Climate optimised aircraft trajectories based on advanced MET service for sustainable aviation

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Aviation climate impact
\( \text{CO}_2 \) and non-\( \text{CO}_2 \) effects

Climate impact of aviation emissions (direct & indirect effects)
- \( \text{CO}_2 \), black carbon (soot) - direct
- Nitrogen oxides \( \text{NO}_x \) (\( \text{O}_3 \), \( \text{CH}_4 \))
- **Contrail cirrus** and \( \text{H}_2\text{O} \)
- soot (AIC, aviation induced cloudiness)

Climate impact of **non-\( \text{CO}_2 \) emissions** depends on
- time and position of aircraft
- actual weather conditions (processes, transport pathways, temperature, humidity)
- background concentrations

⇒ **Climate optimized trajectories avoid sensitive regions**

Ozone production efficiency pf \( \text{NO}_x \) emissions, 18 Dec, 250 hPa (EMAC)
Aviation climate impact
CO₂ and non-CO₂ effects

Climate impact of aviation emissions (direct & indirect effects)

- **CO₂**, black carbon (soot) - direct
- Nitrogen oxides **NOₓ** (O₃, CH₄)
- **Contrail cirrus** and H₂O
- soot (AIC, aviation induced cloudiness)

Grewe et al., 2017, updating Lee et al., 2010 (IPCC)

Climate impact of **non-CO₂ emissions** depends on

- time and position of aircraft
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- background concentrations

⇒ **Climate optimized trajectories avoid sensitive regions**
ATM4E

Environmental-optimised trajectories

- Aviation is concerned by environmental impact of its operations. **Aviation climate impact** is caused by CO₂ and non-CO₂ emissions, comprising contrails, nitrogen oxides impacting ozone and methane, water vapour, etc.

- However, during flight planning currently emission information is available, but no **environmental impact information** is available.

- **ATM4E**, Exploratory Research project **SESAR 2020** (2016-2018)
- **Main objective** of the ATM4E project is to explore the feasibility of a concept for environmental assessment of ATM operations working towards environmental optimisation of air traffic operations in the European airspace.

Grewe et al., 2014a,b
Matthes et al., 2012

ATM4E Overview > Sigrun Matthes, DLR > AeroMetSci 2017 > 9 Nov 2017
Interface between environmental impact and ATM via Environmental Change Functions

How to make available information on environmental impact for flight planning.
How to generate such information?

Evolution of aircraft NO\textsubscript{x} at two different locations

What happens if an aircraft emits NO\textsubscript{x} at location A compared to location B?

Using a Lagrangian approach in a general chemistry climate model EMAC to study photochemical processes and climate impact

Frömming et al., 2011, 2017
Climate chemistry model (EMAC)

Evolution of \( O_3 \) [ppt] following a \( NO_x \) emission

A: 250hPa, 40°N, 60°W, 12 UTC

B: 250hPa, 40°N, 30°W, 12 UTC

Depending on location of emission ozone formed during weeks after emission can be high (here: 30°W) and lower (here: 60°W)

Frömming et al., 2011, 2017
Environmental Change Functions (ECFs)

- The key step in ATM4E is to relate readily-available meteorological data to these existing detailed CCFs to allow the rapid generation of new CCFs (algorithmic CCFs) for specific (forecast) weather situations

  ➞ Advanced MET information

- Integration of environmental impact information via Meteorological interface to SWIM infrastructure (format, architecture) to make it available during flight planning.
Air traffic management for environment: SESAR/H2020-Project ATM4E

Current situation

Aeronautics Research

MET information services

SWIM

Standard MET
- Temperature
- Wind
- Humidity
- Vorticity

Air Traffic
- Demand
- Objective function
- BADA data
- ATC
- Regulations

Aircraft trajectory optimisation

Trajectory performance data
- Fuel efficiency
- Flight time
- Cost efficiency

Trajectory management
Air traffic management for environment: SESAR/H2020-Project ATM4E

Contribution of ATM4E
Environmental-optimized routing impact on ATM changes in air traffic flows
Environmental-optimized routing impact on ATM changes in air traffic flows

- **To optimize trajectories** to minimize the environmental impact of an air traffic sample in the European airspace
- **To analyze ATM network implications** (hot spots) resulting from environmental optimized routing

