ATM4E Stakeholder Webinar
Climate-optimized trajectories
25 April 2018

Exchange with stakeholders on to summarize knowledge, provide guidance and technical insights and discuss research and implementation requirements.

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ATM4E

Air Traffic Management for Environment

25 April, 2018
13:30-15:30
(CET time)

ILA BERLIN
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Climate optimal aircraft trajectories

Aviation has the potential to reduce its environmental impact by optimizing operations, as impacts depend on location of emission. ATM4E has been working towards environmental optimization of air traffic operations in Europe.

ATM4E has successfully completed its **workplan implementation** in April 2018:

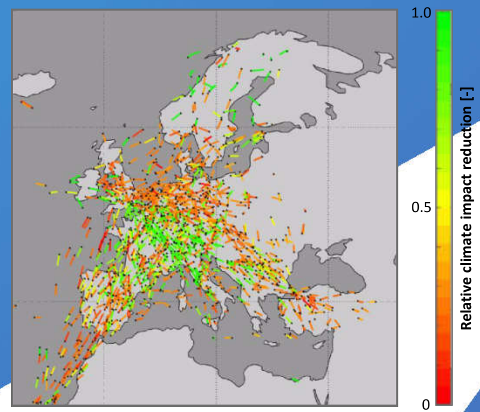
- Performed a feasibility study of an environmental assessment of ATM operations
- Developed a concept for advanced MET service to enable climate-optimized routings
- Studied changes in traffic flows due to environmental optimization of operations in Europe

Key note speakers from the Steering Committee will present project achievements:
13:30 Concept for climate-optimized routing: Use case and MET service
14:00 Climate-optimal trajectories over Europe: A case study
14:30 Lessons learnt on implementation of MET service

As there is only limited space available, please inform us on your intention to participate:
Stavros Stromatas (Communication Manager, **stavros.stromatas@env-isa.com**)
with cc to Dr. Sigrun Matthes (Project Coordinator, **sigrun.matthes@dlr.de**)
Access will also be possible for registered users by WebConference.

Steering Committee

Dr. Sigrun Matthes (Coordinator)
Prof. Keith Shine
Dr. Florian Linke
Benjamin Lührs
Prof. Volker Grewe
Dr. Stavros Stromatas



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DLR envisa TUDelft Manchester Metropolitan University TUHH Technische Universität Hamburg-Harburg University of Reading

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

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ATM4E approach for identifying climate-optimal aircraft trajectories

ATM4E Air Traffic Management for Environment

Sigrun Matthes
DLR, Institute Atmospheric Physics, Oberpfaffenhofen
Coordinator ATM4E (SESAR 2020, Exploratory Project)

Volker Grewe, Keith Shine, Florian Linke,
Benjamin Lührs, Feijia Yi, Stavros Stromatas
and ATM4E Team

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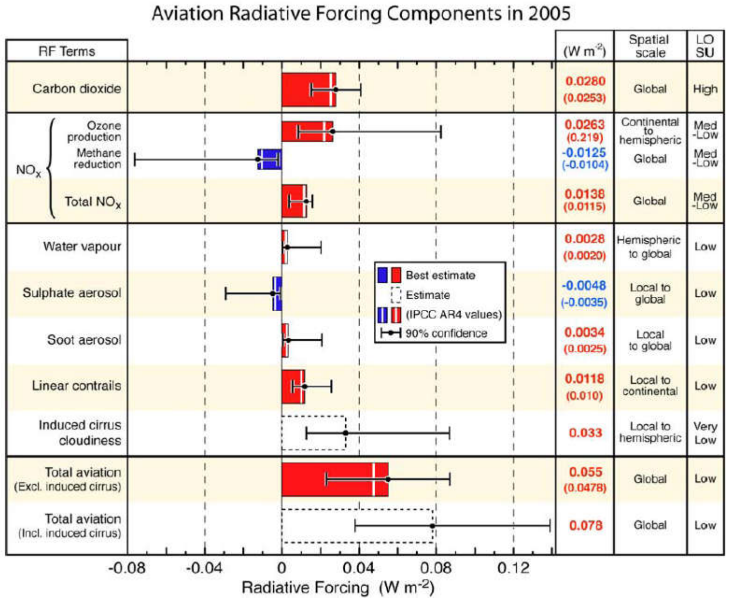
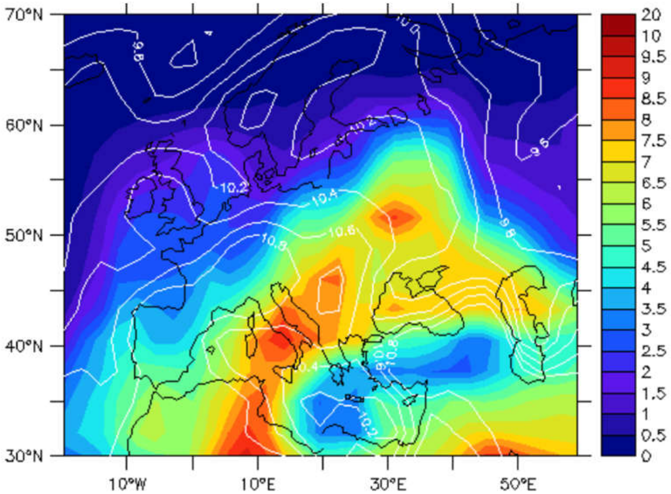
Aviation climate impact
CO_2 and non-CO_2 effects

Climate impact of aviation emissions (direct & indirect effects)

- **CO_2**, black carbon (soot) - direct
- Nitrogen oxides **NO_x** (O_3, CH_4)
- **Contrail cirrus** and H_2O
- soot (AIC, aviation induced cloudiness)



Lee et al., 2010 (IPCC)



Ozone production efficiency pf NO_x emissions, 18 Dec, 250 hPa (EMAC)

Climate impact of **non-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**

Aviation climate impact
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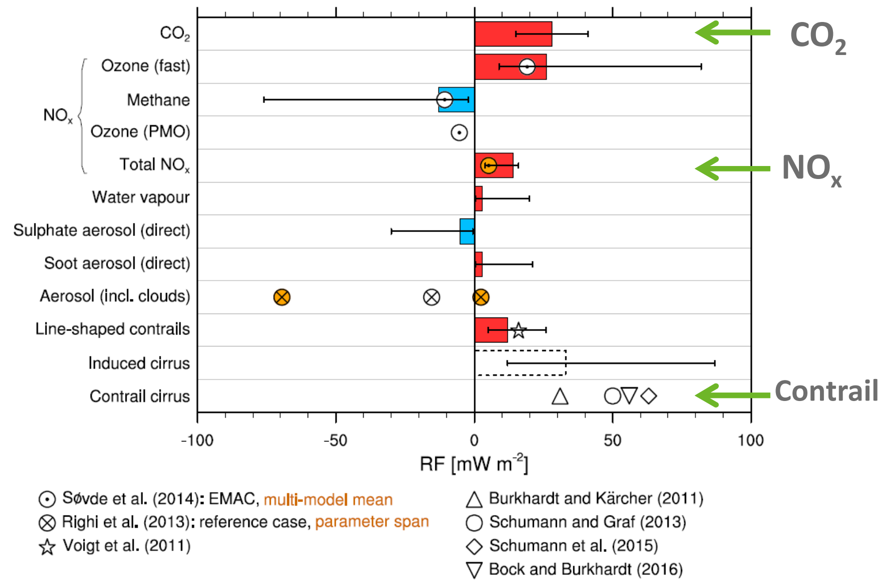
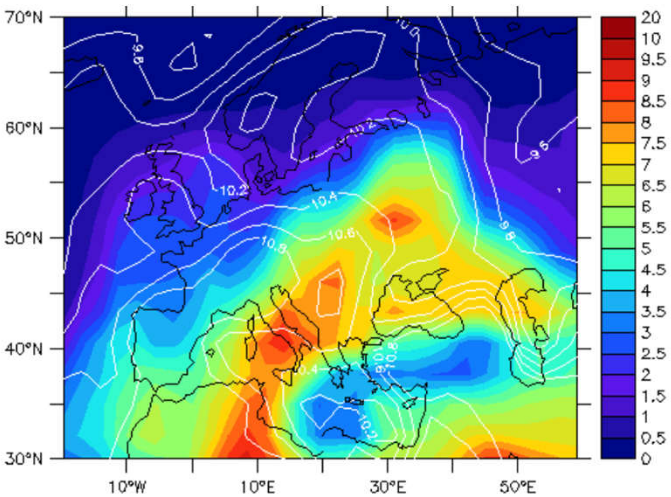


Grewe et al., 2017, updating Lee et al., 2010 (IPCC)



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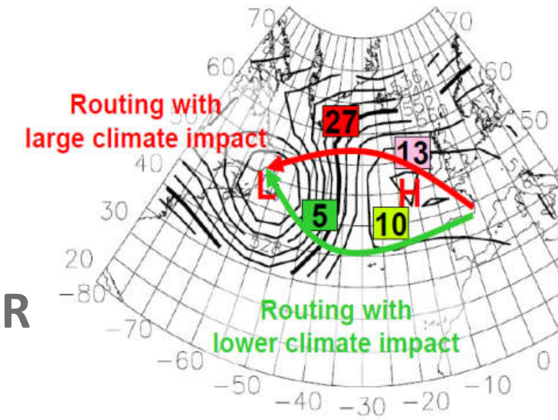
Environmental-optimised trajectories

- Aviation is concerned by environmental impact of its operations. **Aviation climate impact** is caused by CO_2 and non-CO_2 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.



