

FlyATM4E (SESAR ER)

Mitigating aviation climate impact by climate-optimized aircraft trajectories

SESAR Exploratory Research Project, *Grant No 891317*

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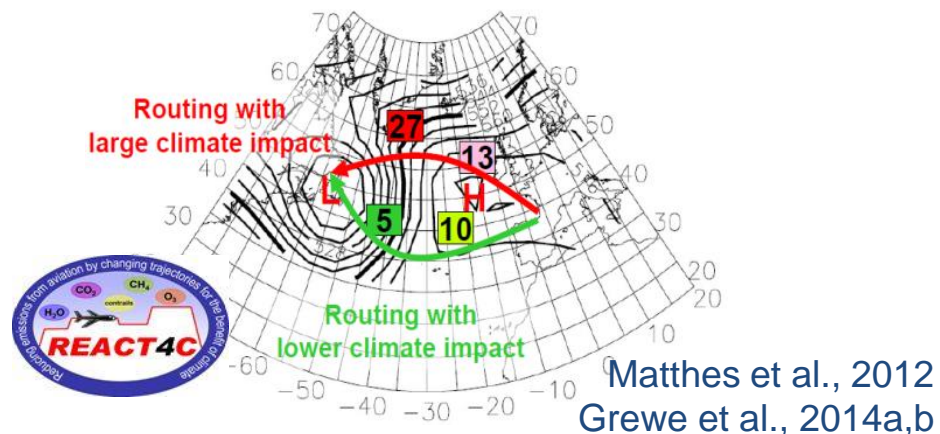
Wissen für Morgen



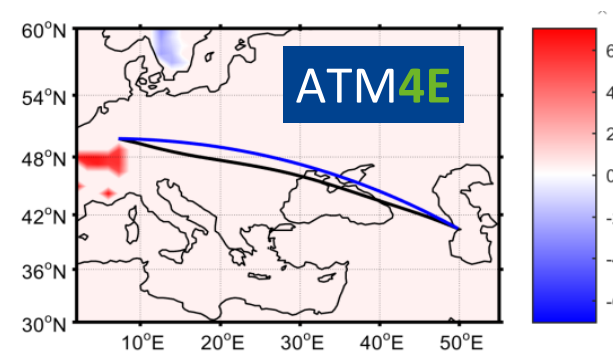
FlyATM4E Climate-optimization of aircraft trajectories

- Aviation is concerned by reducing climate impact of its operations. **Aviation climate impact** is caused by CO₂ and non-CO₂ emissions, comprising impacts of **contrails**, **nitrogen oxides** impacting ozone and methane, **water vapour**, and **aerosol effects**.
- Non-CO₂ climate impacts** show a strong spatial and temporal variation, which can be exploited when identifying **alternative trajectories**, by **avoiding those regions** where emissions have a large impact.
- However, during flight planning currently emission information is available, but no **environmental impact information** linked to the emitted amount is available along the trajectory.

