Project: **1357**

Project title: **D-KULT**

Principal investigator: **Sigrun Matthes**

Report period: **2025-05-01 to 2026-04-30**

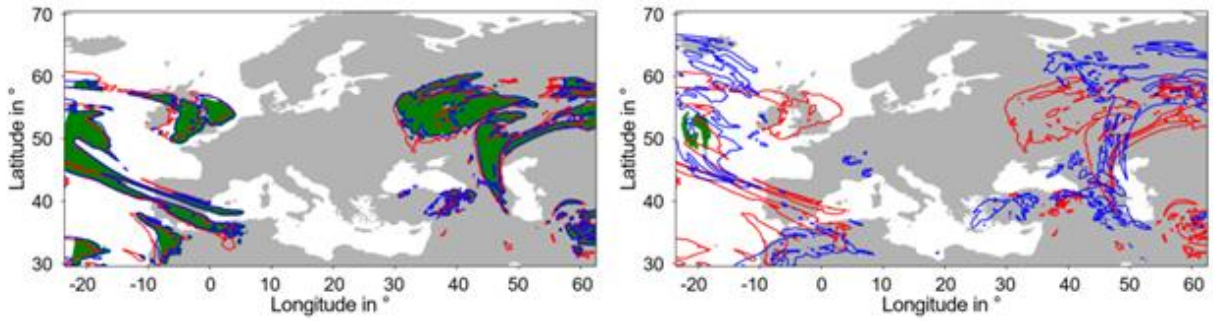
Results obtained in the LuFo-Project D-KULT

Mit den im LuFo-Projekt D-KULT bereitgestellten Daten wurden folgende Ergebnisse erzielt, die sich in peer-reviewed Publikationen finden, die teilweise erschienen und teilweise noch im Reviewverfahren oder in Vorbereitung sind.

Für diesen Report stellen wir hier die bibliographischen Angaben und Auszüge aus den Abstracts zusammen.

1) Hofer, S., K. Gierens, 2025: *Synoptic and microphysical lifetime constraints for contrails*. Atmos. Chem. Phys., 25, 9235–9247. doi.org/10.5194/acp-25-9235-2025.

Contrail lifetime is constrained mainly by the sedimentation of ice, by blowing out of ice crystals from the parent ice-supersaturated regions (ISSRs) as a result of the (horizontal) wind and by large-scale subsidence. The first of these processes can be characterised by a sedimentation timescale. The second and third processes can together be characterised by a synoptic timescale. The synoptic timescale is determined in this paper by trajectory calculations for air parcels that initially reside in ice-supersaturated regions, which leave these either with the wind or where ice supersaturation itself vanishes (see Figure). Here we show that both timescales are of the order of a few hours. Actually, in nature, the three mentioned processes act simultaneously. The combined timescale is half of the harmonic mean of the two timescales in separation.



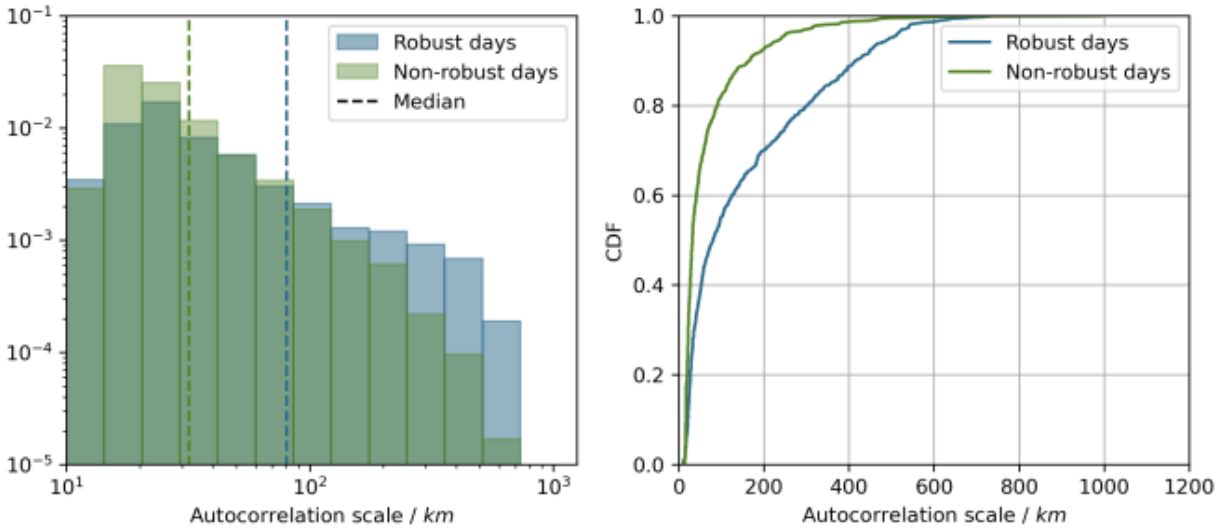
2) Matthes et al., 2026: *D-KULT: data and tools for routine eco-efficient flight operations*. JECATS, Discussions, revision started. doi.org/10.5194/jecats-2026-3

