EDITOR 1 (EC1) RESPONSE

Dear authors,

As the topical editor, I am guiding the review process of your article and will rely on the feedback of the independent reviewers. However, as a scientist, I am also following your work with great interest. I would like to start a discussion and get your view on the similarities and differences in the approach you followed with the CoCiPGrid modelling and the work that we were doing in setting up, what we called, climate change functions (CCF, earlier also called climate cost functions, but then renamed later due to stakeholder feedbacks). Both are Lagrangian approaches, where atmospheric (physical and chemical) processes are considered in advected air parcels and a metric on the radiation change is mapped back to the emission grid. This enables this kind of "short-cut" or parametric link between a local aviation emission and induced changes in the radiative budget over the lifetime of the considered effects with respect to the advected air parcel.

Note this should not be confused with the more simplified approach of the algorithmic climate change functions (aCCF) that constitute a statistical relation between the meteorology at time of emission and the estimated CCF value.

Hence, for the sake of clarity, there are two points that might be of interest to science and to stakeholders (e.g. airspace users):

1. *What are the similarities and differences in the modelling approaches of CoCiPGrid and CCF?*
2. *If the modelling approaches are similar, would it make sense to use one common language and name this specific modelling in a similar way?*

CCF modelling approach:

Grewe, V., Frömming, C., Matthes, S., Brinkop, S., Ponater, M., Dietmüller, S., Jöckel, P., Garny, H., Dahlmann, K., Tsati, E., Søvde, O. A., Fuglestvedt, J., Berntsen, T. K., Shine, K. P., Irvine, E. A., Champougny, T., and Hullah, P.: Aircraft routing with minimal climate impact: The REACT4C climate cost function modelling approach (V1.0), Geosci. Model Dev. 7, 175-201, doi:10.5194/gmd-7-175-2014, 2014.

CCF Modelling results:

Frömming, C., Grewe, V., Brinkop, S., Jöckel, P., Haselrud, A.S., Rosanka, S., van Manen, J., and Matthes, S., Influence of the weather situation on non-CO_2 aviation climate effects: The REACT4C Climate Change Functions, Atmos. Chem. Phys. 21, 9151-9172, https://doi.org/10.5194/acp-21-9151-2021, 2021.

Final remark:

Note that due to my role as topical editor this comment will not influence any decision on a potential acceptance of the publication.

Volker Grewe

- Thank you for this feedback and suggestion. We should have included the these papers in the original manuscript, which are highly relevant. Here, we compare the similarities and differences between the grid-based CoCiP and climate change functions (CCF), focusing specifically only on contrail modelling.
- We have identified the several similarities between the grid-based CoCiP and CCFs:
    i. Both approaches use a Lagrangian framework and parameterised physics to simulate contrails,
    ii. Both simulate the contrail climate forcing throughout their full lifecycle and attribute these effects back to the original grid cell, and
    iii. Both produce a map of regions forecast with warming and cooling contrails, subsequently using it as a cost function for optimising flight trajectories.
- The main differences between the grid-based CoCiP and CCFs are as follows:
    i. The grid-based CoCiP uses reanalysis and forecast data, while CCFs rely on representative weather patterns in the North Atlantic,
    ii. CCFs include second-order effects, such as contrail-atmosphere humidity exchange, changes in temperature lapse rate, and changes in natural cirrus occurrence and properties, all of which are not accounted for in the grid-based CoCiP which runs in an offline mode, and
    iii. CCFs can compute the effective radiative forcing and surface temperature effects, while the grid-based CoCiP only calculates the instantaneous radiative forcing, and
    iv. The grid-based CoCiP includes different aircraft-engine groups, accounting for variations in aircraft mass, overall efficiency, and nvPM number emissions, which can affect the simulated contrail properties as supported by measurements and observations (Gryspeerdt et al., 2024; Jeßberger et al., 2013; Märkl et al., 2024), whereas nvPM effects are not captured in the CCF.
- In summary, both approaches have their strengths and limitations and are suited to different purposes. For example, CCFs may provide a more accurate representation of the contrail climate effects than the grid-based CoCiP, as they account for atmospheric interactions and second-order effects. However, this comes at the expense of significantly greater computational demands, where CCFs require approximately 3.3 CPU hours to compute the aviation-induced climate effects per grid cell and per time slice, as estimated from Section 2.5 of Frömming et al. (2021). The grid-based CoCiP takes around 10 CPU minutes to compute the global 3D $EF_{contrail}$ (0.25° × 0.25° × 18 pressure levels) for each time slice. The large computational demands of CCFs potentially reduces their viability for real-time flight trajectory optimization, unless it is applied in the form of algorithmic climate change functions (aCCF). Additionally, the lower spatiotemporal resolution of the CCFs (168 grid points × 3 emission times) compared to the grid-based CoCiP, which uses ERA5 meteorology (0.25° longitude × 0.25° latitude × 18 pressure levels × 1 h) in our implementation in this manuscript, may limit the CCF's ability to accurately capture the structure and location of ice supersaturated regions (Wolf et al., 2024). Nevertheless, it should also be noted that

the spatiotemporal resolution of the ERA5 HRES is also not high enough to fully address these limitations.

