



# Multi-criteria environmental impact assessment and optimisation of aircraft trajectories

**ATM4E**

**Air Traffic Management for Environment**

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Coordinator ATM4E (SESAR 2020, Exploratory Project)

ATM4E Team



Founding Members



**ATM4E**

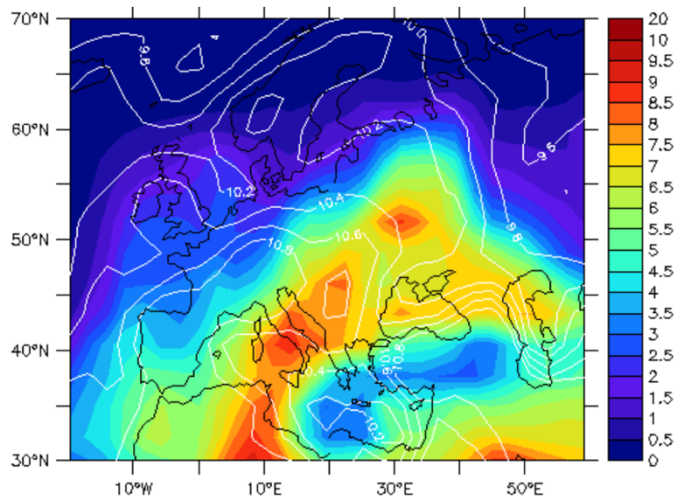
<http://www.atm4e.eu/>



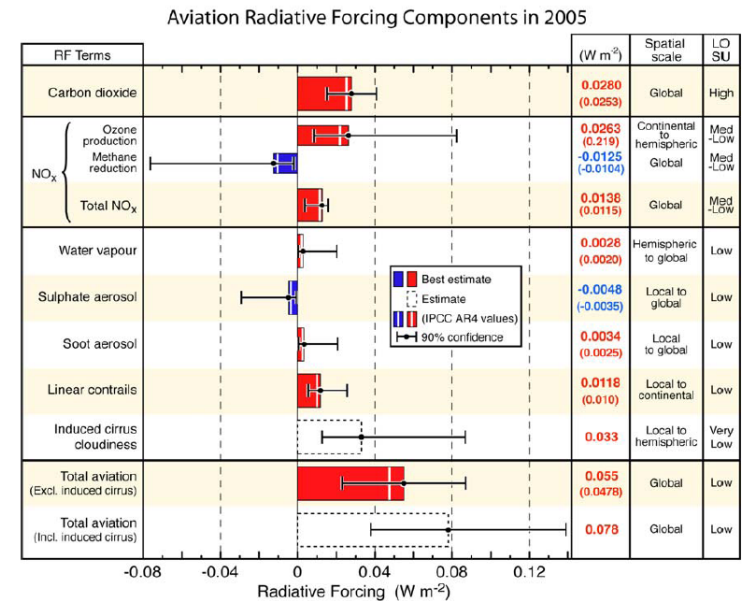
# Aviation climate impact CO<sub>2</sub> and non-CO<sub>2</sub> effects

Climate impact of aviation emissions (direct & indirect effects)

- CO<sub>2</sub>, black carbon (soot) - direct
- Nitrogen oxides NO<sub>x</sub> (O<sub>3</sub>, CH<sub>4</sub>)
- Contrail cirrus and H<sub>2</sub>O
- soot (AIC, aviation induced cloudiness)



Ozone production efficiency of NO<sub>x</sub> emissions, 18 Dec, 250 hPa (EMAC)



Lee et al., 2010 (IPCC)

