Climate-optimized trajectories and robust mitigation potential: flying ATM4E

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- Aviation can **reduce its climate impact** by controlling its CO_2-emission and non-CO_2 effects, e.g. aviation-induced contrail-cirrus and ozone caused by nitrogen oxide emissions. One option is the implementation of operational measures which aim to **avoid those atmospheric regions** that are in particular **sensitive to non-CO_2 aviation** effects, e.g. where persistent contrails form.
- Estimates on overall climate impact reduction from a **one-day case study** are presented relying on best estimate for climate impact information. Specific weather situation that day, containing regions with high contrail impact, results in a potential reduction of total climate impact, by more than 40%, considering CO_2 and non-CO_2 effects, associated with an increase of fuel by about 0.5%.
- The climate impact reduction per individual alternative trajectory shows a **strong variation** and hence also the mitigation potential for an analyzed city pair, with mitigation gains showing **robustness** to use of a range of individual climate impact metrics.

Motivation and Introduction

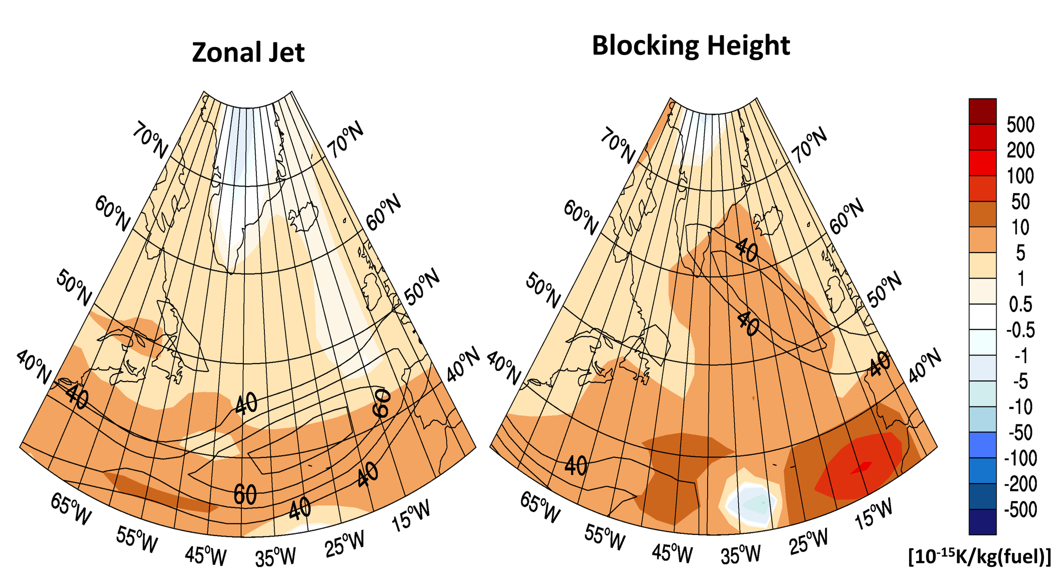
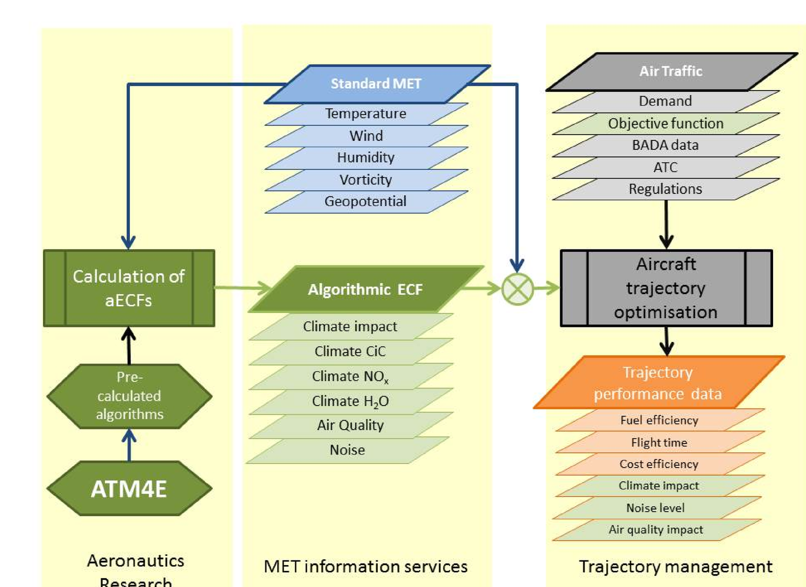