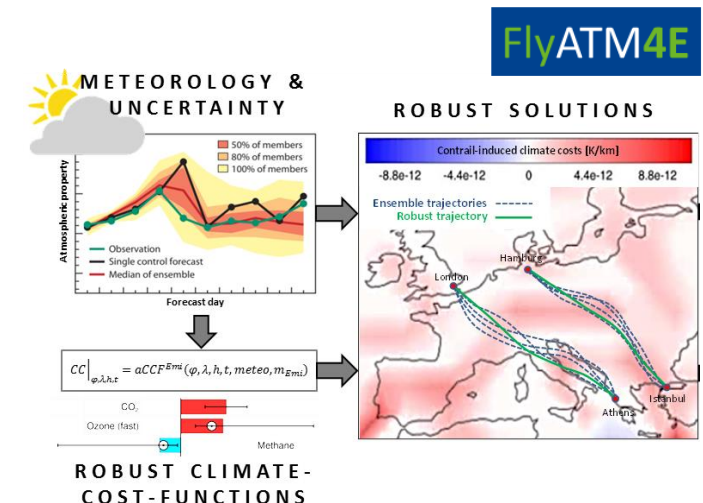
Concept: Feasibility study



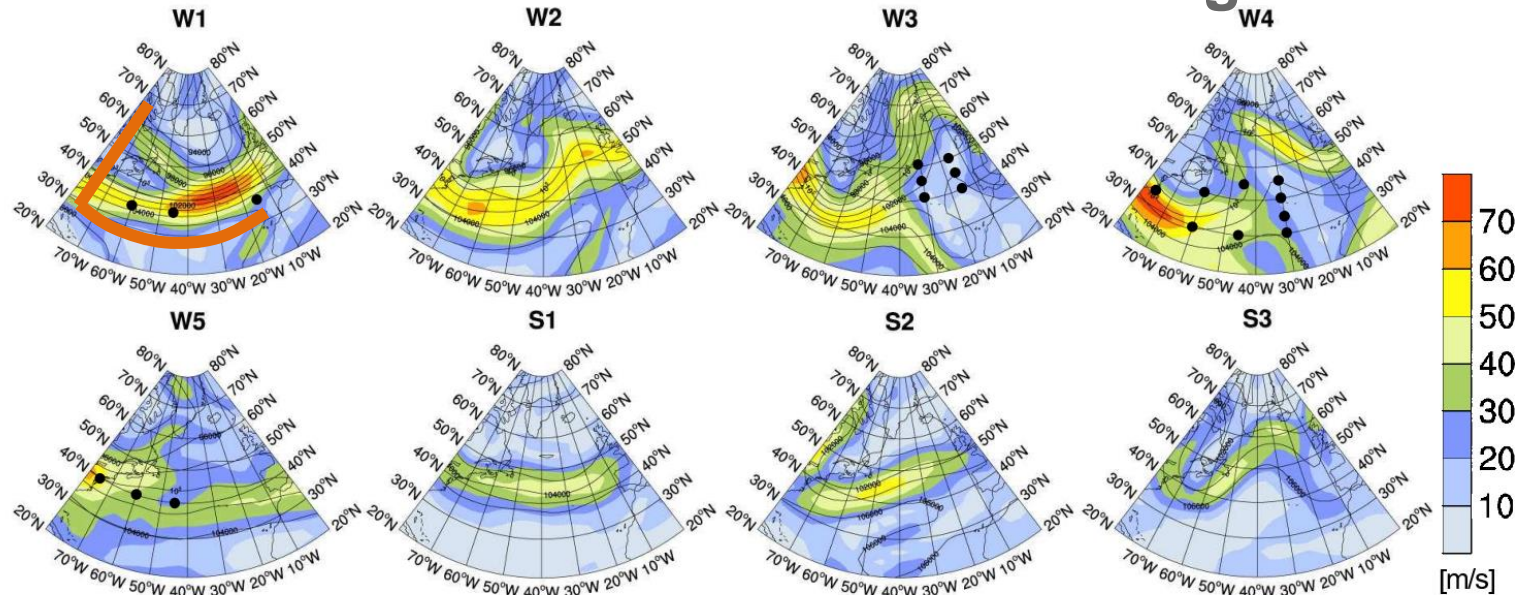
European Application: Case study



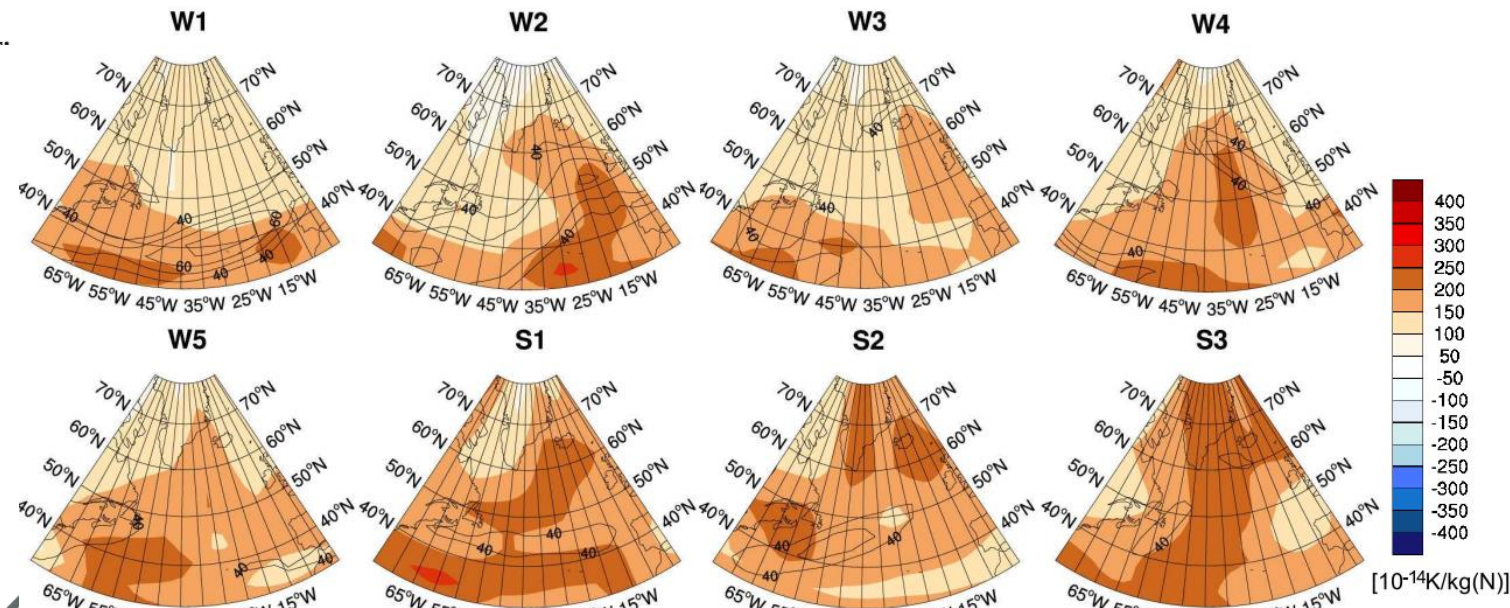
Uncertainties and robustness



Weather data and Ozone Climate-Change-Functions



Climatology of aviation weather situations:
 Winter W1-W5
 Summer S1-S3
 University Reading
 Irvine et al. 2013



Contribution of a local NO_x emission to climate change via ozone formation

Clear relationship between weather and CCFs

Frömming et al. 2021



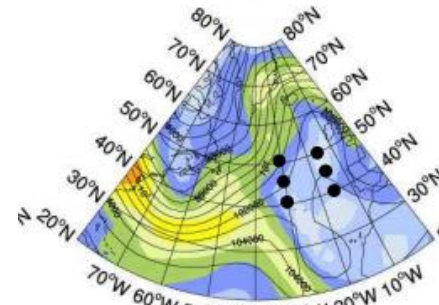
DLR



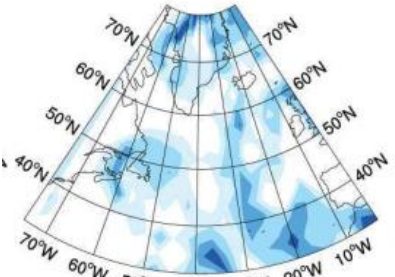
MET Service: Climate Change Functions (CCFs)

