REFEREE 1 (RC1) RESPONSE

General comments

The authors describe the implementation of a new tool for contrail-avoiding flight-routing that is aimed at producing forecasts of fields of the so-called Energy Forcing (EF), similar in format to other fields of standard weather maps. These fields can then be used for flight-routing that optimizes flight tracks in a way that the total path-integrated EF is minimal. I am pleased that the authors see the necessity to test their predictions thoroughly with independent data and to investigate the sensitivity to uncertain parameters of their approach. Thus, this development is on a good way and the description of the code fits well to GMD. However, I have two major reservations to the current approach, which should be addressed in the final paper.

Major comments

1. *All the results that this method produces and will produce and many results that are cited are based on the "parametric RF model" by Schumann et al. (2012). This "model" is not a model but a fit to results from 1000s radiative transfer calculations using a large set of profiles as input. It must be recognized that a fit is not a model. I suggest to search the internet for "fit vs. regression". What would be required for the current purpose is a regression rather than a fit. The fit that is used so far has more than 10 free parameters. It is quite possible that this leads to overfitting (that is, fitting of noise). Testing of the fit against independent test profiles has never been performed, as far as I know. Thus it is unknown whether there is overfitting or not. Moreover, there is to my knowledge no analysis of the residuals, whether they are distributed homogeneously or not over the range of input variables. Thus, it is in particular not known, how the fit behaves under conditions that lead to the strongest warming. There are often statements that 2-3% of contrails contribute 80% of the overall EF, but whether this statement is tenable cannot be judged without an analysis of the residuals.*

   I do not expect that the "RF model" will be thoroughly tested for the current paper, but these tests should certainly by placed on the agenda for the near future. For the present paper I expect to see a section in the discussion where these issues are discussed and I expect that statements that are based on results of this RF model are turned moderate.

- Thank you for this feedback. We have decided to retain the term “parametric RF model” in the revised manuscript to remain consistent with Schumann et al. (2012) while clarifying that this model is indeed a fit to the libRadtran radiative transfer package. Additionally, we have also included a discussion on the sensitivity of $EF_{contrail}$ to various factors and emphasise that both contrail lifetime and RF influence the $EF_{contrail}$ estimates.
- We acknowledge your concerns about potential overfitting and the lack of testing against independent profiles. These issues can be captured within the Monte Carlo simulation framework, for example, using the approach of a recent study which evaluated the $EF_{contrail}$ uncertainties resulting from the parametric RF model and other sources (meteorology, emissions, and model parameter uncertainties) (Platt et al.,

2024). We have noted this approach as part of the future roadmap to improve the grid-based CoCiP (see Lines 256 – 257 and 562 – 563 of the revised manuscript).

- Finally, we have adjusted the EF$_{\text{contrail}}$ values in the revised manuscript, reducing the precision from three to two significant figures, to better reflect the underlying uncertainties.

- The following changes has been made in the revised manuscript:
  - [Main text: Lines 121 – 123] "~~At each time step, a~~ parametric RF model**, which is fitted to the libRadtran radiative transfer package (Mayer and Kylling, 2005), is used to** estimate~~s~~ the local contrail SW and LW RF (RF', the change in radiative flux over the contrail coverage area) **at each time step** (Schumann et al., 2012a)~~,~~**.**"
  - [Main text: Lines 129 – 142] "The EF$_{\text{contrail}}$ is estimated by **integrating the** ~~multiplying~~ local contrail net RF' **over** ~~by~~ its contrail segment length (*L*)**,** ~~and~~ width (*W*)**,** and ~~integrated over its~~ lifetime ($t_{\max}$) (Schumann et al., 2011),

    $$\mathrm{EF}_{\text{contrail}}\ [\mathrm{J}] = \int_0^{t_{\max}} \mathrm{RF}'_{\text{net}}(t) \times L(t) \times W(t)\, \mathrm{d}t. \tag{4}$$

