Final Report for Project **781**

Project title: **REACT4C**

Principal investigator: **Volker Grewe**

Report period: **Jan. 1, 2012 - Dec. 31, 2023**

The DKRZ project 781 (REACT4C) included works of the two research projects REACT4C (EU project FP7, 2010-2014) and WeCare (DLR internal project, 2013-2017). Since 2018 the project was kept as a “data-project” for further analysis of the data. Related works, which are based on project 781 were continued in project 1062 (ÖkoLuft) from 2018 onwards.

REACT4C (Reducing Emissions from Aviation by Changing Trajectories for the benefit of Climate) aimed to investigate the potential of climate-optimised flight routing for aviation climate impact mitigation. The novelty in REACT4C was a modelling chain for the optimisation of aircraft trajectories with respect to their climate impact, while considering weather-dependent climate impact of CO_2 and non-CO_2 aviation emissions. The WeCare project (Utilizing Weather information for Climate efficient and eco-efficient future aviation) investigated solutions for reducing the climate impact of aviation based on an improved understanding of the atmospheric impact from aviation by making use of measurements and modelling approaches.

At DKRZ (blizzard and mistral) the methodology to determine spatially and temporally resolved information on aviation climate effects was initiated. So-called 4-dimensional climate change functions (CCFs) were derived (Grewe et al., 2014, Frömming et al., 2021). For that purpose, a new submodel (AIRTRAC) was developed within EMAC to follow aviation emissions (NO_x, H_2O) and their subsequent effects (e.g. O_3-production and -loss, contrail formation) by means of Lagrangian air parcel trajectories and map these effects back to their original emission release location. A time-region-grid was defined covering the Northern Atlantic Flight Corridor. For each time-region grid point (>4000 in REACT4C) the global climate impact of an emission was calculated for different emission times and typical weather situations for winter and summer. More than 300 short simulations were performed (from a few days up to a few months – depending on species) to compute 4-dimensional CCFs for O_3, CH_4, H_2O and contrails and contrail-cirrus. The CCFs describe the atmospheric sensitivity to aviation emissions with respect to climate, depending on the geographic position, the flight altitude and time and constitute the basis for weather dependent climate-optimised trajectories. It is possible to significantly reduce the overall climate impact of aviation by means of weather dependent flight trajectory optimisation for CO_2 and non-CO_2 impacts at only moderate cost increases (Grewe et al., 2014b).

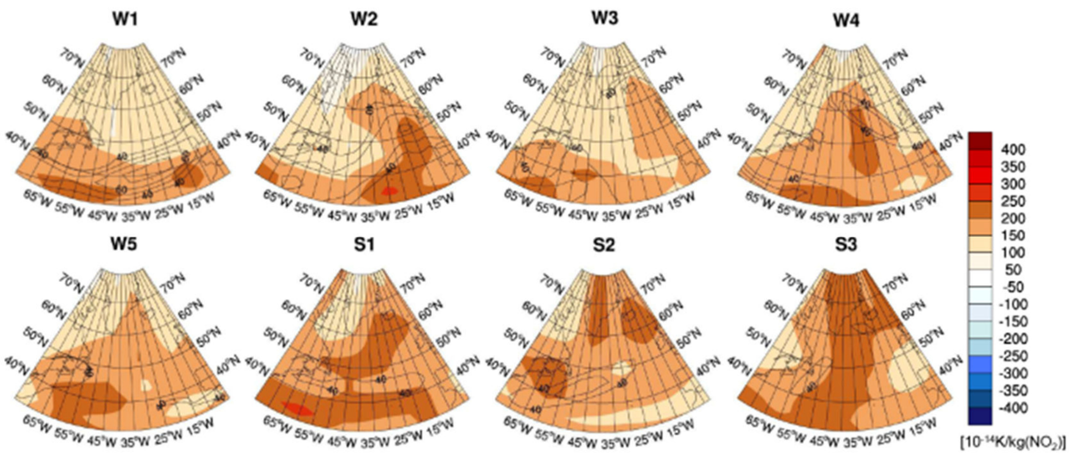

Figure 1: Exemplary climate change functions of aviation induced O3 at 250 hPa for eight representative weather situations. From Frömming et al., 2021.

Since the CCFs are a product of computationally very expensive climate model simulations, they cannot be used for flight planning on a regular basis. Thus, the initial concept of CCFs was extended to algorithmic climate change functions (aCCFs) (van Manen and Grewe, 2019). These functions make use of correlations of CCFs with weather data and provide a very fast computation of individual non-CO_2 climate effects as they are based on mathematical formulas which only need a small number of relevant local meteorological parameters as input.

The methods developed here are currently extended (Maruhashi et al., Yin et al., Rao et al.) and brought to operational use in numerical weather prediction and airline operations (D-KULT, https://www.klimaschutz-portal.aero/wp-content/uploads/2023/07/D-KULT-Info-final.pdf).

