We are grateful to the referee #2 for the very helpful and encouraging comments on the original version of our manuscript. We took all comments into account and rewrote the manuscript accordingly. Here are our replies:

- This paper proposes an updated sub-model in the ECHAM Atmospheric Chemistry model for flight trajectory optimisation and is within the scope of the journal (GMD). The algorithm now enables the flight trajectory to be optimised based on various scenarios, which can assist relevant stakeholders and policymakers to evaluate the tradeoff between economic costs and the overall climate impact. Such a tool is expected to become increasingly important as the focus shifts to minimising aviation's overall environmental impact, including both CO_2 and non-CO_2 emissions.

  While the work is well structured and written, there are several major aspects in the model that were not adequately addressed and must be significantly improved. Therefore, I believe that major revisions are necessary before this paper is accepted for publication.

  Reply: We thank the referee #2 for these positive comments. We have addressed all the major and minor comments as follows.

- **Major Comments:**

  1) [Page 6, Line 12] What is the rationale for selecting a 20-year time horizon for the average temperature response (ATR20)? Given that a proportion of CO_2 can remain in the atmosphere for over a millennium [Ref.1], the ATR20 can lead to a large underestimation in the CO_2 climate impacts. To overcome this, it is suggested that the authors perform a sensitivity analysis on the reported results by considering the use of different ATR time horizons (i.e. 100 years and 1000 years).

  Reply: As the referee pointed out, a choice of the climate metric is an important issue. Grewe and Dahlmann (2015) pointed out that the different climate metrics, although targeting somehow climate change, provide "different physical quantities measuring climate change and hence they provide answers to different questions." From this viewpoint, we selected the climate metric of ATR20 on the basis of the five steps proposed by Grewe and Dahlmann (2015). First, we posed the detailed question: "what potential reduction in climate impact could be achieved by steadily applying a climate optimizing aircraft routing strategy in the next few decades?" From this objective, we considered a business-as-usual future air traffic scenario for one-day trans-Atlantic flights as a reference, and compared that to a scenario where we daily flew trans-Atlantic routings with a low climate impact. To answer the question, finally we selected an appropriate climate metric: the global and temporal average near-surface temperature response over 20 years after introducing the climate-optimized routing strategy. This metric enables the different climate relevant emissions to be placed on a common scale and thus be directly compared.

  We have performed a sensitivity analysis on the climate metrics in previous research (Grewe et al., 2014). We optimized one-day trans-Atlantic air traffic with respect to three climate metrics: the average temperature response with future increasing emissions (F-ATR20) and the absolute global warming potential with pulse emissions at a 20 year time horizon (P-AGWP20) for short-term climate impacts, and P-AGWP100 (time horizon of 100 years) for long-term climate impacts. The results indicated that the Pareto fronts (optimal relation between climate change and costs) are similar for the three metrics (shown in Fig. 3 of Grewe et al., 2014). For each metric, the relative importance of individual species (CO_2, contrails, ozone, methane, and total NO_x (O_3 + CH_4 + PMO)) for a reduction of the climate impact was also investigated, and all metrics showed a similar pattern (shown in Fig. 4 of Grewe et al., 2014). These results were very robust in terms of dependence from the chosen metric and in terms of the role of individual components. We noticed that if we had adopted the more frequently used pulse-based metrics (e.g. Fuglestvedt et al., 2010), we would have found a much stronger sensitivity of the short-lived effects, e.g., contrails; the more contrast between the short-lived effects, such as contrails, and the long-lived emissions, such as CO_2, would also be expected. However, these would not have been the best suited to quantifying the sustained impact of a permanent change in routing strategy on near-term climate change. That is, such metrics are not suitable to answer the aforementioned question.

