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DOI
10.5194/egusphere-egu23-9246

Publication date
2023

Document Version
Final published version

Citation (APA)
Maruhashi, J., Mertens, M., Grewe, V., & Dedoussi, I. C. (2023). *Assessing the appropriateness of different climate modelling approaches for the estimation of aviation NOx climate effects*. Abstract from EGU General Assembly 2023, Vienna, Austria. https://doi.org/10.5194/egusphere-egu23-9246

EGU General Assembly 2023

EGU23-9246, updated on 12 Jun 2023
https://doi.org/10.5194/egusphere-egu23-9246
EGU General Assembly 2023

Assessing the appropriateness of different climate modelling approaches for the estimation of aviation NO_x climate effects

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Aviation's contribution to anthropogenic global warming is estimated to be between 3 – 5% [1]. This assessment comprises two contributions: the well understood atmospheric impact of carbon dioxide (CO_2) and the more uncertain non-CO_2 effects. The latter pertain to persistent contrails and pollutants like nitrogen oxides (NO_x), water vapor (H_2O), sulfur oxides (SO_x) and soot particles. NO_x emissions are involved in non-linear processes that result in the short-term production of ozone (O_3) and longer-term destruction of methane (CH_4), stratospheric water vapor (SWV), and primary mode ozone (PMO). The aviation-attributable impacts arising from this short-term increase in O_3 can vary by more than a factor of 1.5 depending on the selected modelling approach. This O_3 increase is associated with the second largest warming effect across aviation's main climate forcers [1]. We therefore quantify this figure using three modelling approaches (an Eulerian and a Lagrangian tagging scheme as well as a perturbation approach) at three potential aircraft cruise altitudes (200, 250 and 300 hPa) at which NO_x pulse emissions are introduced in the Americas, Africa, Eurasia and Australasia. In general, the tagging method computes the contribution by an emission source to the concentration of a chemical species while a perturbation approach consists in calculating the total impact of an emission to the concentration of a species by means of subtracting two simulations: one with all emissions and a second without the specific source's emissions. We compare results from Eulerian and Lagrangian simulations using the same climate-chemistry code: the ECHAM5/MESSy Atmospheric Chemistry (EMAC) model. With the Eulerian setup, we are able to capture non-linear processes and feedback effects, but not track the transport of emitted species in detail. The Lagrangian setup [2], on the other hand, allows for the accompaniment of thousands of air parcel trajectories, but at the cost of assuming a simplified linear chemistry mechanism. We find that the Lagrangian tagging approach provides the largest estimates for O_3 production and radiative forcing (RF), followed by the Eulerian tagging scheme and lastly by the perturbation method. We therefore investigate the appropriateness of each of these in quantifying aviation's total and marginal climate effects by addressing the following research questions: 1) By how much are the estimates for the short-term NO_x-induced O_3 perturbation and consequent RF varying across the three modelling approaches and why? 2) How does this RF vary with emission altitude within the upper Troposphere/lower Stratosphere (UTLS)?

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