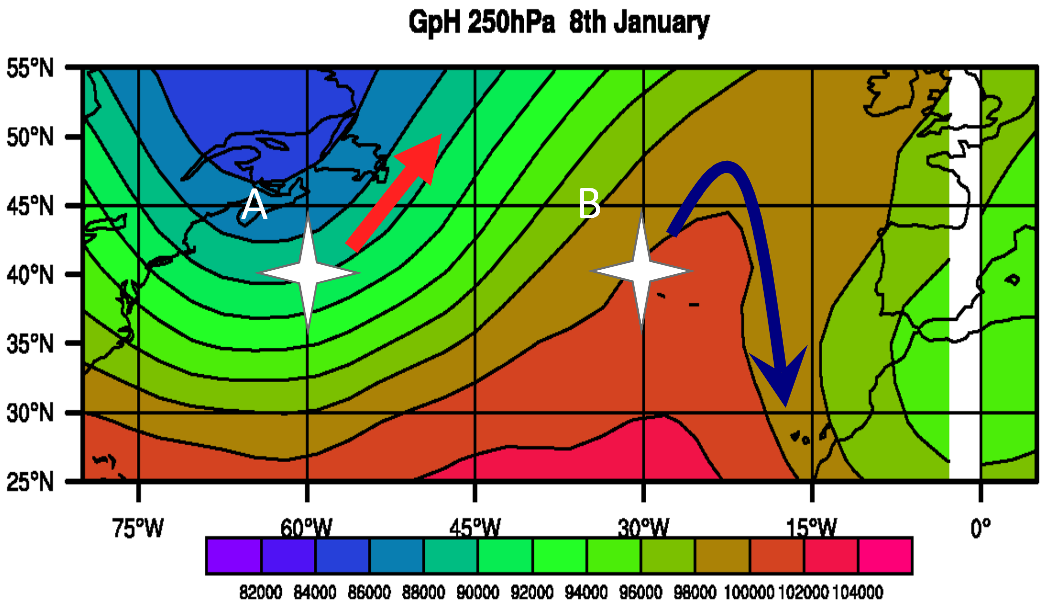
Matthes et al., 2012
Grewe et al., 2014a,b

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_x at two different locations



Frömming et al., 2011, 2018

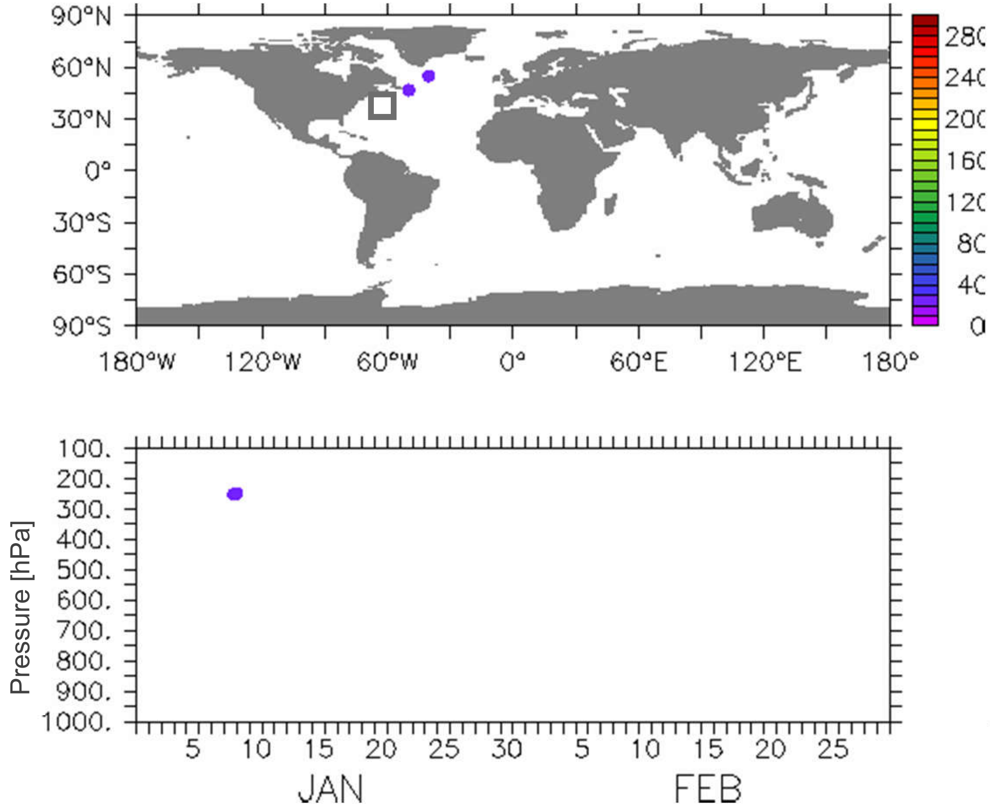
What happens if an aircraft emits NO_x at location A compared to location B?

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

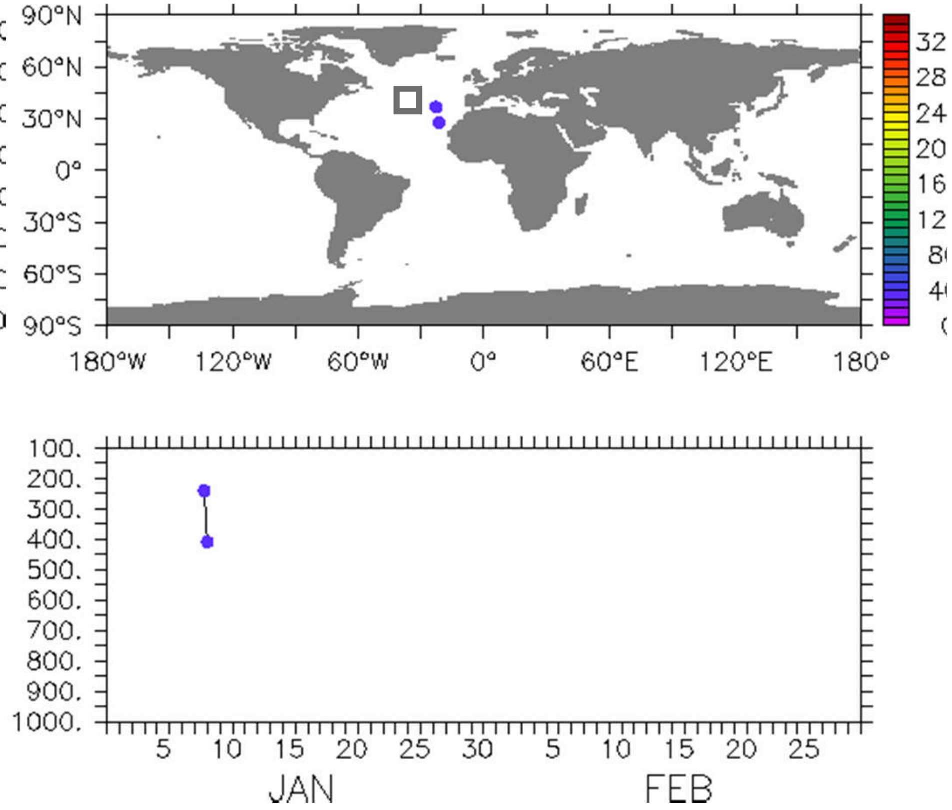
Climate chemistry model (EMAC)

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



Frömming et al., 2011, 2018

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

Climate chemistry model (EMAC)