On the basis of the rationale for selecting ATR20 described above, we applied the metric to the calculated RF, which was obtained from the detailed EMAC model simulations (for contrails, the RF data set was obtained in a different way; details are described in the reply to the referee major comment (2) starting with “Secondly, some contrails” below), and then obtained a relation between locally and temporarily specified emissions and the global-average impact on climate in terms of future temperature changes (ATR20). We call these 4-D response patterns as “climate-change functions (CCFs).” Algorithmic Climate Change Functions (aCCFs) are approximation functions based on regression analyses for the CCFs data set. Thus, aCCFs approximately express the climate impact indicated by ATR20. The aCCFs have already been published as the ACCF submodel in MESSy (version 2.54), and thus the AirTraf submodel uses the ACCF submodel for the climate-optimized routing. We would like to note that the literature, which is given on page 9 lines 17-18, describes how to develop aCCFs from the CCFs data set and why ATR20 was selected (e.g. Section 2.3 of van Manen and Grewe, 2019).

References:
Fuglestvedt, J. S., Shine, K. P., Berntsen, T., Cook, J., Lee, D. S., Stenke, A., Skeie, R. B., Velders, G. J. M., and Waitz, I. A.: Transport impacts on atmosphere and climate: metrics, Atmospheric Environment, 44, 4648–4677, https://doi.org/10.1016/j.atmosenv.2009.04.044, 2010.

Grewe, V., and Dahlmann, K.: How ambiguous are climate metrics? And are we prepared to assess and compare the climate impact of new air traffic technologies?, Atmospheric Environment, 106, 373–374, https://doi.org/10.1016/j.atmosenv.2015.02.039, 2015.

Grewe, V., Champougny, T., Matthes, S., Frömming, C., Brinkop, S., Søvde, O. A., Irvine, E. A., and Halscheidt, L.: Reduction of the air traffic’s contribution to climate change: A REACT4C case study, Atmospheric Environment, 94, 616–625, https://doi.org/10.1016/j.atmosenv.2014.05.059, 2014.

Van Manen, J. and Grewe, V.: Algorithmic climate change functions for the use in eco-efficient flight planning, Transportation Research Part D: Transport and Environment, 67, 388–405, https://doi.org/10.1016/j.trd.2018.12.016, 2019.

- **2)** [Page 8, Section 2.5.4 and Appendix A] While the methodology selected to model the contrail climate impact was commonly used in previous studies, its limitations should be acknowledged and discussed in the paper. An optimization algorithm based on the contrail length might be overly simplistic because it does not account for differences in the contrail radiative forcing, lifetime and coverage area:

Reply: Thank you very much. We acknowledge that this routing option is the simple option for contrail avoidance and has limitations. Thus, we modified Section 2.5.4 to describe more details of what this routing option minimizes, and to clarify its limitations: on page 8 line 9, “… developed the routing option ~~for contrail avoidance~~ **to avoid contrail formations by using the submodel CONTRAIL (version 1.0; Frömming et al., 2014), which calculates the potential persistent contrail cirrus coverage Potcov (Ponater et al., 2002; Burkhardt et al., 2008; Burkhardt and Kärcher, 2009; Grewe et al. 2014b) within an EMAC grid box.** ~~This option avoids regions where persistent contrail formation is expected.~~ **The Potcov represents the fraction of the grid box, which can be maximally covered by contrails under the simulated atmospheric condition. The threshold for contrail formation is determined from a parameterization scheme based on the thermodynamic theory of contrails, i.e., the Schmidt-Appleman theory (Schmidt, 1941; Appleman, 1953; Schumann, 1996). In the CONTRAIL submodel, Potcov indicates the difference between the maximum possible coverage of both, contrails and cirrus, and the coverage of natural cirrus alone; values of Potcov along the waypoints are taken from the nearest grid box (Table 2). With that, we define a contrail distance ($\mathrm{PCC}_{\mathrm{dist}}$) in km(contrail) as Potcov multiplied by the flight distance in km. The corresponding routing option minimizes the total contrail distance of a flight and thus** ~~T~~the objective function ~~represents a total contrail distance km(contrail) of a flight~~ **is formulated as:**….”

In addition, we added the text to the same Section 2.5.4: on page 8 line 19, “**Note that the objective function**

is formulated in the simple form to consider only the contrail distance. Thus, further physical processes such as contrail spreading, changes in contrail coverage area, contrail lifetime, and the contrail radiative forcing are not included.”

