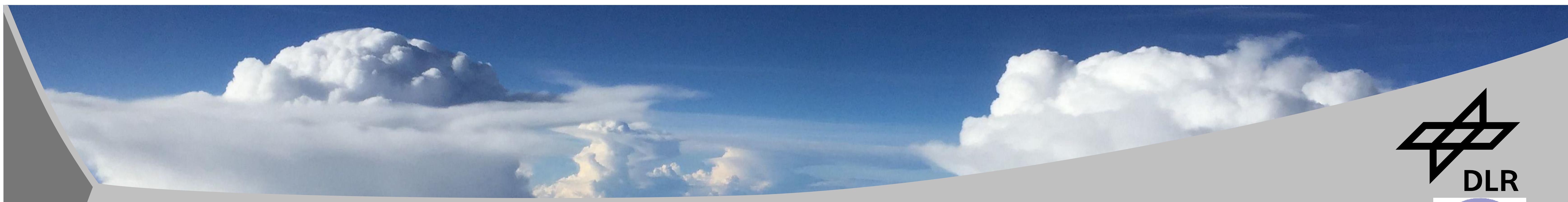

Mitigation of non-CO2 aviation’s climate impact by changing cruise altitudes

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- Aviation is seeking for ways to **reduce its climate impact** caused by CO_2 emissions and non-CO_2 effects. Operational measures which change overall flight altitude have the potential to reduce climate impact of individual effects, comprising CO_2 but in particular non-CO_2 effects. We study impact of **changes of flight altitude**, specifically aircraft flying 2000 feet higher and lower, with a set of chemistry-climate models integrating alternative emission scenarios.
- **Flying lower** is expected to reduce non-CO_2 effects together with slightly increased CO_2 emissions and impacts, in case cruise speed is not modified. **Flying higher** increases in our sensitivity study non-CO_2 effects by about 10%, while flying lower in our study decreases total climate impact by about 20%, due to decreasing non-CO_2 impacts (by about 30%).
- In order to **improve understanding** of mechanisms of aviation climate impact we present geographical distributions of aviation-induced perturbations, together with change in global climate impact.

Motivation and Scope

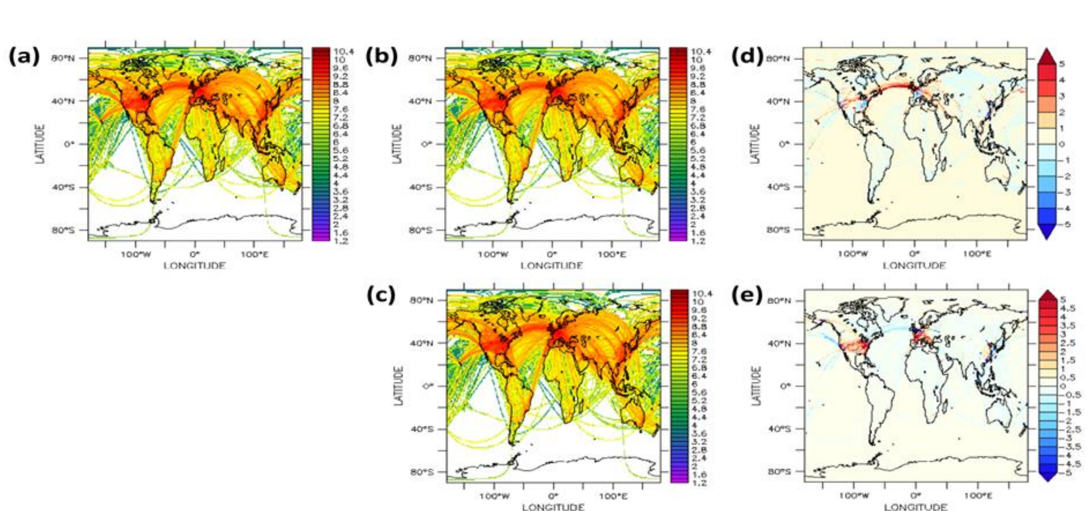


Figure: Global distribution of aviation NO_x emission: reference case (a, R4C), Flying higher (b), Flying lower (c); difference between ‘Flying higher’ and (d) ‘Flying lower’ and reference (e) [5].

- A **modelling concept** and scenarios are presented for assessing **how climate impact changes** when aircraft fly higher or lower compared to their standard flight altitude.
- The behaviour of **non-CO_2 effects** for flight altitude changes, comprising NO_x and contrail cirrus impacts in different regions are presented, as well as a quantitative estimate of indirect aerosol effect on warm clouds.