Evolution of O_3 [ppt] following a NO_x emission

A: 250hPa, 40°N, 60°W, 12 UTC

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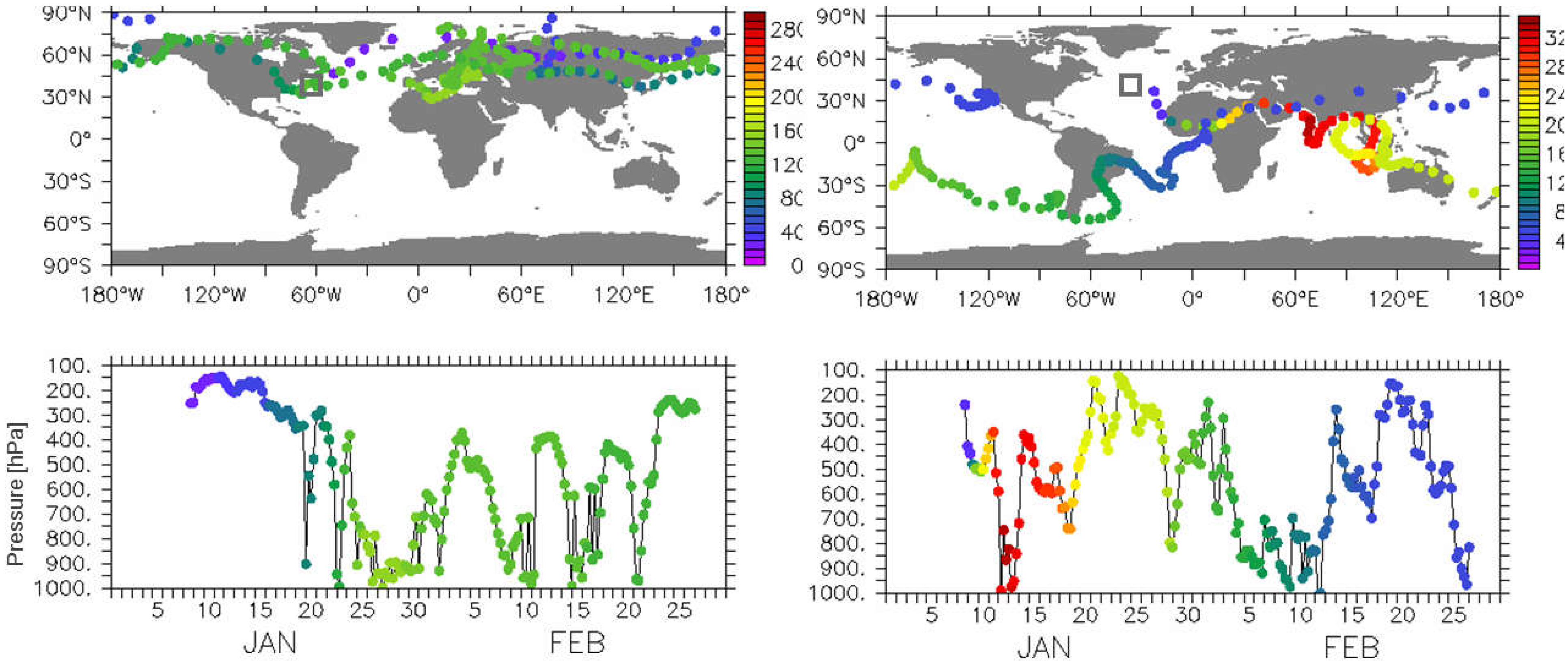


Frömming et al., 2011, 2018

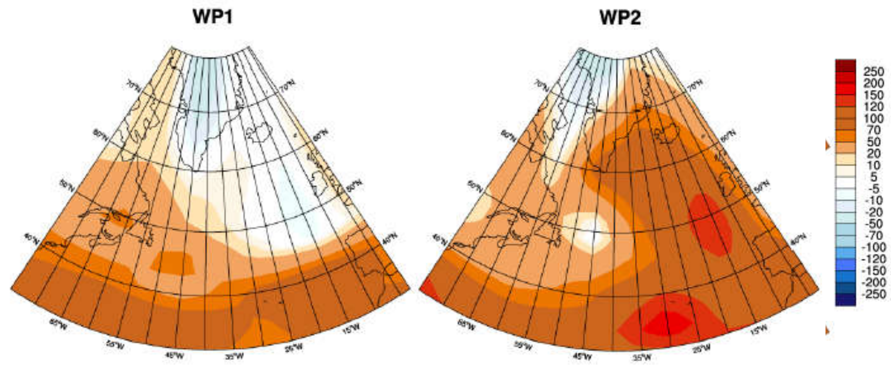
Depending on location of emission ozone formed during weeks after emission can be high (here: 30°W) and lower (here: 60°W)

Environmental Change Functions ECFs

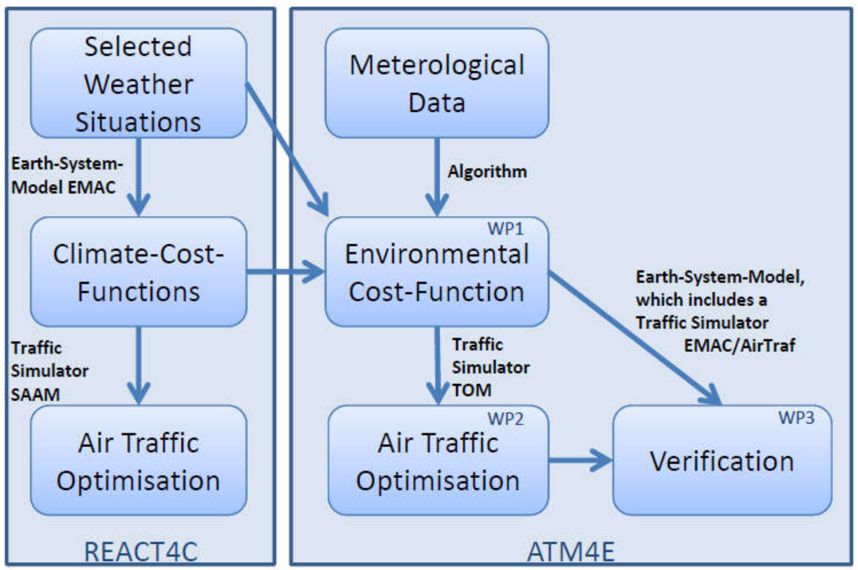
- The key step in ATM4E is to **relate** readily-available **meteorological data** to these existing detailed CCFs to allow the rapid generation of new CCFs (algorithmic CCFs) for specific (forecast) weather situations

  ⇒ **Advanced MET information**

- Integration of **environmental impact information** via Meteorological interface to **SWIM infrastructure** (format, architecture) to make it available during flight planning.