We believe that this contrail routing option (using $\mathrm{PCC}_{\mathrm{dist}}$) is one of the important routing options to study characteristics of aircraft routing strategies regarding contrails. AirTraf 2.0 includes the climate routing option, in which contrail effects are included in a different way (using $\mathrm{ATR20}_{\mathrm{contrail}}$). These two options work differently on contrail avoidance in flight trajectory optimizations; this interesting aspect is additionally discussed (please see the reply to the referee major comment (4)).

This modification is related to our reply to the comment (20) of referee #1.

- Firstly, Eq. (A5) assumes that contrails always cool during the day because it has a negative $\mathrm{aCCF}_{\mathrm{contrail}}$ and $\mathrm{ATR20}_{\mathrm{contrail}}$. However, this is not true as many other studies have shown that contrails can either warm or cool during the day, depending on meteorology (such as ambient cirrus), radiation, and the solar zenith angle.

Reply: The $\mathrm{aCCF}_{\mathrm{contrail}}$ for the day-time contrails, which is defined in Eq. (A5) on page 15 in the Appendix, can take positive and negative values, depending on the outgoing long-wave radiation (OLR) (the threshold is $-193.18\ \mathrm{Wm}^{-2}$).

Through the derivation process of $\mathrm{aCCF}_{\mathrm{contrail}}$, we have investigated the relationships between net RF for the day-time contrails and the relevant meteorological variables. The results showed the highest correlation with OLR (R = 0.86), whereas the introduction of a second parameter, such as temperature and solar zenith angle, did not improve the correlation. Related to this, we are preparing another manuscript for Geoscientific Model Development, which is the model description paper on the submodel ACCF and describes the derivation of $\mathrm{aCCF}_{\mathrm{contrail}}$ in detail; we refer to it as “Yin et al. (manuscript in preparation, 2019),” e.g. on page 9 line 18, and on page 15 line 14.

To make clear the point which the referee noted, we added the text: on page 16 line 6 in the Appendix, “… calculated by AirClim. **The $\mathrm{aCCF}_{\mathrm{contrail}}$ for the night-time contrails takes positive values; if the temperature is less than 201 K, $\mathrm{aCCF}_{\mathrm{contrail}}$ for the night-time contrails is set to zero. The $\mathrm{aCCF}_{\mathrm{contrail}}$ for the day-time contrails can take positive and negative values, depending on the OLR (the threshold is $-193.18\ \mathrm{Wm}^{-2}$).**”

This modification is related to our reply to the comment (22) of referee #1.

- Secondly, some contrails formed during the day could also have lifetimes of up to 19 hours [Ref.2] and persist through the night, subsequently turning to a warming contrail, but the methodology does not appear to have considered the contrail lifetime. In Eq. (A5), it is also unclear on the conditions/time boundaries which constitutes as day-time and night-time.

Reply: Thank you very much. To reply to this referee comment and to the next referee comment, let us explain the derivation of $\mathrm{aCCF}_{\mathrm{contrail}}$ briefly. First, the contrail RF data set was calculated following these steps:

(a) Lagrangian trajectories (air parcels) were computed by using the ERA-Interim reanalysis data (the methodology is described by Irvine et al., 2014); the trajectories were initialized over the north Atlantic (1 degree horizontal spacing) at three vertical levels (300, 250 and 200 hPa) in winters of 1994, 1995 and 2003. The contrail lifetime was calculated by analyzing each of the trajectories to see how long the conditions persisted for: relative humidity with respect to ice above 98 % and a temperature below 235 K.

(b) Contrail properties were calculated along the trajectories by following Schumann et al. (2017), where an effective radius for contrail cirrus ice particle was set to 23 microns described by Schumann et al. (2011). The contrail optical depth was calculated by a simple formula for the extinction coefficient (Unterstrasser and Gierens, 2010), where the initial contrail depth was set to 200 m (Grewe et al., 2014).

(c) The long-wave and short-wave RFs were calculated from the trajectory data by using the parametric equations described by Schumann et al. (2012). The area covered by each contrail was assumed constant along the trajectory. By taking values from Grewe et al. (2014), we used a contrail width of 200 m, and a contrail length of the square root of the grid box area (1 degree by 1 degree grid). The net RF was calculated for each contrail and was converted to a global-mean value by following Grewe et al. (2014). The contrail RF data set was obtained, in which the lifetime of contrails ranges from 3 to 48 hours.