representative winter
weather situation,
250 hPa

Weather



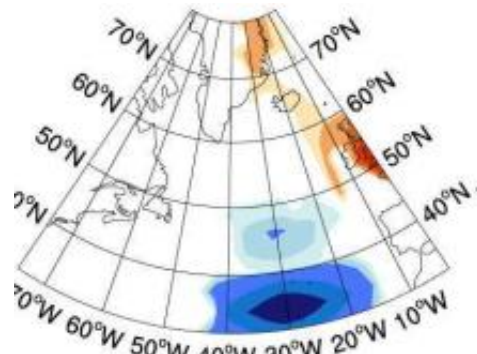
Potential
contrail coverage



Frömming et al. 2021

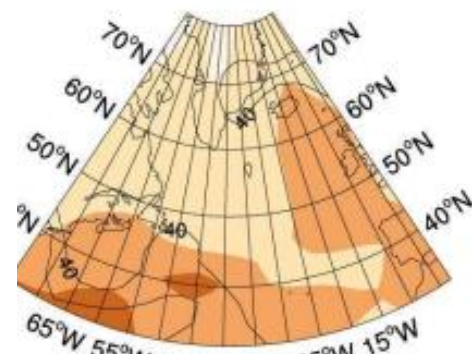
Climate Change Functions = four dimensional functions (space & time)

Contrail CCF



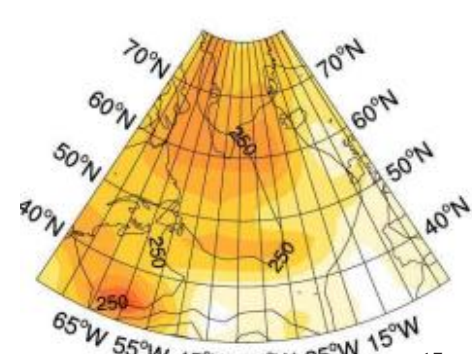
$[10^{-14} \text{K/km(contrail)}]$

Ozone CCF



$[10^{-14} \text{K/kg(N)}]$

Water vapour CCF



$[10^{-17} \text{K/kg(fuel)}]$

- Climate change functions characterize sensitivity of the atmosphere to aviation emissions at specific location (position, altitude, time). \Rightarrow **MET products for climate-optimized trajectory planning** require spatially and temporally resolved climate impact information.

Climate impact mitigation potentials of alternative routings

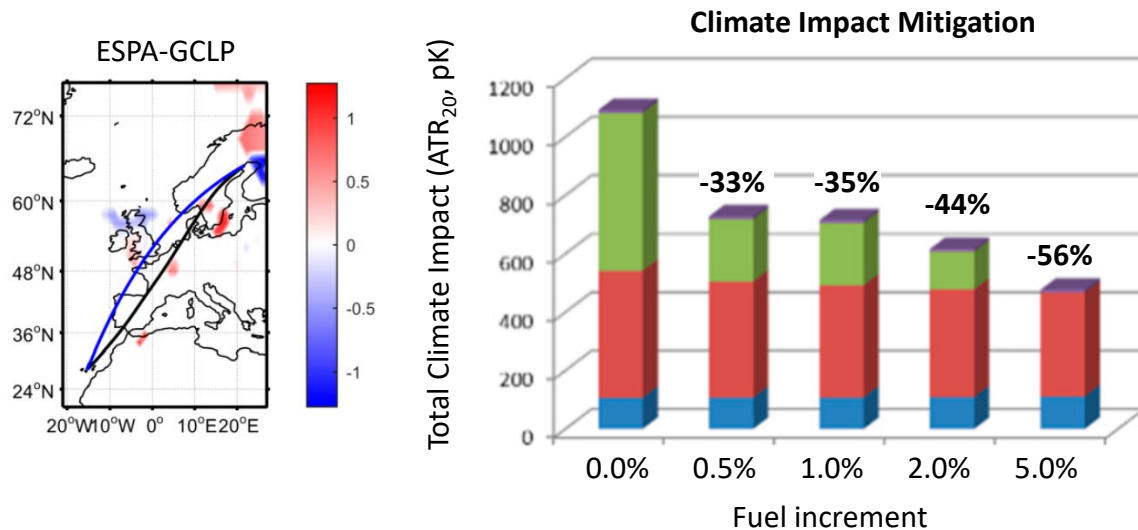
One Day Case Study of European Air Traffic on 18 December 2015

ATM4E

[Matthes et al., 2020](#)

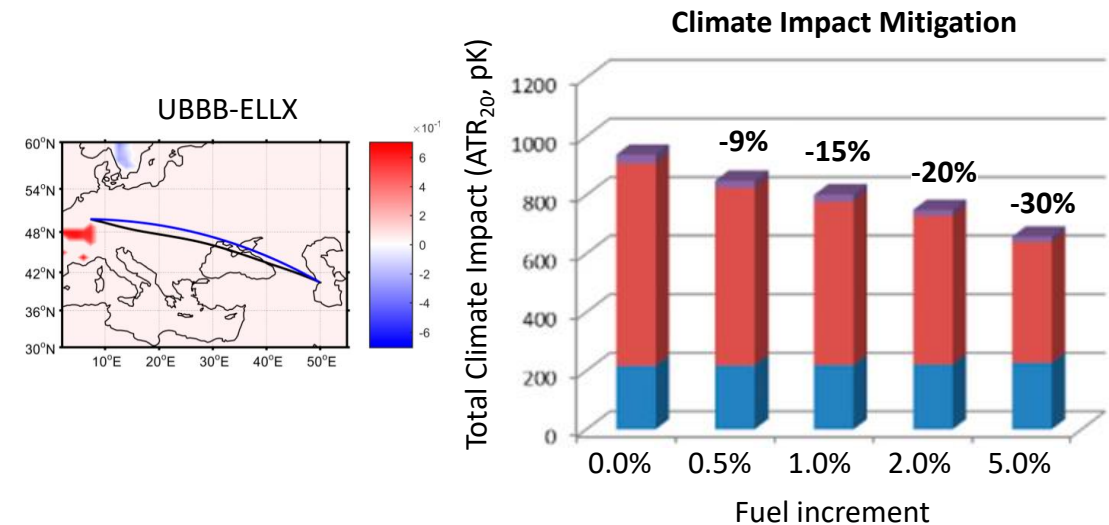
Example 1: Lulea – Gran Canaria (ESPA-GCLP)