    ~~The estimated $\mathrm{RF}'_{\text{net}}$ and EF$_{\text{contrail}}$ account for the presence of natural cirrus above/below the contrail (Schumann et al., 2012), and recent CoCiP studies have further formulated an approach to approximate the change in contrail $\mathrm{RF}'_{\text{net}}$ due to contrail-contrail overlapping (Schumann et al., 2021; Teoh et al., 2024a). For this study, w~~**W**e note that the EF$_{\text{contrail}}$ is ~~contrail diffusivity, ice crystal loss rate, lifetime, and climate forcing are~~ sensitive to **several factors, including the: (i) contrail RF' estimates from the fitted parametric RF model; (ii) humidity fields from the NWP model, which affects the contrail $t_{\max}$ and coverage area (*L* and *W*); and (iii)** ~~the~~ contrail segment angle (α), **which is** the angle between the contrail segment and the longitudinal axis~~)~~. **For (iii),** ~~because~~ α influences the magnitude of wind shear acting **perpendicular** ~~normal~~ to the contrail segment ($\frac{dS_{\mathrm{n}}}{dZ}$) (Schumann, 2012),

    $$\frac{dS_{\mathrm{n}}}{dZ} = \frac{dV}{dZ}\cos(\alpha) - \frac{dU}{dZ}\sin(\alpha), \tag{5}$$

    where $\frac{dV}{dZ}$ and $\frac{dU}{dZ}$ **represent** ~~are~~ the ~~magnitude of~~ wind shear acting on the eastward and northward direction respectively. **The $\frac{dS_{\mathrm{n}}}{dZ}$, in turn, influences the contrail's spreading rate, ice crystal loss rate, and $t_{\max}$. Consequently, contrails with a large EF$_{\text{contrail}}$ are generally long-lived with a large coverage area, while short-lived contrails with a large positive net RF' may have a negligible EF$_{\text{contrail}}$ (Teoh et al. 2020a).**"
  - [Main text: Lines 250 – 257] "**We note that the uncertainties in the simulated EF$_{\text{contrail}}$ can arise from multiple independent sources, including meteorological inputs provided by NWP models, aircraft performance and emissions estimates, contrail model simplifications, the parametric RF model fitted to the libRadtran radiative transfer package, and potentially other unidentified factors (Low et al., 2024; Platt et al., 2024; Schumann et al., 2021; Teoh et al., 2020b, 2024a). While Platt et al. (2024) evaluates various uncertainty sources affecting EF$_{\text{contrail}}$ in an earlier implementation of the grid-based CoCiP, the Monte Carlo simulations in this study focus only on uncertainties related to meteorological inputs and**

the grid-based model simplifications (i.e., aircraft-engine groups and the treatment of α) as a proof of concept. Future updates to the grid-based CoCiP will incorporate additional uncertainty sources to improve the model's robustness. "

  - [Main text: Lines 562 – 563] "Future versions of the grid-based CoCiP are also expected to be prioritised towards: (i) accounting for **different** ~~contrail model~~ uncertaint~~yies~~ **sources** within the ~~framework of the~~ Monte Carlo **contrail** simulation **framework** (Platt et al., 2024);"

2. *Some parts of the model are much more detailed than others. For instance, details on aircraft/engine combinations up to engine details are required as input in order to make a precise prediction of the emission rate of NvPMs. At the same time, the precision of the weather input is certainly much lower (vertical resolution is low, hourly output, problems with the field of relative humidity, etc.), the ERF/RF ratio can only be estimated, other quantities have a very wide 5-95% confidence interval. It seems that this combination of very precise vs quite imprecise parts may lead to funny results. I was puzzled, on page 22, that in the first paragraph some quite uncertain parameters are used while in the next paragraph results are given with a very high precision, e.g. 213,357 +- 0.03 kg. Considering, for instance, the range of social carbon cost, roughly 44 to 410 USD, I would suggest that of the 213,357 kg maybe the first digit is valid, but not more.*
I would like to see what the authors think about this mixture of very detailed vs. very uncertain parts of their model.