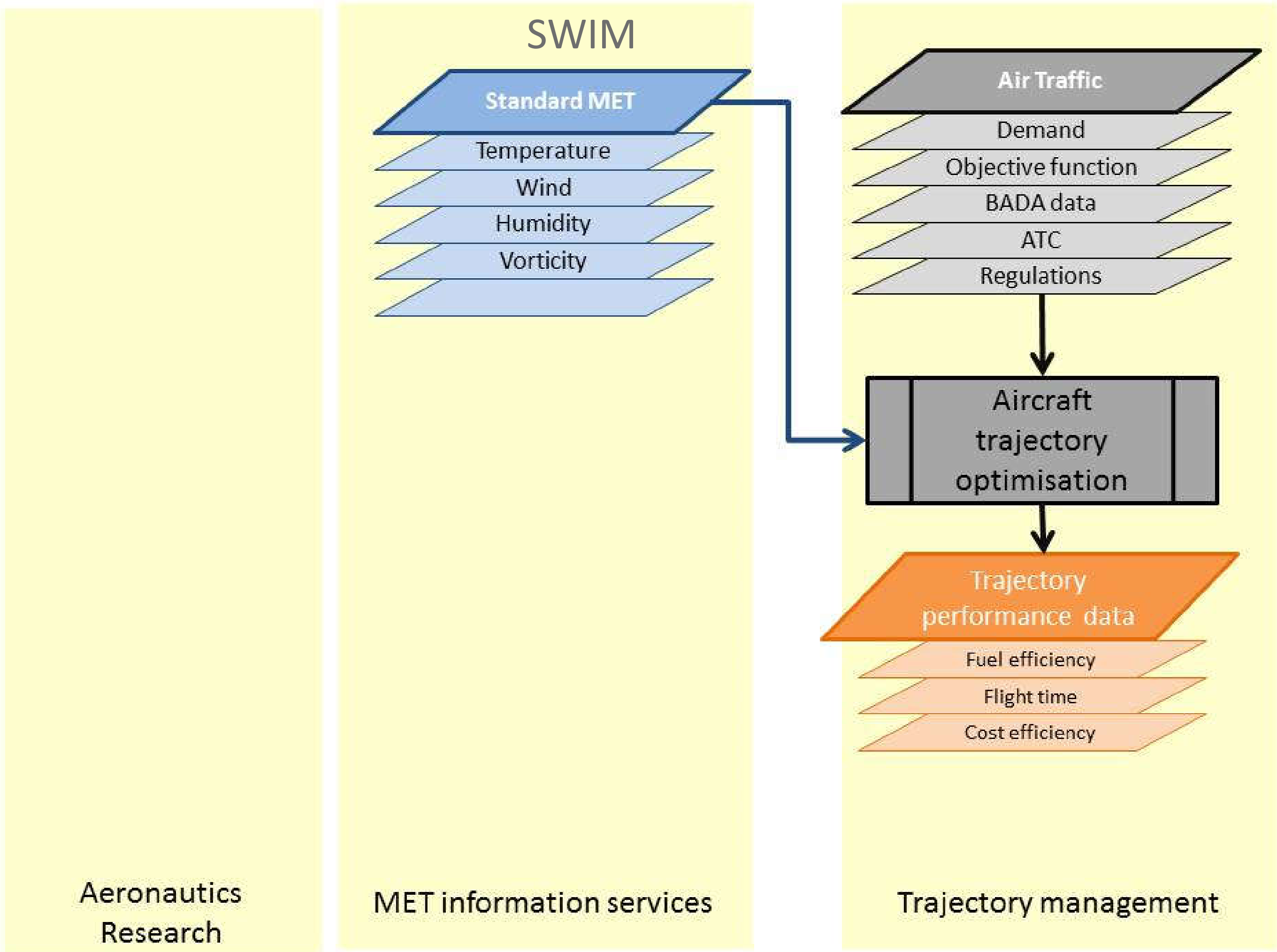


Frömming et al., 2017

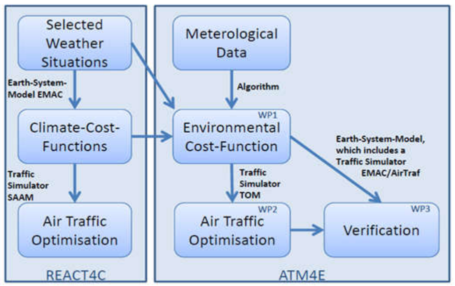


Air traffic management for environment: SESAR/H2020-Project ATM4E

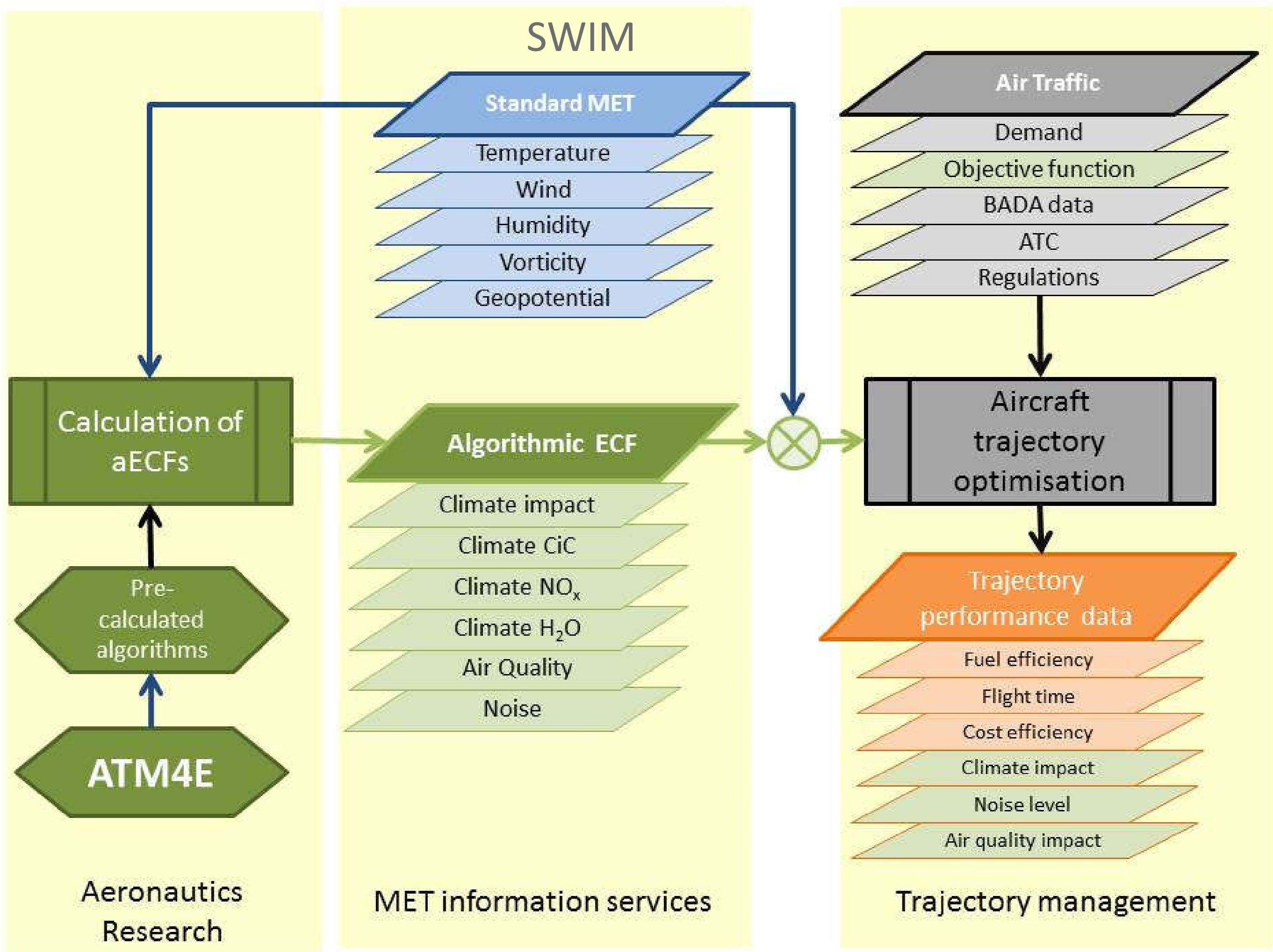
Current situation



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



Contribution of ATM4E



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

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ILT Institut für Lufttransportsysteme

TUHH Technische Universität Hamburg-Harburg

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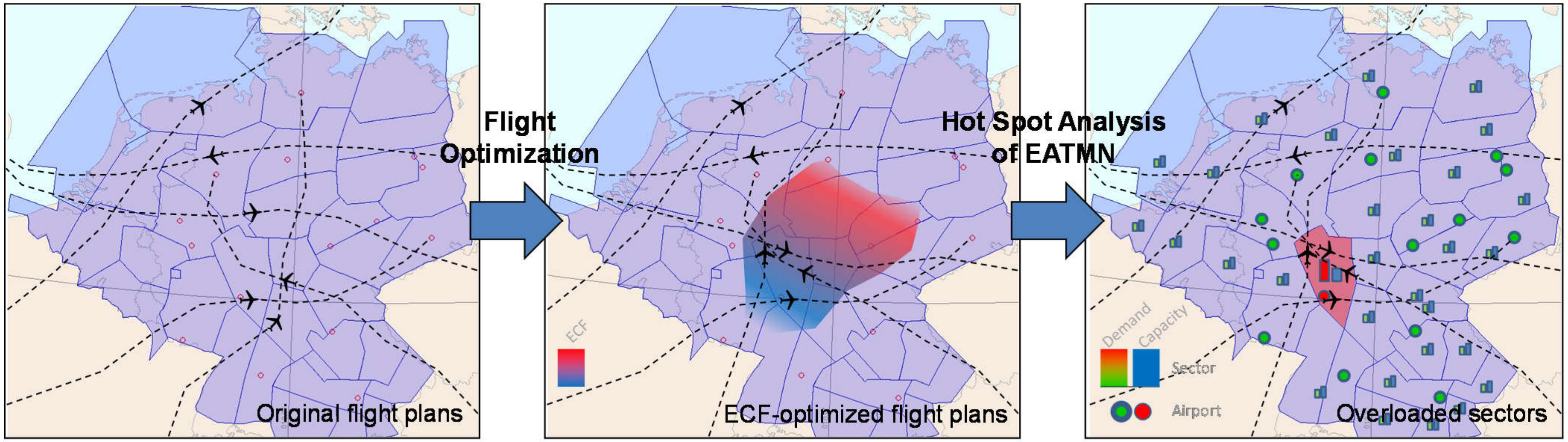
Environmental-optimized routing impact on ATM changes in air traffic flows