D-KULT developed an end-to-end information chain integrating aviation weather forecasting, flight planning, air traffic control, and climate benefit assessment to enable eco-efficient flight routing for testing purposes. Achieving this complex operational and environmental objective required close collaboration across multiple disciplines and substantial upgrades to the majority of participating components. Novel aviation weather products were generated that estimate the climate sensitivity of emissions under prevailing meteorological conditions. Flight planning tools have been extended to take this information into account in the flight planning optimization algorithms in addition to the standard data. In this way, flight planning tools can calculate emissions and corresponding climate effects along flights, both as part of strategic (pre-departure) and tactical (pre-take-off and in-flight) eco-efficient flight optimisation. Developments within D-KULT were tested through a large-scale national contrail avoidance flight trial campaign, including enhanced satellite-based contrail detection methods and assessment of achievable climate benefits. Further evaluation focused on operational integration, examining air traffic control procedures, and workflow implications in a high-fidelity simulator environment.

Results demonstrate substantial progress toward operational climate-optimised aviation but also highlight remaining challenges, including uncertainties in weather forecast and non-CO_2 climate effects, automation needs along the workflow and increased controller workload in dense airspaces. A key requirement for operational implementation is transparent information of prediction uncertainties, enabling informed decision-making when rerouting for climate benefit.

3) Von Koslowski, V.L., Gierens, K., 2026: Characteristics of robust and non-robust days for contrail forecasts. Meteorol. Z. in review.

The potential for formation of persistent contrails, computed from ensemble forecasts and framed into a conditional probability distribution, is used to characterise forecasts from numerical weather prediction (NWP) with robust or non-robust contrail prediction. The robustness of contrail prediction follows a noisy but statistically significant seasonal cycle with robust days occurring in winter, non-robust days in summer. They are best distinguished by the spatial scales of certain fields. Ice supersaturated regions (ISSRs) have larger spatial scales and are more homogeneous on robust days than on non-robust days. Path lengths through ISSRs have at least twice the length (> 200 km) on robust days than on non-robust days (< 100 km). Autocorrelation scales of the vertical air velocity are on average two to three times larger on robust days than on non-robust ones (see Figure). This could point to different formation mechanisms of ISSRs, e.g. convective processes in summer months and frontal systems in winter months.



4) Peter, P., Matthes, S., and Zengerling, Z., 2026: *Sensitivity of contrail avoidance mitigation estimates to meteorology and climate response tools: New insights from the D-KULT trial flights (TF-100),* in Vorbereitung

This paper investigates the sensitivity of estimated benefits of contrail-avoidance routing on the meteorological dataset and climate response tool used for evaluation. The study compares fixed business-as-usual (BAU) and eco-efficient trajectories across multiple modelling setups. The analysis focuses on sensitivities to meteorological background data, forecast lead time, spatial resolution, and the climate response model itself. The trajectory re-evaluation combines different meteorological inputs, including ERA5, operational ICON Data, as well as experimental ICON equipped with a two-moment cloud ice microphysics schema, together with contrail climate effect estimates from both aCCFs and CoCiP-based fields. The central result is that fuel burn is relatively insensitive to the meteorological background, whereas contrail-related climate effects are highly sensitive to both meteorology and the chosen response model which can substantially change estimated mitigation, and in some cases even reverse its sign. Forecast lead time and grid coarsening further modify the results by smoothing gradients and shifting estimated climate effects. Overall, the paper concludes that operational contrail mitigation cannot be treated as model-independent. Robust decision support therefore requires uncertainty-aware evaluation, harmonized preprocessing choices, cross-dataset checks, and comparisons across climate response tools before claiming a mitigation benefit.

5) Matthes, S., et al., 2026: The German TF-100 contrail-avoidance flight trial: concept and scientific evaluation. In Vorbereitung.

The AKKL test flights (TF100) initiative, conducted in 2024 as part of an interdisciplinary collaboration involving research institutions, meteorological services, and industrial partners, is the focus of this study. The primary goals of this study are to report on the successful implementation of an integrated workflow for contrail-avoidance trajectories. Second, methodological sensitivity studies utilizing numerical tools are presented which estimate contrail formation and climate effects, providing valuable insights into concepts on how to assess the overall performance and potential efficacy of avoidance trajectories. Third, the success of contrail avoidance is explored through an initial evaluation of observational data, determining the extent to which alternative flight routes resulted in reduced contrail formation and associated climate impacts.