The $\text{aCCF}_{\text{contrail}}$ was derived based on regression analyses for the RF data set. The methodology was based on that used by van Manen and Grewe (2019) to derive the other aCCFs for ozone, methane and water vapour. For the regression analyses, a constraint on deriving $\text{aCCF}_{\text{contrail}}$ was that only meteorological information available at the time of flight can be used. In addition, we restricted the calculation to conventional meteorological data, so that $\text{aCCF}_{\text{contrail}}$ was simple to implement. This means, for example, no information on the contrail lifetime could be used, because this is not something which can be estimated a priori from meteorological data. Since a lifetime was required to be input to the net RF calculations, we chose a contrail lifetime of six hours for all contrails, because 92 % of contrails have a lifetime up to six hours in the data set. Night-time and day-time contrails were analyzed separately. The night-time contrails referred to contrails with their entire (six hours) lifetime occurring at night; the day-time contrails referred to contrails which existed only during daylight hours and those which had part of their lifetime during the day. The obtained $\text{aCCF}_{\text{contrail}}$ (Eq. (A5) on page 15 in the Appendix) was converted from RF to ATR20 by multiplying a factor of 0.114 (provided by Katrin Dahlmann, DLR).

The derived $\text{aCCF}_{\text{contrail}}$ has been assessed by plotting the original net RF with the RF calculated by using $\text{aCCF}_{\text{contrail}}$. In addition, the performance of $\text{aCCF}_{\text{contrail}}$ has been assessed against the rest of the contrails with lifetimes of 3 to 48 hours in the data set. The Spearman's rank correlation coefficient and the ability to correctly predict the sign of the forcing were examined. For day-time contrails with lifetimes of 6 hours, for example, the coefficient was $R = 0.86$, and the ability (in percentage) was 88 %; for those with lifetimes of 12 hours, $R = 0.83$ and 78 % were obtained. These results provide the confidence in the use of $\text{aCCF}_{\text{contrail}}$ (Eq. (A5)) in the aircraft routing decision.

As for the conditions/time boundaries, the procedure of calculating $\text{aCCF}_{\text{contrail}}$ is as follows: for locations where contrails could form (potcov > 0), the local time and solar zenith angle are calculated. If the contrail forms in darkness, the time of sunrise is then calculated. If the time between the local time and sunrise is greater than six hours, the night-time $\text{aCCF}_{\text{contrail}}$ is applied. If the contrail forms in daylight, or in darkness but with less than six hours before sunrise, the day-time $\text{aCCF}_{\text{contrail}}$ is applied. These calculations are implemented online in EMAC by another submodel named ACCF. The derivation of $\text{aCCF}_{\text{contrail}}$ described above and details of the submodel ACCF will be described in the forthcoming paper of Yin et al. (manuscript in preparation, 2019), which is referred in the present manuscript, e.g. on page 9 line 18, and on page 15 line 14.

We believe that the conditions/time boundaries are useful information for readers. Thus, we added the text: on page 16 line 6 in the Appendix, "**As for the time boundaries of day and night, the local time and solar zenith angle are calculated for locations where contrails could form (potcov > 0). For locations in darkness, the time of sunrise is then calculated. If the time between the local time and sunrise is greater than six hours, the $\text{aCCF}_{\text{contrail}}$ for the night-time contrails is applied. If the contrail forms in daylight, or in darkness but with less than six hours before sunrise, the $\text{aCCF}_{\text{contrail}}$ for the day-time contrails is applied. These calculations are performed online in EMAC by the submodel ACCF.**"

References:

Grewe, V., Frömming, C., Matthes, S., Brinkop, S., Ponater, M., Dietmüller, S., Jöckel, P., Garny, H., Tsati, E., Dahlmann, K., et al.: Aircraft routing with minimal climate impact: the REACT4C climate cost function modelling approach (V1.0), Geoscientific Model Development, 7, 175–201, https://doi.org/10.5194/gmd-7-

175-2014, 2014.

Irvine, E. A., Hoskins, B. J., Shine, K. P.: A Lagrangian analysis of ice-supersaturated air over the North Atlantic, J. Geophys. Res., 119, 1, 90–100, https://doi.org/10.1002/2013JD020251, 2014.