Contrails-dominated climate impact



Example 2: Baku – Luxembourg (UBBB-ELLX)

NO_x-dominated climate impact (no contrails)



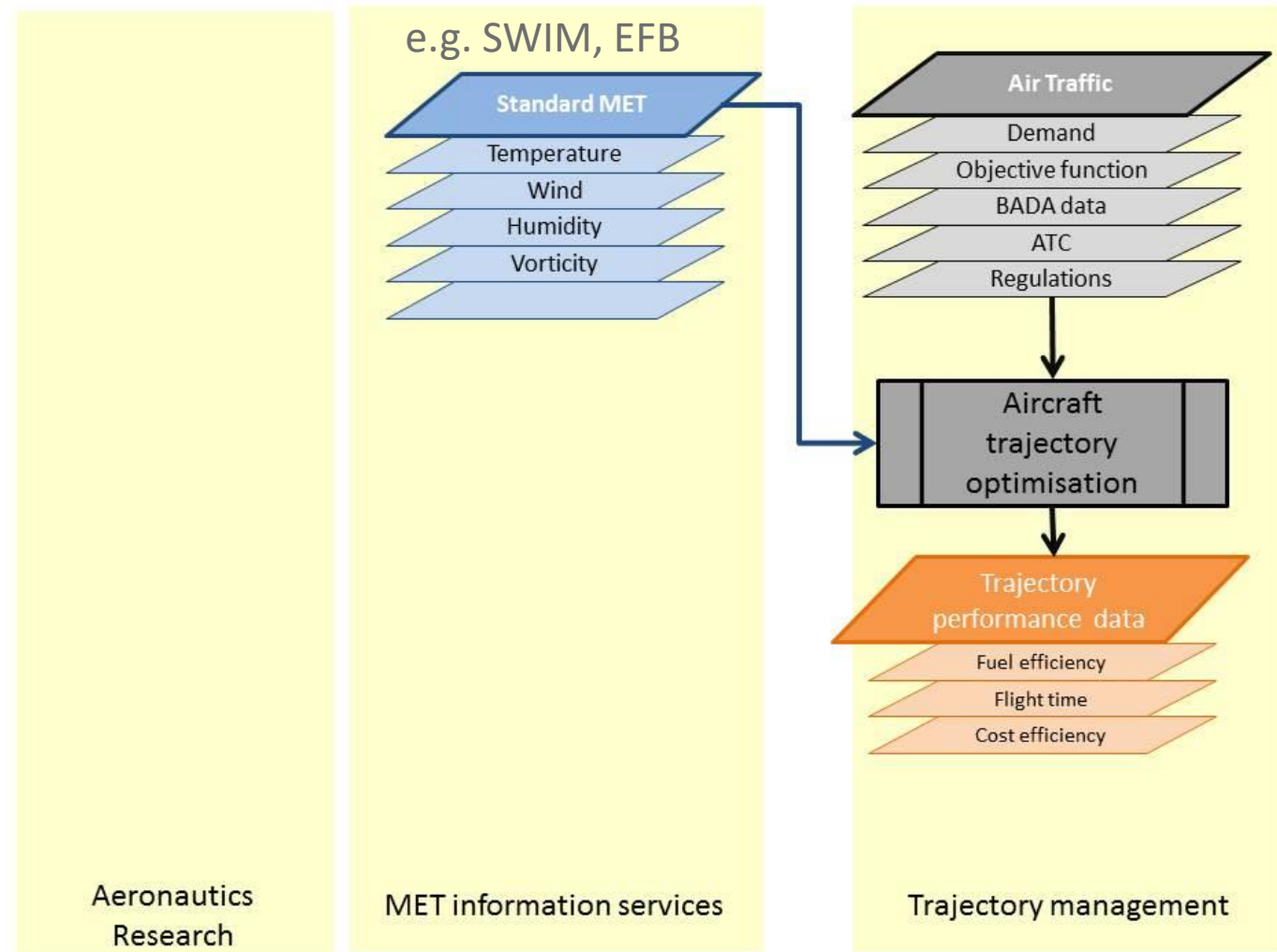
- Climate-optimized routings can mitigate the total climate impact significantly
- The total climate impact of a flight can decrease despite increasing emissions (e.g. -35% ATR₂₀ for +1% fuel increase)
- Climate-optimized routings might not be cost-optimal (need for market-based / policy measures)

H₂O
 AIC
 NO_x
 CO₂

Air traffic management for environment

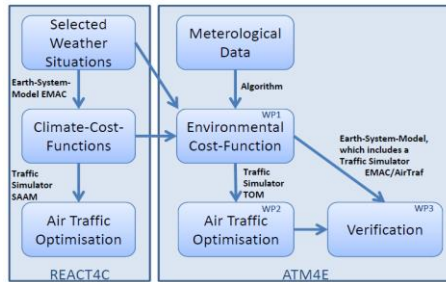
How to integrate climate change information (aCCFs) during flight planning

