We are most grateful to the referee #3 for the very helpful and encouraging comments on the original version of our manuscript. Here are our replies:

1 Introduction:

- The manuscript is well structured, and different aspects of AirTraf are explained by a nice equilibrium of description and examples. The motivation of the work is reasonably well explained. Figures and tables are informative. There is a substantial comparison with results from other studies to give confidence in the results obtained here.

  Implementing aircraft routing strategies in a general circulation model or a numerical weather prediction model is not an easy task. Arriving at the status as described here in the manuscript is already a considerable achievement. However, as the tool is not finished, one wonders whether it is useful to describe the tool in its current status (with only 2 of the 7 optimization options implemented, fuel consumption due to climbing not included, the meteorological fields in the optimization are the ones at the start of the flight,...).

  Publishing the manuscript now shows the status of the work. It makes clear that for specific options the optimization works, and it can trigger discussion with other researchers/institutes on the approaches chosen (is the optimization working well, could other optimization routines be faster,...).

  Reply: We thank the referee #3 for the positive comments. As the referee pointed out, this paper shows the current status of AirTraf. Nevertheless, we think that it is useful to publish AirTraf v.1.0, for several reasons:

  − Our final purpose is to investigate an optimization strategy of aircraft routing for minimizing the climate impact of aircraft emissions and show its mitigation gain for future. We should make clear that this paper introduces the AirTraf submodel in its basic version, technically describes and validates the various components for first, simple aircraft routings (great circle and time-optimal). Eventually, we are aiming at an optimal routing for climate impact reduction. This will be a separate study, which requires a couple of developments beforehand, amongst which the present study documents one of them.

  − The validation refers to standard aircraft applications in this paper, such as great circle and time-optimal calculations. These two options are appropriate to confirm whether AirTraf works well and is fit for the purpose. This is a big step for the AirTraf development.

  − For our purpose, multi-annual (long-term) simulations are required in EMAC: computationally expensive simulations are required. Hence, in the current model we simplify AirTraf to reduce the computational costs, e.g. we concentrate on the cruise mission only.

  − The related issue is discussed in the reply to “2 Principal remarks, Work in progress.”

- I think the manuscript is worth publishing, but is should be considerably improved in several ways. A list of principal remarks is given below, followed by a list of more specific comments. I hope the authors will take them into consideration, and if not give a sound argumentation why they do not.

  Reply: We are grateful to the referee #3 for the useful comments and suggestions that have helped us to improve our manuscript. As indicated in the responses that follow, we have addressed all the comments and suggestions.

2 Principal remarks

- **Work in progress:** The manuscript describes a submodel in MESSy which works, but is not finished yet (only 2 of the 7 optimization options are in place). Why not waiting until all the work is finished? One has to guarantee that this manuscript remains valid and worth all the work once the remaining parts come into place, and that this document is therefore worth publishing.

  Reply: The major reasons are replied in “1 Introduction.” As replied in “1 Introduction”, the currently documented status is a prerequisite for the investigation of climate-optimal routings. Additional reasons are:

  − The GA optimization module is an important part of AirTraf for our purpose. Therefore, we made a thorough assessment of the GA optimization and its performance using the time-optimal option in

this paper. If a new objective function corresponding to other routing options is developed, basically, only the objective function f (shown in Eq. (28), on page 15 line 485) is changed. The AirTraf framework validated in the paper is, thanks to its modular structure, unchanged. Therefore, the current status is a big step for AirTraf development.
− The manuscript is not only about the "routing options", but an important and integral part describes the overall structure of the coupling between a "routing module" and a chemistry-climate model. This is a major achievement and unique.

- **Language:** There is a lot of improvement needed for the language. The use of articles (a/an/the/none) should be improved. Specific expressions (e.g., "trajectories as longitude vs altitude, trajectories as location" or "number of n_p",...) should be modified.

  Reply: Thank you so much. We will recheck and modify articles. Please see the revised manuscript. The modifications of the specific expressions are as follows:

  ["trajectories as longitude vs altitude, trajectories as location"]
  We will change the expression "trajectories as longitude vs altitude, trajectories as location" into "trajectories in the vertical cross-section, trajectories projected onto the Earth":
  − On page 14 line 450, "...the ~~geographic location~~ **projection onto the Earth** (bottom) with three control points (CPs, black circles) and the ~~longitude vs altitude~~ **vertical cross-section** (top) with five CPs."
  − On page 15 line 475, "...B-spline curve with the five CPs ~~as longitude vs altitude~~ **in the vertical cross-section** (bold solid line, Fig. 7 top)...".
  − On page 17 line 553, "...the true-optimal solution ~~as longitude vs altitude~~ **in the vertical cross-section** are plotted...".
  − On page 34 in the caption of Figure 7, "Geometry definition of flight trajectory ~~as longitude vs altitude~~ **in the vertical cross-section** (top) and ~~as geographic location~~ **projected onto the Earth** (bottom)."
  − On page 36 in the caption of Figure 9, "...explored trajectories (solid line, black) from MUC to JFK ~~as longitude vs altitude~~ **in the vertical cross-section** (top) and ~~as location~~ **projected onto the Earth** (bottom)."
  − On page 41 in the caption of Figure 14, "...explored trajectories (black lines) between MSP and AMS ~~as longitude vs altitude~~ **in the vertical cross-section** (top) and ~~as location~~ **projected onto the Earth** (bottom)."
  − On page 45 in the caption of Figure 18, "...the trajectories ~~as longitude vs altitude~~ **in the vertical cross-section** (top) and ~~as location~~ **projected onto the Earth** (bottom)."
  − On page 1 (Supplementary material) in the caption of Figure S1, "...explored trajectories (black lines) between JFK and MUC ~~as longitude vs altitude~~ **in the vertical cross-section** (top) and ~~as location~~ **projected onto the Earth** (bottom),...".
  − On page 2 (Supplementary material) in the caption of Figure S2, "...explored trajectories (black lines) between SEA and AMS ~~as longitude vs altitude~~ **in the vertical cross-section** (top) and ~~as location~~ **projected onto the Earth** (bottom),...".

  ["number of n_p"]
  We will change the expression "number of n_p" into "value of n_p" in the revised manuscript. We also reply to this modification in the following sections: "p 17, l 569 and 570" and "p 19, l 618."

- **CP in trajectories:** Concerning the treatment of CP points, I have several questions.
- (1) As an example, 3 CPs have been used for the geographical location, and 5 for the altitude. Is this fixed? Do all flights use the same number of CPs?

  Reply: Yes. All flights use 3 CPs for the geographical location and 5 for the altitude (as shown in Fig. 7 on page 34). This is now explicitly clarified in the revised text.

- (2) For the 103 flights, which were primarily zonal, rectangles around the CPs could be described by using a

range in latitude and longitude. How is the choice around the CPs when flights cross the equator, e.g., at an angle of 45°? What if flights go from low to high latitudes and defining regions whit fixed ranges in longitude makes them very different in size?

Reply: This is a very important issue for the AirTraf development. In AirTraf version 1.0, the domain size was determined by referring to the literature: Irvine, E. A., et al., "Characterizing North Atlantic weather patterns for climate-optimal aircraft routing," Meteorological applications, 20, 80−93 (2013). They show the many types of flight trajectories between London and New York for different weather conditions. We focused on trans-Atlantic flights in this paper, therefore the current definition of domain size works very well for the trajectory optimizations.

As the referee pointed out, if flights cross the equator (at an angle of 45°) or if flights go from low to high latitudes with almost similar longitude values, the domains are variously shaped in size on the basis of the geometry definitions of the flight trajectory (as described in Sect. 3.2.2 on page 14). This probably increases the computational demand for the trajectory optimization. Nevertheless, the current treatment of the domains is applicable to those flights and trajectory optimization works well. In fact, we have confirmed this issue by test simulations using 1,840 global flight plans including such flights. To improve the computational efficiency of the optimization, we will work on an improvement of the definition of domain size for the next version.

We also reply to this issue in the answer to the referee comment of "p 17, l 554−555."

- (3) For a given trajectory (which is a B-spline curve), how are the waypoints found? Are they equally spaced along that trajectory between the CPs? I am wondering whether it is possible to find explicit expressions for equidistant waypoints on a B-spline curve?

  Reply: The referee is right. In AirTraf, the 3rd order B-spline curve is used to generate the waypoints. If CPs are given, a parameter t, which is the parameter of the 3rd order B-spline basis functions, is assigned with values between 0 and 1 between the CPs. Here, t is equally spaced along the "basis functions" (i.e., equally spaced between $0 \leq t \leq 1$). After that, the coordinates of the waypoints of the trajectory are determined by summation of the basis functions, corresponding to the equidistant t. Therefore, this can not ensure that the waypoints are equally spaced along the trajectory. We reply to this issue in the answer to the referee comment of "p 14, l 464".

- (4) In the example used, 3 CPs were used for the geographical location, 5 CPs for the altitude, and 101 waypoints. However, the condition (101 − 1)modulo(5 + 1) = 0 is not fulfilled. One also gets the impression that the waypoints for the altitude and longitude are not located at the same place (although the manuscript confirms it actually is). Could this be clarified?

  Reply: As described on page 14 line 464, the condition is mod(n_{wp} − 1, n_{CPloc} + 1) = 0. This is only used for the location. Here, n_{wp} = 101 and n_{CPloc} = 3. Therefore, mod(101 − 1, 3 + 1) = 0 is fulfilled. In addition, to clarify the location of waypoints for the altitude and longitude, we will revise the text: on page 15 line 474−478, "A flight trajectory is also represented by a B-spline curve **(3rd-order)** with the five CPs ~~as longitude vs altitude~~ **in the vertical cross-section** (bold solid line, Fig. 7 top) and then waypoints are generated along the trajectory **in such a way that the longitude of the waypoints is the same as that for the flight trajectory projected onto the Earth.** ~~Note, GA creates trajectories represented by two B-splines, one latitude vs longitude and one longitude vs altitude, where longitude-coordinate of waypoints is the same for the two curves.~~" We also reply to this issue in the referee comment of "p 15, l 476−478."

- **GA algorithm:** This algorithm is explained to some detail, but I suggest that all terms used should be explained to some extent (e.g., mating pool). One should also be informed on how the final solution is derived from the population in the last generation. Finally, the abstract uses some terminology related to the optimization routine (e.g., population), which are too technical to be mentioned in the abstract.

Reply: We will add a section “Appendix; Glossary” after the section “7. Conclusions”, where we explain the optimization terminologies: on page 26, **“Appendix; Glossary; Table A1 shows a glossary explaining several terminologies of the GA optimization. The terms from the glossary are written in italics in the text.” In Table A1, we will add the explanations, “Table A1. Glossary of terms. Population: A set of solutions. A Genetic Algorithm starts its search with an initial population (a random set of solutions).; Generation: One iteration of a Genetic Algorithm.; Rank: A ranking assigned to each solution to evaluate a relative merit in a population. A *rank* expresses the number of solutions that are superior to a solution.; Fitness: A value assigned to each solution to emphasize superior solutions and eliminate inferior solutions in a population. *Fitness* = 1/*rank.*; Mating pool: A storage space for solutions.”** We will refer to those terms in the text in italics. Many variables are modified. Therefore, we will show the modifications in the revised manuscript. Related to this, we will revise the text: on page 2 line 21 in Abstract, “The dependence of **the** optimal solutions on **the** initial ~~populations~~ **set of solutions (called population)** was analyzed.” On page 15 line 491, “A solution with **a** higher ***fitness*** value (i.e., **a** smaller ***rank*** value) has a higher probability of being copied into a ***mating pool***.”

In addition, we will add the text to inform on how the final solution is obtained from the optimization: on page 16 line 517, “..., GA quits the optimization and an optimal solution **showing the best *f* of the whole *generation*** is output...”.

- **Abstract, introduction, conclusion:** The abstract is sometimes too much a summing up of what has been done, with vocabulary/terms which have no concrete meaning without a concrete context. There is also much more overlap between these three parts (abstract, introduction, and conclusion) than needed. The abstract should be written differently, and considerably improved.

Reply: By following the remarks and the list of specific comments of the referee #3, we revise the abstract, introduction and conclusion. Please see the revised manuscript.

- **Sensitivity:** In the approach followed here, quite some assumptions and simplifications are introduced. It would be useful to give the reader an idea of the impact of these assumptions on the results. A list of some of the assumptions is:

Reply: Firstly, we would like to make clear again that our final purpose of AirTraf is to investigate an “optimization strategy” of aircraft routing for minimizing the climate impact of aircraft emissions and to show its mitigation gain for the future. It is not our purpose to find detailed flight trajectories. The aim of this paper is to introduce the AirTraf submodel in its basic version, technically describe and validate the various components for first, simple aircraft routings (great circle and time-optimal), in order to confirm whether AirTraf works well and is fit for our purpose. Eventually, we are aiming at an optimal routing for climate impact reduction. This will be a separate study, which requires a couple of additional developments beforehand, amongst which the present study is one of them. In addition, multi-annual (long-term) simulations are required for our purpose (e.g. for ten years) coupled with the Earth System Model: computationally expensive simulations are required. We therefore think that our assumptions are appropriate to perform such AirTraf on-line simulations for long-term periods to reduce the computational costs.

As the referee pointed out, they are all interesting points and might be a future option. However, they are beyond the scope of this paper and we cannot explore all sensitivities. A couple of specific points are as follows:

- (1) line 274 : $dh(t)/dt = 0$ in Eq. (3).

Reply: Looking at the AirTraf trajectories, there is an altitude change visible, but it appears over a long distance and a long period of time. We evaluated dh/dt of the time-optimal flight trajectories for the three selected airport pairs (listed in Table 8 on page 57). The averages of dh/dt (absolute value, ms^{-1}) for the individual flights were: 0.0 (JFK to MUC); 0.0 (MUC to JFK); 0.0 (MSP to AMS); 0.32 (AMS to MSP); 0.24 (SEA to AMS); and 0.13 (AMS to SEA). We therefore conclude that the impact of the zero-assumption is not

a big issue, the more as in AirTraf 1.0, we use so far only a small number of vertical GA control points (shown in Fig. 7 on page 34). If the number of control points increases, the influence of climb/descent rates (dh/dt) will increase. This could be an aspect for a next version of AirTraf.

To clarify our assumptions, we will revise the text: on page 9 line 273−275, "~~In AirTraf (version 1.0), $dh/dt = 0$ is assumed and V_{TAS} is calculated at every waypoint (Table 2). For an aircraft in cruise, Eq. (3) becomes $Thr_i = D_i$ at waypoint i.~~ **For a cruise flight phase, both altitude and speed changes are negligible. Hence, $dh/dt = 0$ as well as $dV_{TAS}/dt = 0$ is assumed in AirTraf (version 1.0) and Eq. (3) becomes the typical cruise equilibrium equation: $Thr_i = D_i$ at waypoint i.**"

- (2) M is set constant. Can this be varied slightly? Or have pilots only a very small envelope of allowed or possible speeds?

  Reply: The constant Mach number, $M = 0.82$, is the officially published cruise Mach number of an A330-301 by Eurocontrol in 2011. It is appropriate for the aim of this paper to perform AirTraf simulations for simple conditions, including a constant M. On page 5 line 136, we describe the assumption for AirTraf (version 1.0) as, "The aircraft performance model of Eurocontrol's Base of Aircraft Data (BADA Revision 3.9, Eurocontrol, 2011) is used with a constant Mach number M...". As the referee noted, a change of Mach number is an interesting topic. However, this will be a separate study. In addition, pilots are not allowed to change flight speed freely in the actual flight operations. The speed is indicated (controlled) from the air traffic management side.

- (3) What if weather not just from $t = 1$ is taken, but from the whole period of the flight?

  Reply: The referee actually points out the important and interesting topic. However, this is a separate study, which would probably use AirTraf, but which is beyond the scope of this technical documentation and first evaluation. On page 7 line 201, we describe the assumption for AirTraf (version 1.0) as, "...local weather conditions provided by EMAC at $t = 1$ (i.e. at the departure day and time of the aircraft) are used to calculate the flight trajectory. The conditions are assumed to be constant during the flight trajectory calculation." Note that a weather forecast, which would be required to optimize not only for time $t = 1$, is not feasible within a climate simulation.

- (4) Leaving out the ascent and descend phase of the flight: how does this impact the optimization?

  Reply: For our final purpose described in the reply to "1 Introduction" and "Sensitivity", it is appropriate to concentrate on the cruise mission only in AirTraf (version 1.0). On page 5 line 140, we describe the assumption for AirTraf (version 1.0) as, "Only the cruise flight phase is considered, while ground operations, take off, landing and any other flight phases are unconsidered." It is maybe worth to mention that the cruise has a larger climatic impact than the other parts of the operation, since the cruise has a longer operation time. Moreover, there are other attempts to reduce emissions during ground operation (taxiing etc.), which are not connected to routing. In any case, there are not much "re-routing" options between ground operations and reaching the cruise altitude.

- **Mathematical formulas:** The mathematical expressions should be improved.
- (1) In mathematical formulas, variables longer than one letter should be written straight.

  Reply: We will recheck all variables and modify them with straight letters. Many variables are modified; therefore, we will show the modifications in the revised manuscript.

- (2) A lot of indices should be straight letters : V_{ground}, V_{wind}, ...

  Reply: We will recheck all indices and modify them with straight letters. Many indices are modified;

therefore, we will show the modifications in the revised manuscript.

- (3) After every equation, there should be a "," or ".", depending on the function of the equation in the sentence.

  Reply: We will add a "," after **Eqs. (1)–(8), Eqs. (11)–(22), Eqs. (24)–(27) and Eq. (29).** We will show the modifications in the revised manuscript.

- (4) Names of trigonometric formulas should not be italic : sin, cos, ...

  Reply: We will modify the all names of trigonometric formulas into normal straight letters: for "sin," **Eq. (21)** is modified; for "cos," **Eqs. (4), (21) and (23)** are modified; and for "arctan," **Eq. (21)** is modified. We will show the modifications in the revised manuscript.

- **Climate model, long/short time scales:** Why is this tool implemented in a climate model? To my opinion, the tool could also have been build such that it uses off-line 3-hourly meteo fields over the range of time it has flights which should be optimized : one thinks over a range of 1 to 10 days. The meteo data might come from a NWP, or a climate model.

  Maybe the authors want to show that it is possible to have such a tool on-line in a NWP or GCM. However, in that case, I would have chosen for a NWP as that is the place where, if the tool is operationally used, might be most appropriate. What was the reason that the authors made the choice of implementing it in a climate model?