Schumann, U., Baumann, R., Baumgardner, D., Bedka, S. T., Duda, D. P., Freudenthaler, V., Gayet, J.-F., Heymsfield, A. J., Minnis, P., Quante, M., Raschke, E., Schlager, H., Vázquez-Navarro, M., Voigt, C., and Wang, Z.: Properties of individual contrails: a compilation of observations and some comparisons, Atmos. Chem. Phys., 17, 403–438, https://doi.org/10.5194/acp-17-403-2017, 2017.

Schumann, U., Mayer, B., Graf, K., and Mannstein, H.: A Parametric Radiative Forcing Model for Contrail Cirrus, Journal of Applied Meteorology and Climatology, 51, 6, https://doi.org/10.1175/JAMC-D-11-0242.1, 1391–1406, 2012.

Schumann, U., Mayer, B., Gierens, K., Unterstrasser, S., Jessberger, P., Petzold, A., Voigt, C., and Gayet, J-F.: Effective Radius of Ice Particles in Cirrus and Contrails, Journal of the Atmospheric Sciences, 68, 2, 300–321, https://doi.org/10.1175/2010JAS3562.1, 2011.

Unterstrasser, S. and Gierens, K.: Numerical simulations of contrail-to-cirrus transition – Part 1: An extensive parametric study, Atmos. Chem. Phys., 10, 2017–2036, https://doi.org/10.5194/acp-10-2017-2010, 2010.

Van Manen, J. and Grewe, V.: Algorithmic climate change functions for the use in eco-efficient flight planning, Transportation Research Part D: Transport and Environment, 67, 388–405, https://doi.org/10.1016/j.trd.2018.12.016, 2019.

- Thirdly, the $\text{ATR20}_{\text{contrail}}$ could also be influenced by contrail spreading and its coverage area. However, Eq. (A5) and "$\text{ATR20}_{\text{contrail}} = \text{aCCF}_{\text{contrail}} \times \text{PCC}_{\text{dist}}$" does not account for the change in contrail coverage area. Further clarification on these aspects are required.

  Reply: To calculate the contrail RF data set, which was used to derive $\text{aCCF}_{\text{contrail}}$, the area covered by each contrail was assumed constant along the contrail trajectory. By taking values from Grewe et al. (2014), we used a contrail width of 200 m, and a contrail length of the square root of the grid box area (1 degree by 1 degree grid). We believe that the replies to the referee major comment (2) (starting with "While the methodology") and to the referee major comment mentioned above (starting with "Secondly, some contrails") answer this referee comment. More details will be described in forthcoming paper of Yin et al. (manuscript in preparation, 2019), which is the model description paper on the submodel ACCF.

  Reference:
  Grewe, V., Frömming, C., Matthes, S., Brinkop, S., Ponater, M., Dietmüller, S., Jöckel, P., Garny, H., Tsati, E., Dahlmann, K., et al.: Aircraft routing with minimal climate impact: the REACT4C climate cost function modelling approach (V1.0), Geoscientific Model Development, 7, 175–201, https://doi.org/10.5194/gmd-7-175-2014, 2014.

- **3)** [Page 10, Lines 17 to 19] The results and Figure 2 show that flight trajectories based on the cash operating cost (COC) optimization and minimum fuel consumption always selects a higher cruising altitude. However, this is very likely due to limitations of BADA 3. According to Nuic et al.[Ref.3], BADA 3 has a tendency to underestimate aircraft fuel consumption at higher altitudes and Mach numbers as the compressibility effect and wave drag are not modelled. While I understand that a more accurate version of BADA (BADA 4) is available, obtaining access to it can be challenging. Despite this, the authors should include more discussion on the effects of BADA 3 on their results, as well as acknowledge the limitations of BADA 3.

