Climate Impact Mitigation Potential of European Air Traffic

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Abstract

- Air traffic contributes to **anthropogenic global warming by about 5%** due to **CO_2-emissions and non-CO_2** effects which are primarily caused by the emission of NO_x and water vapor as well as the formation of contrails
- In the long term, aviation industry is **expected to grow**; therefore **mitigation measures** are required to counteract against the negative effects upon the environment
- One of the promising operational mitigation measures which has been subject of the EU project ATM4E, is **climate-optimized flight planning**
- **Algorithmic climate change functions** which describe the climate sensitivity as a function of emission location and time are applied
- **Optimized aircraft trajectories** are estimated based on an **optimal control approach**
- The optimization problem is formulated as **bi-objective optimization problem** with climate impact and fuel burn being the two objectives
- Results on individual flight basis indicate that there are three major classes of different routes which are characterized by different shapes of the corresponding Pareto-fronts
- Results indicate a **climate impact mitigation potential of about 73%** which is related with a **fuel penalty of 14.5%**.
- A **climate impact reduction of 50%** can already be achieved with **0.75% additional fuel** burn.

Algorithmic Climate Change Functions (aCCFs)

- aCCFs allow for the **quantification of the global climate impact** of local aircraft emissions as a function of emission location and time [1]
- aCCFs consider **CO_2 and non-CO_2 effects**
- aCCFs allow for a **fast-time calculation** of climate impact **using standard weather forecast data**
- Climate impacts of ozone and methane changes resulting from **NO_x emissions**, **water vapor emissions** and **persistent contrail formation** are covered

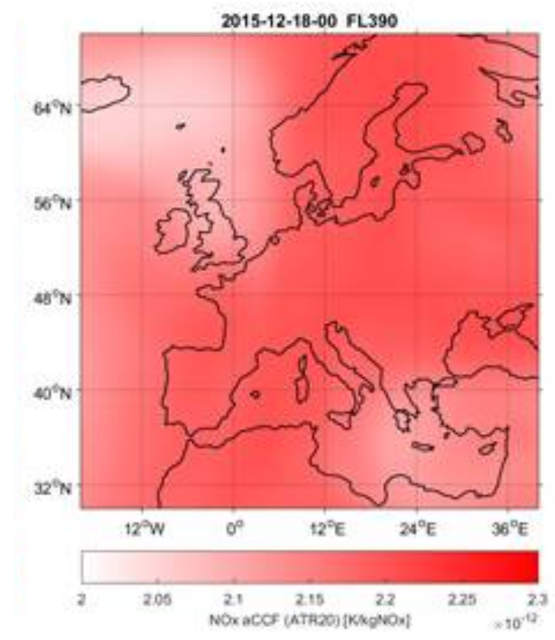

Figure 1: NO_x aCCF on December 18th, 2015, flightlevel 390

Trajectory Optimization

- Continuously optimized trajectories based on an **Optimal control approach** using the Trajectory Optimization Module (TOM) [2]
- **Point-mass model** with variable mass and three degrees of freedom
- Eurocontrol **Base of aircraft data** (BADA) 4.0 aircraft performance models
- Modeling of NOx-emissions based on the **Boeing Fuel Flow method 2**
- **Pareto approach**: cost-benefit analysis for varying weights of climate impact (c_{clim}) and fuel burn (c_{fuel})

climate impact

$$J = c_{\mathrm{clim}} \cdot \boxed{\left\{ \sum_i \int_{t_0}^{t_f} \mathrm{aCCF}_i(\boldsymbol{x},t)\cdot \dot{m}_i(t)\,\mathrm{d}t + \int_{t_0}^{t_f} \mathrm{aCCF}_{\mathrm{CIC}}(\boldsymbol{x},t)\cdot v_{\mathrm{TAS}}(t)\,\mathrm{d}t \right\} \cdot \mathrm{ATR}_{\mathrm{ref}}^{-1}} + \dots$$

$$\dots + c_{\mathrm{fuel}} \cdot \boxed{[m_0 - m_f] \cdot m_{\mathrm{fuel,ref}}^{-1}\,; \quad i \in \{\mathrm{CO_2}, \mathrm{NO_x}, \mathrm{H_2O}\}}$$