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**ATM4E Overview > Sigrun Matthes, DLR > AeroMetSci 2017 > 9 Nov 2017**
Using ECFs for flight planning

\[
J = c_Y \cdot \text{COC}(t_{\text{mission}}, m_{\text{fuel,mission}}) + \int_{t_0}^{t_f} \sum_i (c_{Y,i} \cdot \text{ECF}_i(x,t) \cdot \dot{r}_i) \, dt
\]

Objective function with economic and environmental elements

Synoptical situation
- GpH, wind
- \(T, RH, OLR\)
- Potential Vorticity
- GpH, T

Contrail
- \(H_2O\)
- \(NO_x\)

Algorithmic Climate change function (ECF) given as average temperature response in case study (250 hPa)

\(10^{-12} \, \text{K/km}\)
\(10^{-15} \, \text{K/kg fuel}\)
\(10^{-12} \, \text{K/kg NO}_x\)

TOM work by Linke, Lührs, Niklaß
Environmental Optimization of Aircraft Trajectories

Using advanced MET service ECF to identify Pareto front for use case climate optimized trajectories

Trajectory optimisation assesses climate impact simultaneously with fuel burn.

ATM delivers economic and environmental performance – Pareto Front

Matthes et al., Aerospace, 2017.
Verification of environmental benefit by due to environmental-optimized flight planning
Verification of Environmental Benefit
Using comprehensive global chemistry-climate model
EMAC and routing module: AirTraf

Great circle FL330

Time-optimal

Yamashita et al., GMD, 2016.

Atmospheric model uses algorithm based Environmental change functions.

We will focus on the European Airspace in the ATM4E project
Air traffic management for environment: SESAR/H2020-Project ATM4E

## Contribution of ATM4E

### Calculation of aECFs
- Pre-calculated algorithms

### Algorithmic ECF
- Climate impact
- Climate CiC
- Climate NOx
- Climate H2O
- Air Quality
- Noise

### SWIM
- Standard MET
  - Temperature
  - Wind
  - Humidity
  - Vorticity
  - Geopotential

### Air Traffic
- Demand
- Objective function
- BADA data
- ATC Regulations

### Aircraft trajectory optimisation

### Trajectory performance data
- Fuel efficiency
- Flight time
- Cost efficiency
- Climate impact
- Noise level
- Air quality impact

### Trajectory management

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Summary and Conclusion

- **Environmental change functions (ECFs)** as advanced MET Service establish an interface between climate change knowledge and ATM.
- Use cases for climate-optimised trajectories rely on advanced MET service for providing information on climate impact of aviation emission.
- **Algorithmic ECFs** derived from complex climate chemistry simulations allow to derive climate change functions from standard MET information.
- Communication on implementation has started involving research, service providers, manufacturers and airspace users (Stakeholder Workshop, Jan 18).
- **Performance indicators** need to be developed which are able to demonstrate environmental benefits on climate impact mitigation.


Thank you

6 to 10 November 2017, Météo-France, Toulouse
Thank you
Objective ATM4E
Environmentally-optimized flight planning

- The project aims at integrating existing methodologies for assessment of the environmental impact of aviation, in order to evaluate the implications of environmentally-optimized flight operations to the European ATM network, considering climate, air quality and noise impacts.

- A modelling concept for climate-optimisation which has been developed in a feasibility study for the North Atlantic will be expanded to a multi-dimensional environmental impact assessment, covering climate, air quality and noise.

- Different traffic scenarios (present-day and future) will be analysed to understand the extent to which environmentally-optimized flights that are planned and optimized based on multi-dimensional environmental criteria (assessment) would lead to changes in air traffic flows and create challenges for ATM.

- These findings will be used to prepare a roadmap compliant with SESAR2020 principles and objectives which would consider the necessary steps and actions that would need to be taken to introduce environmentally-optimized flight operations on a large scale in Europe.
Network Flow Environment

- NFE is used for modelling the European Network Management processes, incl. demand-capacity-balancing
- **Research questions** include
  - Studying the impact of disruptive events, new operational concepts and technologies on ATM network performance (delay)
  - Design of new measures for Air Traffic Flow Management
  - Investigation of new optimization strategies
- Application in SESAR IR PJ09 is foreseen