   - Detailed engine information is crucial, as the nvPM number emissions index (EI_n) can vary by up to five orders of magnitude between different aircraft-engine types. We note that the aircraft-engine grouping in the grid-based CoCiP reduces the precision of the nvPM EI_n estimates.

   - Nevertheless, we acknowledge that differences in both the accuracy and precision of the different input parameters (fuel consumption, nvPM, and meteorology) would propagate to the estimated $EF_{contrail}$ from the grid-based CoCiP. To incorporate this feedback, we have rounded the reported $EF_{contrail}$ to 1–2 significant figures. Additionally, we have rounded the total CO_2 mass-equivalent estimates (including both fuel and contrail climate forcing) are rounded to the nearest tonne, rather than rounding to the first digit as suggested by the reviewer, because the accuracy of CO_2 emissions from burning fuel can be estimated to within ±10%, as indicated in an in-house analysis by comparing the aircraft performance model with flight data recorders.

   - We also acknowledge the significant uncertainties in the ERF/RF ratio. By providing a range for the ERF/RF ratio, end users have the option to use the lower bound for a more conservative estimate of the contrail climate effects.

   - We note that the social cost of carbon is included in the text solely to enable end users to monetise the $EF_{contrail}$ if necessary, and it is not required to calculate the CO_2 mass-equivalent emissions.

   - The following changes have been made to the revised manuscript:

- [Main text: Lines 447 – 464] “The 4D $\mathrm{EF}_{\mathrm{contrail}}$ per flight distance fields (shown in Fig. 4a) take the form of a standard weather forecast field and can be incorporated into the flight trajectory optimizer as an additional cost factor alongside existing cost parameters such as the fuel consumption and overflight charges (Martin Frias et al., 2024). To do so, flight planners can convert the $\mathrm{EF}_{\mathrm{contrail}}$ to a CO_2 mass-equivalent ($m_{\mathrm{CO_2}\ \mathrm{eq},\mathbf{contrails}}$) (Teoh et al., 2024a),

  $$m_{\mathrm{CO_2}\ \mathrm{eq},\mathbf{contrails}}\ [\mathrm{kg}] = \frac{\mathrm{EF}_{\mathrm{contrail}} \times (\frac{\mathrm{ERF}}{\mathrm{RF}})}{\mathrm{AGWP}_{\mathrm{CO_2,TH}} \times S_{\mathrm{Earth}}}, \qquad (8)$$

  where the **global mean** ERF/RF ratio of 0.42 **is used** ~~applied~~ as a best estimate ~~value~~ to convert the RF to an ERF estimate (Lee et al., 2021). **Given the significant uncertainties in the global mean ERF/RF ratio (ranging from 0.21 to 0.59, based on four global climate model studies) (Bickel, 2023; Bickel et al., 2019; Ponater et al., 2005; Rap et al., 2010) and its spatiotemporal variabilities, flight planners can choose the lower bound to conservatively incorporate the contrail climate effects.** $\mathrm{AGWP}_{\mathrm{CO_2,TH}}$ is the CO_2 absolute global warming potential over a selected time horizon (TH) (7.54×10^{-7} J m^{-2} per kg-CO_2 for 20 years, or 2.78×10^{-6} J m^{-2} per kg-CO_2 for 100 years) (Gaillot et al., 2023), and S_{Earth} is the Earth surface area (5.101×10^{14} m^2). If necessary, the $m_{\mathrm{CO_2,eq}}$ can be further converted to a monetary value by multiplying it with the social cost of carbon ($\mathrm{SC}_{\mathrm{CO_2}}$), which **we assume to be** ~~is around~~ US$ 185 [US$ 44 – 413, 5–95% range] per tonne of CO_2 (Rennert et al., 2022). Here, we apply Eq. (8) in the ~~flight~~ trajectory optimizer to minimise the total CO_2 **mass-equivalent** emissions ($m_{\mathrm{CO_2,total}} = m_{\mathrm{CO_2,fuel}} + m_{\mathrm{CO_2,eq}}$), ~~and~~ assum**ing**~~e~~ a 100-year time horizon for the CO_2 AGWP**, and rounding the results to the nearest tonne to align with the precision of the input parameters**. We note that this is only one example of cost function, and that many other metrics are possible. The task of defining an appropriate cost function to assess trade-offs between contrail and CO_2 climate forcing remains a critically important topic for future research.”