Schematic ATM system

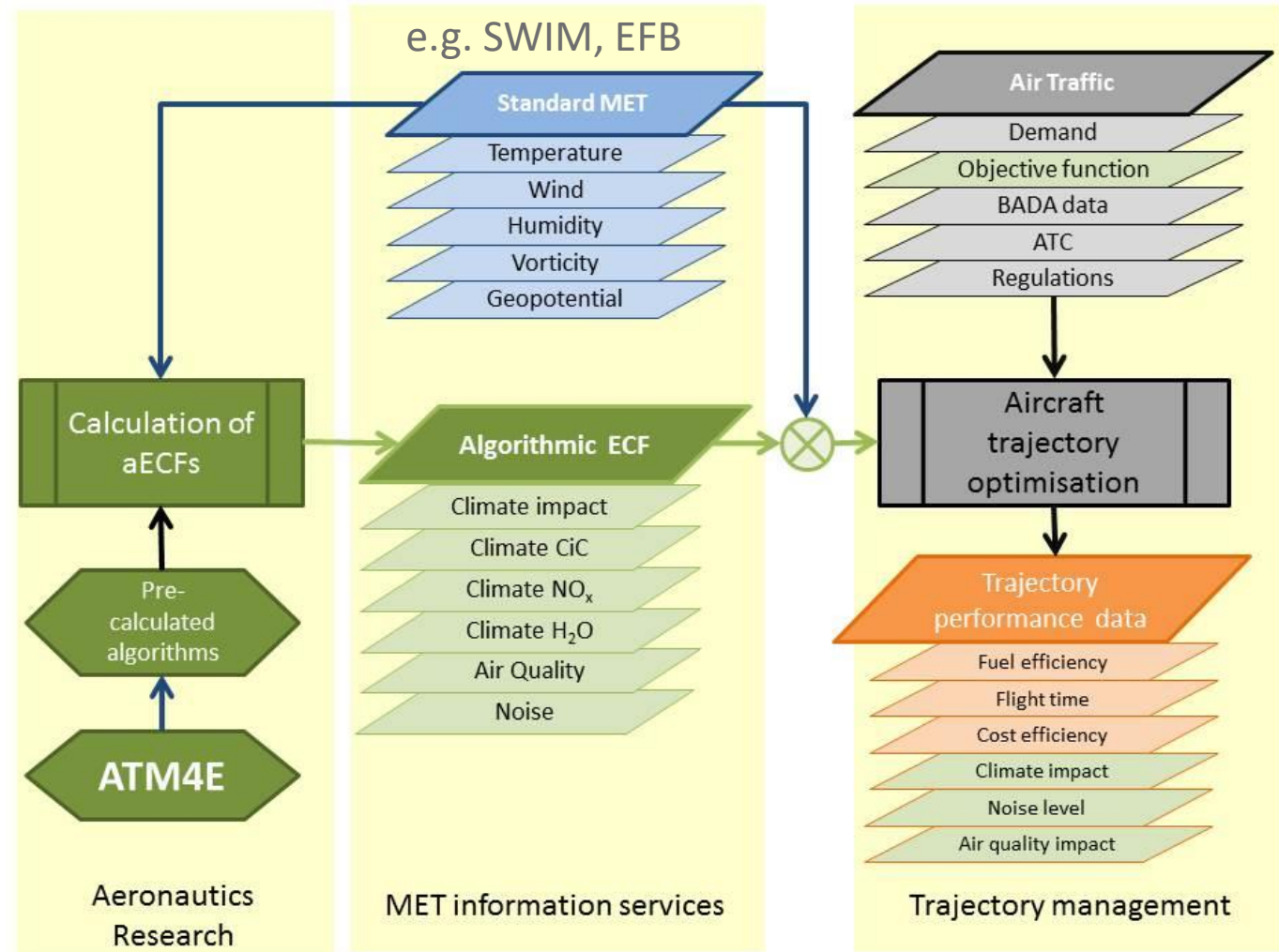


Air traffic management for environment

How to integrate climate change information (aCCFs) during flight planning



Contribution of ATM4E



ATM4E

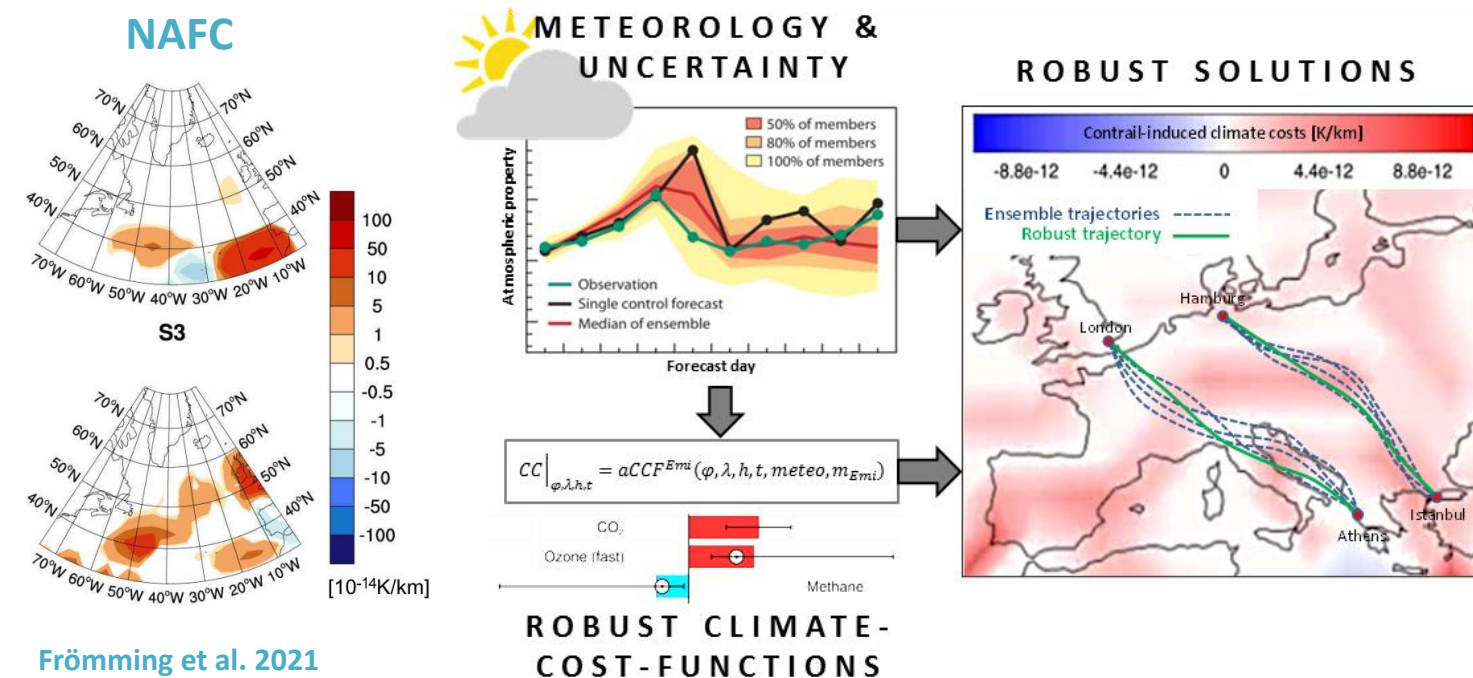


This project has received funding from the SESAR Joint Undertaking under grant agreements No 699395 and No 891317 under European Union's Horizon 2020 research and innovation programme.

Feasibility study: Step towards robustness of climate-optimized trajectories

Using algorithmic Climate Change Functions ECFs (MET service)

- FlyATM4E developed a concept to **identify climate-optimised aircraft trajectories** which enables a robust and **eco-efficient** reduction in aviation's climate impact, quantifying non-CO₂ **mitigation potentials**.
- FlyATM4E **identified those weather situations** and aircraft trajectories, which lead to a **robust climate impact reduction** despite **uncertainties**. Methods on robust decision making under uncertainty conditions are currently under development, resulting in quantitative estimates of robust mitigation potentials.

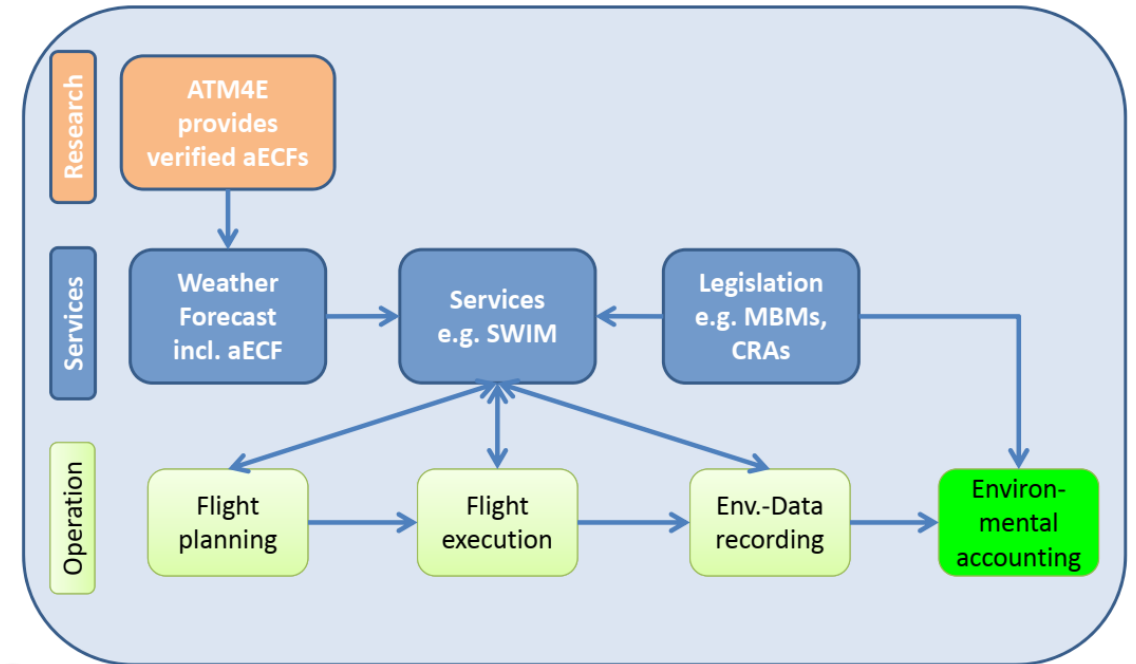


Frömming et al. 2021

- FlyATM4E further identified those weather situations having a **large potential to reduce the climate impact** with only little or even no cost changes (“**Cherry-Picking**”) and those situations where both, climate impact and costs can be reduced (“**Win-Win**”).
- FlyATM4E **formulates recommendations** how to implement these **strategies in meteorological (MET) products**

