Response to Reviewer 1

We would like to thank the anonymous Reviewer for their careful review. We found all the remarks and recommendations to be very relevant and addressing the Reviewer's comments has improved the paper. Below is our response to the comments on a point-by-point basis. The following convention for text fonts is used:

- Review comments in black color
- Our answers in blue color
- *Pieces of text taken from the revised manuscript in red color and in italic font*

Review

This is a very interesting, balanced and well thought-out article analysing the use of climate metrics in the context of contrail avoidance. Using the North Atlantic flight tracks from 2019 as a case study, the authors analyse the influence of the choice of climate metric on the decision to re-route around areas of contrail formation. Their conclusion, that the decision to reroute is largely independent of the climate metric, is very interesting and clearly shows that the implementation of contrail avoidance policies need not be unduly hampered by the choice of climate metric. However, as the authors also conclude, since the climate benefit of rerouting depends on the choice of climate metric as well as contrail efficacy and CO_2 penalty, further research analysing specific contrail avoidance strategies is well warranted.

Overall, the article is logically presented, well-written and appropriate for ACP. I recommend publication of this article subject to minor revision. I have provided my specific comments and questions below, followed by a few technical remarks and suggestions for improvement.

We thank the Reviewer for their positive assessment of the paper.

Main comments

1) Choice of background scenario

The authors calculate a total temperature increase for all flights of 16.9 µK in 2039, 13.5 µK in 2069 and 14.0 µK in 2119 (ln. 19). The late increase in temperature between 50 and 100 years after the emission in my opinion requires further description and justification. In Table S1 and Figure 4(a) (third panel), this temperature increase is attributed to CO_2.

Following the Reviewer's recommendation, we have discussed this late increase in the discussion of Figure 3: *The 0.5 µK rise between 2069 and 2119 is due to CO_2 and the chosen background scenario, SSP4-3.4, which assumes that CO_2 concentration decreases after 2080 (Meinshausen et al., 2019). Because the dependence between radiative forcing and CO_2 concentration is logarithmic (e.g., Etminan et al., 2016), emitted CO_2 has an increased radiative forcing when the atmospheric concentration decreases. In this case, this increase is greater than the decrease from the absorption of CO_2 by the ocean and land surfaces, thus leading to a temperature increase from 11.0 µK in 2069 to 12.1 µK in 2119.*

I assume that the emission inventory is treated as a pulse emission in the year 2019? In that case, I can only attribute this temperature increase to a decreasing background CO_2 concentration. Looking at Meinshausen et al. (2020), the background CO_2 concentration of SSP4-3.4 (ln. 168) does seem to peak in around the year 2080. I thus have a few questions:

1a) SSP4-3.4 is characterised by a low CO_2 concentration in comparison to the other pathways. Why was SSP4-3.4 chosen for this analysis?

1b) I can imagine that the high lingering temperature as a result of CO_2 emissions has a significant influence on the weighting of CO_2 compared to that of contrails. In particular when more fuel is burned for contrail avoidance. Have the authors considered different background CO_2 concentrations?

1c) (How) would the results and conclusions presented in this article change if different background CO_2 concentrations were to be used? Or in other words, what is the impact/sensitivity of the choice of background CO_2 concentration?

We thank the Reviewer for these comments. We address them together.

We chose SSP4-3.4 because it leads to a 2°C warming in the medium term, which currently seems like a plausible trajectory.

The background scenario has indeed a high influence on the perceived climate damage from CO_2, for all long-term metrics, such as AGWP100, ATR100 and AGTP100. However, this influence decreases with decreasing time horizon. The Table below shows the dependence of the total climate impact of the flights considered in our study on the assumed scenario, for AGTP20, 50 and 100. The dependence increases with time horizon, with a maximum range for AGTP100, which varies between 8.9 μK for SSP5-8.5 to 14.4 μK for SSP1-1.9. As the Reviewer correctly notes, SSP4-3.4 is characterised by a low CO_2 concentration in comparison to the other pathways, so the corresponding AGTP100 value ranks among the highest ones, with a value of 14.0 μK.

Total warming	AGTP20	AGTP50	AGTP100
SSP1-1.9	17.1 μK	14.2 μK	14.4 μK
SSP1-2.6	16.8 μK	13.6 μK	13.9 μK
SSP2-4.5	16.6 μK	12.7 μK	12.4 μK
SSP3-7.0	16.5 μK	12.1 μK	10.1 μK
SSP4-3.4	16.9 μK	13.5 μK	14.0 μK
SSP4-6.0	16.6 μK	12.5 μK	11.8 μK
SSP5-3.4-OS	16.3 μK	12.8 μK	14.0 μK
SSP5-8.5	16.4 μK	11.5 μK	8.9 μK

However, as we explained in our study, persistent contrails often induce a warming that is orders of magnitude larger than that due to additional CO_2 emissions because of a rerouting, for all CO_2-equivalence metrics considered. Therefore, apart from the total warming from all flights as presented above, our qualitative and quantitative conclusions are only weakly dependent on the background scenario used. The Table below shows the number of beneficial reroutings, and the absolute perceived benefit from these reroutings, for AGTP20, 50 and 100 and for different scenarios. For each metric, the number of beneficial reroutings is almost the same, the maximum difference being 4,954 reroutings between SSP5-8.5 and SSP4-3.4 for AGTP100, only 3% of the total number of beneficial reroutings. The perceived absolute benefit also changes only weakly, varying from 1.69 µK for SSP5-8.5 to 1.86 µK for SSP1-1.9.