- [Main text: Lines 466 – 472] “Using this cost-based approach, the flight trajectory optimizer successfully lowered the $m_{\mathrm{CO_2}\ \mathbf{eq},\mathrm{total}}$ by 64%, from 597~~,198~~ **tonnes** ~~kg~~ (203~~,285~~ **tonnes** ~~kg~~ of CO_2 emitted from the total fuel consumed + **394**~~393,913~~ **tonnes** ~~kg~~ from contrails) in the original trajectory to 213~~,357~~ **tonnes** ~~kg~~ (213~~,357~~ **tonnes** ~~kg~~ + 0~~.03 kg~~ **tonne**) in the optimized trajectory. In simpler terms, more than 99.9% of the total $\mathrm{EF}_{\mathrm{contrail}}$ (1.3~~3~~ $\times 10^{15}$ J in the original trajectory vs. 1.04×10^{8} J in the optimized trajectory) is mitigated at the expense of a **5**~~4.7~~% increase in total fuel consumption. This is achieved by: (i) lowering the cruise altitude from 36,000 to 30,000 feet between 02:45 and 05:00 UTC; followed by (ii) a further descent to 28,000 feet between 05:00 UTC and 06:30 UTC to avoid regions forecasted with persistent warming contrails; and then (iii) climbing to a final cruise altitude of 40,000 feet at around 06:30 UTC ~~to minimise the fuel consumption rate~~ (Fig. 8a).”

- [Main text: Lines 481 – 486] “Using the 80th percentile contrail-avoidance polygons, the optimizer recommends a trajectory that reduces $m_{\mathrm{CO_2,total}}$ by 6**0**~~1~~%, from 597~~,198~~ **tonnes** ~~kg~~ (203~~,285~~ **tonnes** ~~kg~~ of CO_2 emitted from the total fuel consumed + **394** ~~393,913~~ **tonnes** ~~kg~~ from contrails) in the original trajectory to **236** ~~235,782~~ **tonnes** ~~kg~~ (207~~,379~~ **tonnes** ~~kg~~ + 28~~,403~~ **tonnes** ~~kg~~)

in the optimized trajectory. Put differently, 93% of the total $\mathrm{EF}_{\mathrm{contrail}}$ (1.3~~3~~ $\times 10^{15}$ J in the original trajectory vs. 9.**6**~~59~~ $\times 10^{13}$ J in the optimized trajectory) is avoided with a fuel penalty of 2~~.0~~% ~~(Fig. 8b)~~. This approach involves lowering the cruise altitude from 36,000 to 30,000 feet between 03:00 and 05:00 UTC, followed by a step climb to 40,000 feet at 05:00 UTC to exploit a gap in the contrail-avoidance polygon **(Fig. 8b)**."

Special comments and questions

3. *General: Please be careful to distinguish between strong radiative/energy forcing vs. warming/climate impact. As contrails might have a low efficacy and as that may depend on location and situational circumstances (feedbacks), strong forcing and strong warming are not equivalent.*

   - Thank you for highlighting this important distinction. After careful consideration, we have decided to retain the term "strongly warming contrails" rather than changing it to "strongly forcing contrails", primarily because it is more intuitive for a broader audience. In contrast, "strongly forcing contrails" could imply a large positive or negative value, which may be less clear.