- 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

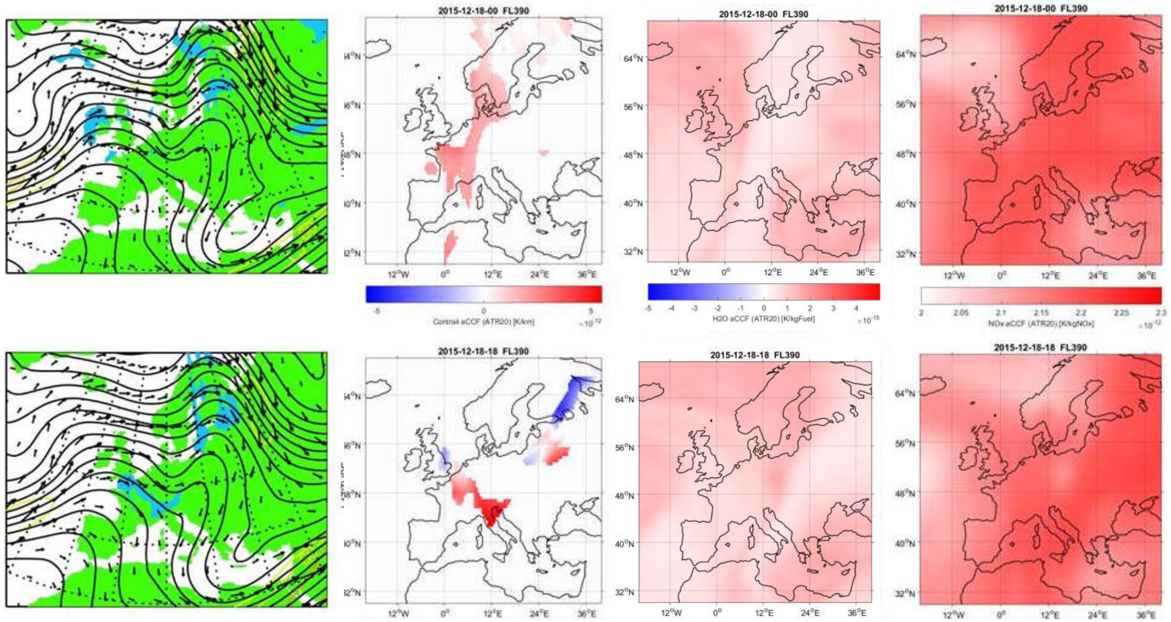


Using ECFs for flight planning

Objective function with **economic** and **environmental** elements

$$\mathcal{J} = c_{Y} \cdot \mathrm{COC}(t_{\mathrm{mission}}, m_{\mathrm{fuel,mission}}) + \int_{t_0}^{t_f} \sum_{i} (c_{\Psi,i} \cdot \mathrm{ECF}_i(\mathbf{x},t) \cdot \dot{r}_i)\, \mathrm{d}t$$

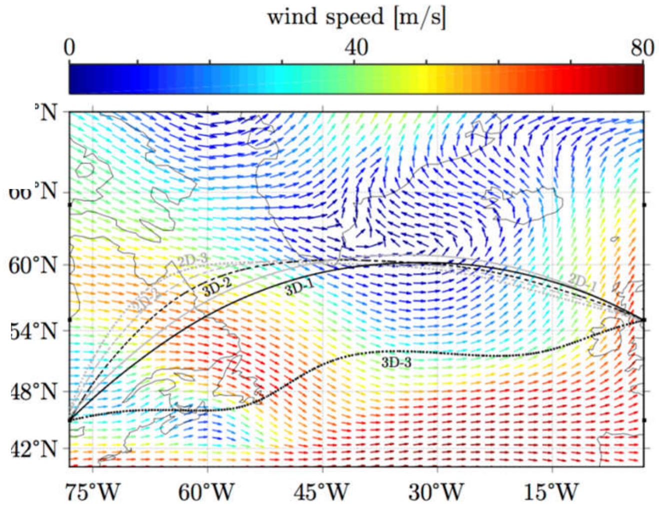
Synoptical situation	Contrail	H_2O	NO_x
GpH, wind	*T, RH, OLR*	*Pot. Vort.*	*GpH, T*

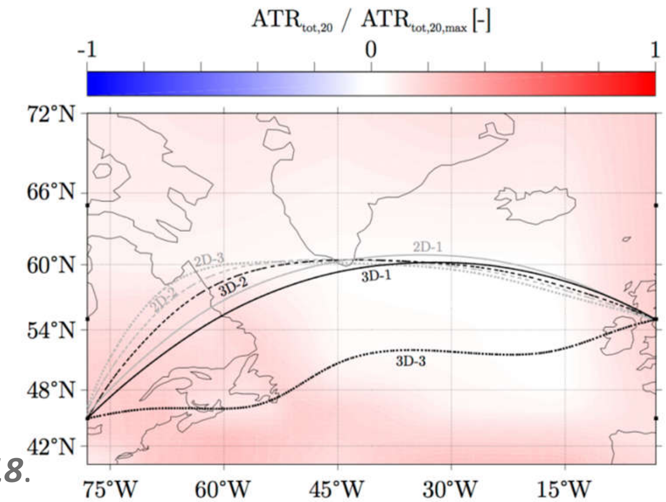


10^{-12} K/km 10^{-15} K/kg fuel 10^{-12} K/kg NO

Irvine and Shine, 2018; Matthes et al. 2017, Van Manen and Grewe, 2018.

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



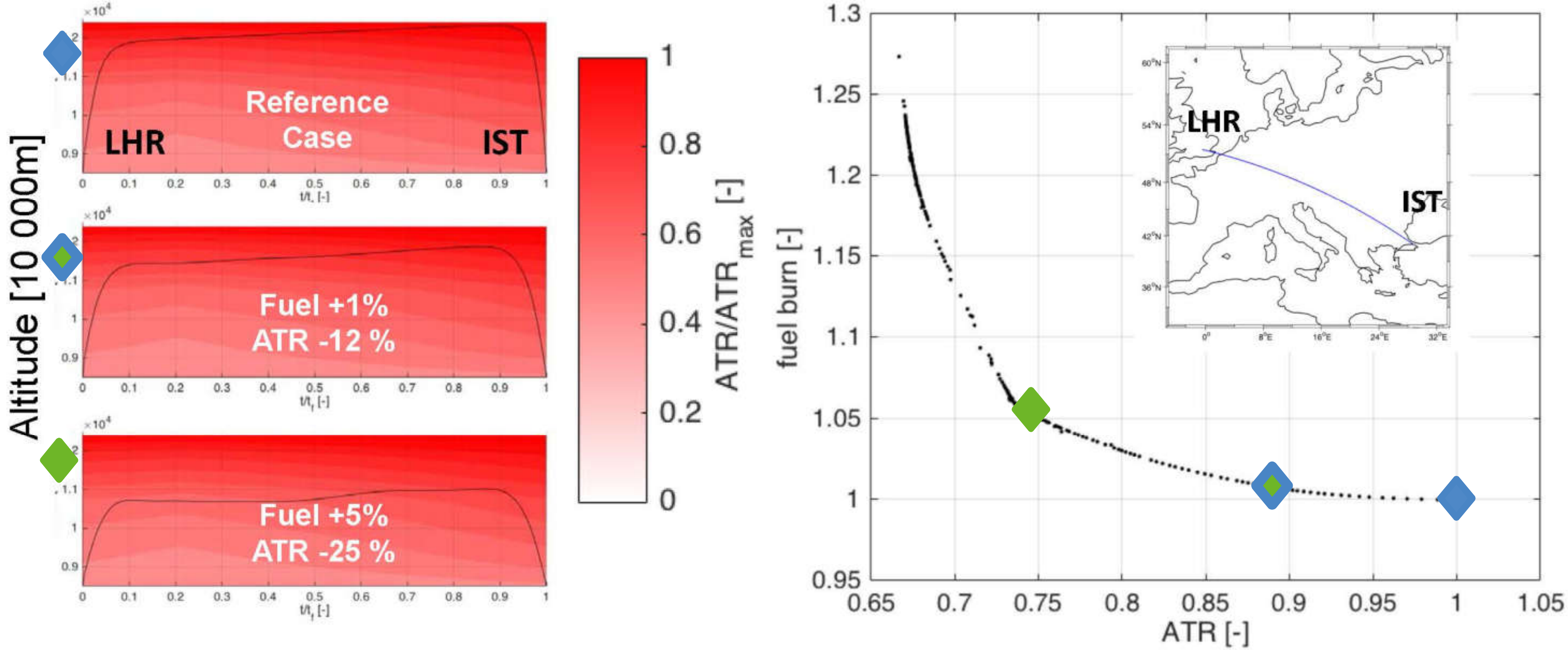


Trajectory optimisation (TOM) by Linke, Lührs, Niklaß

Environmental Optimization of Aircraft Trajectories

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

Matthes et al., Aerospace, 2017.