Number of beneficial reroutings (absolute benefit in brackets)	AGTP20	AGTP50	AGTP100
SSP1-1.9	187,357 (4.62 µK)	182,359 (2.44 µK)	178,593 (1.86 µK)
SSP1-2.6	187,441 (4.58 µK)	182,595 (2.38 µK)	178,560 (1.79 µK)
SSP2-4.5	187,516 (4.58 µK)	183,282 (2.37 µK)	179,871 (1.76 µK)
SSP3-7.0	187,595 (4.57 µK)	183,860 (2.37 µK)	182,057 (1.71 µK)
SSP4-3.4	187,445 (4.61 µK)	182,755 (2.41 µK)	178,502 (1.79 µK)
SSP4-6.0	187,554 (4.59 µK)	183,494 (2.38 µK)	180,419 (1.75 µK)
SSP5-3.4-OS	187,653 (4.56 µK)	183,210 (2.37 µK)	178,693 (1.82 µK)
SSP5-8.5	187,626 (4.55 µK)	184,360 (2.35 µK)	183,456 (1.69 µK)

While such results may be interesting to some readers, they would also lengthen the manuscript, hence we did not include a “Sensitivity to the background scenario” section. However, following the Reviewer’s comments, we have added some text to address this question: *That background concentration is simulated using the emission scenario SSP4-3.4 in our experiment, which is characterised by a low atmospheric CO_2 concentration in comparison to the other pathways. However, conclusions are qualitatively independent on the chosen scenario.*

2) Clarification of the methodology

The methodology and analysis used in section 5.2 "Imperfect contrail avoidance" is not clear to me. Is extra CO_2 emitted for rerouting, as in the previous sections? How are the number of "imperfect avoidance" flights in Table 1 defined and calculated? How is the rerouting efficiency used to obtain these results?

We renamed the “imperfect contrail avoidance scenario” to “partial avoidance scenario”, to clarify the opposition between the partial and the full avoidance scenarios. The partial contrail avoidance strategy is the same as the full one, but with a decreased rerouting efficiency. That efficiency is calculated following the method described in the paper. The rerouting efficiency is applied to calculate the remaining contrail energy forcing after rerouting, while the additional fuel consumed remains the same. Following the Reviewer's comment, we detailed this methodology in the text: *For each rerouting, contrail energy forcing is scaled by this rerouting efficiency factor, which is less than the 100% efficiency assumed in the full contrail avoidance scenario. [...] For the sake of simplicity, the +1% fuel scenario is used for all reroutings, and results for full and partial avoidance are compared.*

Minor comments

ln 35: "Uncertainties [...] and *the* subject of [...]"

Corrected, thanks.

ln 88: "It includes *a* sensitivity analysis [...]"

Corrected.

ΔF is used to denote "radiative forcing" in the definition of the AGWP in ln. 110, but then also to denote "instantaneous contrail RF" in ln. 137. Since these two definitions are not equivalent, I would suggest to use a different symbol for the calculation of EF_contrail.

Following the Reviewer's comment, we changed ΔF to $\Delta F_{contrail}$.

In the climate metrics formulae (ln. 110-123), I would recommend performing the integrals from t_0 -> t_0 + H rather than 0 -> H, where t_0 is the emission year (2019). Or, H should be defined more clearly in the text to make the connection between H and t more clear.

Modified as suggested.

The ATR was initially introduced by Dallara et al. (2011), but has subsequently been modified and is generally used as in this article. In the description of the ATR (ln. 118-122), I would therefore make a brief reference to this.

We have added this reference to the definition of ATR, thank you.

ln. 170: The number of simulations used to provide the best estimate and standard deviation, 1726, is very precise. Why was this specific number of simulations used?

To better explain the origin of these 1726 simulations, we modified the corresponding sentence: *We disregard 274 simulations that did not converge to a solution, which can arise with the Monte Carlo approach, and use the remaining 1726 simulations to provide the best estimate and standard deviation.*

Fig 1: I suggest to use the same units in both the caption and the figure (pW and pK)

Modified as suggested.

Fig. 5 and corresponding text: I believe the term "detrimental" is too strong to be a good antonym of "beneficial". It conveys a very strong sense of harm or negative impact, which in my opinion is not appropriate in this context, in particular in light of the uncertainties involved in contrail avoidance. I would advocate for the use of different term here such as "harmful" or equivalent.

While we agree that uncertainties may change results, we think that “detrimental” is a good antonym of “beneficial” in this context. The uncertainties also apply for the “beneficial” term.

ln. 381-382 & ln. 404: "few orders of magnitude more warming" from contrails than from CO2 is ambiguous. How is warming defined in these instances? At what time horizon?

In these instances, the statement is valid for all CO_2-equivalence metrics investigated in our work. We specified that point in lines 381-382, but we did not change line 404, as this is stated in the following sentence.

ln. 410-411: "[...] like AGWP20 or ATR20, give a much greater climate benefit [...]" I do not think *give* is the right verb here. I would recommend "suggest" or "calculate".

We changed “give” to “calculate”, thanks.

ln. 460: "inflicted by uncertainties" in regards to the ATR is a very loaded wording choice, which I do not think is appropriate. I recommend using more neutral phrasing.

We changed “inflicted with” to “subject to”.