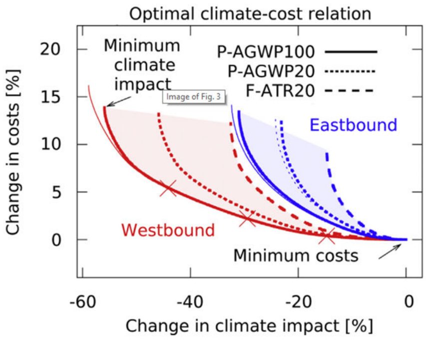

Figure 2: Relation of economic cost changes and climate impact changes for a trans-Atlantic air traffic test case. From Grewe et al., 2014b.

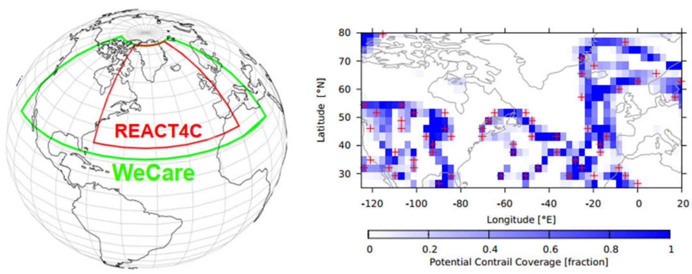

Figure 3: (Left) Region for which climate change functions were calculated in REACT4C and WeCare. (Right) Adaptive grid for calculation of contrail CCFs in WeCare. From Grewe et al., 2017.

Total resources used in project 781:	
Number of simulations	> 300 short simulations
CPU-time	2,5 Mio CPU-h (blizzard), 128 000 node-h (mistral)
Archived Data	450 TB

<u>Publications resulting from project 781:</u>

Frömming, C., Grewe, V., Brinkop, S., Jöckel, P., Haslerud, A. S., Rosanka, S., Van Manen, J., and Matthes, S.: Influence of weather situation on non-CO2 aviation climate effects: The REACT4C climate change functions, Atmospheric Chemistry and Physics, 21, 9151 – 9172, https://doi.org/10.5194/acp-21-9151-2021, 2021.

Grewe, V., Frömming, C., Matthes, S., Brinkop, S., Ponater, M., Dietmüller, S., Jöckel, P., Garny, H., Tsati, E., Dahlmann, K., 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), Geoscientific Model Development, 7, 175–201,195 https://doi.org/10.5194/gmd-7-175-2014, 2014a.

Grewe, V., Champougny, T., Matthes, S., Frömming, C., Brinkop, S., Sovde, O. A., Irvine, E. A., and Halscheidt, L.: Reduction of the air traffic's contribution to climate change: A REACT4C case study, Atmos. Environ., 94, 616–625, https://doi.org/10.1016/j.atmosenv.2014.05.059, 2014b.

Grewe, V., Dahlmann, K., Flink, J., Frömming, C., Ghosh, R., Gierens, K., Heller, R., Hendricks, J., Jöckel, P., Kaufmann, S., Kölker, K., Linke, F., Luchkova, T., Lührs, B., van Manen, J., Matthes, S., Minikin, A., Niklaß, M., Plohr, M., Righi, M., Rosanka, S., Schmitt, A., Schumann, U., Terekhov, I., Unterstrasser, S., Vazquez-Navarro, M., Voigt, C., Wicke, K., Yamashita, H., Zahn, A., and Ziereis, H.: Mitigating the climate impact from aviation: Achievements and results of the DLR WeCare project, Aerospace, 4, 34, 2017.

Grewe, V.; Matthes, S.; Frömming, C.; Brinkop, S.; Jöckel, P.; Gierens, K.; Champougny, T.; Fuglestvedt, J.; Haslerud, A.; Irvine, E.; et al. Feasibility of climate-optimized air traffic routing for trans-Atlantic flights. Environ. Res. Lett. 2017, 12, 034003, doi:10.1088/1748-9326/aa5ba0.

Rosanka, S., Frömming, C., and Grewe, V.: The impact of weather patterns and related transport processes on aviation's contribution to ozone and methane concentrations from NOx emissions, Atmos. Chem. Phys., 20, 12347–12361, https://doi.org/10.5194/acp-20-12347-2020, 2020.

van Manen, J. and Grewe, V.: Algorithmic climate change functions for the use in eco-efficient flight planning, Transportation Research Part D: Transport and Environment, 67, 388–405, 2019.

<u>References:</u>

Maruhashi, J., Grewe, V., Frömming, C., Jöckel, P., and Dedoussi, I.C., Transport patterns of global aviation NOx and their short-term O3 radiative forcing effects - a machine learning approach, Atmos. Chem. Phys., 22, 14253-14282, 2022.

Rao, P., Dwight, R., Singh, D., Maruhashi, J., Dedoussi, I., Grewe, V., and Frömming, C., Estimating aviation's NOx-O3 warming effects with a probabilistic approach, submitted, 2024.

Yin, F., Grewe, V., Castino, F., Rao, P., Matthes, S., Dahlmann, K., Dietmüller, S., Frömming, C., Yamashita, H., Peter, P., Klingaman, E., Shine, K. P., Lührs, B., and Linke, F.: Predicting the climate impact of aviation for en-route emissions: the algorithmic climate change function submodel ACCF 1.0 of EMAC 2.53, Geosci. Model Dev., 16, 3313–3334, 2023.