   - However, we also recognise the need to clarify that in this study, the terms "warming/cooling" refers to the change in net energy balance at the top of the atmosphere (TOA) and the actual surface temperature change depends on the contrail efficacy and spatiotemporal factors. Therefore, we have revised the introduction to make this distinction clear:

     - [Main text: Lines 60 – 66] "Recently, Teoh et al. (2024a) used CoCiP to simulate contrails globally for 2019, estimating that around 20% of all flights produced persistent contrails. Among these persistent contrail-forming flights, 70% of them (17% of all flights) had a net warming effect and 10% of them (2.7% of all flights) were responsible for 80% of the global annual contrail energy forcing ($\mathrm{EF}_{\mathrm{contrail}}$~~;~~**)**. ~~i.e., t~~**The $\mathbf{EF}_{\mathbf{contrail}}$ represents** the cumulative contrail climate forcing over its lifetime**, with a positive value indicating more energy entering the Earth system than leaving it. We use the terms "warming/cooling" effect to describe this net energy balance at the top of the atmosphere, while acknowledging that the actual surface temperature change depends on the contrail efficacy and spatiotemporal factors (Bickel et al., 2019; Ponater et al., 2005, 2021; Schumann and Mayer, 2017)**."

4. *L 42: Isn't a negative exponential distribution simply an exponential distribution?*

   - Thank you for highlighting this. We initially used the term "negative exponential distribution" to emphasize that the distribution declines as contrail age increases. However, upon further investigation, we agree that the terms "exponential distribution" is the correct term and refers to the same concept. We have revised this sentence accordingly:

     - [Main text: Lines 39 – 40] "These persistent contrails exhibit lifetimes that generally follow a**n** ~~negative~~ exponential distribution with a mean duration of 1–3 h (Caiazzo et al., 2017; Teoh et al., 2024a; Vázquez-Navarro et al., 2015)."

5. *L 44: What exactly is meant with the word "localised"?*

   - Thank you for pointing this out. In the context, we used the word "localised" warming effect to refer to the immediate warming effect of persistent contrails on the surrounding air, as opposed to the delayed warming effect on the Earth's surface. However, we realise that this distinction may not be necessary and have decided to remove the word "localised" to prevent confusion:
     - [Main text: Lines 40 – 43] "**During daylight hours, persistent contrails can cause a cooling effect by reflecting incoming shortwave (SW) solar radiation back to space. However, they** ~~Persistent contrails~~ always induce a ~~localised~~ warming effect by absorbing and re-emitting outgoing longwave (LW) infrared radiation~~. They can also cause a cooling effect during daylight hours by reflecting incoming shortwave (SW) solar radiation back to space~~ (Meerkötter et al., 1999)."

6. *L 50ff: The sentence is a bit misleading. Both satellite images and ground based cameras cannot only observe contrail formation, they see old contrails as well when they move through the field of view. That one is currently not able to integrate RF over a contrail's lifetime, is another - independent - issue. Perhaps it is just infeasible for long-living contrails, but in principle it seems possible to me. I have also problems to see the connection between this sentence and the remaining ones in this paragraph.*

   - Thank you. We agree with this feedback and have revised this paragraph to clarify that: (i) satellites and ground-based cameras can observe both contrail formation and evolution; and (ii) the only approach currently available to estimate the cumulative contrail climate forcing is through simulation-based estimates:
     - [Main text: Lines 47 – 50] "**While** ~~O~~observational tools such as satellite imagery and ground-based cameras **have been used for observing** ~~offer the means to monitor~~ contrail formation and ~~early~~ evolution (Duda et al., 2019; Mannstein et al., 2010; Rosenow et al., 2023; Schumann et al., 2013b; Vázquez-Navarro et al., 2015), **estimates of the cumulative contrail climate forcing over their entire lifecycle are currently only available through simulation-based models.** ~~but they are currently unable to determine the RF over a contrail's lifetime.~~"

7. *L 66 ff: The first contrail avoidance trial was the MUAC/DLR trial, not the American Airlines trial. Moreover, the MUAC/DLR trial is, as far as I am aware of, the only one that was thorougly analysed and the experiment and analysis is published in a peer-reviewd paper by Sausen et al. (Can we successfully avoid persistent contrails by small altitude adjustments of flights in the real world? Meteorol. Z., 33(1), 83-98. 10.1127/metz/2023/1157). This paper instead of the grey literature should be cited here. If you know of other peer-reviewed analyses of such trials, please let the reader know.*

   - Thank you for bringing this to our attention. We have replaced the previous citation (Lokman, 2022) with the peer-reviewed journal article (Sausen et al., 2023):
     - [Main text: Lines 68 – 70] "While two small-scale operational contrail avoidance trials have been conducted in recent years (American Airlines, 2023;

~~Lokman, 2022;~~ **Sausen et al., 2023**), several challenges must be addressed to implement a contrail-minimisation strategy at a larger-scale."