Roadmap: Towards implementation of climate-optimized trajectories

- Implementation relies on **provision of climate change functions to ATM** (trajectory optimisation)
- Feasibility study performed on **infrastructure** comprising MET components – resulting in roadmap definition how to expand the current ATM system in order to **enable climate-optimized trajectories**
- Options on how to **develop and how to integrate such novel MET products** have been studied in earlier projects, e.g. DG Aeronautics (**REACT4C**, 2010-2013) and SESAR2020 (e.g. **ATM4E**, 2016-2018).
- Candidate solutions are proposed: enabling solution relying on aCCFs (**Sol-FlyATM4E-01**) and operational solution on climate optimized trajectories (**Sol-FlyATM4E-01**)
- Further options on how to expand current ATM and how to identify overall **mitigation potential by climate-optimized trajectories** are currently explored, e.g. ongoing SESAR2020 (Exploratory Research) FlyATM4E, ALARM, but also Aeronautics ClimOP and ACACIA.
- Concepts on how to deal with **prevailing uncertainties** are required for a **robust decision making**.



Matthes et al. 2017

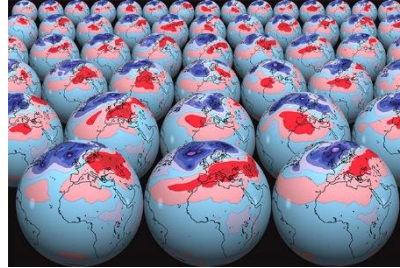
Characterization of prevailing uncertainties when providing climate change functions (CCFs)

Prevailing uncertainties need to be characterized and **mathematical concepts** for a risk assessment on how to integrate identified uncertainties in the overall climate effects assessment need to be introduced.