Trajectory optimisation assesses climate impact simultaneously with fuel burn.

ATM delivers economic and environmental performance – Pareto Front

Verification of environmental benefit by environmental-optimized flight planning relying on algorithmic ECFs

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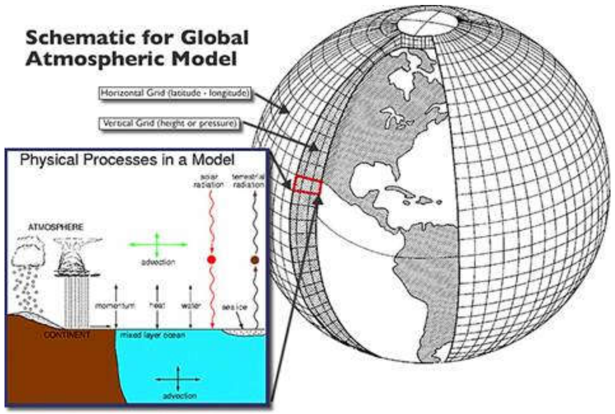
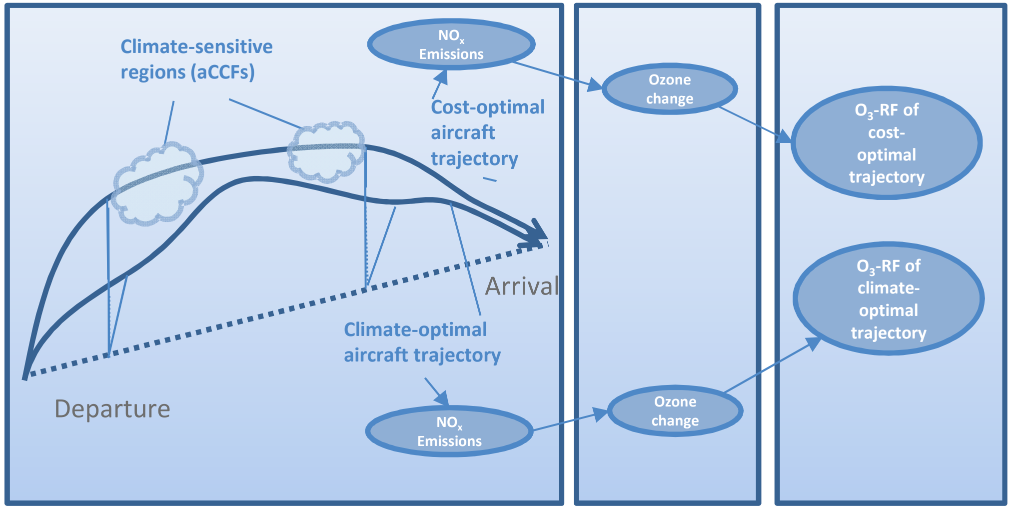
Verification of algorithmic Climate Change Functions

- Implementation of aCCFs in an Chemistry-Climate Model, which includes an Air Traffic Simulator

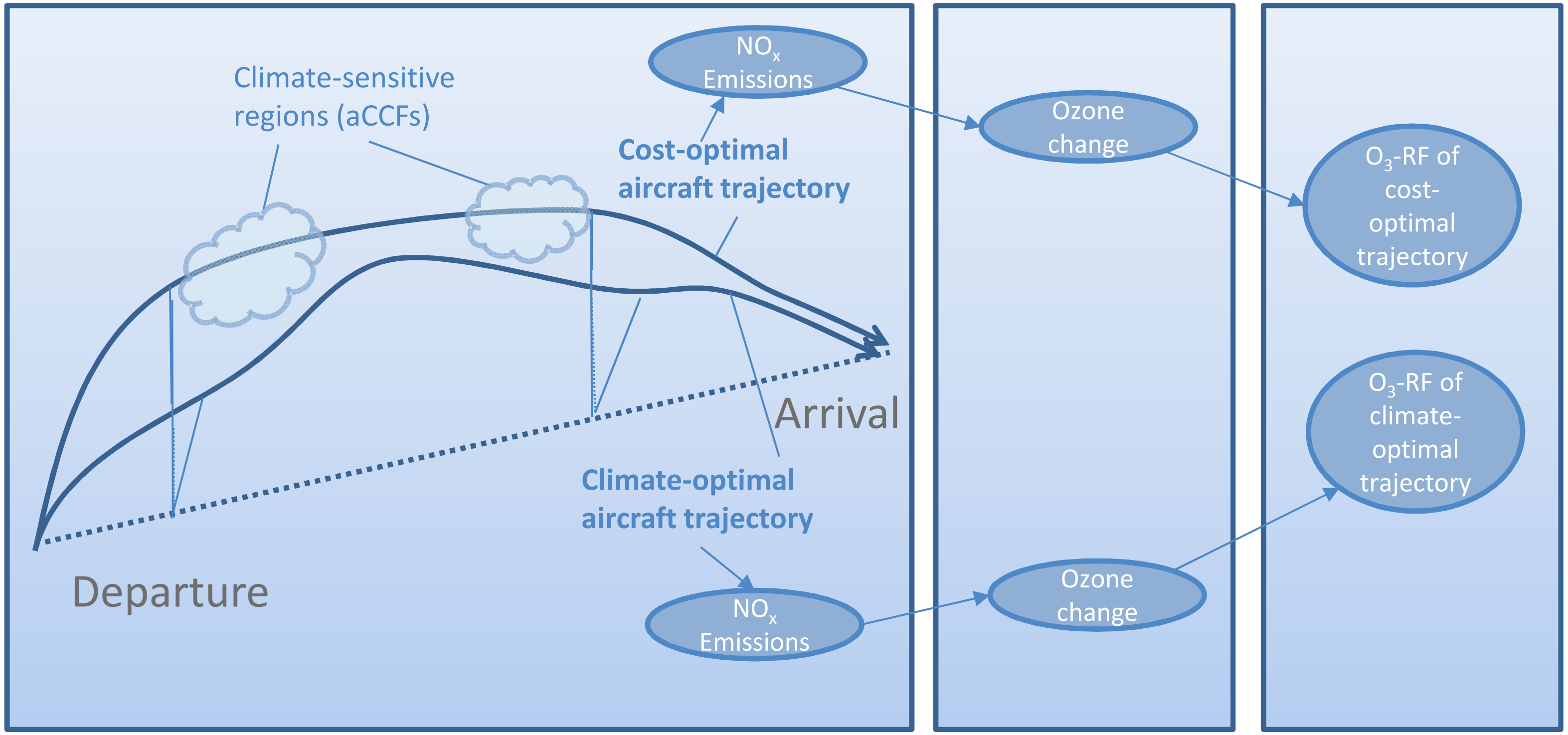
- Compare cost-optimal with climate optimal (aCCFs) trajectories

- Verify that aCCFs estimates lead to less radiative forcing.





Verification approach
Earth-System Modell



Air traffic simulator **Atmospheric Chemistry** **Radiatve Forcing**

Yin et al. (2018)

Verification of Environmental Benefit

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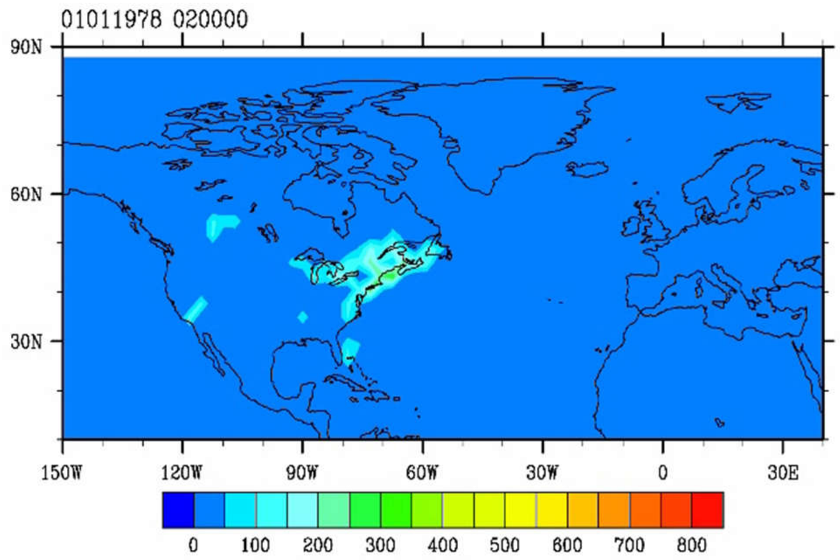
Using comprehensive global chemistry-climate model EMAC and routing module: AirTraf