- Additionally, please note that the "Copernicus Publication" citation style lists references in alphabetical order, so the order of citations should not be interpreted as indicating the timeline of the trials.

8. *L 68 ff: I find the rest of this paragraph a bit too optimistic. It appears as when the list of current problems is quite short and that they are easily solvable by selecting a certain kind of format for model output.*

- Thank you for this feedback. We have revised the manuscript accordingly:
    - [Main text: Lines 70 – 78] "**These** ~~Such~~ challenges include ~~the~~: (i) integrati**ng**~~on of~~ a contrail forecast model into flight planning and management software to **account for airspace and operational constraints**~~ optimize flight trajectories~~; (ii) automati**ng**~~on of operational~~ **airspace** procedures to perform trajectory adjustments**, which is necessary to reduce air traffic controller workload** (~~Lokman, 2022;~~ Molloy et al., 2022**; Sausen et al., 2023**); ~~and~~ (iii) **incorporating** ~~inclusion of~~ meteorological and contrail forecast uncertainties in**to** the decision-making framework for contrail mitigation actions (Agarwal et al., 2022; Gierens et al., 2020; Molloy et al., 2022)**; and (iv) balancing trade-offs between reducing contrail climate forcing and potential increases in fuel consumption**. ~~All three c~~Challenges **(i) to (iii) could** ~~can effectively~~ be addressed **by providing** ~~if the~~ contrail climate forcing forecasts ~~can be provided~~ in a format similar to turbulence forecasts (Turbli, 2024), **thereby facilitating their integration** ~~so that they can be readily integrated~~ into the operational workflow of existing flight planning software (Martin Frias et al., 2024)."

9. *Figure 3: Please explain the strange structures around x,y=+-10(-7).*

- The axes in this figure use a logarithmic scale for $|\mathrm{EF}_{\mathrm{contrail}}| > 10^{7}$ J m^{-1} and a linear scale between 10^{-7} and 10^{7} J m^{-1}. To address this comment, we have updated the figure caption to clarify that the box-like structures around 10^{-7} and 10^{7} J m^{-1} result from the transition between the linear and logarithmic scales:
    - [Main text: Lines 303 – 307] "Figure 3: Pointwise errors between $\mathrm{EF}_{\mathrm{contrail}}^{\mathrm{traj}}$ and $\mathrm{EF}_{\mathrm{contrail}}^{\mathrm{grid}}$ when the grid-based CoCiP is configured: (a) using the exact/original aircraft-engine types (i.e., the same as the trajectory-based CoCiP); and with (b) N=7; (c) N=3; and (d) N=1 aircraft-engine groups respectively. Each panel contains 10,000,000 randomly-sampled flight waypoints. The axes use a logarithmic scale for $|\mathrm{EF}_{\mathrm{contrail}}| > 10^{7}$ J m^{-1} and a linear scale between 10^{-7} and 10^{7} J m^{-1}. **For both axes, the box-like structures observed around 10^{-7} and 10^{7} J m^{-1} arise from the transition between the linear and logarithmic scale.**"

10. *L 365 ff: Please reformulate this sentence "The 2019 ...". It is not clear what you mean.*