  A reason I can imagine is that one could do tests like : how would the optimal routing be in a year 2100 climate, when global climate is considerably different from nowadays?

  Reply: Our final purpose is to investigate the mitigation gain of the climate impact by climate-optimal routing. We would like to make clear that it is not our purpose to find climate-optimal flight trajectories (or optimal flight trajectories corresponding to a selected routing option, e.g. fastest routes) for a specific weather condition. For this, an Earth System Modeling (ESM) is not necessary and this indeed has been achieved, e.g. by Grewe et al., 2014. We eventually want to go one step further and apply an optimization on a daily basis for daily changing weather situations. To investigate then the mitigation gain, multi-annual (long-term) simulations are required (e.g. for ten years). In the simulations over the ten years, each flight trajectory is optimized with respect to a selected aircraft routing option, considering local weather conditions. The released emissions directly (CO_2, H_2O) and indirectly (NO_x) modify the radiative forcing and therefore the climate. Off-line pre-calculated routes would be inconsistent in such an approach. AirTraf can perform these air traffic simulations with the inclusion of the on-line optimization module and the optimal routes will change day by day. In addition, AirTraf can use the framework of EMAC to assess routing options, e.g. surface temperature changes or changes in the background chemical conditions of the atmosphere ten years later corresponding to the selected routing option, by coupling with other submodels of EMAC. The main point is the interactive coupling, i.e. the on-line re-routing immediately affects the climate model (via air traffic emissions). An on-line feedback cannot be replaced by an off-line approach. We think that the implementation of AirTraf on-line in EMAC is appropriate approach for our purpose. This reply it related to the reply to "p4 l 115."

  [Reference] 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, 2014a.

- **Benchmarks:** Is proving that the great circle option works well worth publishing and/or mentioning in an abstract? In addition, I think that the word benchmark puts more importance on a test than it actually deserves.

  Reply: We understand the referee comment. The "great circle calculation" is a commonly used method.

However, we are hesitating to remove the descriptions of the great circle for the following three reasons:

First, the final purpose of AirTraf is to investigate "optimal routing for climate impact reduction." We will compare AirTraf simulation results among several aircraft routing options. As a climate-optimized route will be evaluated in the light of the detour that would be necessary to avoid "climate-sensitive" areas with respect to the reference (trade-off), i.e. "great circle" or time-optimal route. Thus, the great circle routing option is used as reference for our comparisons (note that the great circle is the optimal solution for "minimum flight distance"). In addition, we would like to refer to a future Air Traffic Management system, which aims at having aircraft fly more direct routes, so called user-preferred routes without being constrained to Air Traffic Services routes and waypoints any longer. These future user-preferred routes would be great circle segments in the ideal case (without wind). Hence, AirTraf is developed with the objective to evaluate routing options for the future and the great circle is still an important route in reality. We think that a thorough assessment of the great circle routing module should be made in this paper to demonstrate its ability to generate the routes and working well if coupled to the ESM. The "great circle calculation" is suitable for the validation of AirTraf, because it is a widely used method (the benchmark test of the great circle calculation is described on page 12–13, Sect. 3.1.2). We believe that the result of the assessment is worth publishing.

Second, the above-mentioned assessment of the great circle routing module is also indispensable to show the correct implementation and applicability of the genetic algorithm (GA) approach. Because the validated great circle routing module provides the analytical solution (f_{true} = 25,994.0 s) for the benchmark test of flight trajectory optimization with GA (i.e. the single-objective optimization for minimization of flight time from MUC to JFK). This point is described on page 16 line 530, "...the f_{true} equals the flight time along the great circle from MUC to JFK at FL290: f_{true} = 25,994.0 s calculated by Eq. (23) with h_i = FL290 for i = 1, 2,⋯, 101." The result that the GA reproduces the analytical solution is an important milestone towards other routing optimizations.

Last but not least, we would like to stress that the AirTraf submodel, which embeds a routing module (including GA) into an Earth System Model, is unique. The great circle routing module described in the paper is used to show that the coupled system works well. For example, a flight trajectory consists of waypoints arranged by the waypoint index i (i = 1, 2,⋯, n_{wp}). The geographical and meteorological values, which are used for the great circle calculation (e.g. latitude, longitude, altitude, temperature, wind speed), are provided by the ESM at the individual waypoints i. It is important to show that the great circles are calculated correctly by waypoints through the ESM domain. For this, Eqs. (21)–(27) (on page 11–12) include the terms with the index i. Hence, the description of the great circle routing module should be included.

In addition, we understand the referee comment on the word "benchmark." Nevertheless, we are hesitating to change the word. The tests are performed to confirm the correct performance of the code, which we believe is unique and new, and thus to measure the reliability of the code. We think that those tests are indeed important "benchmark tests."

- **Size of the document:** The files are so large (30 MB) that people will have problems printing the documents. To my opinion it is mainly related to the figures which show different flight trajectories. I assume that the figures contain all the information from all trajectories, while a large central part of the figure is just black. These figures should be made in such a way that they become much smaller in size, without loosing their precision.

Reply: As the referee pointed out, the file size is large. We will make those figures become much smaller in size with almost the current precision and replace them in the revised manuscript: **Figs. 9, 14a, 14b, 18a to 18d, S1a, S1b, S2a** and **S2b** are modified.

3 Comments on the text

Page 1

- **p 1, l 1–5** : The sequence of the first three sentences is a bit strange. I would even skip the first sentence (as it says the same as the first 7 words of sentence 3).

Reply: We will remove the first sentence: on page 1 line 1, "~~Aviation contributes to anthropogenic climate impact through various emissions.~~" Concerning this, we will rephrase the text: on page 1 line 3, "Reducing

~~the~~ **anthropogenic** climate impact from aviation emissions and...".

- **p 1, l 3–6** : "building a climate-friendly", "for a sustainable development", "is an important approach". It makes me wonder whether this is not a too optimistic view on aviation.

  Reply: We agree. The sustainable development of commercial aviation might be optimistic. However, if we want to have a sustainable development of commercial aviation, we need to have a reduction of aviation emissions and a climate-friendly air transportation system.

- **p 1, l 9** : "stable" gas. This is not precise enough.

  Reply: We will delete the word "stable" in the sentence: on page 1 line 9, "CO_2 is a long-lived ~~and stable~~ gas, while...".

- **p 1, l 9** : "vary regionally". I would rather use something like "inhomogeneous distribution".

  Reply: We will rephrase the text: on page 1 line 9, "...non-CO_2 emissions are short-lived and ~~vary regionally~~ ~~is~~ **are inhomogeneously distributed.**"

- **p 1, l 11** : "on long time scales". I assume that the tool takes into account climate impacts on long time scale, via e.g. the CCFs. However, the tool itself is an optimization of only the flights planned within the next few days. There should be no confusion about these very different aspects.

  Reply: In this sentence, we just wanted to say that AirTraf can perform "long-term" simulations, i.e. not only a few days but also more than ten years (arbitrary duration of simulations). The word "on long time scales" seems to be confusing. We will revise the text: on page 1 line 9–11, "This study introduces AirTraf (version 1.0) ~~for climate impact evaluations~~ that performs global air traffic simulations ~~on long time scales~~, including effects of local weather conditions on the emissions." In AirTraf, we apply an optimization on a daily basis for daily changing weather situations. To investigate the mitigation gain of the climate impact by climate-optimal routing, multi-annual (long-term) simulations are required (e.g. for ten years). In the simulations over the ten years, each flight trajectory is optimized with respect to a selected aircraft routing option, considering local weather conditions. Along the optimized flight path, emissions are released. AirTraf can perform such long-term air traffic simulations with the inclusion of the on-line optimization module and the optimal routes will change day by day.

- **p 1, l 15** : were → are (because you describe the functioning of a tool).

  Reply: We will revise the text: on page 1 line 15, "Fuel use and emissions ~~were~~ **are** calculated by...". In the same way, we will revise the text: on page 1 line 16, "The flight trajectory optimization ~~was~~ **is** performed by a Genetic Algorithm...".

- **p 1, l 15** : DLR. This abbreviation should be explained.

  Reply: We will revise the text: on page 1 line 15, "...and **Deutsches Zentrum für Luft- und Raumfahrt (DLR)** fuel flow method."

- **p 1, l 16–17** : "with respect to routing options" : vague.

  Reply: We will revise the text: on page 1 line 16, "...performed by a Genetic Algorithm (GA) with respect to **a selected** routing option~~s~~."

- **p 1, l 17–18** : "two benchmark tests ... for great circle and time routing options" : sounds a bit strange → "benchmark tests ... for the great circle and time routing options".

Reply: We will revise the text: on page 1 line 17, "..., ~~two~~ benchmark tests were performed for **the** great circle and flight time routing options."

- **p 1, l 19** : "by other published code" : vague, and inappropriate language for an abstract.

  Reply: We will revise the text: on page 1 line 19, "...calculated by ~~other published code~~ **the Movable type script**."

- **p 1, l 20** : "optimal solution" → "optimal solution found by the algorithm" (distinguish whether it relates to the real optimal solution, or to the best estimate found by the optimization routine).

  Reply: We will revise the text: on page 1 line 20, "...the optimal solution **found by the algorithm** sufficiently converged to...".

Page 2

- **p 2, l 22** : "initial population" : as such, this is too technical for an abstract. I suggest to skip this from the abstract, or one could also choose to describe a bit better the optimization algorithm/methodology in the abstract.

  Reply: Please see the reply to the referee comment: "GA algorithm."

- **p 2, l 22–23** : "We found that the influence was small (around 0.01 %)" : I suggest to combine this into one sentence with the former sentence.

  Reply: We will revise the sentences: on page 2 line 21–23, "The dependence of optimal solutions on the initial ~~populations~~ **set of solutions (called population)** was analyzed **and** ~~We found that~~ the influence was small (around 0.01 %)."

- **p 2, l 24** : "function evaluations", "generation sizing" : too technical for an abstract.

  Reply: We will add explanations and revise the sentence: on page 2 line 24, "The trade-off between the accuracy of GA optimizations and ~~the number of function evaluations~~ **computational costs** is investigated and the appropriate population and generation **(one iteration of GA)** sizing is discussed."

- **p 2, l 27** "one-day AirTraf simulations are demonstrated ..." : vague.

  Reply: We will remove the word "one-day" in the sentence: on page 2 line 26, "Finally, ~~one-day~~ AirTraf simulations are demonstrated with...". Related to this, we will revise the text: on page 2 line 31, "The consistency check for the ~~one-day~~ AirTraf simulations...". We will also revise the text: on page 4 line 106, "In Sect. 4, ~~one-day~~ AirTraf simulations are demonstrated ~~for~~ **with** the two options **for a typical winter day (called one-day AirTraf simulations)** and the results are discussed."

- **p 2, l 27** : specific winter day → typical winter day.

  Reply: We will revise the text: on page 2 line 27, "...with the great circle and the flight time routing options for a ~~specific~~ **typical** winter day." In the same way, we will revise the text: on page 18 line 599, "The simulation was performed for one ~~specific~~ **typical** winter day..."; on page 25 line 844, "AirTraf simulations were demonstrated in EMAC (on-line) for a ~~specific~~ **typical** winter day...".

- **p 2, l 29** : "for the two options" : it is a long time ago that these were mentioned. So maybe express them explicitly again.

Reply: We are hesitating to express them explicitly again, because the corresponding word “the great circle and the flight time routing option” are mentioned on page 2 line 27. We think that this is not far from line 29. Nevertheless, we will add the text to express the word more clearly: on page 2 line 29, “...AirTraf simulates the air traffic properly for the two **routing** options.”

- **p 2, l 30** : for all airport pairs : too vague for an abstract.

  Reply: We will revise the text: on page 2 line 30, “...for ~~all~~ **103** airport pairs...”.

- **p 2, l 30–31** : ”reflecting” local weather → taking into account (?).

  Reply: We will revise the text: on page 2 line 30, “...airport pairs, ~~reflecting~~ **taking** local weather conditions **into account**.”

- **p 2, l 31** : verified → confirmed.

  Reply: We will revise the text: on page 2 line 31, “...the one-day AirTraf simulations ~~verified~~ **confirmed** that...”.

- **p 2, l 32** : ”comparable to reference data” : too vague.

  Reply: We will revise the text: on page 2 line 31–32, “...calculated flight time, fuel consumption, NO_x emission index and aircraft weights ~~are comparable to~~ **show a good agreement with reference data.**”

- **p 2, l 34** : ”with increasing the number ” → ”with the increasing number”.

  Reply: We will revise the text: on page 2 line 34, “**With the increasing number** of aircraft, the air traffic’s contribution...”.

- **p 2, l 35** : ”a major problem” : too vague.

  Reply: We will revise the text: on page 2 line 35, “...the air traffic’s contribution to climate change becomes **an** ~~major~~ **important** problem.”

- **p 2, l 35** : ”At present” → Nowadays, currently, ...

  Reply: We will revise the text: on page 2 line 35, “~~At present~~ **Nowadays**, aircraft emission...”.

- **p 2, l 35–37** : aircraft emission impacts contribute 4.9 % of total anthropogenic radiative forcing : skip ”impacts”, as radiative forcing is an impact; 4.9 → to 4.9 ; of total → ”of the total”.

  Reply: We will revise the text: on page 2 line 35–37, “..., aircraft emission ~~impacts~~ (this includes still uncertain aviation-induced cirrus cloud effects) contribute**s** approximately **to** 4.9 % (with a range of 2-14 %, which is a 90 % likelihood range) of **the** total anthropogenic radiative forcing...”.

- **p 2, l 39** : will grow → might grow.

  Reply: We will revise the text: on page 2 line 39, “An Airbus forecast shows that the world air traffic ~~will~~ **might** grow...”.

- **p 2, l 40** : the value of 4.9 % → a value of 4.9 %.

  Reply: We will revise the text: on page 2 line 40, “..., while Boeing forecasts ~~the~~ **a** value of 4.9 % over the

same period."

- **p 2, l 41** : indicates → implies.

  Reply: We will revise the text: on page 2 line 41, "This ~~indicates~~ **implies** a further increase of aircraft emissions...".

- **p 2, l 41–42** : "and therefore environmental impacts from aviation increase" : try to avoid to have twice "increase" in this sentence.

  Reply: We will revise the text: on page 2 line 41–42, " This ~~indicates~~ **implies** a further increase of aircraft emissions and therefore environmental impacts from aviation ~~increase~~ **rise**."

- **p 2, l 42–43** : This sentence sounds more positive than one can possibly defend.

  Reply: We will reply to the comment in the above section: "p 1, l 3–6".

- **p 2, l 47** : contrail → contrails.

  Reply: We will revise the text: on page 2 line 47, "The emissions also induce cloudiness via the formation of contrail**s**, contrail-cirrus...".

- **p 2, l 49** : depends → depends partially.

  Reply: We will revise the text: on page 2 line 49, "The climate impact induced by aircraft emissions depends **partially** on...".

- **p 2, l 49–51** : What follows behind the ":" is not an explanation from what is said before ":".

  Reply: We will revise the sentences: on page 2 line 49–50, "The climate impact induced by aircraft emissions depends on local weather conditions~~:~~**. ~~it~~ That is, the impact** depends on...".

- **p 2, l 50** : geographic → geographical (both are possible).

  Reply: We will revise the word "geographic" into the "geographical" in the revised manuscript: on page 2 line 50, "...on geographic**al** location (latitude and longitude) and..."; on page 14 line 449, "...the geographic**al** location..."; on page 34 in the caption of Fig. 7, "...and as geographic**al** location...".

- **p 2, l 51–p3, l 59** : "... and affect the atmosphere from minutes to centuries." Minutes probably refers to the time scale for disappearance of some chemical perturbations. However, every appearance (even if it is only a few minutes) of a GHG, has a century-timescale effect. Although I think I understand what the authors want to say, I think that the whole paragraph is rather inaccurate, and should be rewritten more precisely.

  Reply: In this paragraph, we just wanted to focus on atmospheric composition changes, not on the climate changes, which the referee addressed. We will add the word "on the atmospheric composition" into the text to make clear what we want to say here: on page 2 line 51–53, "In addition, the impact **on the atmospheric composition** has different timescales: chemical effects induced by the aircraft emissions have a range of life-times and affect the atmosphere from minutes to centuries. CO_2 has ~~a~~ long perturbation life-time**s** in the order of decades to centuries."

Page 3

- **p 3, l 61** : "150 km horizontally" : maybe distinguish two directions (is it perpendicular to the flight path, or along the flight path). Isn't this 150 km much too specific? Isn't there a very broad spectrum?

Reply: The mean length of 150 km is from Gierens and Spichtinger (2000). The study showed that: “The mean path length is about 150 km with a standard deviation of 250 km.” Therefore, we will refer the original reference in the text and revise the sentence to make clear that point: on page 3 line 61, “...extend a few 100 m vertically and ~~around~~ **about** 150 km ~~horizontally~~ **along a flight path (with a standard deviation of 250 km)** with a large spatial and temporal variability (**Gierens et al., 2000,** Spichtinger et al., 2003).” This modification is also related to our reply to the comment (1) of referee #1.

- **p 3, l 63** : There ”are” two options ... : this sounds very optimistic.

  Reply: We will revise the text: on page 3 line 63, “**The measures to counteract the climate impact induced by aircraft emissions can be classified into two categories**: technological and operational ~~approaches~~ **measures**,...”.

- **p 3, l 64** : ”approaches” → measures.

  Reply: We will revise the word “approaches” into “measures”: on page 3 line 64, “...: technological and operational ~~approaches~~ **measures**,...”. In the same way, we will revise the word “approach” into “measure” in the manuscript: on page 1 line 6, “...is an important ~~approach~~ **measure** for climate impact reduction...”.

- **p 3, l 69** : ”... are optimized with respect to time and economic costs.” : if both are taken into account, how are they weighted?

  Reply: In this paper, we would like to show that AirTraf works well and is fit for our purpose. Particularly, the ability of the optimization module (GA) to optimize flight routes must be confirmed. For this, we tested the simple “time-optimal routing.” The referee actually points at the interesting future investigation, which is far beyond the scope of this paper. Generally, airlines have own evaluation functions, such as cost index, which uses weight factors on fuel, time, etc., in order to optimize the whole aircraft operating system. This kind of data is almost impossible to get from airlines and depends on their individual strategy.