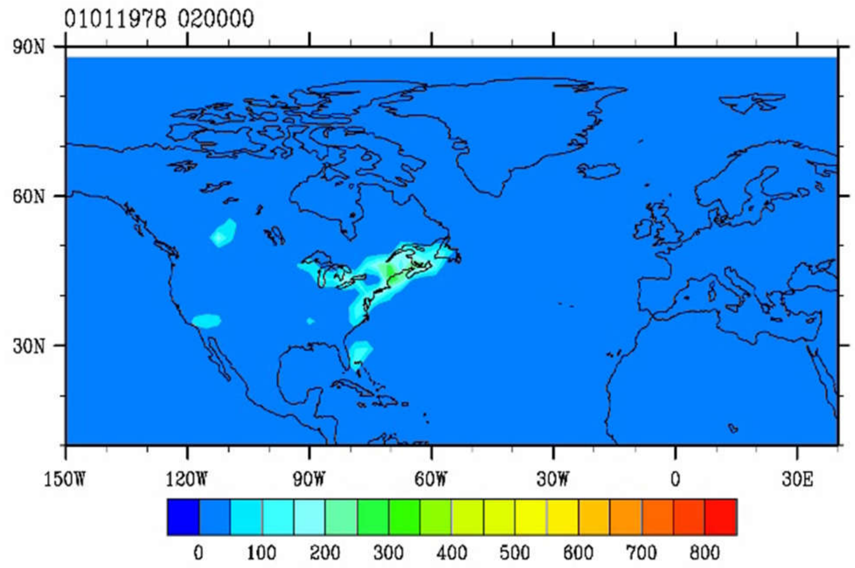
Yamashita et al., GMD, 2016.

Great circle FL330



Kg(fuel)/box/s

Time-optimal

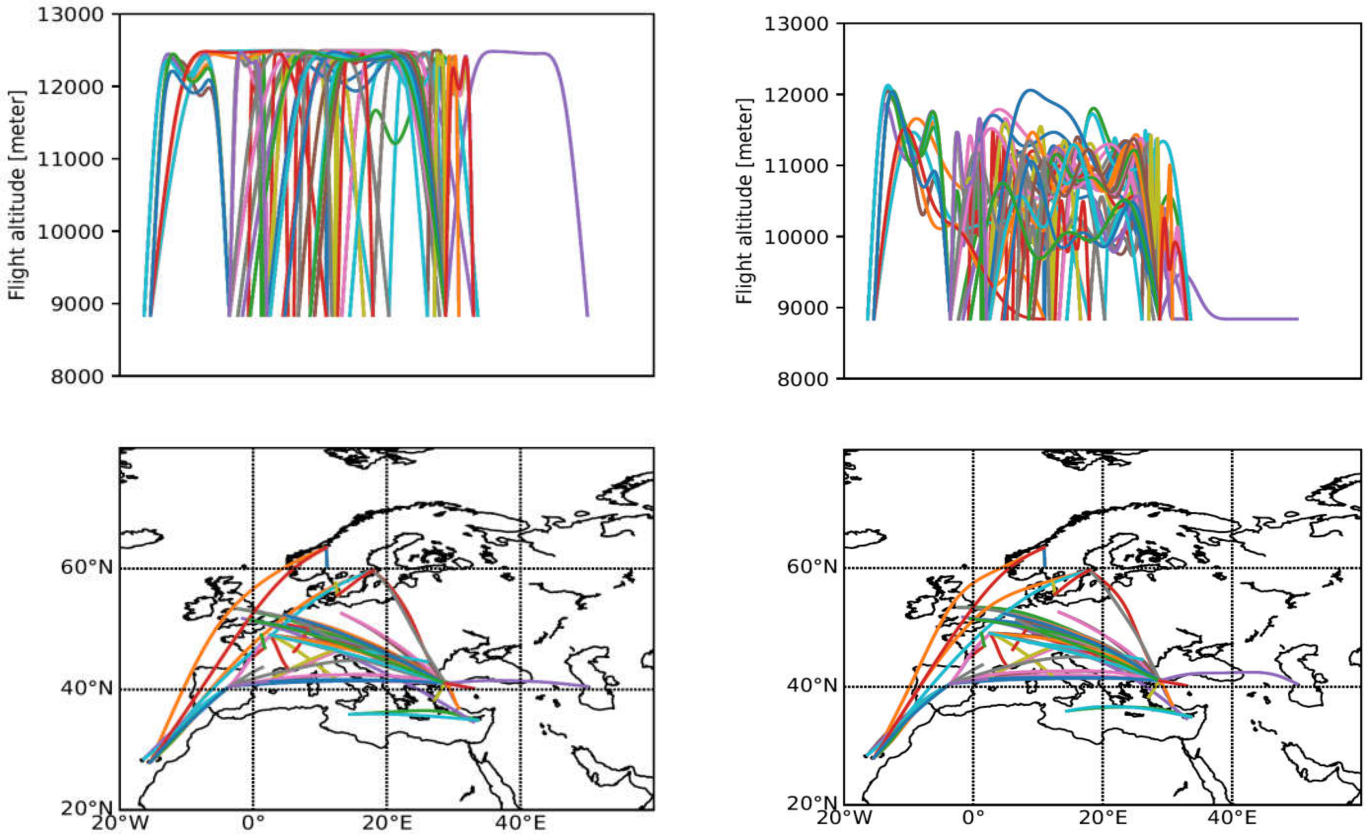


Kg(fuel)/box/s

Atmospheric model uses algorithm based Environmental change functions.

We will focus on the European Airspace in the ATM4E project

Verification in Earth-System Model Simulated Traffic Flow over Europe

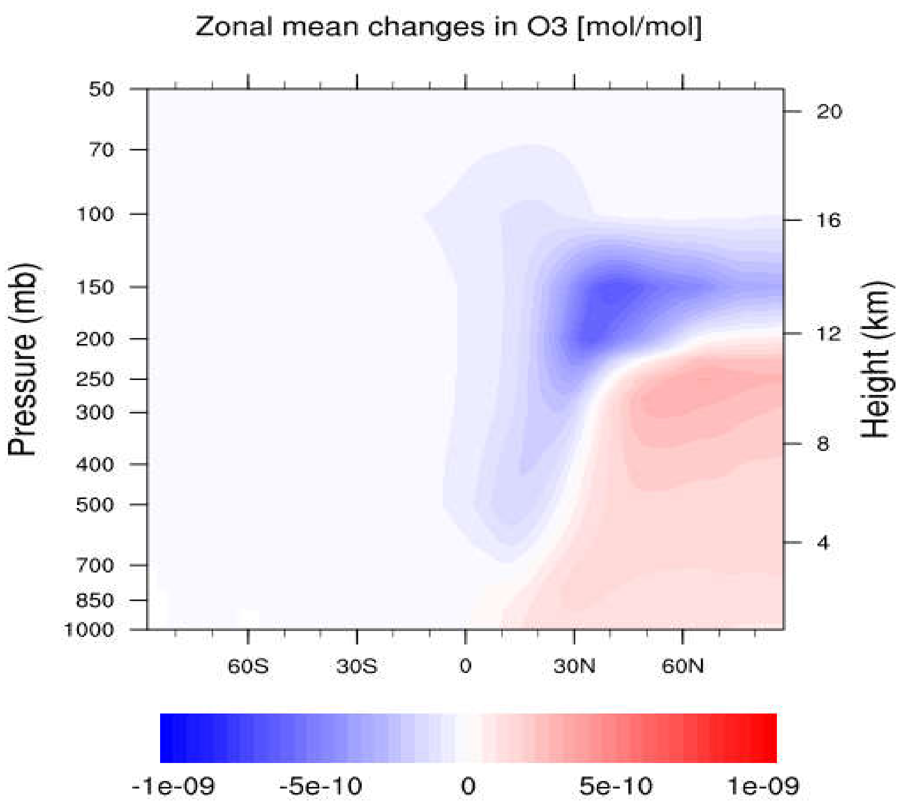


Cost optimal **aCCF optimal**

Yin et al. (2018)

Verification in Earth-System Model

Impact of aircraft trajectory changes on atmospheric composition and climate



Yin et al. (2018)

Aviation-induced ozone changes compared for **climate-optimal** (NO_x-O_3) versus **cost-optimal** trajectory optimisation

Largely reduced ozone concentration at higher altitudes.