Climate impact of **non-CO<sub>2</sub> emissions** depends on

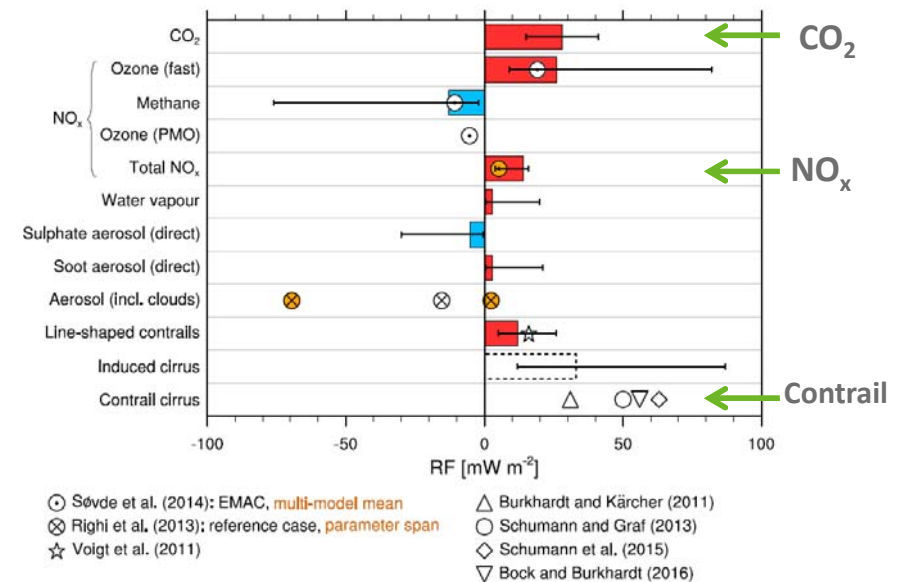
- time and position of aircraft
- actual weather conditions (processes, transport pathways, temperature, humidity)
- background concentrations

⇒ **Climate optimized trajectories avoid sensitive regions**

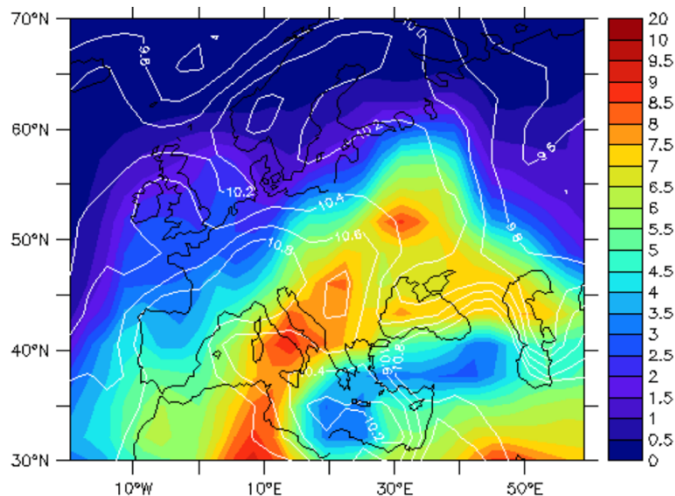
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Grewe et al., 2017, updating Lee et al., 2010 (IPCC)



Ozone production efficiency pf NO<sub>x</sub> emissions, 18 Dec, 250 hPa (EMAC)

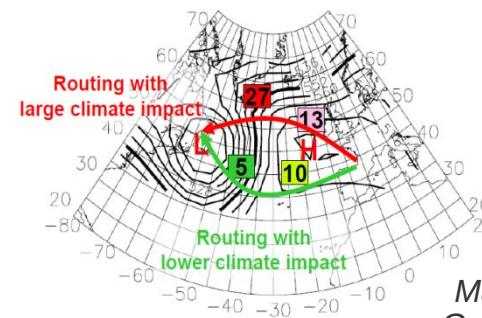
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## Environmental-optimised trajectories

- Aviation is concerned by environmental impact of its operations. **Aviation climate impact** is caused by CO<sub>2</sub> and non-CO<sub>2</sub> 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.



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

- 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.