fuel burn

Results for individual routes

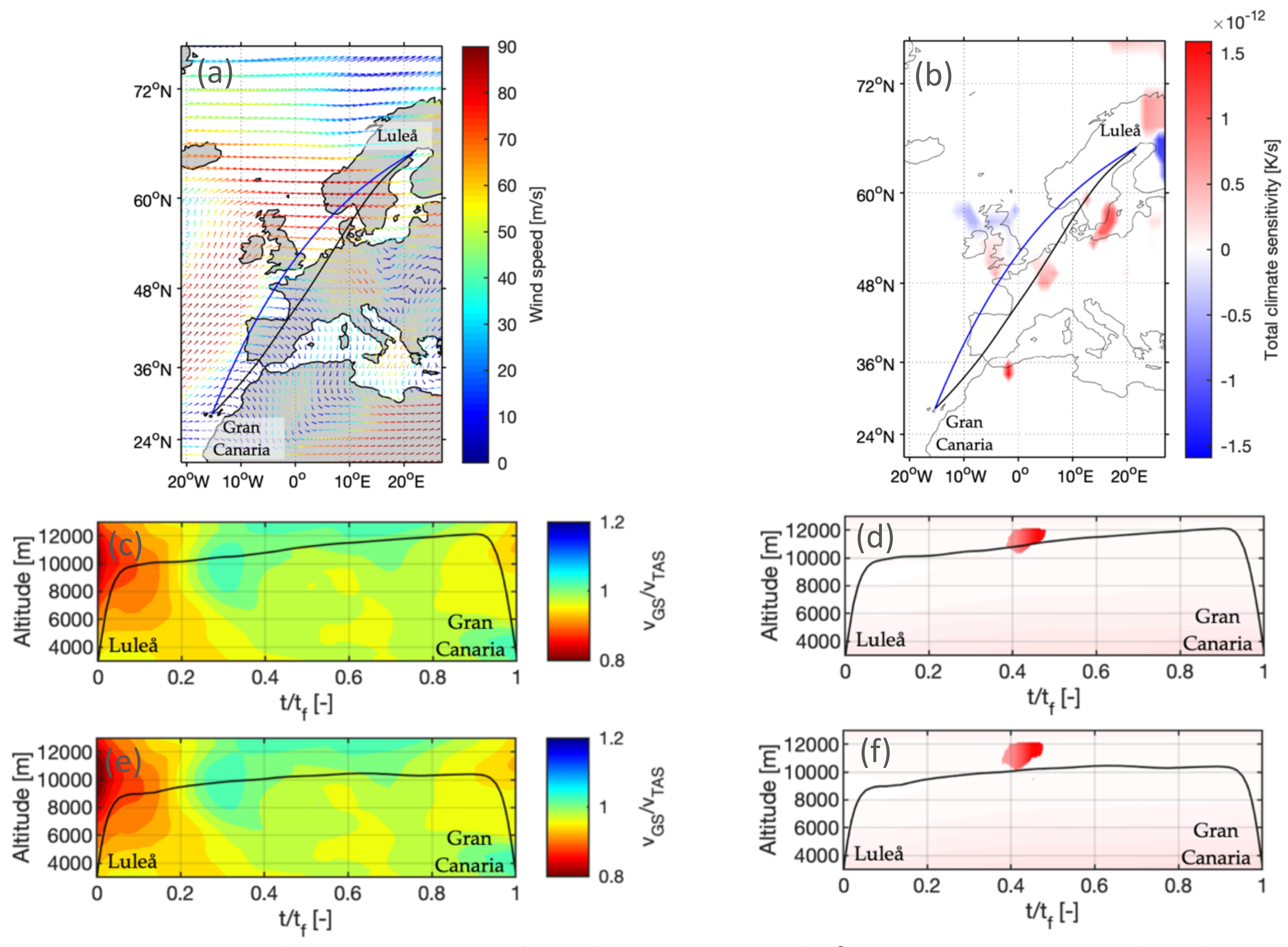

Figure 2: Optimized trajectories for the route Luleå-Gran Canaria. The lateral path of the minimum fuel trajectory (black) is illustrated including the wind situation (a) and the total climate sensitivity (b) at an average altitude of 10,686 m. The orthodrome is depicted in blue. Vertical trajectories along the cross section of the lateral path are shown for the minimum fuel case (c), (d) and the minimum climate impact case (e), (f). The wind situation for the vertical trajectories is indicated as ratio between ground speed v_{GS} and true airspeed v_{TAS}. Values greater than one indicate tailwind areas, values smaller than one indicate headwind areas.