- We agree that the both grid-based CoCiP and CCFs aim to quantify the contrail climate effects, albeit using different metrics ($\mathrm{EF}_{\mathrm{contrail}}$ versus ATR, AGTP, and AGWP). However, we have decided against using a common naming convention to delineate the differences between the instantaneous radiative effects and longer feedbacks. While we can roughly convert $\mathrm{EF}_{\mathrm{contrail}}$ to other climate metrics that can account for second-order and longer-term climate feedback, we aim to create a stronger link between the computationally efficient $\mathrm{EF}_{\mathrm{contrail}}$ calculation and the more rigorous CCF calculations in future work. This has now been mentioned in the conclusions. We have made the following changes in the revised manuscript to incorporate these comments:
    - [Main text: Lines 50 – 58] "~~To simulate the full contrail lifecycle and climate forcing, earlier studies have relied on~~ **Various** physics-based modelling approaches **have been employed for this purpose**, including**: (i)** large-eddy simulations (LES) (Lewellen, 2014; Lewellen et al., 2014; Unterstrasser, 2016)**; (ii)** ~~and~~ parameterised Lagrangian models such as the Contrail Cirrus Prediction Model (CoCiP) (Schumann, 2012), Contrail Evolution and Radiation Model (CERM) (Caiazzo et al., 2017), and Aircraft Plume Chemistry, Emissions, and Microphysics Model (APCEMM) (Fritz et al., 2020)**; and (iii)** ~~. Contrails have also been parameterized in~~ general circulation models (GCMs) **which simulate the interactions between contrails and different atmospheric** ~~to capture the physical~~ processes ~~of the atmosphere and longer-range spatiotemporal~~**, including second-order** feedback **mechanisms** (Bier and Burkhardt, 2022; Chen and Gettelman, 2013; **Grewe et al. 2014;** Ponater et al., 2021). **Specifically, approaches (ii) and (iii) have been applied to investigate the spatiotemporal variations in contrail climate effects and used for flight trajectory optimisation purposes (Frömming et al., 2021; Grewe et al., 2017; Schumann et al., 2011; Teoh et al., 2020b).**"
    - [Main text: Lines 86 – 89] "~~The~~ **Our** contrail forecasting **tool uses** ~~strategy is based in~~ a Lagrangian model instead of LES and GCMs **for two key reasons: (i)** ~~because~~ it can **utilise** ~~most efficiently compute the $\mathrm{EF}_{\mathrm{contrail}}$ using~~ reanalysis or forecast meteorolog**ical**~~y~~ **data** provided by numerical weather prediction (NWP) models**, rather than relying on representative weather conditions from GCMs (Grewe et al., 2014); and (ii) it can compute the $\mathrm{EF}_{\mathrm{contrail}}$ efficiently within the time constraints required for flight planning and operational use**."
    - [Main text: Lines 527 – 535] "To implement this mitigation strategy in the real-world, we developed a tool that **uses reanalysis or forecast meteorology to** generate~~s~~ global maps **of** ~~forecasting regions with~~ persistent contrail~~s~~ ~~and their~~ **climate forcing within the timeframe necessary for flight planning and operational deployment**. This is achieved by extending the existing trajectory-based CoCiP, which simulates contrails formed along flight trajectories, to a grid-based approach, which initializes an infinitesimal contrail segment at every point in a spatiotemporal grid and simulates the contrail climate forcing over its lifecycle. The model outputs of the grid-based CoCiP (i.e., the 5D $\mathrm{EF}_{\mathrm{contrail}}$ per flight distance with dimensions of longitude × latitude × altitude × time × *N* aircraft-engine groups) are **similar to the concept of climate change functions (CCF) introduced in previous studies (Frömming et al., 2021;**

Grewe et al., 2014), and provided in a format that is consistent with standard weather and turbulence forecasts so it can be readily integrated into existing flight planning software."

- [Main text: Lines 537 – 544] "Our comparison of the $EF_{contrail}$ estimates between the grid-based and trajectory-based CoCiP demonstrates a good agreement for use as a prototype contrail forecasting tool (Table 4). When the grid-based CoCiP is configured with $N \geq 7$, the mean error across all performance metrics is up to 3% when compared with the configuration without any aircraft-engine grouping. Alternatively, a configuration of $N = 3$ for the grid-based CoCiP provides operational simplicity for end users, but this comes at an expense of increasing the mean error across all metrics to 13%. **While the model simplifications required for the grid-based CoCiP inevitably lead to additional uncertainties in the absolute $EF_{contrail}$ values, we consider their relative spatiotemporal variabilities to be more relevant for the study's objective of identifying regions with strongly warming contrails (i.e., $EF_{contrail}$ > 80th or 95th percentile) for flight trajectory optimisation (Grewe et al., 2014).**"
- [Main text: Lines 557 – 562] "We acknowledge that the widespread adoption of our contrail forecasting tool in real-world operations depends on a successful validation of its predictions against independent observations. The ongoing focus on observational validation for both CoCiP variants underscores the active efforts in this critical area. **While multiplying the $EF_{contrail}$ by the ERF/RF ratio, c.f., Eq. (8), was used in this study to provide a highly approximate estimate of second-order and longer-term climate feedback, our future work aims to establish a stronger connection between this computationally efficient $EF_{contrail}$ calculation and the more rigorous CCF calculations (Frömming et al., 2021).**"

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