- **p 3, l 69** : ”fuel, crew, operating costs” : isn’t fuel part of the operating costs?

  Reply: We will revise the text: on page 3 line 69, “...economic costs (fuel, crew, **other** operating costs)...”.

- **p 3, l 72** : ”systematic routing changes” : reading this, one gets the impression that there are different options. However, later it is reduced to just ”i.e. flight altitude change”. I suggest to just say ”systematic flight altitude changes”.

  Reply: We will revise the text: on page 3 line 72, “Earlier studies investigated the effect of **systematic** ~~routing changes, i.e.~~ **flight altitude changes**~~,~~ on the climate impact...”.

- **p 3, l 74** : has a strong effect on the reduction of the climate impact → has a strong impact on climate. (From the original formulation it is not clear whether the increase or the decrease in flight altitude leads to a reduction of the climate impact.)

  Reply: We understand the referee comment. Nevertheless, we are hesitating to change the text. The four studies referred here showed clearly that the changed altitude has a strong effect on the reduction of the climate impact. However, the studies were performed with respect to different flight plans, different climate impact metrics and different duration of simulations (i.e. atmospheric conditions). We think that it is not appropriate to describe whether the increase or the decrease in flight altitude leads to a reduction of the climate impact. More studies are needed before generalizing that point.

- **p 3, l 74–77** : ”the” climate-optimized routing → climate-optimized routing.

Reply: We will revise the text: on page 3 line 74–77, “A number of studies have investigated the potential of applying ~~the~~ **climate-optimized routing** for real flight data. Matthes et al. (2012) and Sridhar et al. (2013) addressed weather-dependent trajectory optimization using real flight routes and showed a large potential of ~~the~~ **climate-optimized routing**.”

- **p 3, l 79** : ”the” climate sensitive regions → climate-sensitive regions.

  Reply: We will revise the text: on page 3 line 79, “...by considering regions described as ~~the~~ **climate-sensitive regions** and...”.

- **p 3, l 80** : ”This study” → ”That study”.

  Reply: We will revise the text: on page 3 line 80, “~~This~~ **That** study reported...”.

- **p 3, l 81** : by only small increase → by only a small increase.

  Reply: We will revise the text: on page 3 line 81, “...can be achieved by only **a** small increase in economic costs...”.

- **p 3, l 80–81** : This study reported: ”large reductions ...” → That study reported that large reductions ...

  Reply: We will revise the text: on page 3 line 80–81, “~~This~~ **That study reported that large reductions** in the climate impact of up to 25 % can be achieved by only **a** small increase in economic costs of less than 0.5%.”

- **p 3, l 82** : useful : is useful what one wants to express?

  Reply: We just want to express that the climate-optimized routing is effective to reduce the climate impact. Therefore, we will revise the text: on page 3 line 82, “The climate-optimized routing therefore seems to be **an** ~~a useful~~ **effective** routing option **for the climate impact reduction,**...”.

- **p 3, l 85–86** : The current study wants apparently to investigate something (how much the climate impact of aircraft emissions can be reduced) that already has been investigated before (see lines 80–81: large reductions in the climate impact of up to 25 % can be achieved). One should be more specific of what the current study will do extra with respect to the former study.

  Reply: Our final purpose (yet beyond the scope of the present manuscript) is to investigate the mitigation gain of climate-optimal routing. We would like to stress that the mere construction of climate-optimal flight trajectories for a specific weather condition is not our goal. The latter has been achieved, e.g. by Grewe et al., 2014. We eventually want to go one step further and apply an optimization on a daily basis for daily changing weather situations. To investigate then the mitigation gain, multi-annual (long-term) simulations with full feedback from the re-routed air traffic emissions are required (e.g. for ten years). In such simulations over at least the ten years, each flight trajectory is optimized with respect to a selected aircraft routing option, considering local weather conditions. The air traffic emissions are released into the ESM atmosphere and modify its chemical composition. AirTraf can perform such air traffic simulations with the inclusion of the on-line optimization module and the optimal routes will change day by day. This is an important difference to former studies.

  As the referee pointed out, the subject of this paper (line 84–85) seems to be confusing. We make clear that this paper introduces the AirTraf submodel in its basic version, and technically describes and validates the various components for first, simple aircraft routings (great circle and time-optimal). Eventually, we are aiming at an optimal routing for climate impact reduction. This will be a separate study, which requires a couple of additional developments beforehand, amongst which the present study is only one of

them.

Here, we will revise the sentences: on page 3, final paragraph (line 84–87), "~~This study aims to investigate how much the climate impact of aircraft emissions can be reduced by aircraft routing. Here, we present a new assessment platform AirTraf (version 1.0, Yamashita et al., 2015) that is a global air traffic submodel coupled to the Chemistry-Climate model EMAC (Jöckel et al., 2010). Figure 1 shows the research road map for this study (Grewe et al., 2014b)~~ **This paper presents the new submodel AirTraf (version 1.0, Yamashita et al., 2015) that performs global air traffic simulations coupled to the Chemistry-Climate model EMAC (Jöckel et al., 2010). This paper technically describes AirTraf and validates the various components for simple aircraft routings: great circle and time-optimal routings. Eventually, we are aiming at an optimal routing for climate impact reduction. The development described in this paper is a prerequisite for the investigation of climate-optimal routings. The research road map for our study is as follows (Grewe et al., 2014b):** ~~T~~**t**he first step is to investigate...".

- **p 3, l 84–87** : Do you mean by "this study" = "this manuscript"? Or is "this study" broader? After reading the manuscript, I have the impression that line 84–85 is not what is answered by this manuscript.

  Reply: We agree. We will reply this point in the section above: "p 3, l 85–86."

- **p 3, l 87** : The first step "is" → The first step "was".

  Reply: We will revise the text: on page 3 line 87, "The first step ~~is~~ **was** to investigate...".

- **p 3, l 87–89** : The first step is to investigate specific past weather situations, in particular the climate impact of locally released aircraft emissions → The first step was to investigate the influence of specific weather situations on the climate impact of aircraft emissions.

  Reply: As the referee described, this correction makes the sentence more clearly. Thank you very much. We will revise the text: on page 3 line 87–89, "**The first step was to investigate the influence of specific weather situations on the climate impact of aircraft emissions** (Matthes et al., 2012, Grewe et al., 2014b)."

- **p 3, l 89** : "The resulting data are ..." : too vague. Maybe one could say : "This results in climate cost functions ...".

  Reply: Thank you very much. We will revise the text: on page 3 line 89, "~~The resulting data are~~ **This results in climate cost functions** (CCFs, Frömming et al., 2013, Grewe et al., 2014a, Grewe et al., 2014b) that identify...".

- **p 3, l 91** : Why is CO_2 in this list? I can understand that the impact of adding CO_2 depends on the altitude, but this comes a bit unexpected after formulating earlier that CO_2 is well-mixed.

  Reply: We will delete the word "CO_2" in the sentence: on page 3 line 91, "...climate sensitive regions with respect to ~~CO_2,~~ O_3 , CH_4 , H_2O and contrails."

- **p 3, l 91** : "They are specific climate metrics, i.e. climate impact per unit of emission" → "per unit amount of emission."

  Reply: We will revise the text: on page 3 line 91, "They are specific climate metrics, i.e. climate impact **per unit amount of emission**,...".

- **p 3, l 92** : "and are used ..." → "will/might be used".

  Reply: We will revise the text: on page 3 line 92, "...climate impact **per unit amount of emission**, and ~~are~~ **will be used** for optimal aircraft routings."

Page 4

- **p 4, l 92** : ”In a further step, weather proxies are identified for the specific weather situations.” It is not clear whether this has been done.

  Reply: This has not been done. To clarify this point, we will revise the text: on page 4 line 92, “In a further step, weather proxies ~~are~~ **will be** identified for the specific weather situations,...”.

- **p 4, l 102–104** : ”A benchmark test for the great circle routing option is performed and ...” : the part before and after the ”and” actually express more or less the same.

  Reply: As the referee noted, that part can be reduced. Therefore, we will revise the text: on page 4 line 102–104, “A benchmark test ~~for the great circle routing option is performed and~~ **provides a comparison of** resulting great circle distances ~~are compared to~~ **with** those calculated by ~~other published code~~ **the Movable type script (MTS, Movable type script, 2014)**.”

- **p 4, l 103** : ”by other published code” : too vague.

  Reply: We will revise the text: on page 4 line 103, “...calculated by ~~other published code~~ **the Movable type script (MTS, Movable type script, 2014).**” Related to this, we will also revise the text: on page 12 line 401, “...calculated with ~~the Movable type script (MTS, Movable type script, 2014)~~ **MTS**.”

- **p 4, l 103–104** : ”Another ... also ...” : I suggest to skip one of these words.

  Reply: We will remove the word “also” from the sentence. In addition, we will revise the text by considering the reply to the comment on “p 4, l 103–105”: “Another benchmark test ~~is **also** performed for the flight time routing option.~~ **compares**...”.

- **p 4, l 103–105** : I would transform this into one sentence.

  Reply: We will transform this into one sentence. We will revise the text: on page 4 line 103–105, “Another benchmark test ~~is also performed for the flight time routing option.~~ **compares the** optimal solution ~~is compared~~ to the true-optimal solution.”

- **p 4, l 105–106** : This sentence is too technical with ”population” and ”generation sizing”.

  Reply: We will add explanations to the words: on page 4 line 105, “The dependence of optimal solutions on the initial ***populations*** **(a technical terminology set in italics is explained in the glossary in Appendix)** is examined...”. On page 4 line 106, “...appropriate ***population*** and ***generation*** sizing is discussed.” This reply is related to the reply to “GA algorithm”.

- **p 4, l 107** : ”consistency” is too general. One has not enough background information at this point in the text to understand this.

  Reply: We will rephrase the text: on page 4 line 107, “Section 5 verifies **whether** ~~the consistency for~~ **the AirTraf simulations are consistent with reference data** and...”.

- **p 4, l 108** : ”states” : I suggest to use another word.

  Reply: We will revise the text: on page 4 line 108, “...and Sect. 6 ~~states~~ **describes** the code availability.”

- **p 4, l 112–116** : This paragraph should be rewritten.

Reply: We will rephrase this paragraph (line 112–116): on page 4 line 112–116, "~~AirTraf was developed as a submodel of EMAC (Jöckel et al., 2010). This is reasonable, because we perform global air traffic simulations on long time scales considering local weather conditions. Geographic location and altitude at which emissions are released should be also considered. In addition, various submodels of EMAC can be used to evaluate climate impacts. Therefore, EMAC is a well suited development environment for AirTraf.~~ **AirTraf was developed as a submodel of EMAC (Jöckel et al., 2010) to eventually assess routing options with respect to climate. This requires a framework, where we can optimize routings everyday and assess them with respect to climate changes. EMAC provides an ideal framework, since it includes various submodels, which actually evaluate climate impact, and it simulates local weather situations on long time scales. As stated above, we were focusing on the development of this model. A publication on the assessment of routing changes will be published as well.**"

- **p 4, l 112** : "reasonable" : I think this is not enough as a motivation.

  Reply: We will rephrase this paragraph to make clear the motivation. Please see the reply to the comment: "p 4, l 112–116".

- **p 4, l 113** : "because we perform global air traffic simulations on long time scales considering local weather conditions." : I think this is a vague argumentation.

  Reply: We will rephrase this paragraph. Please see the reply to the comment: "p 4, l 112–116".

- **p 4, l 114** : "geographic location and altitude at which emissions are released should be also considered" : vague.

  Reply: This part is already explained in Introduction: on page 2 line 49–50, "The climate impact induced by aircraft emissions depends on local weather conditions: it depends on geographic location (latitude and longitude) and altitude at which the emissions are released (except for CO_2) and time." We will rephrase this paragraph. Please see the reply to the comment: "p 4, l 112–116".

- **p 4, l 115** : This is maybe the main reason why the effort is done to implement AirTraf in a climate model, and not just in a NWP, or using off-line available weather forecasts. So make this more explicit, and give examples of which climate impacts can be evaluated.

  Reply: Yes. We need the framework of EMAC to assess routing options. By following the referee comment, we will rephrase this paragraph. Please see the reply to the comment: "p 4, l 112–116".

- **p 4, l 117** : Explain what "entries" are.

  Reply: We will rephrase the word "entries" into "parameters" to make clear the meaning of the word: on page 4 line 117, "...AirTraf ~~entries~~ **parameters** are read in messy_initialize,...". In addition, we will modify Fig. 2 and its caption: on page 30 in Fig. 2, "AirTraf ~~entries~~ **parameters**"; and in the caption, "...AirTraf ~~entries~~ **parameters** are input in the initialization phase."

- **p 4, l 121–124** : This sentence should be improved. You have to put "here PE is synonym to MPI task" possibly between brackets. I am also not sure whether "while" is the most appropriate word to use here.

  Reply: As the referee noted, we will put "here PE is synonym to MPI task" between brackets. In addition, we will remove "while" and transform the sentence into two sentences: on page 4 line 121–124, "the one-day flight plan is decomposed for a number of processing elements **(PEs~~)~~, here PE is synonym to MPI task)**, so that each PE has a similar work load**.**~~, while a~~ **A** whole flight trajectory between an airport pair is handled by the same PE." Related to this modification, we will also modify the caption of Fig. 3: on page 31 in Fig. 3, "A one-day flight plan is distributed among many processing elements (PEs) in messy_init_memory

(blue)~~., while a~~ **A** whole trajectory of an airport pair is handled by the same PE...".

- **p 4, l 125** : I think one should be more specific about what a "time loop" is : isn't rather meant "time step"?

  Reply: We used the word "time loop" according to the following publication, which is one of the basic documents about on the ECHAM5/MESSy Atmospheric Chemistry (EMAC) model: "Jöckel, P., Sander, R., Kerkweg, A., Tost, H., and Lelieveld, J.: Technical Note: The Modular Earth Submodel System (MESSy) - a new approach towards Earth System Modeling, Atmos. Chem. Phys., 5, 433-444, doi:10.5194/acp-5-433-2005, 2005." AirTraf is developed as a submodel of EMAC. Therefore, we think that the word "time loop" is helpful for readers (specifically EMAC users) to understand the flowchart of the AirTraf.

- **p 4, l 125–126** : Thus, naturally short-term and long-term simulations consider the local weather conditions for every flight in EMAC. I think this should be explained more clearly.

  Reply: We will revise the sentence: on page 4 line 125–126, "Thus, ~~naturally~~ **both** short-term and long-term simulations ~~consider~~ **can take into account** the local weather conditions for every flight ~~in EMAC~~...".

- **p 4, l 126–127** : "(AirTraf continuously treats overnight flights)" : this is not logically related to the sentence it is attached to. What is meant by this? Because the weather patterns used in AirTraf are the ones at the time of take-off, it seems to me that there is no large complexity about it. Is it therefore still worth mentioning?

  Reply: We agree. The one-day flight plan includes many flight schedules on a single day. Some international (long-distance) flights fly over two days. For example, NH215 departs at MUC on 21:35 and arrives at Tokyo on 15:50 + 1day. We wanted to say here that AirTraf simulates such flights correctly. Indeed, we have been asked about this issue many times so far. Therefore, we believe that it is still worth mentioning.

  Further, from the comment (4) of the referee #1, we will modify the text "(AirTraf continuously treats overnight flights)" into "(AirTraf continuously treats overnight flights **with arrival on the next day**)." After that, the modified text will be moved from the current position to an appropriate position in the manuscript, which is related logically: on page 4 line 125, "Thus, ~~naturally~~ **both** short-term and long-term simulations ~~consider~~ **can take into account** the local weather conditions for every flight ~~in EMAC (AirTraf continuously treats overnight flights with arrival on the next day)~~."; and on page 7 line 225, "pos_{new} and pos_{old} are stored in the memory and the aircraft continues the flight from pos_{new} = 2.3 at the next time step **(AirTraf continuously treats overnight flights with arrival on the next day)**."

Page 5

- **p 5, l 131–132** : What is meant by these "global fields"? Give examples.

  Reply: This means "three dimensional emission fields" and we call this "global fields" in the paper. We will add the text to make clear this point: on page 5 line 131–132, "...the calculated flight trajectories and global fields **(three dimensional emission fields)** are output (Fig. 2, rose red). The results are gathered from all PEs for output ~~of global fields~~."

- **p 5, l 132–134** : What is meant by the sentence "Other evaluation models ... on the climate impact"? I suggest to make this more concrete.

  Reply: We just wanted to say that other objective functions (or other evaluation models) will be integrated into AirTraf in order to assess routing options on climate impact reduction. However, this is not necessary for our argument here. Therefore, we will modify the sentence: on page 132–134, "~~Other evaluation models, e.g. climate metric models, can easily be integrated into AirTraf and hence t~~**T**he output ~~is~~ **will be** used to eval uate the reduction potential of the routing option on the climate impact."

- **p 5, l 135–136** : "R_E = 6371 km" : I don't know whether this level of detail should be mentioned in the manuscript.

Reply: We believe that this information is important, because great circle distances can vary considerably with differences of R_E. Concerning this issue, we will revise the caption of Table 4 from the comment (2) of the referee #2 as "...column 4 (d_{MTS}) shows the result calculated with the Movable type scripts (MTS), ~~which output only integer values~~ **using the Haversine formula with a spherical Earth radius of R_E = 6,371 km**."

- **p 5, l 137–138** : The Mach number is a (→ "the") velocity divided by a (→ "the") speed of sound.

  Reply: We will revise the text: on page 5 line 137–138, "...the Mach number is ~~a~~ **the** velocity divided by ~~a~~ **the** speed of sound."

- **p 5, l 138** : "true air speed" → "the true air speed". Maybe add to the sentence : "When an aircraft flies at a constant Mach number". Isn't "vary along flight trajectories" enough? I don't think that "latitude, longitude, altitude and time" should be added. If one really wants to be more specific, I would rather add temperature and wind speed as factors modifying the true air speed and ground speed.

  Reply: By following the referee comment, we will revise the text: on page 5 line 138, "~~Therefore~~ **When an aircraft flies at a constant Mach number, the** true air speed V_{TAS} and ground speed V_{ground} vary along the flight trajectories ~~corresponding to a given latitude, longitude, altitude and time~~."

- **p 5, l 142** : limits rates → limit rates.

  Reply: We will correct the word: on page 5 line 142, "...and **limit~~s~~ rates** of aircraft climb...".