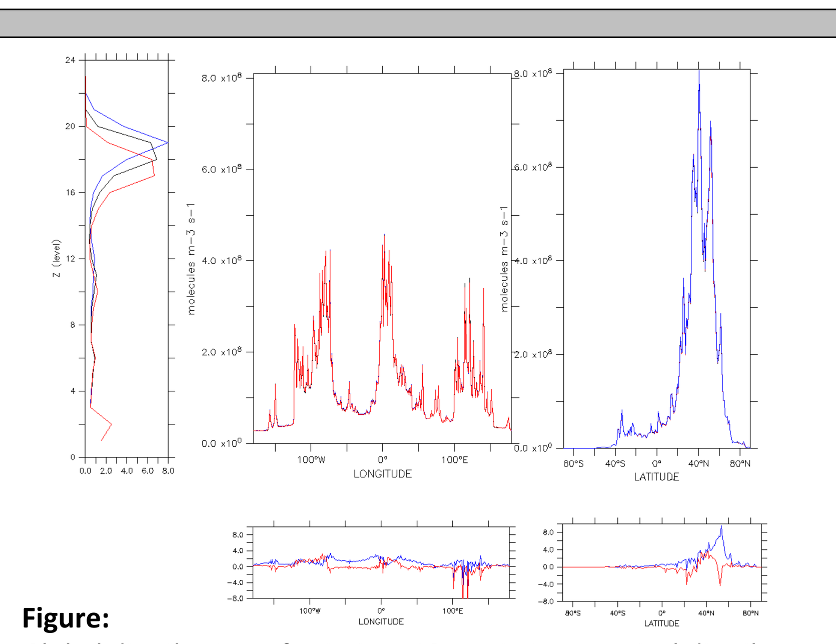
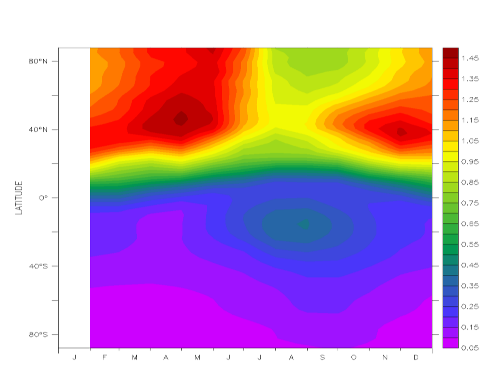


Figure: Global distribution of aviation NO_x emission; vertical distribution (left), meridional distribution (middle), zonal distribution (right): reference case (REACT4C, black), flying higher (blue), flying lower (red) and difference Higher-Ref and Lower-Ref (bottom row) [5].

- A comprehensive overview on the set of non-CO_2 effects induced by aviation emissions, comprising trade-off effects is provided.

Changes in atmospheric distributions and climate impact

- Within the introduced set of state-of-the-art atmospheric **chemistry-climate models** we use above described emission inventories and calculate aviation-induced changes of radiative active species, using perturbation approach (difference).



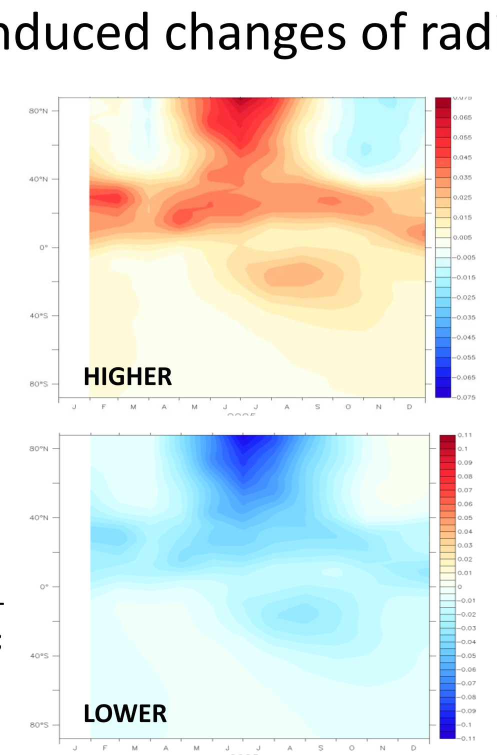


Figure: Aviation-induced ozone (partial columns in DU), seasonal change over latitudes (top left); changes in aviation-induced ozone on alternative altitudes; ‘Flying higher’ (top right) and ‘Flying lower’ (bottom right) [6].