  Reply: Thank you very much. We added the new figure "Figure 3" and rewrote the text to discuss the effects of BADA 3 and its limitations: on page 10 line 18, "… flight altitudes (~FL410, 12.5 km)~~,~~**. Figure 3 shows**

the mean fuel consumption (in kg(fuel)/min^{-1}) vs. mean flight altitude (in km) for individual flights for the three routing options. Because fuel consumption decreases ~~due to~~ **as a result of** aerodynamic drag reduction **at high altitudes** (Fichter et al., 2005; Schumann et al., 2011; Yamashita et al., 2016)**, the COC optimum trajectories select the high flight altitudes, as shown in Fig. 3. We acknowledge that limitations of BADA 3 affect the selection of the flight altitudes (the same applies to the fuel, the NO$_x$, the H$_2$O and the SOC options; see Fig. S3 in the Supplementary material). According to Nuic et al. (2010), BADA 3 has a tendency to underestimate aircraft fuel consumption at high altitudes and Mach numbers, as the compressibility effect and wave drag are not modeled. These effects will cause differences in the selection of the flight altitudes.**"

Related to this, we added the paper to the References:
− On page 20 line 10, "**Nuic, A., Poles, D., Mouillet, V.: BADA: An advanced aircraft performance model for present and future ATM systems, Int. J. Adapt. Control Signal Process., 24, 10, 850−866, https://doi.org/10.1002/acs.1176, 2010.**"

As we add the new figure, we changed the original figure number: on page 10 line 21, "Figure ~~3~~**4** shows …"; on page 10 line 25, "… it is apparent from Fig. ~~3~~**4** …"; and on page 24 in the caption, "Figure ~~3~~**4**."

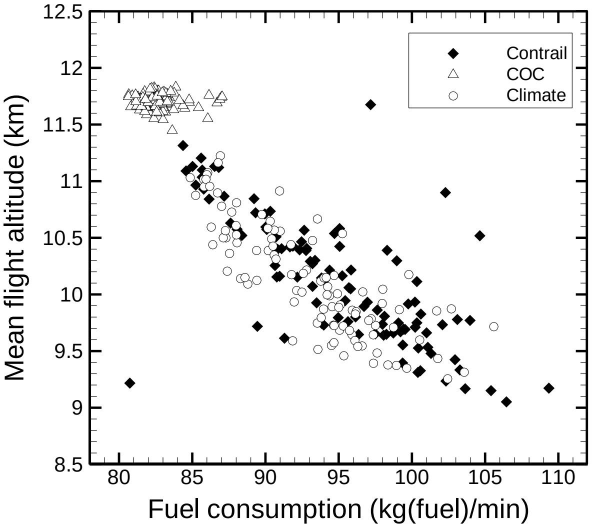

Figure 3. Mean fuel consumption vs. mean flight altitude for 103 individual flights obtained by the contrail formation, the COC and the climate impact routing options.

- **4)** [Page 11, Lines 9 to 11] "The contrail option shows the minimum contrail distance and decreases ATR20$_{\mathrm{total}}$… This option allows aircraft to widely detour the potential contrail regions". This sentence requires further clarification: given that the authors mentioned in Page 9 Line 26 that the "ATR20$_{\mathrm{contrail}}$ can take positive and negative values, because of the day-time and night-time contrail effects", it should be made clear in the discussion on if the algorithm: (i) actively forms cooling contrails during the day and avoids forming warming contrails during the night; or (ii) minimises the overall contrail length at all times.

Reply: Thank you very much. We added the new figure "Figure 5" and rewrote the text to make clear how the algorithm works on contrail avoidance: on page 11 line 11, "… is used in Eqs. (1) and (5)**; see below for more discussion**)"; and on page 11 line 24, "**Figure 5 shows the contrail distance (in ×10^3 km) vs. ATR20$_{\mathrm{contrail}}$ (in ×10^{-7} K) for individual flights for the contrail, the COC, and the climate options. We see that the contrail option decreases the contrail distance drastically and shows the positive values of ATR20$_{\mathrm{contrail}}$ for almost all the flights. On the other hand, the climate option has the longer contrail distances than those of the contrail option (although the climate option achieves the second-shortest total contrail distance, as shown in Table 4) and shows the negative values of ATR20$_{\mathrm{contrail}}$ for many**

flights. These results imply that the contrail option minimizes the overall contrail distance at all times, whereas the climate option actively forms cooling contrails during the day and avoids the formation of warming contrails during the day and night.”