# Interface between environmental impact and ATM via Environmental Change Functions

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



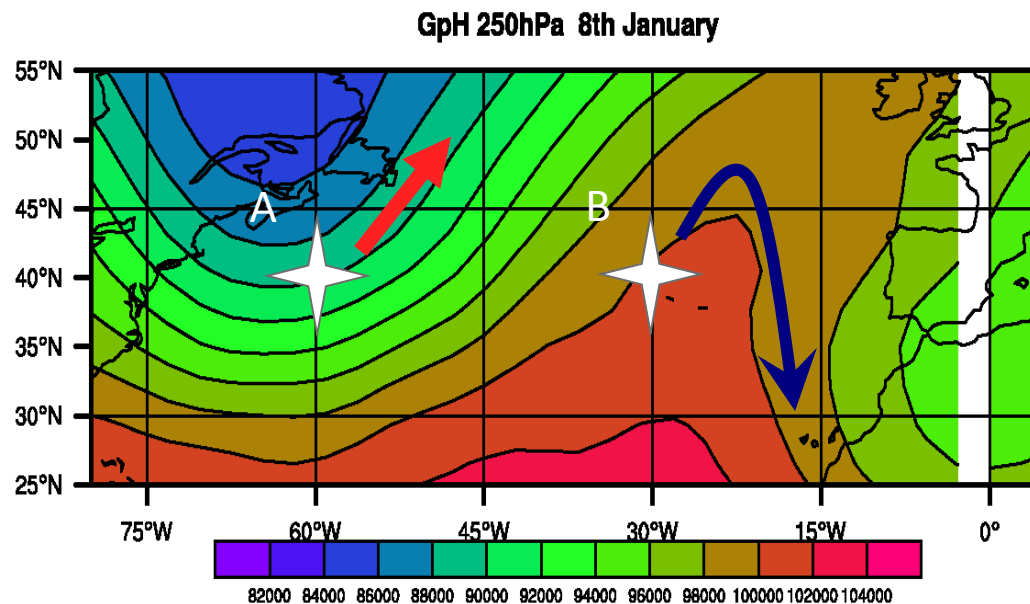
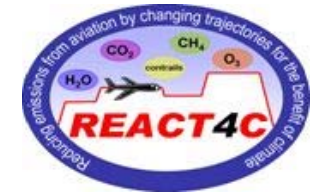
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# How to generate such information?

## Evolution of aircraft $\text{NO}_x$ at two different locations

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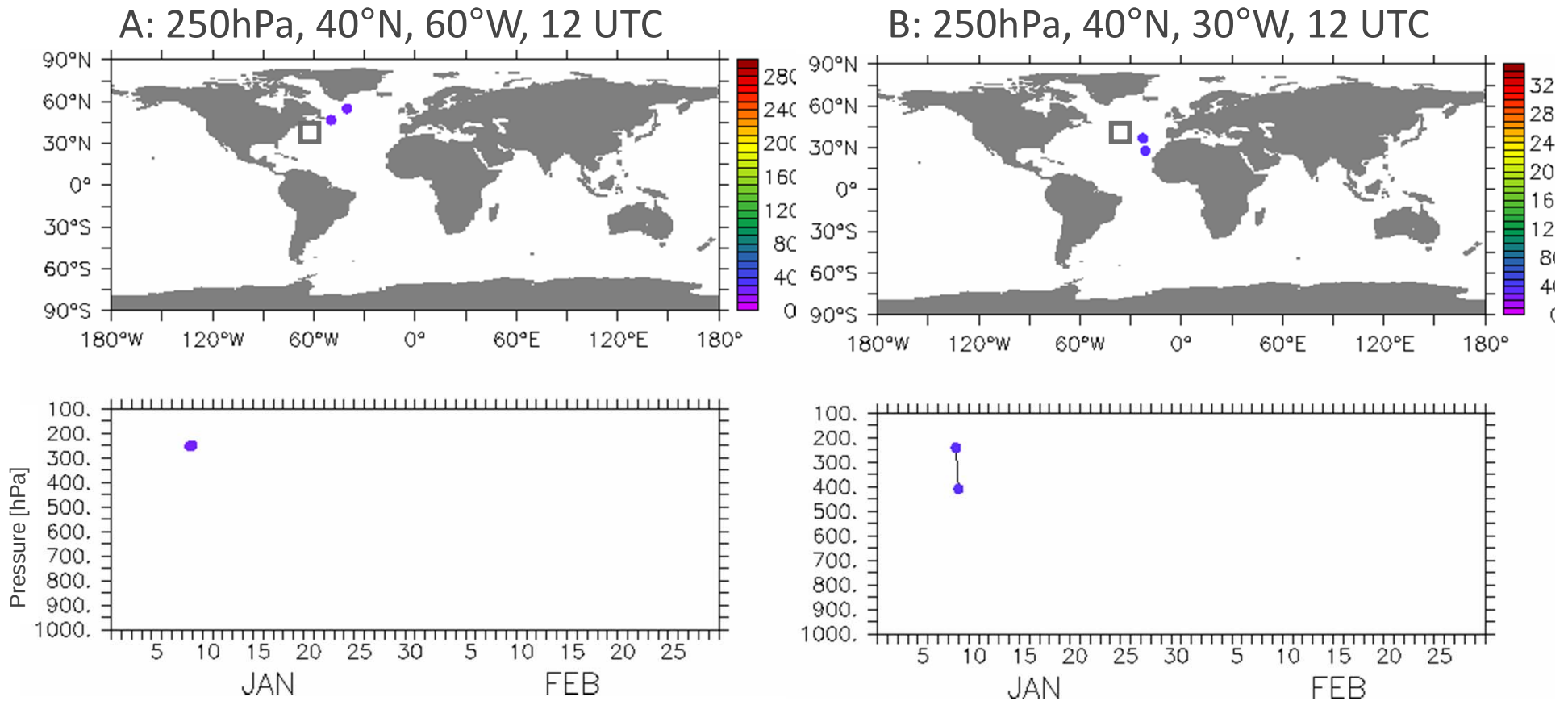
What happens if an aircraft emits  
 $\text{NO}_x$  at location A compared to location B?