Figure: Weather pattern: climate change function of overall impact comprising contrail-cirrus, NO_x-induced impacts on ozone and methane, and water vapour in two distinct patterns (see [3]). *Frömming et al., 2020*

- We present **environmental** and **economic performance** of aircraft trajectories for individual city pairs under different optimization criteria resulting in a set of distinct **climate-optimized aircraft trajectories**.
- We compare climate optimized trajectories to fuel optimal trajectories in order to provide an estimate of overall **mitigation potential** and **gain** associated with climate-optimized aircraft trajectories.



Matthes et al., 2017

Figure: Flowchart of aircraft trajectory management using ATM4E algorithmic environmental change functions (aECF) concept, with elements newly introduced by ATM4E in green (see [2], Fig. 2).

- We evaluate the climate impact using a set of different **climate impact metrics** in order to assess robustness of proposed solutions.

Eco-efficient aircraft trajectories and climate impact mitigation

- Climate-optimized trajectories are presented with overall performance in terms of fuel efficiency and environmental efficiency by comparing the fuel-optimal solution with climate-optimized solutions, , with, e.g. up to 40% climate impact reduction associated with 0.5% fuel penalty (EFHK-GCLP).

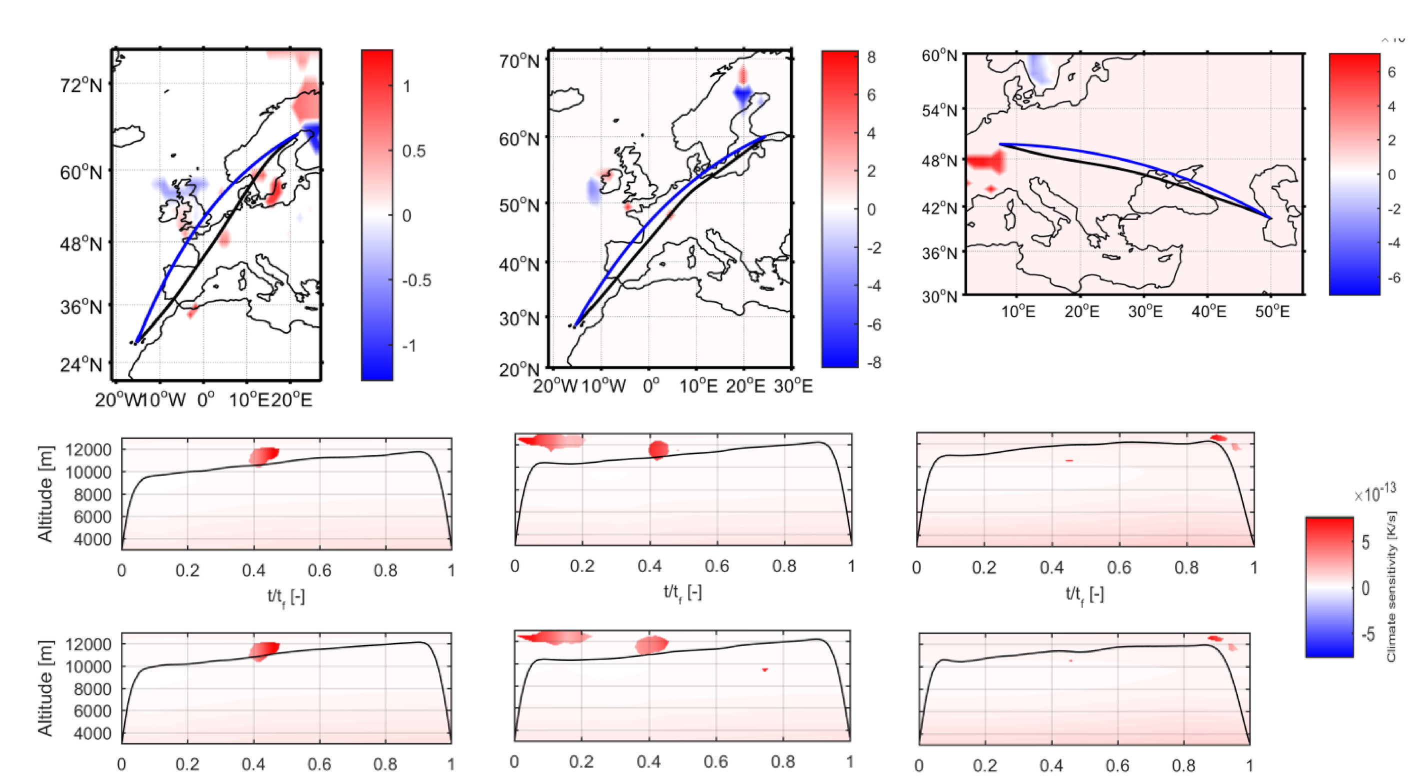
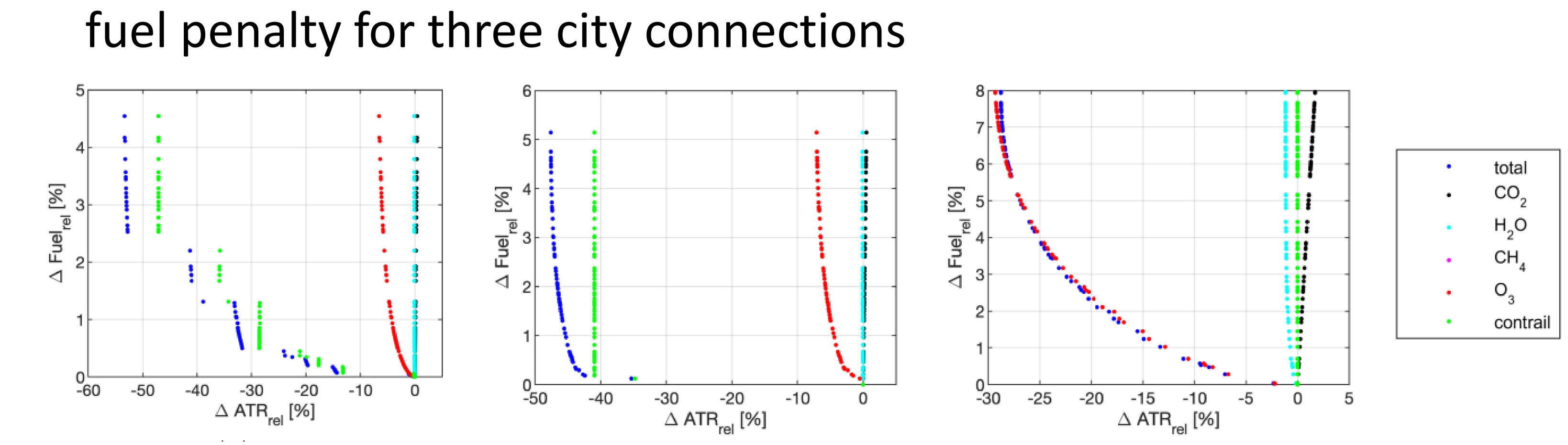