- **p 5, l 142** : Explain "semi-circular rule", and "sector demand analysis".

  Reply: We will modify the words to explain them clearly: on page 5 line 142, "...such as the semi-circular rule **(the basic rule for flight level)** and limits rates of aircraft climb and descent, are disregarded. However, a ~~sector demand~~ **workload** analysis of **air traffic controllers** can be performed on the basis of the output data."

- **p 5, l 144** : "mention" : I do not think this is the appropriate wording.

  Reply: We will revise the text: on page 5 line 144, "The following sections ~~mention~~ **describe** the used models briefly...".

- **p 5, l 149** : What is meant by "interactions with human influences"?

  Reply: This means the influence coming from anthropogenic emissions. AirTraf describes one of them. We will rephrase the text: on page 5 line 149, "...and their interaction with oceans, land and ~~human~~ influences **coming from anthropogenic emissions** (Jöckel et al., 2010)."

- **p 5, l 153** : T42L31ECMWF-resolution → T42L31ECMWF resolution

  Reply: We will revise the word: on page 5 line 153, "...in the **T42L31ECMWF resolution**,...". On page 18 line 599, "...in the **T42L31ECMWF resolution**."

- **p 5, l 159** : Can it exist out of more than one day? On page 6, line 163 : "Any arbitrary number of flight plans is applicable to AirTraf". So one can give flight plans for many days at once?

  Reply: As the referee noted, this point is not clear what we mean by the phrase "one-day flight plan." As shown in Fig. 3 on page 31, the one-day flight plan, which includes many flight schedules on a single day, is used in AirTraf. This flight plan is reused for simulations longer than two days, as described on page 8 line

240. To clarify this point, we will add a short description the first time we use the phrase “one-day flight plan”: on page 4 line 121, “As shown in Fig. 3, the one-day flight plan**, which includes many flight schedules of a single day,** is decomposed for...” (this reply is related to the comment (3) of the referee #1).

- **p 5, l 160** : of A330-301 → of an A330-301 aircraft.

  Reply: We will revise the word in the revised manuscript: on page 5 line 160, “...the primary data of **an** A330-301 **aircraft** used...”. The caption of Table 1 on page 51, “Primary data of **Airbus** A330-301 **aircraft** and...”.

- **p 5, l 162** : a departure time → the departure time.

  Reply: We will revise the word: on page 5 line 162, “...latitude/longitude of the airports, and ~~a~~ **the** departure time.”

- **p 5, l 162** : as values [-90,90] → as values in the range [-90,90].

  Reply: We will add the text “in the range” in the revised manuscript: on page 5 line 162, “The latitude and longitude coordinates are given as values **in the range** [−90, 90] and...”.

Page 6

- **p 6, l 164** : the data are required → these data are required.

  Reply: We will revise the word: on page 6 line 164, “...; ~~the~~ **these** data are required to calculate...”.

- **p 6, l 165** : ”As for ...” → ”Concerning ...”.

  Reply: We will revise the text: on page 6 line 165, “~~As for~~ **Concerning** the engine performance data,...”.

- **p 6, l 166** : flows (plural) while index (singular).

  Reply: Thank you so much. We will revise the text: on page 6 line 166, “...reference fuel **flow**~~s~~ f_{ref} (in kg(fuel)s^{-1}) and...”.

- **p 6, l 168** : What is meant by an ”overall” weight factor?

  Reply: The word “overall” means “passenger/freight/mail”. we will add this text: on page 6 line 168, “An overall **(passenger/freight/mail)** weight load factor is also provided...”. On page 51 at the line with OLF in Table 1, “ICAO overall **(passenger/freight/mail)** weight load factor **in 2008**[d]”.

- **p 6, l 171** : are described ”here” step by step.

  Reply: We will add the word “here” in the revised manuscript: on page 6 line 171, “The calculation procedures in the AirTraf integration are described **here** step by step.”

- **p 6, l 172** : a flight status → the flight status.

  Reply: We will revise the text: on page 6 line 172, “...~~a~~ **the** flight status of all flights is initialized...”.

- **p 6, l 178** : moving aircraft position → aircraft position calculation.

  Reply: We will revise the word “moving aircraft position” into “aircraft position calculation” in the revised manuscript: on page 6 line 178, “...fuel/emissions calculation, ~~moving aircraft position~~ **aircraft position cal culation** and gathering global emissions.” Further, on page 30 in the Fig. 1 (bold-black box, light blue),

"~~Move aircraft position~~ **Aircraft position calc.**" On page 32 in the caption of Fig. 4, "(c) ~~Moving aircraft position~~ **aircraft position calculation**."

- **p 6, l 182–183** : differ to → differ from.

  Reply: We will revise the text: on page 6 line 182–183, "...fuel (might differ ~~to~~ **from** H_2O,...".

- **p 6, l 184** : can be used → can currently be used.

  Reply: We will add the word "currently" in the revised manuscript: on page 6 line 184, "...the great circle and the flight time routing options can **currently** be used."

- **p 6, l 187** : for a selected option → for the selected option.

  Reply: We will revise the text: on page 6 line 187, "...a single-objective minimization problem is solved for ~~a~~ **the** selected option...".

- **p 6, l 191–194** : Why adding these sentences? It makes the text confusing. In addition, it is not well defined how an optimization might work when one optimizes according to two criteria (time and cost). One should also mention then how to weight or compare both (trade-off between them).

  Reply: We have a reason why we added the sentence. Here, we would like to show clearly that a time-optimal route is different from a wind-optimal route. In this paper, we optimize flight trajectories with respect to "time" by taking into account wind effects. These routes are the time-optimal routes, not the wind-optimal routes, because the objective function is different between the time-optimal and the wind-optimal routing options, as described on page 6 line 191–194. We have seen situations many times that people assumed the time-optimal route including wind effects as "the wind-optimal route." To avoid this situation, we distinguish the routes clearly.

  To explain this better, we will revise the text: on page 6 line 191–196, "Generally, a wind-optimal route means an economically optimal flight route taking the most advantageous wind pattern into account. This route minimizes total costs with respect to time, **fuel** and **other** economic costs ~~(fuel, crew and others)~~, i.e. it has multiple objectives. ~~On the other hand,~~ AirTraf ~~distinguishes~~ **will provide** ~~between~~ the flight time and the fuel routing options separately to investigate trade-offs (conflicting scenarios) among different routing options. ~~Thus, the time-optimal route is not always the same as the wind-optimal route.~~" This reply is related to the reply to "p 3, l 69".

- **p 6, l 197** : The CCF is → The CCFs are.

  Reply: We will revise the text: on page 6 line 197, "The CCF**s** ~~is~~ **are** provided by the...".

- **p 6, l 199** : "total" climate impacts versus "some" aviation emissions : this sounds strange.

  Reply: We will remove the word "total" from the text: on page 6 line 199, "...and estimates ~~total~~ climate impacts due to some aviation emissions."

Page 7

- **p 7, l 211** : $n_{wp-1} \rightarrow n_{wp} - 1$.

  Reply: Thank you so much. We will correct the text: on page 7 line 211, "...the flight segment index (i = 1, 2, ..., ~~n_{wp-1}~~ $\boldsymbol{n_{wp} - 1}$)."

- **p 7, l 212–213** : calculation/calculation/calculate : try to vary the wording more.

Reply: We will revise the text: on page 7 line 212–213, "~~Next, the fuel/emissions calculation linked to the fuel/emissions calculation module (Fig. 2, light orange) calculates fuel use, NO_x and H_2O emissions by using a total energy model based on the BADA methodology (Schaefer, 2012) and the DLR fuel flow method (Deidewig et al., 1996, see Sects. 2.5 and 2.6 for more details)~~ **Next, fuel use, NO_x and H_2O emissions are calculated by the dedicated module (Fig. 2, light orange); this module comprises a total energy model based on the BADA methodology (Schaefer, 2012) and the DLR fuel flow method (Deidewig et al., 1996, see Sects. 2.5 and 2.6 for more details).**"

- **p 7, l 218–219** : corresponding to time steps → corresponding to "the" time steps.

  Reply: We will add the word "the" in the sentence: on page 7 line 218–219, "...along the flight trajectory corresponding to **the** time steps of EMAC (Fig. 4c)."

- **p 7, l 219–220** : "present" and "previous" is a bit vague : isn't it the position at the beginning of a time step of EMAC, and at the end of a time step?

  Reply: Thank you so much. We will revise the text: on page 7 line 219–220, "...aircraft position parameters pos_{new} and pos_{old} are introduced to indicate ~~a~~ **the** present **position (at the end of the time step)** and previous position **(at the beginning of the time step)** of the aircraft along the flight trajectory."

- **p 7, l 220** : "a" present and previous position → "the" present and previous position.

  Reply: We will revise the text: on page 7 line 220, "...aircraft position parameters pos_{new} and pos_{old} are introduced to indicate ~~a~~ **the** present and previous position...".

- **p 7, l 221** : by real numbers of the waypoint index → by real numbers as a function of the waypoint index.

  Reply: We will revise the text: on page 7 line 221, "They are expressed by real numbers **as a function** of the waypoint index...".

- **p 7, l 224** : I would rather say : "This means that the aircraft moves 100% of the distance between $i = 1$ and $i = 2$, and 30 % of the distance between $i = 2$ and $i = 3$ in one time step."

  Reply: Thank you so much. We will revise the text: on page 7 line 224, "This means that the aircraft moves **100% of the distance between $i = 1$ and $i = 2$, and** 30 % of the distance between $i = 2$ and $i = 3$ in one time step."

- **p 7, l 233** : is used → are used.

  Reply: We will revise the text: on page 7 line 233, "...the coordinates of the $(i+1)^{th}$ waypoint ~~is~~ **are** used to find the...".

- **p 7, l 233** : This is a little bit inaccurate (see also Fig. 4). Assess the impact of this inaccuracy.

  Reply: Unfortunately, we do not understand the referee comment. In this sentence, we describe how to gather the aircraft emissions for the case $NO_{x,\,i}$, as example. This treatment is the same for the cases $NO_{x,\,i-2}$ and $NO_{x,\,i-1}$: as shown in Fig. 4d on page 32, for the fraction of $NO_{x,\,i-2}$, the coordinates of the $(i-1)^{th}$ waypoint is used to find the nearest grid point. Nevertheless, we improve the caption of Fig. 4: on page 32 in the caption of Fig. 4, "...(d) Gathering global emissions; the fraction of $NO_{x,\,i}$ corresponding to the ~~EMAC grid box~~ **flight segment *i*** is mapped onto the nearest grid box."

Page 8

- **p 8, l 237** : "If $t \geq 2$ of the day" : express this better.

Reply: We will revise the text: on page 8 line 237, "~~If $t \geq 2$ of the day (i.e. o~~**Once the status becomes 'in-flight'**~~)~~, the departure check is false **in subsequent time steps ($t \geq 2$)** and...".

- **p 8, l 239** : without recalculating flight trajectory and fuel emissions → without recalculating the flight trajectory or fuel emissions.

  Reply: Thank you so much. We will revise the text: on page 8 line 239, "...the aircraft moves to the new air craft position without recalculating **the** flight trajectory ~~and~~ **or** fuel/emissions."

- **p 8, l 240–241** : "For more than two consecutive days simulations" → "For simulations longer than two days".

  Reply: Thank you so much. We will revise the text: on page 8 line 240–241, "For **simulations** ~~more~~ **longer than two** ~~consecutive~~ **days** ~~simulations~~, the same flight plan...".

- **p 8, l 243** : Twice "calculation".

  Reply: We will remove the first "calculation" in the sentence: on page 8 line 243, "The ~~calculation~~ methodologies of the fuel/emissions calculation module (Fig. 2, light orange) are described."

- **p 8, l 246** : are used → is used.

  Reply: Thank you so much. We will revise the word "are" into "is" in the revised manuscript: on page 8 line 246, "A total energy model based on the BADA methodology and the DLR fuel flow method ~~are~~ **is** used."

- **p 8, l 246–247** : the first trip fuel estimation → a first trip fuel estimation.

  Reply: We will correct the text: on page 8 line 246–247, "The fuel use calculation consists of the following two steps: ~~the~~ **a** first rough trip fuel estimation and...".

- **p 8, l 247** : the second fuel calculation : a bit vague. Maybe mention that it is more detailed.

  Reply: We will add the word "detailed" in the text: on page 8 line 247, "...~~the~~ **a** first rough trip fuel estimation and the second **detailed** fuel calculation...". Related to this issue, we will add the word "detailed" into the text in Fig. 2 (dashed box, light orange): on page 30, "2nd **detailed** fuel calc.".

- **p 8, l 256** : mean flight altitude of the flight → mean altitude of the flight.

  Reply: We will remove the first "flight" from the sentence: on page 8 line 256, "F_{BADA} is calculated by inter polating the BADA data (assuming nominal weight) to the mean ~~flight~~ altitude of the flight...".

- **p 8, l 260** : it is assumed as → it is assumed to be.

  Reply: Thank you so much. We will revise the text: on page 8 line 260, "It is assumed ~~as~~ **to be** 3 % of the $\mathrm{FUEL}_{\mathrm{trip}}$...".

Page 9

- **p 9, l 274–275** : "For an aircraft in cruise ..." : express this better.

  Reply: Please see the reply to the referee comment: "Sensitivity (1)."

- **p 9, line 276–278** : One should have a "," or a "." after most of the formula.

Reply: As the referee pointed out, we will recheck the all equations and add "," or "." after most of them. We will reply to this issue in the section of "Mathematical formulas (3)."

- **p 9, line 280** : The numerical value of ρ_i is not given in Table (2) (as for S, C_{D0} and C_{D1} in Table 1).

  Reply: The referee is right. We will revise and add the text: on page 9 line 280, "The performance parameters (S, C_{D0} and C_{D2}) **are given in Table 1,** ~~and the air density~~ ρ_i **is the air density (Table 2)** ~~are given in Tables 1 and 2~~. **and** $V_{TAS,i}$ **is calculated at every waypoint (Table 2).**"

- **p 9, l 281** : a fuel flow → the fuel flow.

  Reply: We will revise the text: on page 9 line 281, "...and ~~a~~ **the** fuel flow of the aircraft...".

- **p 9, l 282** : I suggest to skip "for jet aircraft".

  Reply: We will skip the text "for jet aircraft" in the sentence: on page 9 line 282, "...calculated assuming a cruise flight ~~for jet aircraft~~:".

- **p 9, l 283–284** : "," after the equations.

  Reply: We will add "," after Eqs. (7) and (8). We will reply to this issue in the section of "Mathematical formulas (3)."

- **p 9, l 287** : Oneday : I suggest to find another name for this variable in the manuscript. In addition, its units in Table 1 should be "sec day^{-1} ".

  Reply: We agree. We will change the name for the variable "Oneday" into the "SPD" (the Seconds Per Day) throughout the revised manuscript: Eq. (9) on page 9 line 287, "$\mathrm{FUEL}_i = F_{cr,i}\,(ETO_{i+1} - ETO_i)$ ~~Oneday~~ **SPD**". Further, on page 9 line 288, "...is converted into seconds by multiplying ~~Oneday~~ **with Seconds Per Day (SPD,** Table ~~2~~**1**)." On page 12 line 383−385 in Eqs. (26) and (27), "$V_{\mathrm{ground,i-1}} \times$ ~~Oneday~~ **SPD** (denominator)" and "$FT = (\mathrm{ETO}_{\mathrm{nwp}} - \mathrm{ETO}_1) \times$ ~~Oneday~~ **SPD**." On page 51 in Table 1, "(Parameter) ~~Oneday~~ **SPD**; (Value) 86,400; (Unit) s **day^{-1}** ; (Description) Time (Julian date) × ~~Oneday~~ **SPD** = Time (s)." On page 52 in Table 2, description of row 15, "$FT = (\mathrm{ETO}_{\mathrm{nwp}} - \mathrm{ETO}_1) \times$ ~~Oneday~~ **SPD**."

- **p 9, l 289** : "reflects" → "incorporates" or "is impacted by".

  Reply: We will revise the text: on page 9 line 289, "The FUEL_i ~~reflects~~ **incorporates** the tail/head winds effect...".

- **p 9, l 290** : $(m) \rightarrow (m_i)$.

  Reply: We will revise the text: on page 9 line 290, "The relation between the FUEL_i and the aircraft weight ($\boldsymbol{m_i}$) is...".

- **p 9, l 294** : next to the last → at the one but last.

  Reply: Thank you so much. We will revise the text: on page 9 line 294, "...the aircraft weight ~~next to the last~~ **at the one but last** waypoint...".

- **p 9, l 296–297** : I do not think this last sentence gives new information. Or formulate it nicer.

  Reply: We agree. We will remove the last sentence in the revised manuscript: on page 9 line 296−297, "~~As the~~

~~aircraft weight is pre-calculated in this module, it reduces during the flight as fuel is burnt, corresponding to the time steps of EMAC.~~".

Page 10

- **p 10, l 302** : first → First.

  Reply: We will revise the text: on page 10 line 302, "The calculation procedure follows four steps: ~~f~~**F**irst, the reference fuel flow...".

- **p 10, l 310–311** : corresponding sea level values → corresponding values at sea level.

  Reply: Thank you so much. We will revise the text: on page 10 line 310−311, "P_0 and T_0 are the corresponding ~~sea level~~ values **at sea level**...".

- **p 10, l 314–315** : "," after equations.

  Reply: We will add "," after Eqs. (14) and (15). We will reply to this issue in the section of "Mathematical formulas (3)."

- **p 10, l 327** : "... and q_i is the specific humidity at h_i " : mention units of q_i (kg kg^{-1}, g kg^{-1}, ...).

  Reply: We will add the unit in the sentence: on page 10 line 327, "...and q_i **(in kg(H_2O)(kg(air))$^{-1}$)** is the specific humidity at h_i...".

- **p 10, l 329** : pre-calculated → calculated.

  Reply: We will modify the word: on page 10 line 329, "...using the ~~pre-~~**calculated** FUEL$_i$...".

- **p 10, l 330–331** : "," after equations. I do not think it is a good idea to have variables whit names as $NO_{x,i}$ and H_2O_i. I would rather use names like m_{NOx}.

  Reply: We will add "," after Eqs. (19) and (20). We will reply to this issue in the section of "Mathematical formulas (3)." Further, we understand the referee comment. Nevertheless, we are hesitating to change the variable names, because "m" is already used for the aircraft weight, as described on page 9 line 290. Maybe the names are not the best ones, however, we think that the "$NO_{x,i}$" and "H_2O_i" show clearly that these emissions are calculated for the i^{th} flight segment.