2.2% reduced climate impact

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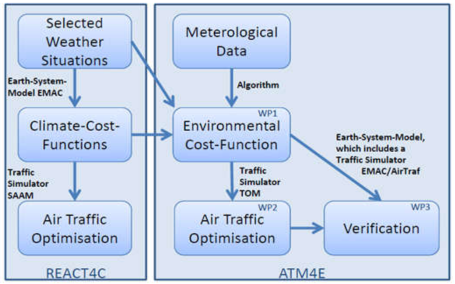
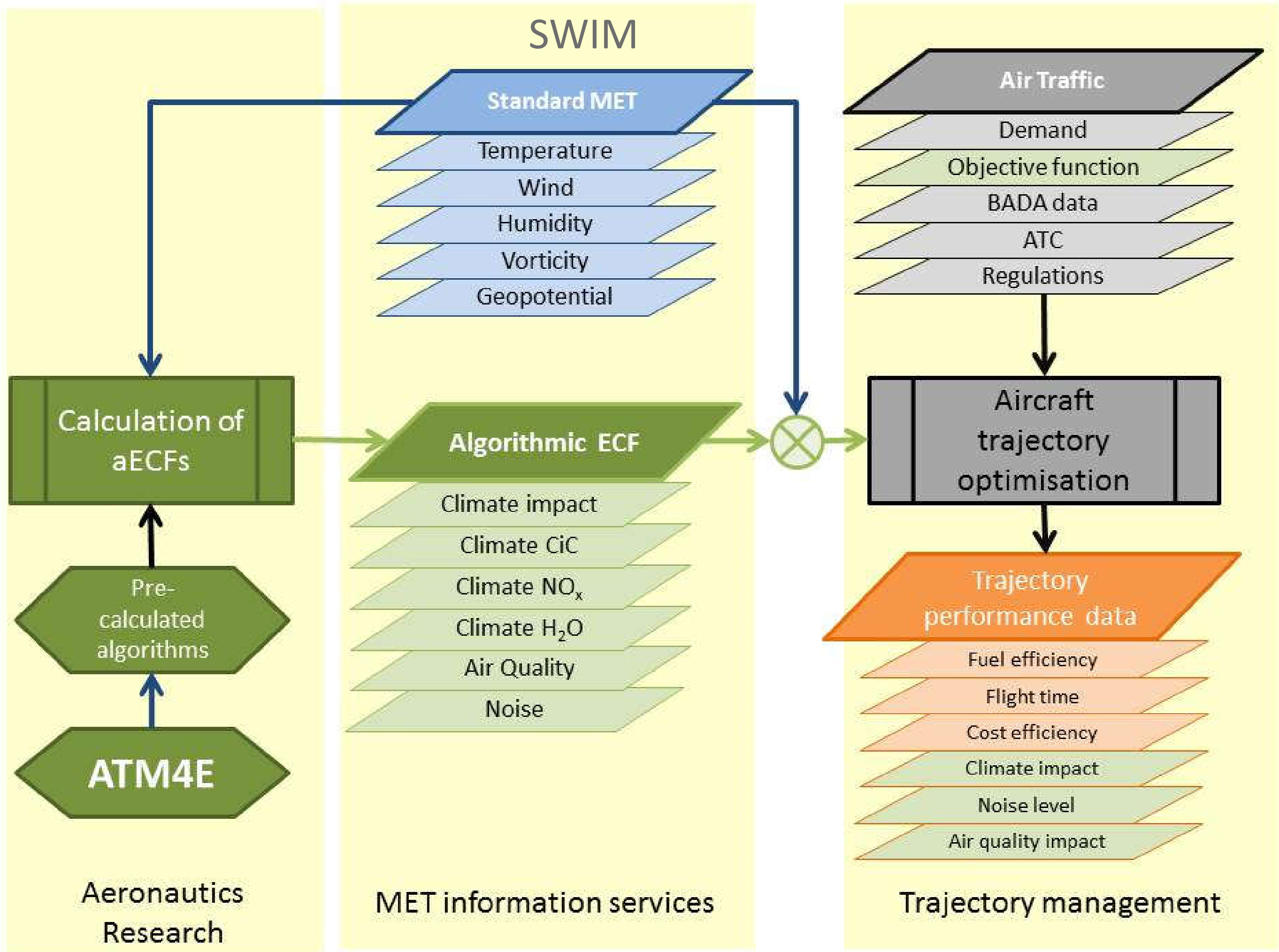


Contribution of ATM4E



Summary and Conclusion
Environmentally-optimized flight planning

- **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 a **roadmap on implementation** considering necessary steps and actions **to introduce environmentally-optimized flight operations** has started involving research, service providers, manufacturers and airspace users
    - Stakeholder Workshop, ILA, April 2018, Berlin
- **Performance indicators** are proposed in order to be able to assess and demonstrate environmental benefits on climate impact mitigation.

Matthes, S.; Grewe, et al. A Concept for Multi-Criteria Environmental Assessment of Aircraft Trajectories. Aerospace 2017, 4, 42.
Grewe, V.; Matthes, S.; et al. Feasibility of climate-optimized air traffic routing for trans-Atlantic flights. Environ. Res. Lett. 2017, 12, 034003.

Environmental impact assessment and optimization of aircraft trajectories

Sigrun Matthes, DLR

→ Case study for Europe

→ Lesson learnt on MET service implementation

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No [number]

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ATM4E – Achievements & Conclusions

Achievements (Maturity)

- ✓ Information on the climate impact of aviation emission **has been successfully integrated** in flight planning systems by the use of environmental change functions (ECFs), and proof of concept has been demonstrated.
- ✓ A case study on climate-optimisation **has been performed** for Europe in a flight planning tool, and mitigation gain has been verified with a chemistry-climate model.
- ✓ An initial network study on **changes in traffic flows** due to climate-optimisation has been completed.

Conclusion

- Providing **environmental change functions** to flight planning systems is required in order to enable assessment of environmental performance data for aircraft trajectories and to identify **environmental-optimal trajectories**.
- In a case study for the Europe airspace, a **mitigation potential** of 10% climate impact reduction has been found for a large set of flights. Individual flights showed to have a significantly higher mitigation potential for environmental impacts.
- Additional **performance indicators** are required to demonstrate benefits for environment (KP05) in order to gain the confidence of the stakeholder community.

ATM4E – Potential Next Steps

How to use results in the next phase (ER/IR)

- Prototype of algorithmic Environmental Change functions (ECF) can be used to identify climate impact mitigation potential by **improving TRL** and geographic coverage.
- Concept can be expanded by development of **robustness measure** for trajectories.
- Expand **algorithmic** ECF concept to **multi-criteria approach,** climate impacts combined with local impacts (noise, LAQ), with systematic analysis of associated trade-offs.
- Use aECFs to perform a **large-scale numerical demonstration** exercise evaluating mitigation potential of climate-optimisation for real-world trajectories.

Impacted SESAR2020 Projects/Solutions

Projects on trajectory optimisation (PJ18-04b, PJ18-04c), environmental performance

Impact on ATM Master Plan

ATM4E addressed high-level environmental SES targets, by identifying mitigation potential to enable reduction in the effects that flights have on the environment

ATM4E expands performance improvement to environmental perspective.

Summary and Conclusion
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- **Performance indicators** are proposed in order to be able to assess and demonstrate environmental benefits on climate impact mitigation.
- **Stakeholder Workshop, ILA, April 2018, Berlin**
    - *Identify key issues to present and discuss with regards to implementation*

ATM4E

Air Traffic Management for Environment

Stakeholder Event

Wednesday, April 25, 2018

15:00-16:00 (CET time)

ATM4E is working towards the objective to enable **climate-optimized trajectories** in the future air transport system. The project aims at defining a conceptual assessment framework for the deployment of the produced environmental change functions involving environmental performance indicators. Additionally, a roadmap is under development with recommendations and an implementation strategy for the environmental optimization of aircraft trajectories.

Effective communication with stakeholders and aviation experts is key when working toward the environmental optimisation of air traffic operations in the European airspace.

This Stakeholder Event will be a great opportunity to summarize the **acquired knowledge**, provide **guidance** and technical insights and discuss research and implementation requirements to enable, encourage and accompany stakeholders in the implementation of the **necessary steps** and actions that would need to be taken to ultimately introduce environmentally-optimized flight operations in European airspace.

See you in Berlin at ILA 2018!

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Environmental impact assessment and optimization of aircraft trajectories

Sigrun Matthes, DLR

Thank you very much for your attention!

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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.

ATM4E [ref DoA]