Figure: Aircraft trajectories (top) Lulea-Gran Canaria (ESPA-GCLP, left), Helsinki-Gran Canaria (EFHK-GCLP, middle), Baku-Luxembourg (UBBB-ELLX, right): great circle (blue line), fuel-optimized trajectory (black line). Altitude profile: fuel optimal case (middle row) and climate optimized case with 0.5% additional costs (bottom row) (see [4], Fig. 1]

- Pareto fronts showing **mitigation of climate impacts** by avoidance of contrails and reduction of NO_x-induced warming and associated fuel penalty for three city connections



- Initial mitigation relies on contrails avoidance showing **large mitigation gains**, 18 pK/kg fuel, while NO_x-induced effets in this case study show about 8 pK/kg fuel.

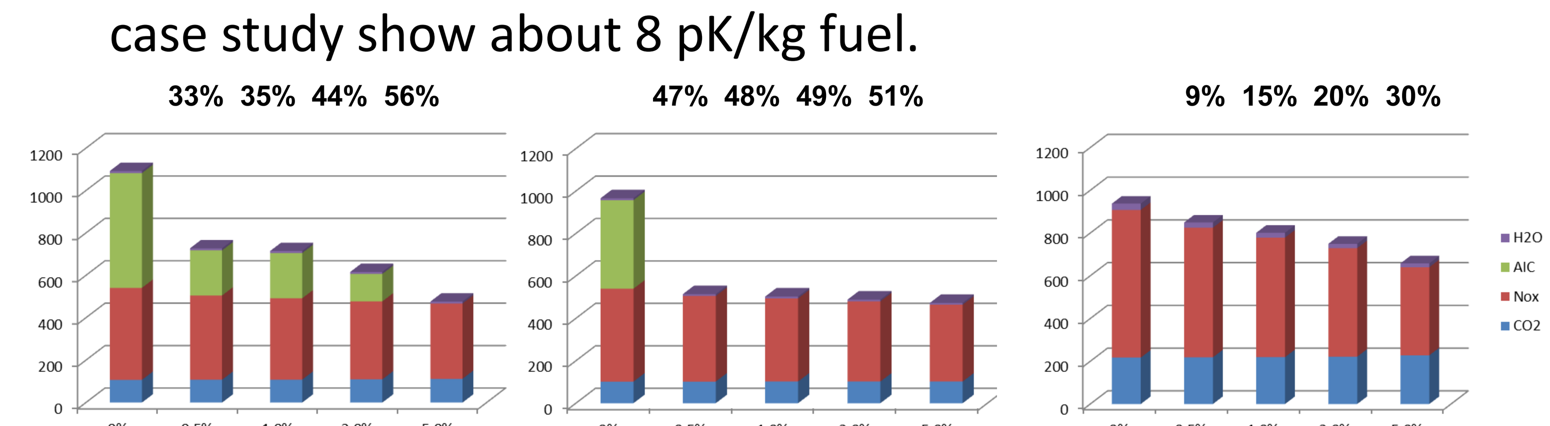


Figure: Individual contributions to total climate impact (ATR20, pK) shown for individual mitigation trajectories allowing fuel increase by 0.5%, 1%, 2% and 5% and fuel optimal (0%). (see [4], Fig. 2,3]

Robustness analysis

- Overall **robustness analysis** shows that identified alternative trajectories are robust under the selected set of climate impact metrics.

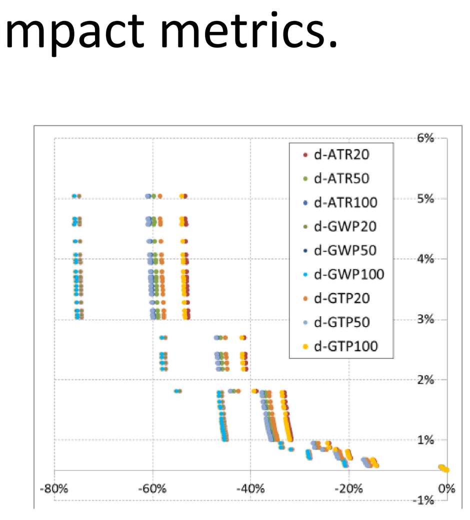


Figure
Pareto front on climate impact reduction vs. fuel increase [%] for different climate metrics: average temperature response (ATR), global warming potential (GWP), global temperature potential (GTP), (see [4], Fig. 4).