Page 11

- **p 11, l 339** : one-day → one day of.

  Reply: From the reply to the referee comment on "p2, line 27," we will define the word "one-day AirTraf simulation": on page 4 line 106, "In Sect. 4, ~~one-day~~ AirTraf simulations are demonstrated ~~for~~ **with** the two options **for a typical winter day (called one-day AirTraf simulations)** and the results are discussed." Therefore, we will also use the word here.

- **p 11, l 343** : works → works only.

  Reply: We will add the word "only" in the sentence: on page 11 line 343, "The current aircraft routing module (Fig. 2, light green) works **only** with respect to the great circle and...".

- **p 11, l 351** : arctan, sin, cos, ... should not be italic.

  Reply: We will modify the all names of trigonometric formulas into normal straight letters in the revised

manuscript. We will reply to this issue in the section of “Mathematical formulas (4).”

- **p 11, l 351** : ”,” after equation.

  Reply: We will add “,” after Eq. (21). We will reply to this issue in the section of “Mathematical formulas (3).”

- **p 11, l 362** : Why mentioning ”km” here? Better to write on line 355 : d_i (km).

  Reply: The “km” is described here for the flight altitude “h_i” (not for the great circle distance d_i), because Table 2 shows the unit of h is “m”. To clarify this, we will add the text in the sentence: on page 11 line 362, “...(***h*** **is used in** km in Eqs. (22) and (23)) and...”.

- **p 11, l 363** : i.e. the → i.e.

  Reply: We will remove the word “the” in the sentence: on page 11 line 363, “...hence the great circle distance between airports, i.e. ~~the~~...”.

- **p 11, l 365** : ”based on Polar coordinates”? Explain this better.

  Reply: We think that the word “based on” seems to be confusing. We will revise the text: on page 11 line 365, “...by linear interpolation ~~based on~~ **in** Polar coordinates.”

- **p 11, l 365** : therefore → in that case.

  Reply: We will revise the word “therefore” into “in that case” in the revised manuscript: on page 11 line 365, “...~~based on~~ **in** Polar coordinates. ~~Therefore~~ **In that case**,...”.

Page 12

- **p 12, l 370** : of the i^{th} waypoint → at the i^{th} waypoint.

  Reply: We will change the word “of” into “at” in the revised manuscript: on page 12 line 370, “...the true air speed V_{TAS} and the ground speed V_{ground} ~~of~~ **at** the i^{th} waypoint are calculated...”.

- **p 12, l 371–372** : ”,” after equations.

  Reply: We will add “,” after Eqs. (24) and (25). We will reply to this issue in the section of “Mathematical formulas (3).”

- **p 12, l 374** : where M is ”the” Mach number.

  Reply: We will add the word “the” in the sentence: on page 12 line 374, “...where M is **the** Mach number,...”.

- **p 12, l 378–379** : Although it is mentioned that V_{TAS}, V_{wind} and V_{ground} are scalars, Eq. (25) on line 372 is actually a vector equation.

  Reply: As described on page 12 line 377−379, the flight direction is firstly calculated for every flight segment. Thereafter, the values of $V_{TAS,i}$ $V_{wind,i}$ and $V_{ground,i}$ “corresponding to the flight direction” are calculated. For example, $V_{ground,i}$ is a component of the wind vector along the flight direction (i.e. scalar value). Therefore, Eq. (25) on line 372 is a scalar equation.

- **p 12, l 386** : ”reflects” : this is not the only aspect which is reflected. I suggest to use ”incorporates”.

Reply: Thank you so much. We will revise the text: on page 12 line 386, "...and ETO_i ~~reflects~~ **incorporates** the influence of tail/head winds...". In the same way, we will revise the text: on page 21 line 700, "..., which ~~reflects~~ **incorporates** the influences of both V_{TAS} and winds...".

- **p 12, l 390** : for the five → for five.

  Reply: We will revise the text: on page 12 line 390, "Great circles were calculated for ~~the~~ five representative routes...".

- **p 12, l 393–395** : 180 → 180° (while "deg" on line 397).

  Reply: We will revise the sentence: on page 12 line 393−395, "...the difference in longitude between them was $\Delta\lambda_{airport} < 180^\circ$ ~~(in deg)~~; R2 consisted of an airport pair in the northern hemisphere (HND-JFK) with $\Delta\lambda_{airport} > 180^\circ$ (discontinuous longitude values...".

- **p 12, l 398** : Missing deg?

  Reply: Thank you so much. We will revise the sentence: on page 12 line 397−398, "..., where $\Delta\lambda_{airport} = 0^\circ$ and the difference in latitude was $\Delta\phi_{airport} \neq 0^\circ$; and R5 was another special route with $\Delta\lambda_{airport} \neq 0^\circ$ and $\Delta\phi_{airport} = 0^\circ$."

- **p 12, l 399** : ";" → ",".

  Reply: We will modify the text: on page 12 line 399, "...as follows: $M = 0.82$~~;~~**,** $h_i = 0$,...".

Page 13

- **p 13, l 403** : varying n_{wp} in "the range" [2, 100].

  Reply: We will add the text "the range" in the revised manuscript: on page 13 line 403, "...n_{wp} was analyzed varying n_{wp} in **the range** [2, 100]."

- **p 13, l 404** : and the MTS → and MTS.

  Reply: We will delete the word "the" in the sentence: on page 13 line 404, "...by Eqs. (22) and (23) and ~~the~~ MTS."

- **p 13, l 406** : I do not think that $\Delta d_{eq23,eq22}$, etc. are appropriate choices for variable names. As these are difference, I think they should not not have a specific variable name attributed.

  Reply: We understand the referee comment. Nevertheless, we are hesitating to change those variable names. We define the variable name for a flight distance as "d", as shown in Table 2, and we use the variable "d" consistently in the manuscript: on page 11 Eqs. (22) and (23), on page 15 Eq. (28), etc. We think that the current expressions make sense. This reply is related to the reply to "5 Comments on tables, Table 4."

- **p 13, l 409–410** : "shows" versus "showed".

  Reply: We will revise the text: on page 13 line 409−410, "Figure 6 shows the result of the sensitivity analysis of n_{wp} on the great circle distance. The results **showed** ~~d~~ that the distance...".

- **p 13, l 413** : I would not call it linear interpolation : one goes straight whereas the other follows an arc. Shouldn't you also add that n_{wp} maybe should depend on the length of the flight?

  Reply: We will remove the word "linear interpolation" in the sentence. This is not necessary for our argument

here: on page 13 line 413, “...when using fewer n_{wp}~~, as a result of the linear interpolation~~.” The referee actually points out the important issue. However, we think that it is more important for readers (specifically AirTraf users) to show a criteria to use Eq. (23). For this, we describe as: on page 13 line 414, “Therefore, $n_{wp} \geq 20$ is practically desired for the use of Eq. (23).”

- **p 13, l 417** : with respect to the flight time routing option → with respect to the flight time.

  Reply: We will revise the text: on page 13 line 417, “The flight trajectory optimization with respect to the flight time ~~routing option~~ was...”.

- **p 13, l 418** : algorithms → algorithm.

  Reply: We will correct the word: on page 13 line 418, “..., which is a stochastic optimization algorithm~~s~~.”

- **p 13, l 422** : The ARMOGA → ARMOGA.

  Reply: We will revise the text: on page 13 line 422, “~~The~~ ARMOGA will be implemented...”.

- **p 13, l 424–425** : With a routing option → For each routing option (except ...). I also suggest to skip ”on the selected routing” in the second part of the sentence.

  Reply: We will revise the sentence: on page 13 line 424−425, “~~With a~~ **For each** routing option**,** except for the great circle routing option, a single-objective optimization problem ~~on the selected routing option~~ is solved.”

- **p 13, l 427** : Explain what an objective function in this context is.

  Reply: The word “objective function” means “evaluation function.” The word “objective function” is the technical term (commonly used in GA-optimization terminology). Therefore, we will revise the sentence: on page 13 line 427, “Therefore, various ~~objective~~ **evaluation functions (called objective functions)** can easily be adapted...”.

- **p 13, l 432-433** : ”Is called ”an” optimal solution” and ”is called ”the” true-optimal solution”.

  Reply: We will revise the sentence: on page 13 line 432−433, “A solution found in GA is called **an** optimal solution, whereas a solution having the theoretical-optimum of the objective function is called **the** true-optimal solution.”

- **p 13, l 434** : Say what is meant by converge : larger initial population, or just more generations?

  Reply: The word “converge” means “becomes close to” in this context. As described on page 13 line 432−433, there are two solutions: an optimal solution and the true-optimal solution. When we solve an optimization problem, we expect that the optimal solution (our solution) “converges” to the true-optimal solution by optimization algorithms. This is what we wanted to say here.

- **p 13, l 435** : Will every flight have the same size for its initial population, and the same number of generations? Is that independent of the length of the flight?

  Reply: This paper aims to confirm the ability of the optimization module (GA) to optimize flight routes. Therefore, we solved the simple time-optimal optimization problem using the common optimization setup (the same size for initial populations and the same number of generations for every flight). We understand that the referee pointed out an important issue. However, this is beyond the scope of this paper. If we could choose the setup individually for every flight, the computational requirements for the trajectory optimization could probably be decreased. However, it is difficult to find an appropriate GA setup for every flight before

solving the optimization problem. As the referee noted, the flight length can be used to adjust the population size and the number of generations for a flight. On the other hand, if a day shows complicated weather situations, GA needs a larger population size and more generations to converge. This issue will be one of our future investigations.

Page 14

- **p 14, l 440–441** : I do not think that ”definitions” is the appropriate word to be used here.

  Reply: We believe that the word “definitions” is appropriate here. To solve an optimization problem, firstly, one has to define the optimization problem itself concerning variables, ranges of variables, evaluation functions, constraints, etc. Thereafter, one can solve the problem. On page 14, Sect. 3.2.2 describes the definitions of the flight trajectory optimization, which we solve here.

- **p 14, l 441** : of objective functions → of the objective function.

  Reply: We will revise the text: on page 14 line 441, “..., the definition of **the** objective function and the genetic operators.”

- **p 14, l 444** : used interchangeably to mean a flight trajectory → used interchangeably to flight trajectory.

  Reply: We will revise the text: on page 14 line 444, “...the term is used interchangeably to ~~mean a~~ flight trajectory...”.

- **p 14, l 445** : $n_{\mathrm{dv}} = 11$ should not be here.

  Reply: We will remove the word “$n_{\mathrm{dv}} = 11$” in the sentence and modify the text: on page 14 line 445, “...the design variable index j (j = 1, 2,···, n_{dv}~~; $n_{\mathrm{dv}} = 11$~~),..”. On page 15 line 487, “...where $\boldsymbol{n_{\mathrm{dv}}}$ **= 11,** d_i and $V_{\mathrm{ground,i}}$ are calculated...”.

- **p 14, l 456** : centering → centered.

  Reply: We will revise the text: on page 14 line 456, “...domains ~~centering~~ **centered** around the central points...”.

- **p 14, l 463–464** : how are these waypoints calculated? Will the arc lengths be equal?

  Reply: We reply to this issue in the section of “CP in trajectories (3).”

- **p 14, l 458–459 and 470–471** : ”GA provided the values” : Do you mean already the final optimal values?

  Reply: Here, we just want to say that the values of the eleven design variables are provided by the GA optimization process. In other words, one does not have to determine the values. In fact, the sentence on page 15 line 479−480 says, “The initial ***population*** operator (Fig. 2, dark green) provides initial values of the eleven design variables as random numbers...”. Naturally, GA provides not only initial values, but also the final optimal values regarding the design variables.

- **p 14, l 462** : Explain a little bit more a B-spline curve.

  Reply: We will add the text to specify the curve: on page 14 line 462, “...trajectory is represented by a B-spline curve **(3$^{\mathrm{rd}}$-order)** with the three CPs...”. On page 15 line 474, “...trajectory is also represented by a B-spline curve **(3$^{\mathrm{rd}}$-order)** with the...”.

- **p 14, l 464** : Are the waypoints on the B-spline curve still equidistant?

Reply: No. The referee is right. We explain this issue in the sections of “CP in trajectories (3) and (4).” Here we will modify the text: on page 14 line 464, “To generate the ~~waypoints at even intervals~~ **same number of waypoints between the CPs**, n_{wp} was calculated...”. Related to this issue, we will delete the text: on page 7 line 206, “...the trajectory consists of waypoints generated ~~at even intervals~~ along the trajectory, and flight segments...”.

- **p 14, l 461 and 472** : ”Here x_1 , ... indicate longitudes/latitudes/altitude values”. Shouldn’t this be mentioned earlier in the paragraphs, i.e. on lines 452 and 466?

  Reply: The referee is right. We will revise the manuscript: on page 14 line 461, “~~Here x_1, x_3 and x_5 indicate longitudes, while x_2, x_4 and x_6 indicate latitudes.~~”, and on line 452, “...as shown in Fig. 7 (bottom). ***x*₁, *x*₃ and *x*₅ indicate longitudes, while *x*₂, *x*₄ and *x*₆ indicate latitudes.**” On page 14 line 472, “~~Here x_7 to x_{11} indicate altitude values.~~”, and on line 466, “...were used (Fig. 7, top). **Here *x*₇ to *x*₁₁ indicate altitude values.**”

Page 15

- **p 15, l 477** : where longitude-coordinate of waypoints → where ”the” longitude of the waypoints.

  Reply: We will modify the sentence in the revised manuscript. Please see the reply to the referee comment on the “CP in trajectories (4).”

- **p 15, l 476–478** ”where longitude-coordinate of waypoints is the same for the two curves.” Is this true in the example here? The lon-lat curve contains 3 CPs and thus 4 intervals. The the lon-altitude curve contains 5 CPs and 6 intervals. The number of waypoints is 101, so 100 intervals. This is however not a multiple of 6, so I don’t see that the longitude of the waypoints for both B-spline curves are automatically identical.

  Reply: This is true. The longitude of the waypoints for both B-spline curves are identical. A flight trajectory is also represented by a B-spline curve (the lon-altitude curve) and waypoints are generated along the curve. These waypoints are tentative points ($> n_{wp}$). And then, we create actual waypoints on the lon-altitude curve, by interpolating the lon-altitude curve to the longitude-coordinate of the lon-lat curve. We modify the related sentences in the section of “CP in trajectories (4).”

- **p 15, l 479** : ”provides initial values by random numbers” : this is too cryptic.

  Reply: As described on page 13 line 418, GA is a stochastic optimization algorithm. Thus, the optimization proceeds using random numbers. Maybe the current sentence is a little bit unclear, therefore we will modify the sentence in the revised manuscript: on page 15 line 479, “The initial ***population*** operator (Fig. 2, dark green) provides initial values of the eleven design variables ~~by random numbers~~ **at random within the lower/upper bounds described above**,...”.

- **p 15, l 481** : ”The operator creates divers solutions defined by a fixed population size n_p.”: This is a complicated way to say: ”The operator creates n_p different solutions (where n_p is the population size).”

  Reply: We agree. We will revise the text: on page 15 line 480−481, “The operator creates ~~diverse solutions defined by a fixed population size n_p~~ ***n*ₚ different solutions (where *n*ₚ is the *population* size)**...”.

- **p 15, l 481** : ”a random set” : do you mean the random set which is just described (then I suggest to use ”the”), or is it even another random set? I would put the sentence ”GA starts its search with a random set of solutions (population approach)” at the beginning of the paragraph.

  Reply: “a random set” means the random set which is already described. We will move the sentence at the beginning of the paragraph (in this case, the word “a random set” is used). Finally, we will revise the sentence: on page 15 line 479 (at the beginning of the paragraph), “**GA starts its search with a random set**

of solutions (*population* approach). The initial ***population*** operator...".

- **p 15, l 483** : By summing the flight time for flight segments → by summing the flight time over all flight segments.

  Reply: We will revise the text: on page 15 line 483, "...for each of the solutions by summing the flight time ~~for~~ **over all** flight segments...".

- **p 15, l 483–484** : "The .. optimization solved here" : too cryptic and vague.

  Reply: We will revise the text: on page 483−484, "The single-objective optimization **problem on the flight time** ~~solved here is~~ **can be written** as follows:".

- **p 15, l 485** : "Minimize" and "Subject to" should not be italic.

  Reply: We will modify the words "Minimize" and "Subject to" with straight letters in the revised manuscript: on page 15 line 485, "~~*Minimize*~~ **Minimize**" and "~~*Subject to*~~ **Subject to**".

- **p 15, l 490** : What is meant by "solutions that dominate it"?

  Reply: This expression shows an inferior-to-superior relationship among solutions, and is commonly used in GA optimization terminology. In optimization problems, for example, if a solution A is superior to a solution B on an objective function, we can say that the solution A dominates the solution B.

- **p 15, l 489–491** : Why is "rank" written in italic, but "fitness" not?

  Reply: We will add the glossary and refer the word "rank" in italics in the revised manuscript: on page 15 line 489−492, "A ***rank*** of a...was computed by 1/***rank***. A solution...smaller ***rank*** value...". This reply is related to the reply to "GA algorithm".

- **p 15, l 493** : made → makes (because "are identified" on line 488).

  Reply: We will revise the text: on page 15 line 493, "...Sampling Selection (Baker, 1985) ~~made~~ **makes** duplicates...".

- **p 15, l 492** : What is meant by a "mating pool"?

  Reply: We will add the glossary in the revised manuscript to explain the technical term "mating pool". Please see the reply to the referee comment on the "GA algorithm."

- **p 15, l 500** : "This operator was applied to each design value." : Isn't this said already in the sentence before?

  Reply: By following the referee comment, we will delete the sentence and add the word "$n_{dv} = 11$" into the previous sentence: on page 15 line 500−501, "...with $\gamma = (1 + 2\alpha)u_1 - \alpha$ and j varies in $[1, n_{dv}]$ **($\boldsymbol{n_{dv} = 11}$)**. ~~This operator was applied to each design variable; $n_{dv} = 11$.~~"

- **p 15, l 504** : "added a disturbance to the child solution." : It does if for both child solutions I presume.

  Reply: The referee comment is correct. We will correct the word "the child solution" into "the child solutions": on page 15 line 504, "...added a disturbance to the child solution**s** by...".

Page 16

- **p 16, l 515** : the population of "the" solutions → the population of solutions.