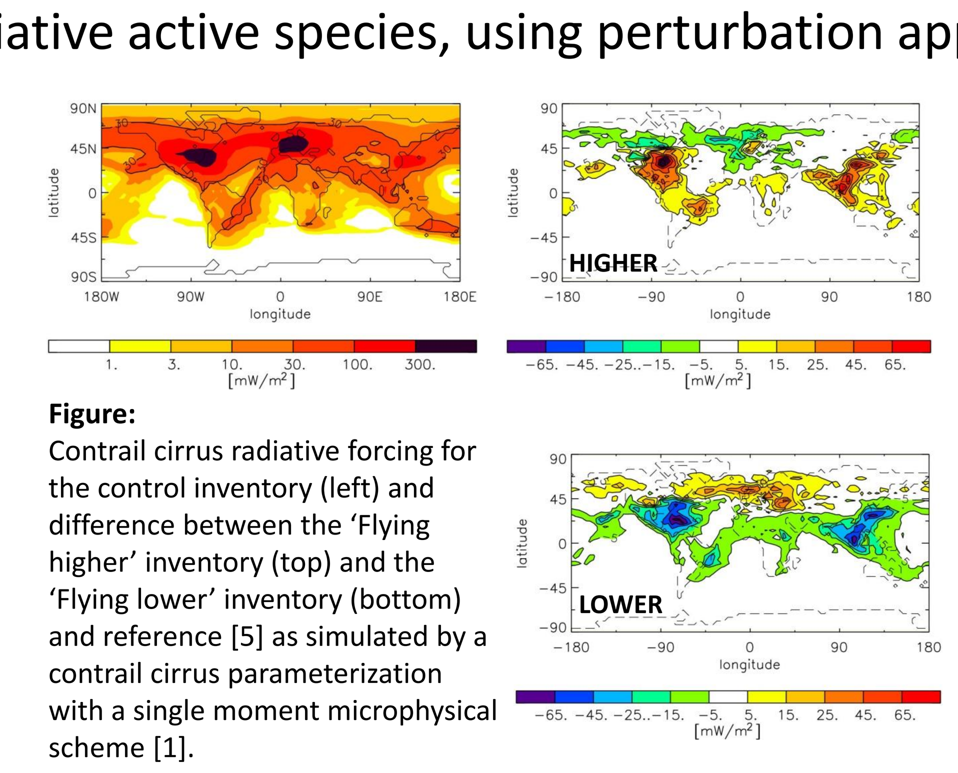


Figure: Contrail cirrus radiative forcing for the control inventory (left) and difference between the ‘Flying higher’ inventory (top) and the ‘Flying lower’ inventory (bottom) and reference [5] as simulated by a contrail cirrus parameterization with a single moment microphysical scheme [1].