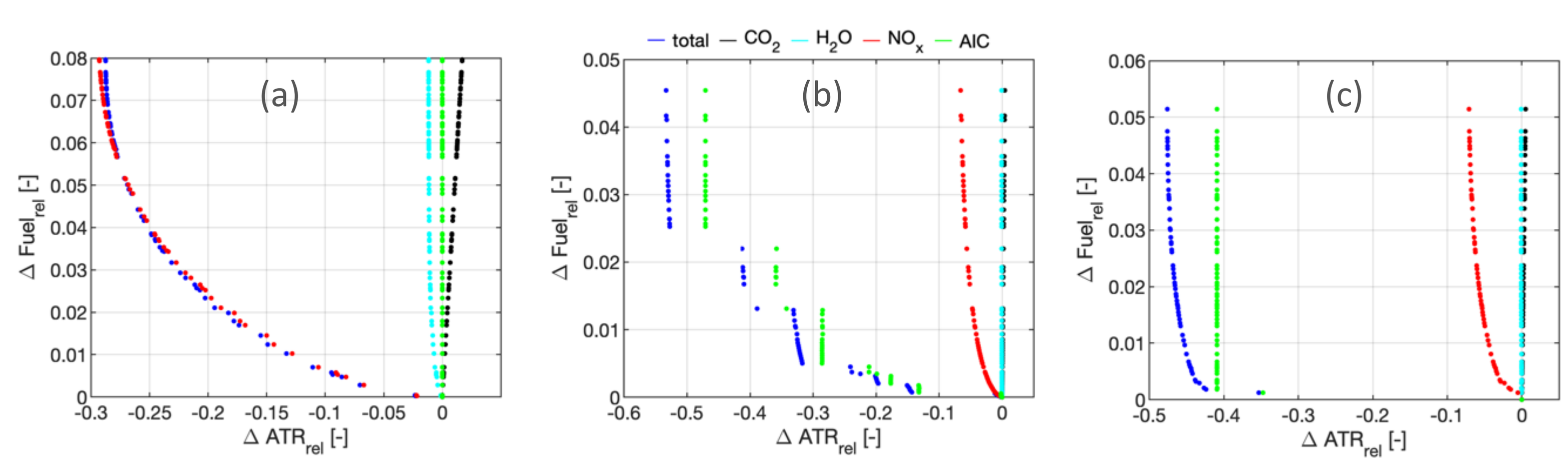

Figure 3: Pareto-fronts for Baku-Luxembourg (a), Luleå-Gran Canaria (b) and Helsinki-Gran Canaria (c). The colored dots indicate the individual contribution of CO2 (black), H2O (cyan) NOx (red) and contrails (green) to the overall climate impact reduction (blue) for a given fuel increase. Results are expressed relative to the fuel burn and the total climate impact of the minimum fuel case.

- One-day case study for the **18th December 2015** performed (high traffic volume, low number of regulations, large persistent contrail formation areas over central Europe)
- Traffic sample containing **13,276 flights** within intra-ECAC (European Civil Aviation Conference) area
- c_{clim} and c_{fuel} systematically varied in order to estimate a **pareto front** for each route
- **Large climate impact mitigation efficiencies** for minor fuel burn changes observed
- Three characteristic shapes have been identified (see figure 3): **smooth curves** (a) which are driven by the reduction of the NO_x impact and **discontinuous pareto fronts** (b,c) characterized by a strong impact of persistent contrail formation