Reply: We will remove the word “the” in the revised manuscript: on page 16 line 515, “...it is expected that the ***population*** of ~~the~~ solutions is...”.

- **p 16, l 517** : ”an optimal solution is output.” : How is that solution found based on the last generation?

  Reply: We will add the text to inform on how the final solution is obtained from the optimization. Please see the reply to the referee comment on the “GA algorithm.”

- **p 16, l 518** : ”corresponding to the routing option”: I don’t think this has to be repeated here.

  Reply: We will remove the word “corresponding to the routing option” in the revised manuscript: on page 16 line 517−518, “..., GA quits the optimization and an optimal solution **showing the best *f* of the whole *generation*** is output ~~corresponding to the routing option~~:...”.

- **p 16, l 518** : ”the best” : one cannot guarantee that it is the best I think.

  Reply: By following the referee comment, we will change the word “the best” into “the superior” in the revised manuscript: on page 16 line 518, “The optimal solution has the ~~best~~ **superior** combination of the...”.

- **p 16, l 519** : ”naturally” : is this the appropriate wording?

  Reply: We will revise the sentence: on page 16 line 519, “~~Naturally, t~~**T**he flight properties of the optimal solution are **also** available...”.

- **p 16, l 521–522** : can be applied to any routing option (I thought that was not possible yet in version 1.0?) → could.

  Reply: We agree. We will correct the word “can” into the “could” in the revised manuscript: on page 16 line 521−522, “The flight trajectory optimization methodology described here ~~can~~ **could** be applied to any routing option...”.

- **p 16, l 529** : ”As V_{TAS} and V_{ground} were set to 898.8 km h^{-1}” : Isn’t it better to mention first explicitly that we have set $V_{\mathrm{wind}} = 0$, and from that it follows that V_{TAS} and V_{ground} are 898.8 km h^{-1} (and not set).

  Reply: By following the referee comment, we will revise the sentence: on page 16 line 529, “**$\boldsymbol{V}_{\mathbf{wind}}$ was set to 0 km h^{-1} (no-wind conditions);** ~~As~~ V_{TAS} and V_{ground} were set to 898.8 km h^{-1} (constant) ~~under no-wind conditions,~~**. Hence,** ~~the~~ f_{true} equals the flight time along the great circle from MUC to JFK at FL290:...”.

- **p 16, l 531** : Maybe one should say why flying at FL290 will be faster than at other altitudes. I assume that this depends on the value of *T*. Are the initial and final points at FL290? Mention that $M = 0.82$.

  Reply: To show clearly why flying at FL290 will be faster than at other altitudes, we will add the text in the revised manuscript: on page 16 line 530−531, “...f_{true} equals the flight time along the great circle from MUC to JFK at FL290 **(having its minimum d_i in the range of [FL290, FL410])**: f_{true} = 25,994.0 s...”.

  In this benchmark test (off-line), V_{wind} = 0 km h^{-1} and $V_{\mathrm{TAS}} = V_{\mathrm{ground}}$ = 898.8 km h^{-1} were set, as described on page 16 line 529. Hence, the results do not depend on the values of *T* and *M* (see Eqs. (24) and (25)).

  In addition, the initial and final points were at FL290. Table 5 summarizes the calculation conditions for the test. In Table 5, the altitudes of departure (MUC) and arrival airport (JFK) are described as, “alt. = FL290.”

- **p 16, l 537** : total 1000 independent → a total of 1000 independent.

Reply: We will revise the text: on page 16 line 537, "...i.e. **a** total **of** 1,000 independent GA simulations...".

- **p 16, l 532–538** : Isn't the first experiment also included in the second setup?

  Reply: Yes. To clarify this point, we will modify the text: on page 16 line 532−538, "~~With regard to the dependence of the optimal solutions on initial populations, 10 independent GA simulations from different initial populations were performed. In these simulations, both n_p and n_g were set to 100, while other calculation conditions were set as shown in Table 5. In the same way, to discuss an appropriate n_p and n_g sizing,~~ 10 independent GA simulations from different initial ***populations*** were performed for each combination of n_p (10, 20,⋯, 100) and n_g (10, 20,⋯, 100), i.e. total 1,000 independent GA simulations were performed. ~~Other calculation conditions were also set as shown in Table 5.~~" Related to this modification, we will add the text: on page 17 line 559, "...the 10 independent GA simulations **from different initial *populations*** with n_p = 100 and n_g = 100."

Page 17

- **p 17, l 540** : generation number n_g → number of generations n_g.

  Reply: We will revise the text: on page 17 line 540, "The influence of the ***population*** size n_p and the **number of *generations*** ~~number~~ n_g...". In the same way, we will revise the manuscript as follows: on page 16 line 517, "...computed for a fixed **number of *generations*** ~~number~~ n_g,...". On page 35 in the caption of Fig. 8, "...and **the number of *generations*** ~~number~~ n_g." On page 35 in the x-axis label of Fig. 8, "~~generation number n_g~~ **number of generations n_g**". On page 36 in the caption of Fig. 9, "...and **the number of *generations*** ~~number~~ n_g **is** 100." On page 38 in the caption of Fig. 11, "...and **the number of *generations*** ~~number~~ n_g **is** 100." On page 39 in the caption of Fig. 12, "...and **the number of *generations*** ~~number~~ n_g." On page 44 in the caption of Fig. 17, "...and **the number of *generations*** ~~number n_g = 100~~ n_g **is** 100." On page 55 in Table 5, "~~Generation number~~ **Number of generations**". On page 56 in Table 7, "~~Generation number~~ **Number of generations**". On page 8 (Supplementary material) in the caption of Table S1, "...and **the number of *generations*** ~~number~~ n_g = 100." On page 9 (Supplementary material) in the caption of Table S2, "...and **number of *generations*** ~~number~~ n_g...". On page 9 (Supplementary material) in Table S2, "~~Generation number n_g~~ **Number of generations** n_g".

- **p 17, l 541** : Is "confirmed" the appropriate wording?

  Reply: We will modify the word: on page 17 line 540−541, "...the convergence properties of GA was ~~confirmed~~ **examined**."

- **p 17, l 542** : sufficiently come close → come sufficiently close.

  Reply: We will revise the text: on page 17 line 542, "...the optimal solutions ~~sufficiently~~ come **sufficiently** close to the f_{true}...".

- **p 17, l 542, 543, 545** : the f_{true} → f_{true} .

  Reply: We will revise the word: on page 17 line 542, "...close to ~~the~~ $\boldsymbol{f}_{\mathbf{true}}$ with increasing..."; on page 17 line 543, "...closest flight time to ~~the~~ $\boldsymbol{f}_{\mathbf{true}}$ was..."; and on page 17 line 545, "...between the f_{best} and ~~the~~ $\boldsymbol{f}_{\mathbf{true}}$ was...". In the same way, we will correct the word "the $\boldsymbol{f}_{\mathbf{true}}$" in the revised manuscript: on page 16 line 530, "...~~the~~ $\boldsymbol{f}_{\mathbf{true}}$ equals the flight time..."; on page 17 line 565, "0.01 % of ~~the~~ $\boldsymbol{f}_{\mathbf{true}}$"; on page 17 line 566, "0.001 % of ~~the~~ $\boldsymbol{f}_{\mathbf{true}}$"; and on page 35 in the caption of Fig. 8, "as close to ~~the~~ $\boldsymbol{f}_{\mathbf{true}}$...".

- **p 17, l 545** : Δf : you do not need an extra variable name for something you express only once.

  Reply: We understand the referee comment. Nevertheless, we are hesitating to remove the variable name. We

use the variable "Δf" consistently in the manuscript to express the difference in flight time: on page 17 line 564−565; on page 18 line 575, 581, 588−590; on page 39 in the caption of Fig. 12; on page 8 (Supplementary material) in the caption of Table S1, etc. We think that this variable name is reasonable.

- **p 17, l 547** : What is meant by "diversity" of GA optimization?

  Reply: This word "diversity" is one of the performance indices of an optimization algorithm and is used to show whether the algorithm explores solutions widely or not. It is important to confirm the diversity of the algorithm. On page 17 line 549, we confirmed it for our optimization results as, "It is clear that GA explored diverse solutions from MUC to JFK...".

- **p 17, l 547–548** : we focus on the optimization results, which found the best solution → we focus on the optimization setup which gave the best solution.

  Reply: We believe that the word "optimization results" is appropriate here. We performed the optimizations for each combination of n_p (10, 20,⋯, 100) and n_g (10, 20,⋯, 100). Here, we say that we focus on the optimization case of n_p = 100 and n_g = 100; this case includes the best solution f_{best}. In fact, Fig. 9 shows the results obtained from this optimization case, which includes all solutions (10,000 trajectories, black lines) and the best solution (red line) explored by GA. Nevertheless, we modify the sentence by following the referee comment: on page 17 line 547−548, "To confirm the diversity of GA optimization, we focus on the optimization ~~results, which found~~ **yielding** the best solution...".

- **p 17, l 548** : "all the solutions" : Are these the 100 × 100 = 10000?

  Reply: Yes. Figure 9 shows the 10,000 trajectories explored by GA. Related to this, we will correct the text "1,000" into "10,000" in the revised manuscript: in the captions of Figs. 9 (p 36), 14 (p 41), S1 (Supplementary material, p 1) and S2 (Supplementary material, p 2), "~~1,000~~ **10,000** explored trajectories (solid line, black)...".

- **p 17, l 548–549** : solutions explored by GA as longitude vs altitude (top) and as location. This should be worded correctly.

  Reply: We will modify the sentence in the revised manuscript: on page 17 line 548−549, "Figure 9 shows all the solutions explored by GA ~~as longitude vs altitude (top) and as location (bottom)~~." We reply to this issue in the section of "Language."

- **p 17, l 552** : "To confirm the difference" : I don't think confirm is appropriate to be used here.

  Reply: We will revise the text: on page 17 line 552, "To ~~confirm~~ **investigate** the difference between the solutions,...".

- **p 17, l 554–555** : Isn't this conclusion too fast? What if the trajectory is not so zonal, but the trajectory crosses the equator at an angle of 45°: how would the CPs and regions around be defined?

  Reply: We will reply to this issue in the section of "CP in trajectories (2)." We will add the text into the sentence to confine this conclusion with more precision: on page 17 line 554−555, "Therefore, GA is adequate for finding an optimal solution with sufficient accuracy **(in a strict sense, this conclusion is confined to the benchmark test)**."

- **p 17 , l 552** : "confirm" is not appropriate here.

  Reply: (The "p 17, line 552" means probably "p 17, line 557") We will change the word "confirm" into "analyze": on page 17 line 557, "To ~~confirm~~ **analyze** the dependence of...".

- **p 17, l 552** : To confirm the dependence of optimal solutions on initial populations → To ”analyze” the dependence of ”the” optimal solution on ”the” initial population, ...

  Reply: (The “p 17, line 552” means probably “p 17, line 557”) We will revise the text: on page 17 line 557, “To ~~confirm~~ **analyze** the dependence of **the** optimal solution~~s~~ on **the** initial ***population***~~s~~,...”.

- **p 17, l 552–553** : I don’t think one should use words like ”best-of-generation”.

  Reply: (The “p 17, line 552−553” means probably “p 17, line 557−558”) We will remove the word “best-of-generation” in the sentence: on page 17 line 557−558, “...Fig. 11 shows the ~~best-of-generation~~ flight time vs the number of objective function evaluations...”.

- **p 17, l 558–559** : corresponding to → for.

  Reply: We will modify the text: on page 17 line 558−559, “...function evaluations (= $n_p \times n_g$) ~~corresponding to~~ **for** the 10 independent GA simulations...”.

- **p 17, l 653** : ”there is a small degree of variation in the objective function”. Stated like this, it gives the impression that a different objective function is used. Probably, what is meant is that the value of the objective function for the final flight is different.

  Reply: (The “p 17, line 653” means probably “p 17, line 563”) By following the referee comment, we will revise the text: on page 17 line 563, “As indicated in Table S1, ~~there is a small degree of variation in the objective function *f* (= flight time)~~ **the value of the objective function *f* (= flight time) is slightly different.**”

- **p 17, l 564** : Writing $f - f_{\text{true}}$ is a bit strange. For me, f and f_{true} are solutions, i.e. flights defined by x_1,...x_{11}. Here, f and f_{true} seem to indicate the value of the flight time.

  Reply: f (and also f_{true}) means the objective function value for a solution (i.e. a flight trajectory), which is defined by the eleven design variables x_1, x_2,$\cdots$, x_{11}. As Eq. (28) defines, f (also f_{true}) actually indicates the value of the flight time here.

- **p 17, l 569 and 570** : ”number of n_p and n_g ” and ”size of n_p and n_g ”. One should use : ”the value of n_p ”, or ”the size of the population”, not something hybrid like ”the number of n_p ”.

  Reply: We will modify the expression: on page 17 line 569, “With ~~an~~ **increased** ~~in number of~~ n_p and n_g, GA ~~can discover~~ **tends to find** an improved solution.”

- **p 17, l 569** : ”discover” : I suggest to use a different word.

  Reply: We will change the word “discover” into “find” in the revised manuscript. In addition, we will modify the word “can” into “tends to” to show exactly the meaning of the sentence: on page 17 line 569, “With ~~an~~ **increased** ~~in number of~~ n_p and n_g, GA ~~can~~ **tends to** ~~discover~~ **find** an improved solution.” As shown in Fig. 11, the optimal solution finally converges with increasing n_p and n_g. The word “can” seems to mean that the solution is improved unlimitedly. Therefore, we think that the word “tend to” is appropriate.

- **p 17, l 570** : ”is problem dependent, e.g. weather situations” : this should be formulated properly.

  Reply: This sentence on line 570−571 seems to be confusing. We will modify the sentence: on page 17 line 570−572, “...the required size of n_p and n_g is problem-dependent~~, e.g. weather situations, and therefore estimating appropriate n_p and n_g could be different~~. However, following a simple initial guess for n_p and n_g

is a good starting point for their sizing."

- **p 17, l 571** : "estimating appropriate n_p and n_g could be different" : I suggest to formulate this differently.

  Reply: We will reply to the comment in the above section: "p 17, l 570".

Page 18

- **p 18, l 573–574** : unclear sentence. What is, e.g., the difference between accuracy of GA optimizations and variation in the optimal solutions? I also had the impression that the impact of the initial population was already studied in Sect. 3.2.5.

  Reply: The word "accuracy of GA optimizations" shows how close a solution converges to the true-optimal solution. On the other hand, a variation in optimal solutions is caused by different initial populations. Because GA is a stochastic optimization algorithm (not a deterministic optimization method, such as the gradient-based method). In addition, the impact of the initial population was studied in Sect. 3.2.5 regarding the results with "n_p = 100 and n_g = 100." The impact also depends on n_p and n_g and is investigated in Sect. 3.2.6 in detail. Those results are necessary for the population and generation sizing.

- **p 18, l 574** : Skip "calculated".

  Reply: We will remove the word "calculated" in the sentence: on page 18 line 574, "Figure 12 shows the ~~calculated~~ Δf and...".

- **p 18, l 581** : the variation of the Δf and the $s_{\Delta f}$ → Skip "the".

  Reply: We will remove the word "the" in the sentence: on page 18 line 581, "Figure 13 shows the variation of ~~the~~ Δf and ~~the~~ $s_{\Delta f}$ for all...".

- **p 18, l 582** : the Δf → Skip "the".

  Reply: We will remove the word "the" in the sentence: on page 18 line 582, "The symbols and error bars in the figure correspond to ~~the~~ Δf and $s_{\Delta f}$,...".

- **p 18, l 589** : that reduction → a reduction.

  Reply: We will correct the text: on page 18 line 589, "Similarly, ~~that~~ **a** reduction of 97 % can be achieved...".

- **p 18, l 591** : "by selecting n_p and n_g for different purposes." This should be formulated differently.

  Reply: Values of Δf and $s_{\Delta f}$ are the basis for selecting n_p and n_g. As described on page 18 line 586, the enlarged drawing in Fig. 13 shows that if one selects the number of function evaluations (= $n_p \times n_g$) of 800, the large reduction of computational costs of 92 % can be achieved, keeping Δf less than 0.05 % ($s_{\Delta f} \approx 0.02$ %), compared to the optimal solution by 10,000 function evaluations. For $n_p \times n_g$ = 800, one can select any combination of n_p and n_g: for example, n_p = 10 and n_g = 80; n_p = 20 and n_g = 40 etc. A user makes his/her own choice on n_p and n_g by referring the values of Δf and $s_{\Delta f}$, as shown in Fig. 13. The formulae of Δf and $s_{\Delta f}$ are described clearly in the caption of Fig. 13.

  We will add this explanation to the revised manuscript: on page 18 line 586−589, "~~As shown in the enlarged drawing in Fig. 13,~~ **The enlarged drawing in Fig. 13 shows that if one selects the number of function evaluations (= $n_p \times n_g$) of 800,** the large reduction ~~in number of function evaluations~~ **of computational costs of 92 %** can be achieved, keeping Δf less than 0.05 % ($s_{\Delta f} \approx 0.02$ %), compared to the optimal solution obtained by 10,000 function evaluations (n_p = 100 and n_g = 100). **For $n_p \times n_g$ = 800, one can select any combination of n_p and n_g: n_p = 10 and n_g = 80; n_p = 20 and n_g = 40 etc. A user makes his/her own choice on n_p and n_g by referring the values of Δf and $s_{\Delta f}$ shown in Fig. 13.**"

- **p 18, l 595** : for demonstrations → for demonstration.

  Reply: We will correct the text: on page 18 line 595, "...one-day AirTraf simulations were performed in EMAC (on-line) with the respective routing options for demonstration~~s~~."

- **p 18, l 596, 598** : Calculation conditions : too vague.

  Reply: We will change the word "Calculation conditions" into "Simulation setup" in the revised manuscript: on page 18 line 596, "4.1 ~~Calculation conditions~~ **Simulation setup**". On page 18 line 598, "Table 7 lists the ~~calculation conditions~~ **setup** for the one-day simulations." On page 56 in the caption of Table 7, "Table 7. ~~Calculation conditions~~ **Setup** for AirTraf one-day simulations."

- **p 18, l 598–599** : simulation"s" and simulation.

  Reply: We will correct the text: on page 18 line 598−599, "Table 7 lists the calculation conditions for the one-day simulations. The simulation**s** ~~was~~ **were** performed for...".