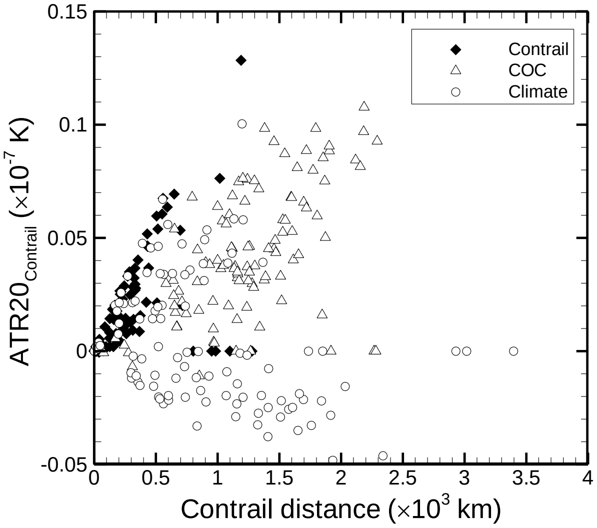

Figure 5. Contrail distance vs. $ATR20_{contrail}$ for 103 individual flights obtained by the contrail formation, the COC and the climate impact routing options.

- **Minor Comments:**
  1) [Page 1, Line 22] Replace “non-volatile black carbon (BC or soot)” with “non-volatile particulate matter such as BC” for correctness in terminology [Ref.4]. This is because black carbon (BC) is a subset of non-volatile particulate matter (nvPM), while the term “soot” includes both nvPM (BC and metallic compounds) and organic compounds.

  Reply: Thank you very much. We rewrote the word: on page 1 line 22, “… ~~nonvolatile black carbon (BC or soot)~~ **non-volatile particulate matter such as black carbon (BC)**….”

- **2)** [Page 2, Line 7] The sentence, “The emitted CO_2 has a long residence time (a century)”, should be corrected. According to Joos et al.1, however, the emitted CO_2 can remain in the atmosphere after a millennium.

  Reply: Thank you very much. In this sentence, we would like to note a long-lasting CO_2 impact in the atmosphere. Thus, we modified the sentence: on page 2 line 6, “~~The emitted CO2 has a long residence time (a century) and becomes uniformly mixed in the whole atmosphere,~~ **the emitted CO_2 becomes uniformly mixed in the whole atmosphere and its perturbation remains for millennia.**” This modification is related to our reply to the comment (9) of the referee #1.

- **3)** [Page 3, Line 15] Remove “the” from this sentence “the today’s aircraft routing focuses on the minimum economic cost”.

  Reply: We removed the word “the” from the sentence: on page 3 line 15, “… ~~the~~ today’s aircraft routing focuses on ~~the~~ minimum economic cost….”

- **4)** [Page 8, Line 22] There appears to be inconsistencies in the acronyms: C_{time} and C_{fuel} was used in line 22. However, c_t and c_f are used in Eq. (6). This can confuse future readers.

  Reply: Thank you very much. On page 8 line 22, we explain the definition of the cost index: Cost Index (CI)

= time cost / fuel cost, where CI is a kind of dimensionless coefficient showing the ratio of time cost [USDollar] to fuel cost [USDollar]; and C_{time} and C_{fuel} represent the "time cost" and the "fuel cost" of the definition. On the other hand, c_t and c_f used in Eq. (6) are the unit costs of time [USDollar/s] and fuel [USDollar/kg(fuel)], respectively, as listed in Table 1. Thus, C_{time} and C_{fuel} are different from c_t and c_f, respectively.

We agree that those parameters can confuse readers, and thus we rewrote the sentence: on page 8 line 22, "(CI = ~~C_{time}~~ **time cost** / ~~C_{fuel}~~ **fuel cost**~~, where C denotes a cost~~)." Related to this, we moved the phrase "where *C* denotes a cost" from the current position to the new position: on page 9 lines 13-14, "f = COC = …. + C_{engine}~~.~~**, where *C* denotes a cost.** A detailed…."

- **5)** [Section 2.5.7] Please acknowledge the large uncertainties in the global temperature response, especially from contrails (ATR20$_{\text{contrail}}$) due to uncertainties in the contrail efficacy [Ref.5,6].