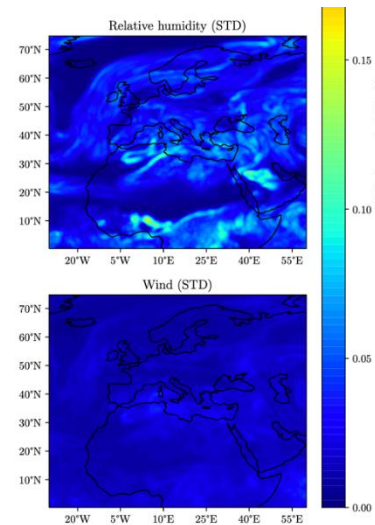
This is a prerequisite in order to **characterize robustness** of alternative **climate-optimized aircraft** trajectories and associated mitigation gains.

Quality of the meteorological forecast

Ensemble Prediction System (EPS)



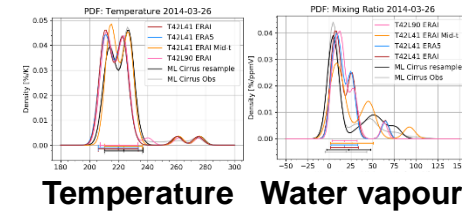
Statistical analysis of key parameters in individual ensemble members, e.g. humidity, temperature, wind.



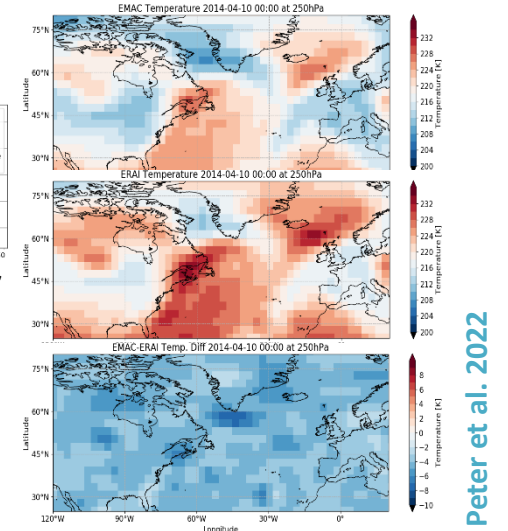
Simorgh et al. 2022
Dietmüller et al., 2022

Representation atmospheric processes

Nudged simulations in chemistry-climate model EMAC



Systematic evaluation of chemistry-climate model EMAC with reanalysis and observation data to determine uncertainty.

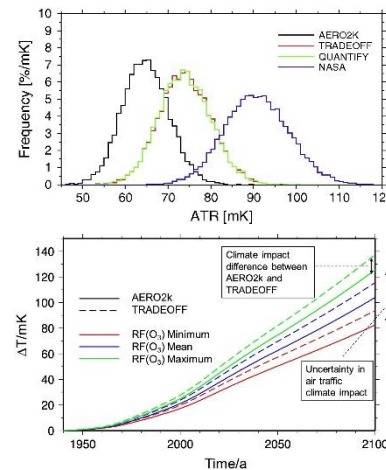


Peter et al. 2022

Physical climate metrics

Climate metrics are calculated with climate response model AirClim

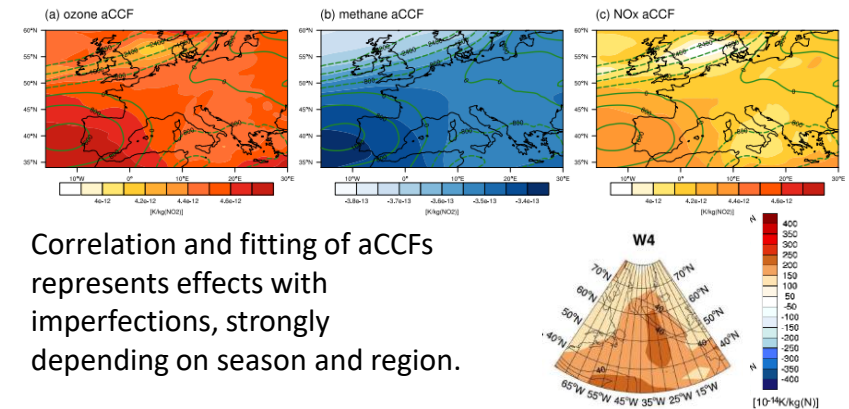
Calculation of temperature change of CO₂ and non-CO₂ effects requires a physical metric definition, as well as assumptions on background conditions, resulting in uncertainty ranges identified by Monte Carlo simulations.



Dahlmann et al. 2016

Development aCCFs

Comprehensive Lagrangian simulations in chemistry-climate



Correlation and fitting of aCCFs represents effects with imperfections, strongly depending on season and region.

Frömming et al. 2021
Yin et al. 2022, Dietmüller et al., 2022

Characterization of prevailing uncertainties when providing climate change functions (CCFs)

Implementation of prototype climate change functions

Reanalysis data in order to identify mitigation potentials in real weather situations

Assessing weather situations and their mitigation potentials shows strong variation of climate effects with synoptic situation, season and geographic region of flight.