- **p 18, l 605** : "On the other hand" → "In addition".

  Reply: We will change the word "On the other hand" into "In addition": on page 18 line 605, "~~On the other hand~~ **In addition**, a single one-day simulation was...".

- **p 18, l 606–p19, l 607** : in [FL290, FL410] → in the range of ..

  Reply: (The "p 19, line 607" means probably "p 18, line 607") We will add the text "the range of" in the revised manuscript: on page 18 line 606, "...altitude changes in **the range of** [FL290, FL410]."

- **p 18, l 607** : "and therefore" : I think V_{ground} also varies for other reasons, e.g., due to varying wind speed and direction.

  Reply: We just wanted to say here that the values of V_{TAS} and V_{ground} are different at every waypoint. We will modify the sentence: on page 18 line 607, "For the two options, the Mach number was set to $M = 0.82$ and therefore ~~V_{TAS} and V_{ground} varied along the waypoints~~ **the values of $\boldsymbol{V_{\text{TAS}}}$ and $\boldsymbol{V_{\text{ground}}}$ were different at every waypoint (Eqs. (24) and (25)).**"

Page 19

- **p 19, l 615** : Does "case" refers to just one flight, or to all 103 flights together?

  Reply: The "case" means the one-day simulation including all 103 flights. We will revise the sentence: on page 19 line 614−615, "The one-day simulation required approximately 15 min for ~~a~~ **the** great circle ~~case~~ routing option, while it took approximately 20 hours for ~~a~~ **the** ~~time-optimal case~~ **flight time routing option**."

- **p 19, l 616** : It is initially unclear what "it" refers to.

  Reply: The word "it" means "the computational time." We will change the word "it" into "this time" in the sentence: on page 19 line 616, "...the computational time is consumed by the trajectory optimizations. Therefore ~~it~~ **this time** can be reduced by...".

- **p 19, l 617** : "right" : This is maybe not the most appropriate wording.

  Reply: We will change the word "right" into "appropriately": on page 19 line 617, "...choosing all GA parameters ~~right~~ **appropriately**, using more PEs,...".

- **p 19, l 618** : by a small → by ”using” a small.

  Reply: We will add the “using” in the text: on page 19 line 618, “...a large reduction in computing time of roughly 90 % can be achieved by **using** a small ~~number of~~ n_p...”.

- **p 19, l 618** : ”a small number of n_p” → ”a small value of n_p ”, or ”a small population size”

  Reply: We will modify the text: on page 19 line 618, “...a large reduction in computing time of roughly 90 % can be achieved by **using** a small ~~number of~~ n_p...”.

- **p 19, l 619** : with sufficient accuracy → with ”still” sufficient accuracy.

  Reply: We will add the word “still” in the text: on page 19 line 619, “...and n_g with **still** suffcient accuracy of the optimizations.”

- **p 19, l 620** : I think the title of Sect. 4.2 does not describe well the content : only one airport pair is discussed (Amsterdam - Minneapolis) really in depth. I suggest something more general.

  Reply: In Sect. 4.2, we have focused on the results of three airport pairs and discussed the one. The rest is in the Supplementary material. To make the title more general, we will delete the word “three” in the title: on page 19 line 620, “4.2 Optimal solutions for ~~three~~ selected airport pairs.”

- **p 19, l 623** : trajectories : Is meant the final trajectories?

  Reply: Yes. The “trajectories” mean the optimized flight trajectories (final solutions). We will modify the sentence: on page 19 line 623, “...we classified ~~the~~ **those optimized flight** trajectories according to their altitude changes into three categories.”

- **p 19, l 627** : we have selected ”the” three airport pairs → we have selected three airport pairs.

  Reply: We will remove the word “the” in the sentence: on page 19 line 627, “We have selected ~~the~~ three airport pairs of...”

- **p 19, l 633** : in [FL290,FL410] → in the range of [FL290,FL410].

  Reply: We will add the text “the range of” in the revised manuscript: on page 19 line 633, “...altitude changes in **the range of** [FL290, FL410].”

- **p 19, l 633–634** : ”when calculating for the selected solutions” : This should be formulated better.

  Reply: This text seems to be confusing. We will revise the text: on page 19 line 633−634, “Similar results were obtained ~~when calculating~~ for the selected solutions of Type I and III,...”.

- **p 19, l 634** : in the supplements → in the supplementary material.

  Reply: We will change the text “in the supplements” into “in the supplementary material” in the revised manuscript: on page 19 line 634, “..., as shown in Figs. S1 and S2 in the ~~Supplements~~ **Supplementary material**.” In the same way, we will modify the text: on page 17 line 562, “Table S1 in the ~~Supplement~~ **Supplementary material** shows a summary of...”. On page 18 line 583, “...Table S2 in the ~~Supplement~~ **Supplementary material**...”. On page 20 line 657, “see ~~Supplements~~ **Supplementary materials**”. On page 22 line 719, “are shown in the ~~Supplement~~ **Supplementary material**.”

- **p 19, l 638–639** : east and west direction → eastern and western directions.

  Reply: We will revise the text: on page 638−639, “To calculate tail/head winds in ~~east~~ **eastern** and ~~west~~ **western** directions,...”.

- **p 19, l 639** : major wind component : What is meant by this?

  Reply: We just wanted to express the wind component, which has a dominant influence on the flight trajectory, to show the relation clearly between the wind fields and optimal flight trajectories. In fact, the contours in Fig. 15 show the zonal wind speed *u*; they do not include *v* and *w*.

- **p 19, l 640–641** : at the *h* → at *h*.

  Reply: We will modify the text: on page 19 line 640−641, “...direction at the departure time at ~~the~~ *h*.”

Page 20

- **p 20, l 646** : Supplements → Supplementary material.

  Reply: We will modify the text: on page 20 line 646, “...take advantages of the wind fields (see ~~Supplements~~ **Supplementary materials**, Figs. S3 and S4).”

- **p 20, l 647** : the behaviour of altitude changes → the behaviour of the altitude changes.

  Reply: We will revise the text: on page 20 line 647, “To understand the behavior of **the** altitude changes of the optimal flight...”.

- **p 20, l 647** : Fig. 16 plots → Fig. 16 shows.

  Reply: We will revise the text: on page 20 line 647, “Fig. 16 ~~plots~~ **shows** the altitude distribution of the true air speed...”.

- **p 20, l 650–651** : this means tail winds (≥ 1.0) and head winds (< 1.0) to the flight direction : Formulate better.

  Reply: We will add the text to the sentence: on page 20 line 650−651, “...; this means tail winds (**(**V_{ground} **/**V_{TAS}**)** ≥ 1.0) and head winds (**(**V_{ground} **/**V_{TAS}**)** < 1.0) to the flight direction.”

- **p 20, l 655, 662** : ”reflects” → ”takes into account”, or ”accounts for”.

  Reply: We will revise the word: on page 20 line 655, “...GA correctly ~~reflects~~ **takes into account** the weather conditions and...”. On page 20 line 662, “...GA correctly ~~reflects~~ **takes into account** weather conditions for the...”.

- **p 20, l 658** : confirmed → compared. Skip ”quantitatively”.

  Reply: We will revise the text: on page 20 line 658, “Next, we ~~confirmed~~ **compared** the resulting flight **times** ~~quantitatively~~ for the selected solutions.”

- **p 20, l 659** : as indicated → as shown.

  Reply: We will revise the text: on page 20 line 659, “As ~~indicated~~ **shown** in Table 8...”.

- **p 20, l 659–662** : decreased → is lower.

  Reply: We will revise the sentences: on page 20 line 659−662, “As ~~indicated~~ **shown** in Table 8, the flight time ~~decreased~~ **is lower** for the time-optimal case compared to the great circle cases. In addition, the flight time ~~decreased~~ **is lower** for the eastbound time-optimal flight trajectories compared to that for the westbound time-optimal flight trajectories.”

- **p 20, l 664** : ”sufficiently” : I think this is a bit vague.

  Reply: (The “p 20, line 664” means probably “p 20, line 666”) We will delete the word: on page 20 line 666, “...the solutions ~~sufficiently~~ converged to each optimal solution.”

- **p 20, l 667** : that the reduction → a reduction.

  Reply: We will revise the text: on page 20 line 667, “It is also clear from Fig. 17 that ~~the~~ **a** reduction in...”.

- **p 20, l 668** : ”sizing” → ”reducing” or ”choosing properly”.

  Reply: We will revise the text: on page 20 line 668, “...the reduction in computing time can be achieved by ~~sizing~~ **choosing properly** n_p and n_g...”.

- **p 20, l 671** : This is not a nice first sentence for a paragraph.

  Reply: We will modify the sentence: on page 20 line 671, “**Next, the** one-day ~~AirTraf~~ simulation~~s~~ **results** for 103 trans-Atlantic flights are ~~discussed~~ **analyzed**.”

- **p 20, l 673–674** : trans-Atlantic Ocean → Atlantic ocean.

  Reply: We will remove the word “trans-” in the text: on page 20 line 673−674, “...flight trajectories congregated around 50° N over the ~~trans-~~Atlantic Ocean to take advantage...”.

- **p 20, l 675** : of ”the” region → of ”that” region.

  Reply: We will revise the text: on page 20 line 675, “...the westbound time-optimal flight trajectories were located to the north and south of ~~the~~ **that** region...”.

Page 21

- **p 21, l 681** : plot → show.

  Reply: We will revise the text: on page 21 line 681, “Figures 19a and 19b ~~plot~~ **show** the...”.

- **p 21, l 683** : with linear fitted lines : be more precise.

  Reply: We will modify the text: on page 21 line 683, “...with linear ~~fitted~~ lines **fitted by the Least Squares algorithm**.” Related to this issue, we will also modify the text: on page 18 line 586, “...~~least-squares~~**Least Squares** algorithm...”.

- **p 21, l 683** : increased → is higher.

  Reply: We will revise the text: on page 21 line 683, “Figure 19a shows that V_{TAS} ~~increased~~ **is higher** at low altitudes.”

- **p 21, l 688–689** : which had high V_{TAS} values → with high V_{TAS} values.

  Reply: We will revise the text: on page 21 line 688−689, “GA successfully found the flight trajectories~~, which had~~ **with** high V_{TAS} values~~,~~ as time-optimal flights.”

- **p 21, l 691** : increases → is larger.

  Reply: We will revise the text: on page 21 line 691, “...time-optimal case (solid line, red) ~~increases~~ **is larger** between...”.

- **p 21, l 696** : increases → is larger.

  Reply: We will revise the text: on page 21 line 696, “...time-optimal case (solid line, blue) is distributed widely in altitude and ~~increases~~ **is larger** between”.

- **p 21, l 700** : Supplement → Supplementary material.

  Reply: We will modify the text: on page 21 line 700, “...is shown in the ~~Supplement~~ **Supplementary material** (Fig. S7)...”.

- **p 21, l 703** : correctly selected the airspace : improve this formulation.

  Reply: We will modify the sentence: on page 21 line 703, “Therefore, ~~GA correctly selected the airspace by altitude changes, where V_{ground} values increased~~ **the trajectories found by GA through altitude changes passed areas, which correctly lead to larger V_{ground}.**”

- **p 21, l 705** : This behaviour of altitude changes → These altitude changes.

  Reply: We will revise the text: on page 21 line 705, “~~This behavior of~~ **These** altitude changes affect~~s~~ the...”.

- **p 21, l 705** : affects the variation in fuel consumptions → affects the fuel consumption.

  Reply: We will revise the text: on page 21 line 705, “**These** altitude changes affect~~s~~ the ~~variation in~~ fuel consumption~~s~~...”.

- **p 21, l 705** : the terms are used interchangeably to mean fuel flows : improve the formulation.

  Reply: We will improve the text: on page 21 line 705, “...affect~~s~~ the ~~variation in~~ fuel consumption~~s~~ (the term~~s~~ ~~are~~ **is** used interchangeably to ~~mean~~ fuel flow~~s~~).”

- **p 21, l 708** : increases → is higher.

  Reply: We will revise the text: on page 21 line 708, “The results show that the fuel consumption ~~increases~~ **is higher** at low altitudes...”.

- **p 21, l 708** : the mean value → the mean value of the fuel consumption.

  Reply: We will revise the text: on page 21 line 709, “In addition, the mean value **of the fuel consumption** for the time-optimal case is high...”.

- **p 21, l 714** : increases → is higher.

Reply: We will revise the text: on page 21 line 714, "...the mean value for the eastbound time-optimal case ~~increases~~ **is higher** owing to its low mean flight altitude...".

Page 22

- **p 22, l 718** : corresponding to "the 103" individual flights.

  Reply: We will revise the text: on page 22 line 718, "Figure 21 shows the flight time corresponding to **the 103** individual flights...".

- **p 22, l 718–719** : the similar figures → similar figures.

  Reply: We will revise the text: on page 22 line 718−719, "...(~~the~~ similar figures for the fuel use, NO_x and H_2O emissions are shown...".

- **p 22, l 720** : showed → show.

  Reply: We will revise the text: on page 22 line 720, "The results show~~ed~~ that all symbols...".

- **p 22, l 720** : in the right-hand domain : choose a better expression.

  Reply: We will rephrase the text: on page 22 line 720, "...all symbols lay ~~in the right-hand domain~~ **on the right side of the 1:1 solid line**."

- **p 22, l 721** : decreases → is lower. Put "for all airport pairs" at the end of the sentence.

  Reply: We will revise the sentence: on page 22 line 721, "...the flight time for the time-optimal flights ~~decreased~~ **is lower** ~~for all airport pairs~~ compared to that for the great circle flights **for all airport pairs**."

- **p 22, l 723 and 725** : increased → increases.

  Reply: We will revise the sentences: on page 22 line 722−725, "The total value ~~was~~ **is** certainly minimal for the time-optimal case, while in relative terms the value ~~increased~~ **increases** by +1.5 %, +2.5 %, +2.9 % and +2.9 % for the great circle cases at FL290, FL330, FL370 and FL410, respectively. Regarding the total value of fuel use, Table 11 indicates that the value ~~increased~~ **increases** by +5.4%."

- **p 22, l 740–741** : "Consistency" : just by reading the section title, it is not clear what is meant by this.

  Reply: We will change the section title: on page 22 line 740, "5 ~~Consistency check for~~ **Verification of** the AirTraf simulations."

- **p 22, l 742** : were → are.

  Reply: We will revise the text: on page 22 line 742, "...the one-day simulation results described in Sect. 4 ~~were~~ **are** compared to reference data...".

- **p 22, l 742–743** : The data → Data.

  Reply: We will revise the text: on page 22 line 742−743, "~~The d~~**D**ata obtained under similar conditions...".

- **p 22, l 744** : "they" is ambiguous.

  Reply: We will revise the text: on page 22 line 742−744, "~~The d~~**D**ata obtained under similar conditions (aircraft/engine types, flight conditions, weather situations, etc.) were selected for the comparison, although ~~they~~

the conditions are not completely the same as the calculation conditions for the one-day simulations."

Page 23

- **p 23, l 723** : I would not say explicitly that the table shows "a comparison".

  Reply: (The "p 23, line 723" means probably "p 23, line 749") We will revise the text: on page 23 line 749, "...Table 12 shows ~~a comparison of~~ the flight time ~~between~~ **for** the seven time-optimal flight trajectories simulated by AirTraf and three reference data...".

- **p 23, l 758 and 764** : literature → write the correct reference.

  Reply: We will revise the text: on page 23 line 758, "...(see Fig. 3 in ~~the literature~~ **Irvine et al. (2013)**)." On page 23 line 764, "...(see Tables 2 and 3 in ~~the literature~~ **Grewe et al. (2014a)**)."

- **p 23, l 758** : indicated → indicates.

  Reply: This part will be deleted. Please see the reply to the comment below: "p 23, l 758–759 / 764–765".

- **p 23, l 758–759 / 764–765** : Is it worth mentioning this?

  Reply: As the referee pointed out, those sentences are not necessary here. Therefore, we will revise the sentences: on page 23 line 758–759, "~~This indicated that the flight time increased for westbound flights on the trans-Atlantic region in winter due to westerly jet streams.~~". On page 23 line 764–765, "~~This also indicated the increased flight time for westbound trans-Atlantic flights in winter due to westerly jets streams.~~". Related to this issue, we will modify the text: on page 23 line 765–767, "The ~~magnitude in~~ flight times ~~of~~ **between** the seven airport pairs ~~is~~ **are** close **to the reference data** and the variation shows **a** good agreement with the trend of the flight **times** for westbound **trans-Atlantic** flights in winter **due to westerly jets streams**, as indicated from the reference data."

- **p 23, l 764** : "indicate" : I don't think this is the appropriate word.

  Reply: This part will be deleted. Please see the reply to the comment above: "p 23, l 758–759 / 764–765".

- **p 23, l 765** : "close" → "close to".

  Reply: We will revise the text: on page 23 line 765, "The ~~magnitude in~~ flight times ~~of~~ **between** the seven airport pairs ~~is~~ **are** close **to the reference data** and the variation shows...".

- **p 23. l 769** : reference data → the reference data.

  Reply: We will revise the text: on page 23 line 769, "...using the mean fuel consumption value of 103 flights and **the** reference data,...".

- **p 23, l 774** : indication : shouldn't one use a different word?

  Reply: We will remove the word "indication" and revise the text: on page 23 line 774, "...the **overall** load factor of the worldwide air traffic ~~indication in 2008~~ was used (Table 1)."

- **p 23, l 778** : decreased → is lower.

  Reply: We will revise the text: on page 23 line 778, "Table 13 shows that the obtained mean $EINO_x$ value ~~decreased~~ **is lower** at high altitudes...".

- **p 23, l 783** : installed → contains.

  Reply: We will revise the text: on page 23 line 783, “The 2GE051 ~~installed~~ **utilizes** the new 1862M39 combustor,...”.

Page 24

- **p 24, l 787** : ”duplicates” : What is meant by this?

  Reply: We just wanted to say here as, “estimates” or “simulates.” We will revise the text: on page 24 line 787, “AirTraf ~~duplicates~~ **simulates realistic** fuel consumptions...”.

- **p 24, l 790** : for 103 flights → for ”the” 103 flights.

  Reply: We will revise the text: on page 24 line 790, “Here the obtained m_1 and m_{nwp} for **the** 103 flights were compared...”.

- **p 24, l 792** : safety flight operations → flight operations safety.