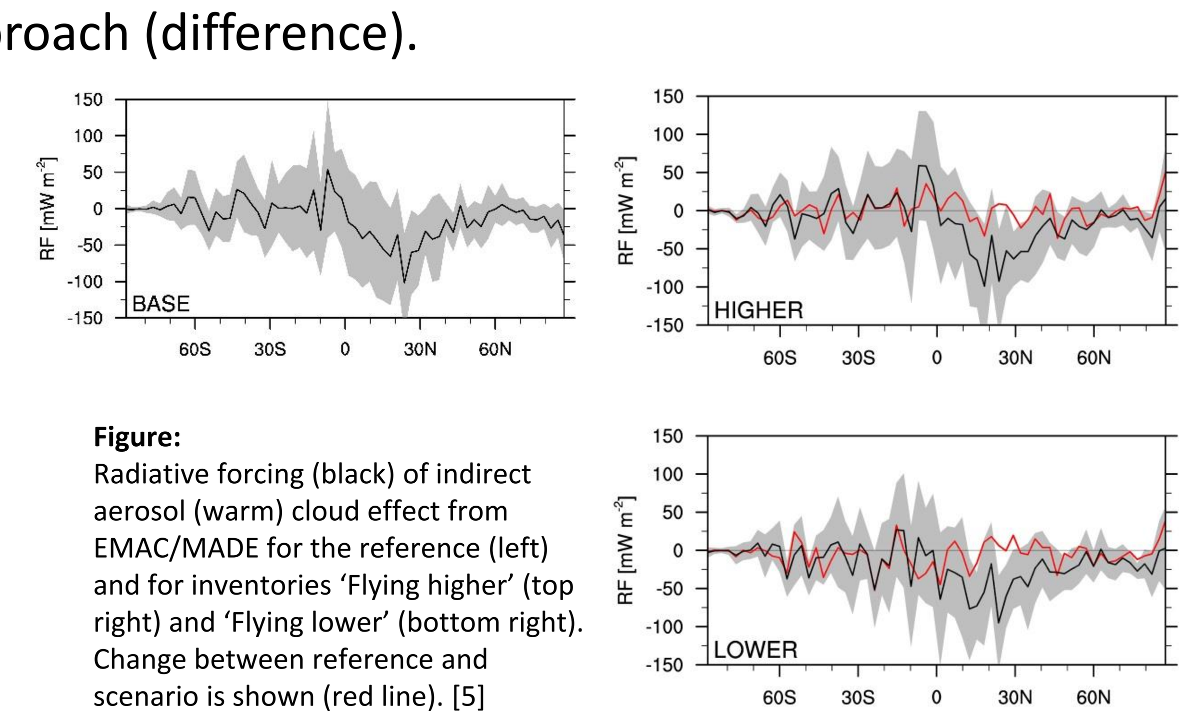


Figure: Radiative forcing (black) of indirect aerosol (warm) cloud effect from EMAC/MADE for the reference (left) and for inventories ‘Flying higher’ (top right) and ‘Flying lower’ (bottom right). Change between reference and scenario is shown (red line). [5]

- Changes of partial ozone columns shows that spring and winter maxima originate from additional ozone induced in Northern hemisphere (upper troposphere). Aerosol indirect effect on warm clouds causes a negative forcing while showing a low signal to noise ratio. This indirect aerosol effect includes both direct effects from sulphate and indirect aerosol cloud induced effect.

Total mitigation

- When aircraft fly higher **non-CO_2 effects** increase (by ~10%), and when aircraft fly lower non-CO_2 climate impacts decrease (by ~30%).
- No best estimate for the **uncertainty** can be given. But uncertainty connected, e.g. with changes in cloudiness (aerosol cloud interaction and contrail cirrus) are very large.

Impact	Reference[1]	Lower[2,3]	Higher	Reference
Net NO_x	20.0	17.6	22.6	Update[1]
NO_x-Ozone	30.6	28.5	33.1	Update[1]
NO_x-Methane	-7.0	-7.1	-6,9	Update[1]
NO_x-PMO	-2.8	-2.9	-2,8	Update[1]
NO_x-H_2O	-0.8	-0.8	-0,8	Update[1]
Direct H_2O	1.5	1.1	2.0	Multi-model mean[2]
Aerosol-Cloud (warm)	-14.8	-21.9	-14.4	EMAC/MADE
(sensitivity)	(-65.2)	(-65.5)	(-66.3)	EMAC/MADE
Contrail Cirrus	45	40	48	ECHAM4-CCMod[2]
..				
Total[3]	70.2	55.6	77.1	this work
Total[3] non-CO_2	48.7	33.9	55.8	this work

[1] Søvde et al., 2014, [2] Lim et al., 2015, [3] comprising CO_2, direct effects of soot and sulphate described in the text.

Figure: Radiative forcings [mW/m²] of individual effects for reference case and Flying Higher and Lower scenarios, non-CO_2 presenting sum of all non-CO_2 effects [5].

Climate impact mitigation

- Changes in individual climate impacts

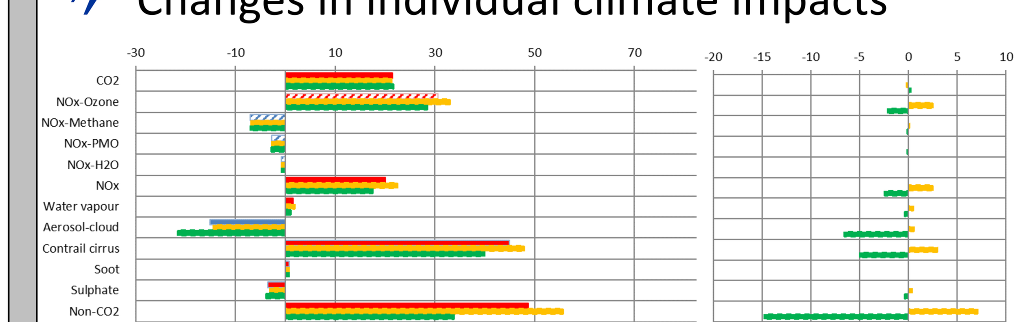


Figure: Global radiative forcing [mW/m²] of aviation emissions: reference case (*solid red & blue*), flying higher (*orange*) and flying lower (*green*) as absolute radiative forcing (*left*) and changes for alternative flight altitudes compared to reference case (*right*) [5].