Consolidated results

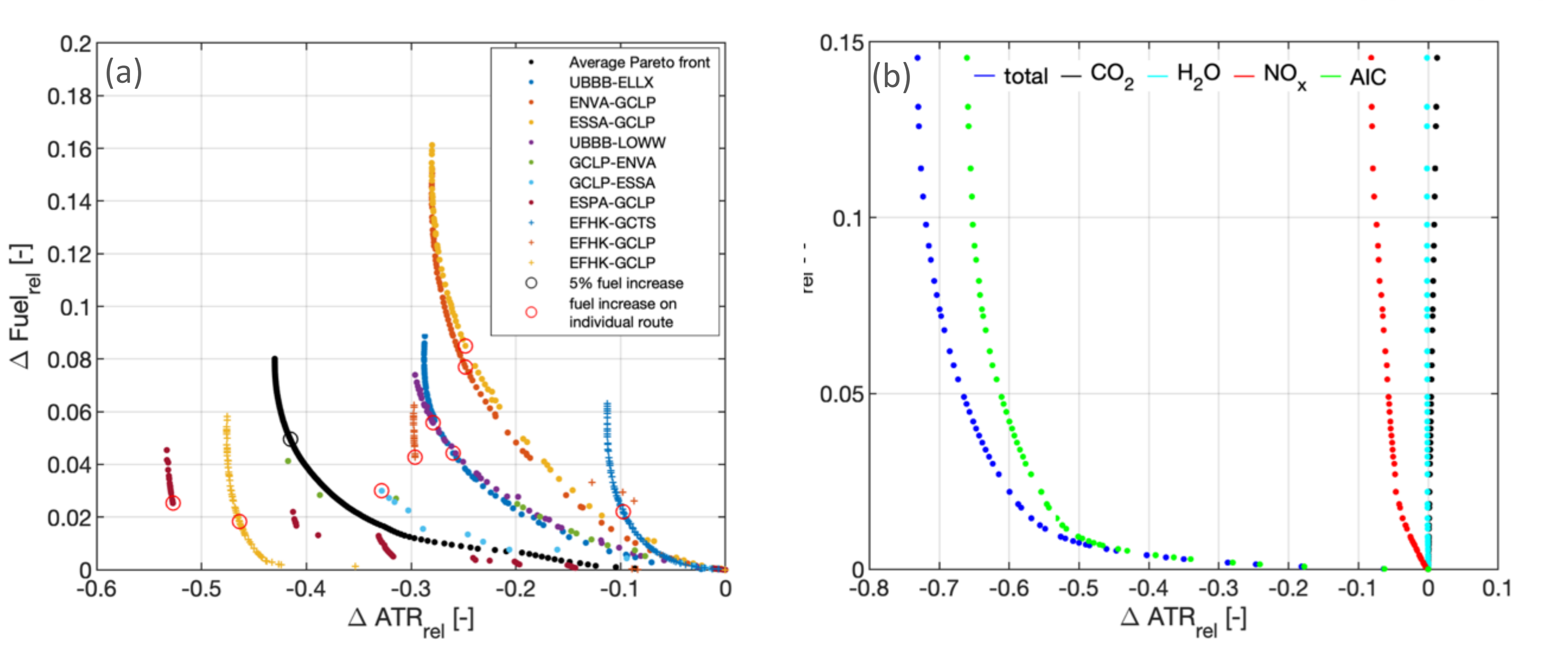

Figure 4: Top 10 single route Pareto-fronts and corresponding average Pareto-front (a) and average Pareto-front (b) for the top 2000 routes with individual contribution of the species CO2 (black), H2O (cyan), NOx (red) and AIC (green) to the overall climate impact reduction (blue) for a given fuel increase. Results are expressed relative to the minimum fuel case.

- **Individual pareto fronts** (see figure 3) are estimated for all 13,276 routes
- On this basis, an **average pareto front** is created where one point on each individual Pareto-front is selected such, that a given overall fuel penalty for all routes is not exceeded and the total climate impact of all routes is minimized
- Figure 4a shows the individual pareto fronts for the top 10 routes and the corresponding average pareto front (black)
- **Different fuel penalties** and **climate impact gains** are highlighted on the different routes (red circles) which lead to an overall 5% fuel penalty and corresponding maximum total climate impact reduction of 42% (black circle)
- According to figure 4b, a **maximum climate impact reduction of 73%** can be achieved, however, this is related with a **fuel penalty of 14.5%**
- Nevertheless, a **climate impact reduction of 50%** can already be obtained with only **0.75% of additional fuel burn**
- The climate impact reduction is **dominated** by the reduction of the climate impact of **contrails** (green curve)

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