confusion) and numbers for the specific model-related RFs are now given in Fig. 7.

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Fig. 2. (see Fig. 2 of the final version of the paper): Zonally averaged vertical profiles of aerosol extinction in the visible and near infrared spectrum: λ=0.52 μm (top panels a,b,c) and at λ=1.02 μm (bottom panels d,e,f) for ULAQ-CTM calculations (solid lines) and SAGE-II derived values (asterisks). Left panels (a,d) refer to wintertime averages (December, January, February) at 45°N; middle panels (b,e) refer to summertime averages (June, July, August) at 45°N; right panels (c,f) show averages over March-April-May at the Equator. Units are 10^{-4}km^{-1}. Extinction values are averaged over years 2001−2002 (non-volcanic background conditions).

Fig. 3. (see Fig. 3 of the final version of the paper): Zonally averaged vertical profiles of aerosol extinction in the far infrared spectrum: λ=3.46 μm (top panels a,b,c) and at λ=5.26 μm (bottom panels d,e,f) for ULAQ-CTM calculations (solid lines) and HALOE derived values (asterisks). Left panels (a,d) refer to wintertime averages (December, January, February) at 45°N; middle panels (b,e) refer to summertime averages (June, July, August) at 45°N; right panels (c,f) show averages over March-April-May at the Equator. Units are 10^{-4}km^{-1}. Extinction values are averaged over years from 1999 to 2004 (non-volcanic background conditions).

Fig. 4. (see Fig. 4 of the final version of the paper): Annually and zonally averaged fields of sulphuric acid aerosol surface area density: ULAQ-CTM calculations (solid lines) and SAGE-II derived values (asterisks). The three panels show averages over the following latitudinal bands: 75°N−30°N (left panel a); 30°N−30°S (mid panel b); 30°S−75°S (right panel c). Units are 10^{-8} cm^{-1}. Surface area density values are averaged over the following volcanically quiet years: December 1988 − November 1989 and June 1996 − May 1998. ULAQ-CTM values are calculated for particles with radius larger than 0.05 μm (see text).

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