  Reply: We will revise the text: on page 24 line 792, “...to provide ~~safety~~ **flight operations safety**, and...”.

- **p 24, l 794** : constrains to → constraints

  Reply: We will revise the text: on page 24 line 794, “...no model that **constrains** ~~to~~ the structural ~~limit~~ weight~~s~~ **limits** was included in AirTraf.”

- **p 24, l 800–801** : This sentence should be improved.

  Reply: We will improve the sentence: on page 24 line 800–801, “For these 15 flights, actual flight planning data ~~probably~~ indicate ~~altitude changes (generally~~ higher flight altitudes~~)~~ to increase ~~a~~ **the** fuel mileage, ~~which decreases~~ **leading to the decrease in** m_1.”

- **p 24, l 802** : to prevent ”the” structural damage → to prevent structural damage.

  Reply: We will revise the text: on page 24 line 802, “To prevent ~~the~~ structural damage to the landing gear...”.

- **p 24, l 803** : ”aircraft has” → ”aircraft have” or ”an aircraft has”.

  Reply: We will revise the text: on page 24 line 803, “...**an** aircraft has to reduce the total weight...”.

- **p 24, l 803** : ”to reduce below” → ”to reduce until” or ”to bring below”.

  Reply: We will revise the text: on page 24 line 803, “...**an** aircraft has to reduce the total weight ~~below~~ **until** MLW prior to landing.”

- **p 24, l 808** : Why not using ≤?

  Reply: We will revise the text: on page 24 line 808, “This always satisfies the third constraint ZFW ≦≤ MZFW.”

- **p 24, l 806, 810** : of A330-301 → of an A330-301 aircraft.

  Reply: We will revise the word in the revised manuscript: on page 24 line 806, “The MZFW of **an** A330-301

aircraft is...". On page 24 line 810, "...minimum operational weight of **an** A330-301 **aircraft** in the...".

- **p 24, l 812** : more → higher.

  Reply: We will revise the text: on page 24 line 812, "..., all the m_{nwp} (open circle) were ~~more~~ **higher** than the MLOW."

- **p 24, l 814** : Skip "calculations".

  Reply: We will remove the word "calculations": on page 24 line 814, "...AirTraf simulates fairly good fuel use ~~calculations~~."

- **p 24, l 816** : an submodel → a submodel.

  Reply: We will revise the text: on page 24 line 816, "AirTraf is published for the first time as ~~an~~ **a** submodel of the Modular Earth Submodel System...".

- **p 24, l 817** : "applied" : shouldn't it be "used"?

  Reply: We will revise the text: on page 24 line 817, "The MESSy is continuously further developed and ~~applied~~ **used** by a consortium of institutions."

Page 25

- **p 25, l 823–824** : What is meant by this sentence?

  Reply: This sentence is not necessary for our argument here. Therefore, we will delete the sentence: on page 25 line 822−825, "Some improvements will be performed and AirTraf 1.0 will be updated for the latest version of the code. ~~For example, evaluation functions corresponding to the NO_x, H_2O, fuel, contrail and CCF routing options will be added.~~ The status information for AirTraf including the licence conditions will be available at the website."

- **p 25, l 829** : the benchmark test → a benchmark test.

  Reply: We will revise the text: on page 25 line 829, "First, ~~the~~ **a** benchmark test was performed...".

- **p 25, l 831–832** : by other published code : this is too vague.

  Reply: We will revise the text: on page 25 line 831–832, "...calculated by ~~other published code~~ **MTS**."

- **p 25, l 832** : the benchmark test → a benchmark test.

  Reply: We will revise the text: on page 25 line 832, "Second, ~~the~~ **a** benchmark test was performed...".

- **p 25, l 836** : dependence on the initial population.

  Reply: We will revise the text: on page 25 line 836, "The dependence of the optimal solution~~s~~ on **the** initial ***population*~~s~~** was investigated...".

- **p 25, l 835 and 838** : The fact that both values are 0.01 % is maybe not a good sign. I would think that you want the second one to be much smaller than the first one.

  Reply: The referee pointed out a very important issue. However, these values are sufficiently small and the performance of GA is well enough to find an optimal solution. In fact, we showed in Fig. 21 that GA found

the trajectories for all airport pairs; the trajectories could decrease flight time compared to the great circle flights. This performance is sufficient for our purpose. In fact, the second “0.01 %” is actually smaller than what we expected. As replied to the referee comment in the section of “p 18, l 573–574”, GA is a stochastic optimization algorithm. Hence, optimal solutions calculated from different initial populations are not always the same.

Regarding the performance of GA, Deb, K., (1991) reported that “the welded beam structure is a practical design problem (minimization of the total cost f) that is often used as a bench-mark problem in testing different optimization techniques.” Rekliatis, G. V., et al., (1983) studied this test and reported the optimal solution of $f^* = 2.38$. Deb, K., (1991) performed 3 independent GA calculations with different initial populations to this problem: the obtained (optimal) solution was $f = 2.43$ (the best among the three solutions), $f = 2.59$ and $f = 2.49$. The difference in the total cost between the f (the best solution: 2.43) and f^* was $\Delta f = f - f^* = 0.05$ (2.1 % of f^*). Δf also ranged from 0.05 to 0.21 (2.1 to 8.8 % of f^*). This shows that both values “0.01 %” are indeed small. Of course, the performance of GA largely depends on the optimization problem and GA parameters. Therefore, we analyzed the performance on our trajectory optimization problem with our setting in Sects. 3.2.4 and 3.2.5.

[Reference]
Rekliatis, G. V., et al., Engineering Optimization Methods and Applications, Wiley, New York, 1983.
Deb, K., “Optimal design of a welded beam via genetic algorithms,” AIAA Journal, 29 (11), 1991.

Page 26

- **p 26, l 860 and 866** : Please be more specific about what ”reference data” is.

  Reply: We will revise the text: on page 26 line 860, “The consistency of the one-day simulations was verified with reference data **(published in earlier studies and BADA)** of flight time...”. On page 26 line 866, “The mean $EINO_x$ values were in the same range as the reference ~~data~~ **values of earlier studies.**”

- **p 26, l 862** : close → (very) similar.

  Reply: We will revise the text: on page 26 line 862, “...the reference data showed that the values were ~~close~~ **similar** and...”.

- **p 26, l 869** : fuel use calculation model → fuel use model.

  Reply: We will revise the text: on page 26 line 869, “Thus, AirTraf comprises a sufficiently good fuel use ~~calculation~~ model.”

- **p 26, l 871** : ”is sufficient” : But some things do not work yet?

  Reply: We will revise the sentence: on page 26 line 871, “AirTraf 1.0 ~~is sufficient to investigate a reduction potential of aircraft routings on air traffic climate impacts~~ **is ready for more complex routing tasks**.”

- **p 26, l 871** : ”a” reduction potential → ”the” reduction potential.

  Reply: This part will be deleted. Please see the reply to the comment above: “p 26, l 871”.

4 Remarks on figures

- **Figure 1** : I presume parts of this are already done in other optimized studies. Mention what is already done, what is part of this manuscript, and what shall be done in the future.

  Reply: By following the comment (2) of the referee #1, we will remove Fig. 1 (on page 29).

- **Figure 7** : Bizarre first sentence in caption. Consisting of → determined by. $\Delta\lambda_{airport} \rightarrow \Delta\lambda_{\mathrm{airport}}$.

Reply: We will revise the caption: on page 34 in the caption of Fig. 7, “Geometry definition of flight trajectory ~~as longitude vs altitude~~ **in the vertical cross-section** (top) and ~~as geographic location~~ **projected onto the Earth** (bottom). The bold solid line indicates a trajectory from MUC to JFK. •: control points ~~consisting of~~ **determined by** design variables....which divide the ~~$\Delta\lambda_{airport}$~~ $\mathbf{\Delta\lambda_{airport}}$ into four equal parts...the coordinates divide the ~~$\Delta\lambda_{airport}$~~ $\mathbf{\Delta\lambda_{airport}}$ into six equal parts.”

- **Figure 8** : Conclusions/observations/interpretations should not be written in figure captions. I would not use the word ”discovers”.

  Reply: We will revise the caption: on page 35 in the caption of Fig. 8, “Figure 8. Optimal solutions ~~are shown~~ varying with the ***population*** size n_p and **the number of *generations*** ~~number~~ n_g. Δf means the difference in flight time between the optimal solution f and the true-optimal solution f_{true} **(= 25,994.0 s)**. The Δf (in %) is calculated as $(\Delta f / f_{\text{true}})\times 100$. ~~GA discovers the solutions as close to the f_{true} (= 25,994.0 s) with increasing n_p and n_g. For each n_p, the optimal solution shows minimum flight time for n_g = 100. For each n_g, the optimal solution shows minimum flight time for n_p = 100.~~ The flight time of the best solution is f_{best} = 25,996.6 s (for n_p = 100 and n_g = 100, Δf < 3.0 s (less than 0.01 %)).”

- **Figure 9** : Change the first sentence. ”The population size n_p = 100 ...” : This is not a good sentence. Replace ”=” by ”is”.

  Reply: We will revise the caption: on page 36 in the caption of Fig. 9, “~~1,000~~**10,000** explored trajectories (solid line, black) from MUC to JFK ~~as longitude vs altitude~~ **in the vertical cross-section** (top) and ~~as location~~ **projected onto the Earth** (bottom). The ***population*** size ~~n_p = 100~~ n_p **is** 100 and **the number of *generations*** ~~number n_g = 100~~ n_g **is** 100.” In the same way, we will revise the caption: on page 38 in the caption of Fig. 11, “The ***population*** size ~~n_p = 100~~ n_p **is** 100 and **the number of *generations*** ~~number n_g = 100~~ n_g **is** 100.” On page 44 in the caption of Fig. 17, “**The *population*** size ~~n_p = 100~~ n_p **is** 100 and **the number of *generations*** ~~number n_g = 100~~ n_g **is** 100.”

- **Figure 10** : Skip ”Comparison of”.

  Reply: We will remove the word “Comparison of” in the caption: on page 37 in the caption of Fig. 10, “Figure 10. ~~Comparison of t~~**T**rajectories for the best solution (red line) and the true-optimal solution (dashed line, black).”

- **Figure 11** : Don’t use expressions like ”Best-of-generation”. ”vs function evaluations” → ”vs number of function evaluations”. f_{true} → f_{true}. Change ”On the ... and ...”.

  Reply: We will revise the caption: on page 38 in the caption of Fig. 11, “~~Best-of-generation f~~**F**light time vs **number of** function evaluations...and the true-optimal solution ~~f_{true}~~$\mathbf{f_{true}}$...is calculated as $(\Delta f / $ ~~f_{true}~~$\mathbf{f_{true}})$...”.

- **Figure 17** : Don’t use expressions like ”Best-of-generation”.

  Reply: We will revise the caption: on page 44 in the caption of Fig. 17, “~~Best-of-generation f~~**F**light time (in %) vs **number of** function evaluations...”.

- **Figure 22** : Shouldn’t one have as unit for the emissions : kg(fuel) $m^{-2}s^{-1}$? The figures are 2-hourly averages. However, the ranges are not clear from just mentioning 14:00:00, 16:00:00, 18:00:00, 20:00:00. Is it 14:00:00–16:00:00, 16:00:00–18:00:00, ..., or rather 12:00:00–14:00:00, 14:00:00–16:00:00, ...

  Reply: By following the comment (8) of the referee #1, we will remove Fig. 22 (on page 49).

5 Comments on tables

- **Table 1** 101.325 → 101,325. Why is there ”(jet)” at the end of the line with C_{f1}? There should be a small space between ”kg” and ”min”. I would not give a variable the name ”Oneday”. P_0 and T_0 are not total pressure or temperature, but reference pressure and temperature.

  Reply: Thank you so much. We will correct the value: on page 51 at the line with P_0 in Table 1, “~~101.325~~ **101,325**.” Eurocontrol, 2011 publishes the thrust specific fuel consumption coefficient for jet, turboprop and piston engines. The word ”jet” means “jet engines”. We will modify the line: at the end of the line with C_{f1}, “...(jet **engines**)[a]”. As the referee pointed out, we will add a space between ”kg” and ”min”: at the line with C_{f1}, “**kg min^{-1}kN^{-1}**.” Regarding the variable name “Oneday”, please see the reply to the referee comment on “p 9, l 287.” In addition, we will correct the word on P_0 and T_0: at the line with P_0 and T_0, “~~Total~~ **Reference** pressure” and “~~Total~~ **Reference** temperature”.

- **Table 2** : $n_{\mathrm{wp}-1} \rightarrow n_{\mathrm{wp}} - 1$.

  Reply: Thank you so much. We will correct the text: on page 52 in the caption of Table 2, “..., flight segments (i = 1, 2,..., ~~$n_{\mathrm{wp}-1}$~~ $\boldsymbol{n_{\mathrm{wp}} - 1}$).”

- **Table 4** : I think it makes no sense to introduce all these new variable names. Put in the heading (first row) of the table just : ”Eq. (22)”, ”Eq. (23)”, ...

  Reply: We understand the referee comment. Nevertheless, we are hesitating to change those variable names. We define the variable name for a flight distance as “d”, as shown in Table 2, and we use the variable “d” consistently in the manuscript: on page 11 Eqs. (22) and (23), on page 15 Eq. (28), etc. We think that the current expressions are reasonable.

- **Table 5** : For population size and generation number : ”· · ·” → ”. . .”.

  Reply: We will modify and add the variable names “n_p” and “n_g” in the Table: on page 55 in Table 5, “Population size, $\boldsymbol{n_p}$, 10,20,**...**,100” and “~~Generation number~~**Number of generations**, $\boldsymbol{n_g}$, 10,20,**...**,100”. This reply is related to the reply to “p 17, l 540.” In addition, we will add the text at the line with design variable: on page 55 in Table 5, “Design variable, n_{dv}, 11 **(6 locations and 5 altitudes)**.” Related to this, we will modify the text: on page 56 in Table 7, “Design variable, n_{dv}, 11 **(6 locations and 5 altitudes)**.”

- **Table 9** : ”that of” → ”average of”. Why ”medium”?

  Reply: We will modify the caption of Table 9: on page 58 in the caption of Table 9, “Eastbound: ~~mean value~~ **average** of 52 eastbound flights; Westbound: ~~that~~ **average** of 51 westbound flights; and Total: ~~that~~ **average** of 103 flights.” In the same way, we will modify the caption of Table 10: on page 58 in the caption of Table 10, “Eastbound: ~~mean value~~ **average** of 52 eastbound flights; Westbound: ~~that~~ **average** of 51 westbound flights; and Total: ~~that~~ **average** of 103 flights.” Unfortunately, we didn’t understand the comment: Why ”medium”.

- **Table 12** : Skip ”Comparison of”.

  Reply: We will remove the word “Comparison of” in the caption: on page 60 in the caption of Table 12, “~~Comparison of t~~**T**he flight time for time-optimal flight trajectories from one-day AirTraf simulations...”.

- **Table 14** : ”Constraints on” → ”Constraints from”. Why not just using ≥ and ≤? Why have on all the four lines A330-301 after some ”.” at the end of the line?

  Reply: We will revise Table 14: on page 62 in the caption of Table 14, “Constraints ~~on~~ **from** the structural ~~limit~~ weight **limits** (MTOW, MLW and MZFW) and one specific ~~limit~~ weight **limit** (MLOW)...”. In column 1, “m_1 ≦≤ MTOW; m_{nwp} ≦≤ MLW; Zero fuel weight ≦≤ MZFW; and m_{nwp} ≧≥ MLOW.” In column 3, “Maximum take-off weight~~. A330-301~~; Maximum landing weight~~. A330-301~~; Maximum zero fuel weight.

MZFW = OEW + MPL. ~~A330-301~~; and Planned minimum operational weight in the international standard atmosphere.[b] MLOW = 1.2 × OEW. ~~A330-301.~~[b]”

Related to this, we will change the word “limit weights” into “weight limits” in the revised manuscript: on page 24 line 791, “three structural ~~limit~~ weight~~s~~ **limits**...”; on page 24 line 792, “...,and one specified ~~limit~~ weight **limit**...”; on page 24 line 793, “...and the four ~~limit~~ weight~~s~~ **limits**...”; on page 24 line 794, “...constrains to the structural ~~limit~~ weight~~s~~ **limits**...”; on page 24 line 797, “...with the ~~limit~~ weight~~s~~ **limits**...”; on page 26 line 867, “...the three structural ~~limit~~ weight~~s~~ **limits** and one specified ~~limit~~ weight **limit** of...”; on page 26 line 868, “...the values satisfied the four ~~limit~~ weight~~s~~ **limits** and...”; on page 50 in the caption of Fig. 23, “Comparison of aircraft weights with structural ~~limit~~ weight~~s~~ **limits** (MTOW and MLW) and one specified ~~limit~~ weight **limit** (MLOW)”; on page 62 in column 2 of Table 14, “~~Limit w~~**W**eight **limit**, kg”.

6 Supplementary material

- Fig. S1 and S2 : including ”the” time-optimal flight trajectories.

  Reply: We will add the word “the” in the caption: on page 1 (Supplementary material) in the caption of Fig. S1, “...(bottom), including **the** time-optimal flight trajectories...”. On page 2 (Supplementary material) in the caption of Fig. S2, “...(bottom), including **the** time-optimal flight trajectories...”. In the same way, we will add the word: on page 41 in the caption of Fig. 14, “...(bottom), including **the** time-optimal flight trajectories...”.

- Fig. S3 and S4 : Skip ”Comparison of”.

  Reply: We will remove the word “Comparison of” in the caption: on page 3 (Supplementary material) in the caption of Fig. S3, “~~Comparison of t~~**T**rajectories for the time-optimal...”. On page 3 (Supplementary material) in the caption of Fig. S4, “~~Comparison of t~~**T**rajectories for the time-optimal...”. In the same way, we will remove the word: on page 42 in the caption of Fig. 15, “~~Comparison of t~~**T**rajectories for the time-optimal...”.

- Fig. S7 : Skip ”that”.

  Reply: We will remove the word “that” in the caption: on page 6 (Supplementary material) in the caption of Fig. S7, “Linear fits of the time-optimal (solid line, red (eastbound) and blue (westbound)) and ~~that~~ of the great circle...”. In the same way, we will remove the word: on page 46 in the caption of Fig. 19, “Linear fits of the time-optimal (solid line, red (eastbound) and blue (westbound)) and ~~that~~ of the great circle...”.