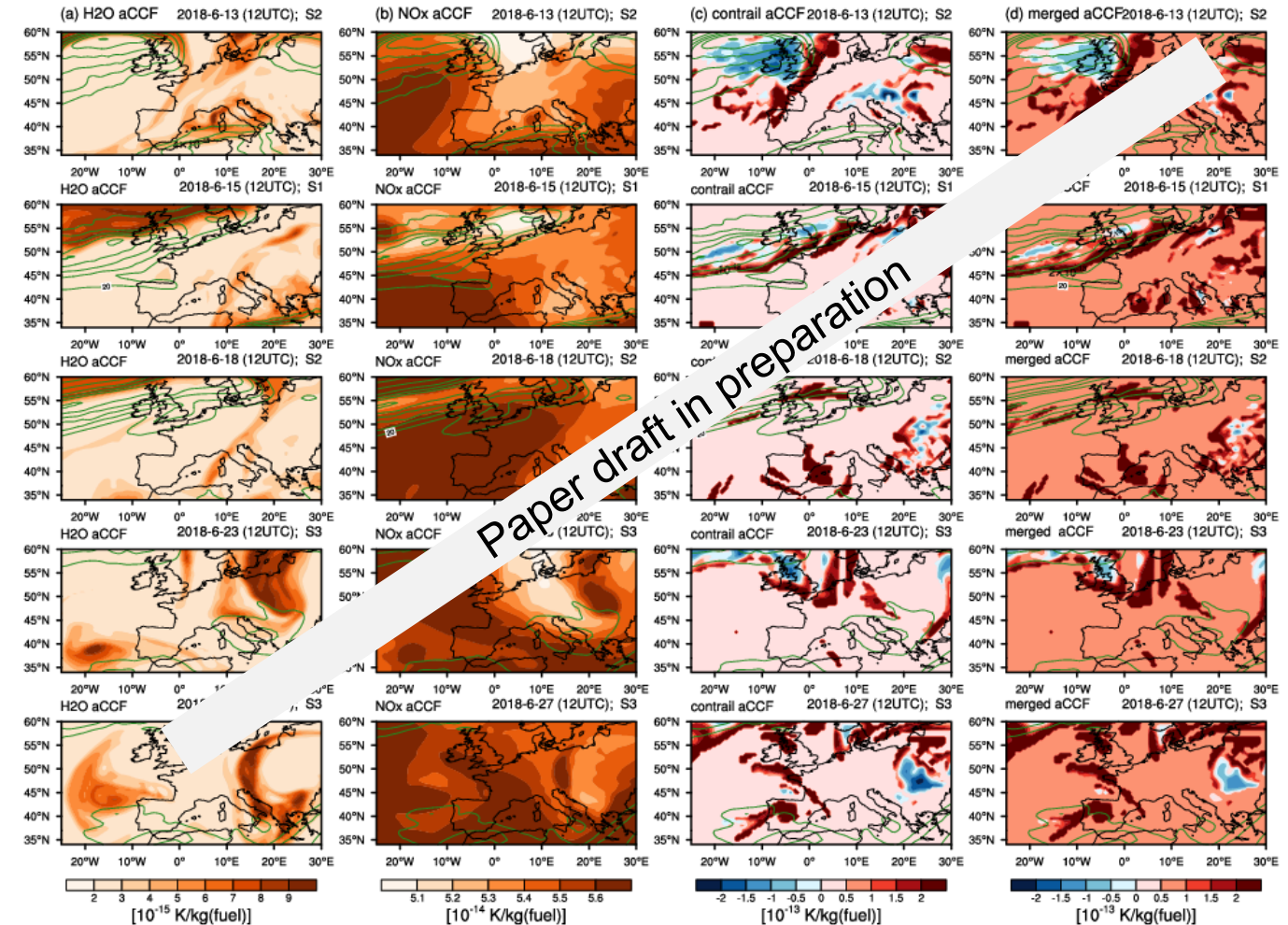
Further research is needed in order to consolidate estimates of climate effects and mitigation gains. However, feasibility studies on possible implementation are required in order to prepare for future implementation.

From earlier comprehensive climate chemistry simulations for summer and winter algorithmic climate change functions have been derived.

Applying these algorithms to reanalysis data allows to quantify anticipated climate effect for a given geographic position and time of flight.

Climate metrics (ATR) were calculated with climate response model AirClim

Individual non-CO₂ climate effects show different type of granularity, strength and temporal variation of regions with high impact.



Matthes et al. 2022

Characterization of prevailing uncertainties when providing climate change functions (CCFs)

Source of uncertainty	Origin of uncertainty
Meteorological Forecast	
Quality of meteorological forecast	Weather forecast data contains deviation from real world situations measured by quality of the forecast and its skill.
Calculation of climate effects and impact	
Representation of atmospheric processes	Chemistry scheme (e.g. O ₃ production), cloud parametrization, horizontal and vertical resolution.
Change in GHG concentration/contrails	Background (e.g. temperature bias in EMAC).
Radiative forcing (RF)	Estimate of RF depends on assumption of linearity for radiative transfer calculations.
Temperature calculation	Temperature change calculation depends on assumptions on efficacy and temporal evolution of emissions/RF.
Physical climate metric	Climate metric has to be appropriate for the targeted climate objective but should still allow some variation with respect to assumptions on background emission scenario/model, emissions evolution (pulse/sustained/future scenario), climate indicator (e.g. averaged temperature response), and time horizon (e.g. ATR20).
Development of Algorithms to represent CCFs (=aCCFs)	
Development of algorithms in aCCFs	Due to the fitting of CCF data to meteorology at the location of emission, imperfections in the relationships are identified.
Emission calculation in emission model	
Emission index/conversion merged aCCFs	Assumptions in emission model.

Table from FlyATM4E: List of sources of uncertainties for individual aCCFs and for their associated calculations on climate effect.

FlyATM4E has developed a concept to **characterize prevailing uncertainties** and introduced **mathematical concepts** on how to integrate identified uncertainties in the overall climate effects assessment. This is a prerequisite in order to **characterize robustness** of alternative **climate-optimized aircraft trajectories**.

This methodology has been applied in a **case study** (summer & winter, 2018) for aircraft movements in the European Airspace where **mitigation potentials due to climate-optimized routing** have been identified (Matthes et al., 2022, *in prep.*) and their associated **uncertainty ranges** have been quantified.





Thank you



Literature and references

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