Climate impact mitigation

- On that specific day (case study) climate impact can be mitigated by 46% for an increase in fuel of 0.5%.

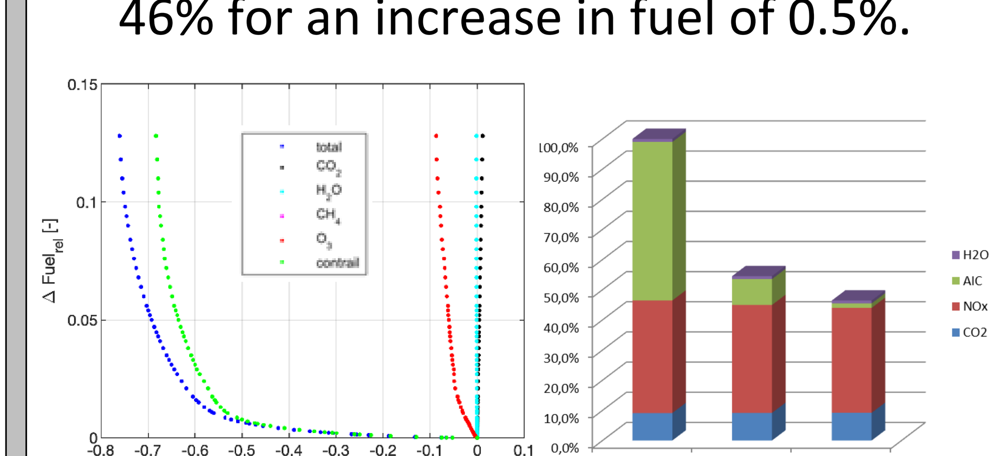


Figure: Pareto front: change in climate impact versus fuel penalty, 1-day case study in Europe (18 Dec 2015, traffic sample, 2000 routes) and individual climate impacts comprising CO_2 and non-CO_2 (see [4], Fig. 5].

References

[1] Grewe, V.; Frömming, C.; Matthes, S.; Brinkop, S.; Ponater, M.; Dietmüller, S.; Jöckel, P.; Garny, H.; Tsati, E.; Dahlmann, K.; et al. *Aircraft routing with minimal climate impact: The REACT4C climate cost function modelling approach (V1.0)*. Geosci. Model Dev. 2014, 7, 175–201.

[2] Matthes, S., Grewe, V., Dahlmann, K., Frömming, C., Irvine E.; Lim L., Linke F., Lührs B., Owen B., Shine, K. P, Stromatas S., Yamashita H., and Yin F. *A Concept for Multi-Criteria Environmental Assessment of Aircraft Trajectories*, Aerospace 2017, 4, pp. 42. doi:10.3390/aerospace4030042.

[3] Frömming, C., Grewe, V., Brinkop, S., Jöckel, P., Haslerud, A. S., Rosanka, S., van Manen, J., and Matthes, S., *Influence of the actual weather situation on non-CO_2 aviation climate effects: The REACT4C Climate Change Functions*, Atmos.Chem.Phys.Dis., 2020, 1, 30, doi:10.5194/acp-2020-529.

[4] Matthes, Sigrun, Lührs, B, Dahlmann, K., Grewe, V. Linke, F., Yin, F., Klingaman, E., and Shine, K., *Climate-optimized trajectories and robust mitigation potential: flying ATM4E*, 2020. In Special Issue, 3rd ECATS conference, Aerospace 2020, under revision.

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