  Reply: We added the sentence to acknowledge the point: on page 9 line 26, "… ATR20$_{\text{contrail},i}$ can take positive and negative values, because ~~of~~ **the aCCF$_{\text{contrail}}$ consists of two formulas for** the day-time and night-time contrail effects **(see Eqs. (12) and (A5) in the Appendix)**. **We acknowledge the large uncertainties in the global temperature response, especially from contrails (ATR20$_{\text{contrail}}$) due to uncertainties in the efficacy of the contrail forcing (Hansen et al., 2005; Ponater et al., 2005). In addition,** ~~T~~the aCCFs are derived…." The rewriting highlighted by blue texts comes from our reply to the comment (22) of the referee #1.

  Related to this, we added the two papers to the References:
  − On page 19 line 4, "**Hansen, J., Sato, M., Ruedy, R., Nazarenko, L., Lacis, A., Schmidt, GA., Russell, G., Aleinov, I., Bauer, M., Bauer, S., Bell, N., Cairns, B., Canuto, V., Chandler, M., Cheng, Y., Genio, A Del., Faluvegi, G., Fleming, E., Friend, A., et al.: Efficacy of climate forcings, Journal of Geophysical Research: Atmospheres, 110, D18104, 1−45, https://doi.org/10.1029/2005JD005776, 2005.**"
  − On page 20 line 15, "**Ponater, M., Marquart, S., Sausen, R., Schumann, U.: On contrail climate sensitivity, Geophysical Research Letters, 32, L10706, 1–5, https://doi.org/10.1029/2005GL022580, 2005.**"

- **6)** [Section 4: Discussion] The authors should highlight that these results (climate benefits) is likely an upper limit, because airspace congestion and air traffic management could minimise the flexibility for flights to perform these trajectory optimisations.

  Reply: We agree with the referee comment. We rewrote the text: on page 11 line 24, "… on December 1, 2015, as shown in Table 3). **Finally, we believe that the climate benefits described above are most likely an upper limit, because airspace congestion and air traffic management could reduce the flexibility for flights to perform these trajectory optimizations.**" Similarly, we added the sentence to the conclusions to highlight the same point: on page 15 line 1, "… performance than the contrail option. **We believe that these climate benefits are most likely an upper limit.** The simulation results were…."

- **7)** [Eq. (5) and Table 1] Consider using different notations for the mass fuel flow rate (f_{ref}), as this is similar to the objective function (f) and can lead to confusion.

  Reply: We understood the referee comment, and we reconsidered to change the notation of f_{ref}. Nevertheless, we are hesitating to change it, because "f_{ref}" has been already used from the previous version of AirTraf 1.0 (Sect. 2.3, Sect. 2.6 and Table 1 of Yamashita et al., 2016). For the sake of consistency, it could be better for readers to use the same notation. Nevertheless, if this change is essential for the revision of the manuscript, we will follow the suggestion by the referee #2 and change the notation, if the editor decides to do so.

  Reference:
  Yamashita, H., Grewe, V., Jöckel, P., Linke, F., Schaefer, M., and Sasaki, D.: Air traffic simulation in

chemistry-climate model EMAC 2.41: AirTraf 1.0, Geoscientific Model Development, 9, 3363–3392, https://doi.org/10.5194/gmd-9-3363-2016, 2016.

- **8)** [Appendix A, Eq. (A5)] $\mathrm{aCCF}_{\mathrm{contrail}} = \ldots$, if Potcov ≥ 0: should this be > 0 instead? Similarly, $\mathrm{aCCF}_{\mathrm{contrail}} = 0$, if Potcov < 0: should this be ≤ 0 instead?

  Reply: Thank you very much. We corrected the equations: on page 15 Appendix A, Eq. (A5), $\mathrm{aCCF}_{\mathrm{contrail}} = \ldots$, if Potcov ~~≥~~ > 0 .and. nighttime; $\mathrm{aCCF}_{\mathrm{contrail}} = \ldots$, if Potcov ~~≥~~ > 0 .and. daytime; $\mathrm{aCCF}_{\mathrm{contrail}} = 0$, if Potcov ~~<~~ ≤ 0.

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