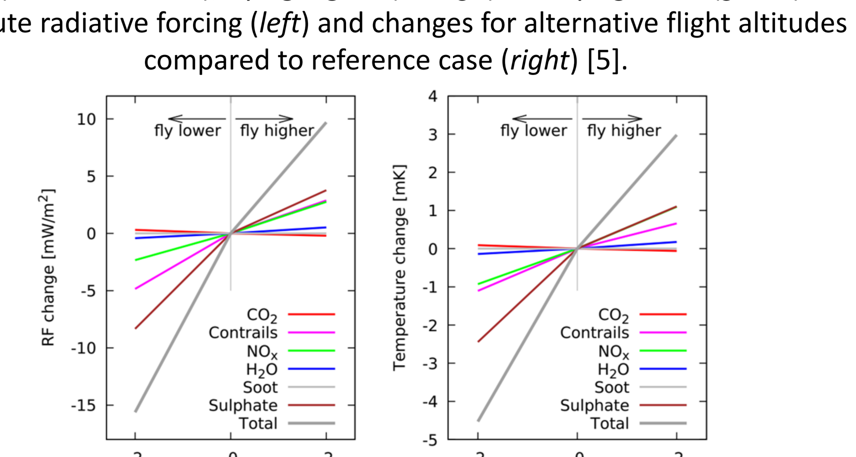


Figure: Change in radiative forcing [mW/m²] (left) and change in temperature (right) assuming aircraft had always be flying lower and higher by 2000 ft compared to reference case.

References

[1] Burkhardt, U., Kärcher, B. Global radiative forcing from contrail cirrus. Nat.Clim. Change 2011, 1, 54-58. http://dx.doi.org/10.1038/nclimate1068.

[2] Dahlmann, K., Grewe, V., Ponater, M., Matthes, S., 2011. Quantifying the contributions of individual NO_x sources to the trend in ozone radiative forcing. Atmos. Environ. 2011 45, 2860 – 2868.

[3] Grewe, V., Dameris, M., Fichter, C., Lee, D.S. Impact of aircraft NO_x emissions. Part 2: effects of lowering the flight altitude. Meteorol. Z., 2002, 11 (3), 197e205. http://dx.doi.org/10.1127/0941-2948/2002/ 0011-0197.

[4] Lim, L.L., Lee, D.S., Owen, B., Skowron, A., Matthes, S., Burkhardt, U., Dietmüller, S., Pitari, G., Di Genova, G., Iachetti, D., Isaksen, I., Søvde, O., 2015. REACT4C: Simplified mitigation studies, TAC-4 Proceedings, 22-25 June 2015, Bad Kohlgrub.

[5] Matthes, S., Lim, L., Burkhardt, U., Dahlmann, K., Dietmüller, S., Grewe, V., Haslerod, A., Hendricks, J., Lee, D.S., Owen, B., Pitari, G., Righi, M., Skowron, A., Mitigation non-CO_2 aviation’s climate impact by changing cruise altitudes, 3rd ECATS Book Abstracts, 2020, ISBN 978-1-910029-58-9.

[6] Søvde, O., Matthes, S.; Skowron, A.; Iachetti, D.; Lim, L.; Owen, B., Hodnebrog, T., Di Genova, G., Pitari, G.; Lee, D. Aircraft emission mitigation by changing route altitude: A multi-model estimate of aircraft NO_x emission impact on O_3 photochemistry. Atmos. Environ., 2014, 95, 468–479.

Funding and Acknowledgments

Individual authors of this study were supported by the European Commission Seventh Framework Project, ‘REACT4C’ (contract no. ACP8-GA-2009-233772) and receive funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 875036 within the Aeronautics project ACACIA. Work in this article was supported by DLR project Eco2Fly (2018-2022) and by ECATS working group “Aviation climate impact”. High performance supercomputing resources were used from the German DKRZ Deutsches Klimarechenzentrum Hamburg.