- Thank you for highlighting this. We have revised this paragraph for clarity improvements:
    - [Main text: Lines 389 – 396] "Unlike a map of the ISSR coverage area, which identifies regions **likely** ~~prone~~ to **form** persistent contrails ~~formation~~, the 4D $\text{EF}_{\text{contrail}}$ per flight distance **accounts for the intensity of contrail-induced warming and allows for more** ~~estimates the expected contrail climate forcing of flying through a specific airspace. This approach enables~~ targeted mitigation**. For example, in 2019, the** ~~by identifying regions forecast to produce strongly warming contrails (i.e., grid cells with $\text{EF}_{\text{contrail}}$ greater than the 80th percentile), rather than all persistent contrails. When considering navigational contrail avoidance, this approach minimises potential disruptions to air traffic management and airspace capacity. The 2019~~ global annual mean percentage of airspace volumes forecasted with strongly warming contrails **was**~~, i.e.,~~ 0.44% for $\text{EF}_{\text{contrail}}$ > **95th percentile (**1.54×10^{9} J m^{-1} ~~(95th percentile~~), **and** 1.6% for $\text{EF}_{\text{contrail}}$ > **80th percentile (**5.0×10^{8} J m^{-1} ~~(80th percentile~~)**. These values are up to 91% smaller than the airspace volumes with net warming contrails (**~~, and~~ 4.8% for $\text{EF}_{\text{contrail}} > 0$ ~~(net warming contrails~~), **and** ~~are~~ up to 93% smaller than the ISSR coverage area (6.6%, for $\text{EF}_{\text{contrail}} \neq 0$) (Fig. 5a). **Thus, using this approach to navigational contrail avoidance could minimise potential disruptions to air traffic management and airspace capacity, as it focuses only on the most warming contrails rather than avoiding all persistent contrails.**"

11. *L 386 ff: It is counterintuitive that areas with high cirrus coverage lead to strongly warming contrails. Please explain.*

- We have revised this paragraph to explain how regions with high albedo, which includes areas with high natural cirrus coverage, can increase the likelihood of strongly warming contrails:
    - [Main text: Lines 416 – 423] "Background radiation fields, such as the solar direct radiation (SDR), ~~reflected solar radiation (~~RSR~~)~~, ~~outgoing longwave radiation (~~OLR~~)~~ and albedo (RSR/SDR), are **mainly** influenced by latitude, natural cirrus occurrence, and surface temperature and **reflectance** ~~albedo~~. In general, **strongly warming contrails are more likely in** regions with**: (i)** ~~a~~ high~~er~~ ~~relative~~ albedo (e.g., poles, Siberia, and areas with high natural cirrus coverage)~~,~~**; (ii) high** OLR (e.g., tropics and the Sahara Desert)~~,~~**;** and **(iii)** ~~a~~ low~~er relative~~ SDR (e.g., wintertime) ~~tend to exhibit more strongly warming contrails~~ (Fig. 6 and 7). **Condition (i) limits the contrail SW RF because a higher proportion of incoming solar radiation is already reflected without contrails, while condition (ii) drives the contrail LW RF especially in cloud free conditions.** In contrast, regions and times with a larger relative SDR-to-OLR ratio (e.g., Southeast Asia, springtime at high latitudes) are associated with ~~more~~ strongly cooling contrails (Fig. 7b, 7d, and 7f)."

12. *P 22: The precision of the quoted input and output values does not fit together, see major comment above.*

- Thank you. We have addressed this in Comment 2.

13. *L 521/22: I am pleased that the authors acknowledge this necessity and agree completely!*
    - Thank you.

14. *L 636: Please try to find a combination of entries in a contingency table that results in ETS=-1. If you find one, please let the reader know.*
    - Thank you for highlighting this. After further investigation, we confirm that an ETS score of -1 represents a theoretical lower bound and have revised this paragraph to clarify this point:
        - [Main text: Lines 709 – 713] "The ERA5-corrected RHi from both methodologies (i.e., global humidity correction and quantile mapping) were compared against in-situ RHi measurements from the mid-latitude region (30°N – 70°N and 125°W – 145°E) (Hofer et al., 2024). These comparisons ~~were conducted~~ us**ed**~~ing~~ the equitable threat score (ETS) metric, where an ETS **score of** = 1 **represents** ~~suggests~~ a perfect agreement between the ERA5-corrected and in-situ RHi **measurements**, an ETS **score of** = 0 suggests a random **agreement** ~~relationship~~, and an ETS **score below 0 signifies** ~~= -1 suggests~~ an inverse relationship."

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