Frömming et al., 2011, 2017

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

# Climate chemistry model (EMAC)

Evolution of O<sub>3</sub> [ppt] following a NO<sub>x</sub> emission



Frömming et al., 2011, 2017

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

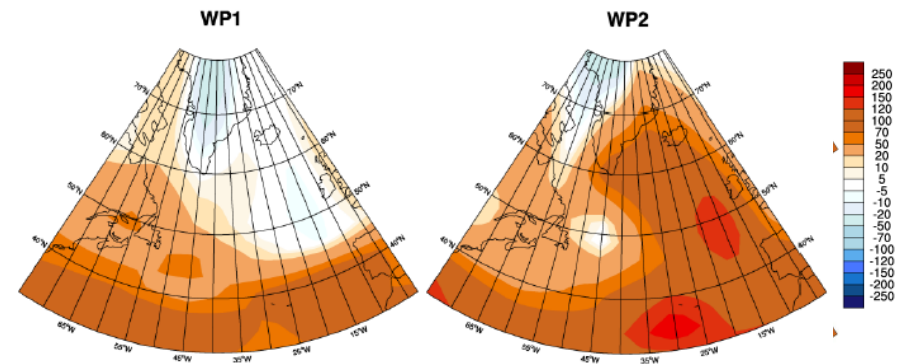
# Environmental Change Functions

## ECFs

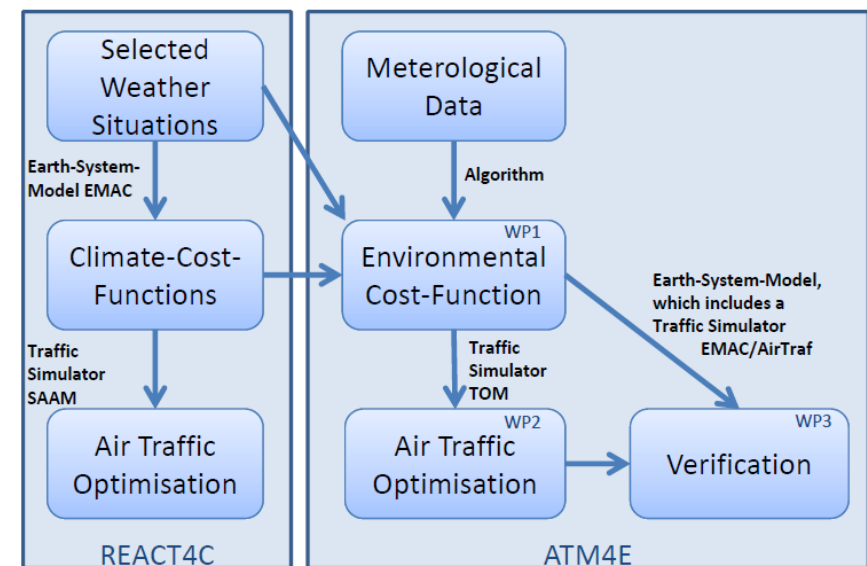
- The key step in ATM4E is to **relate** readily-available **meteorological data** to these existing detailed CCFs to allow the rapid generation of new CCFs (algorithmic CCFs) for specific (forecast) weather situations

⇒ **Advanced MET information**

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



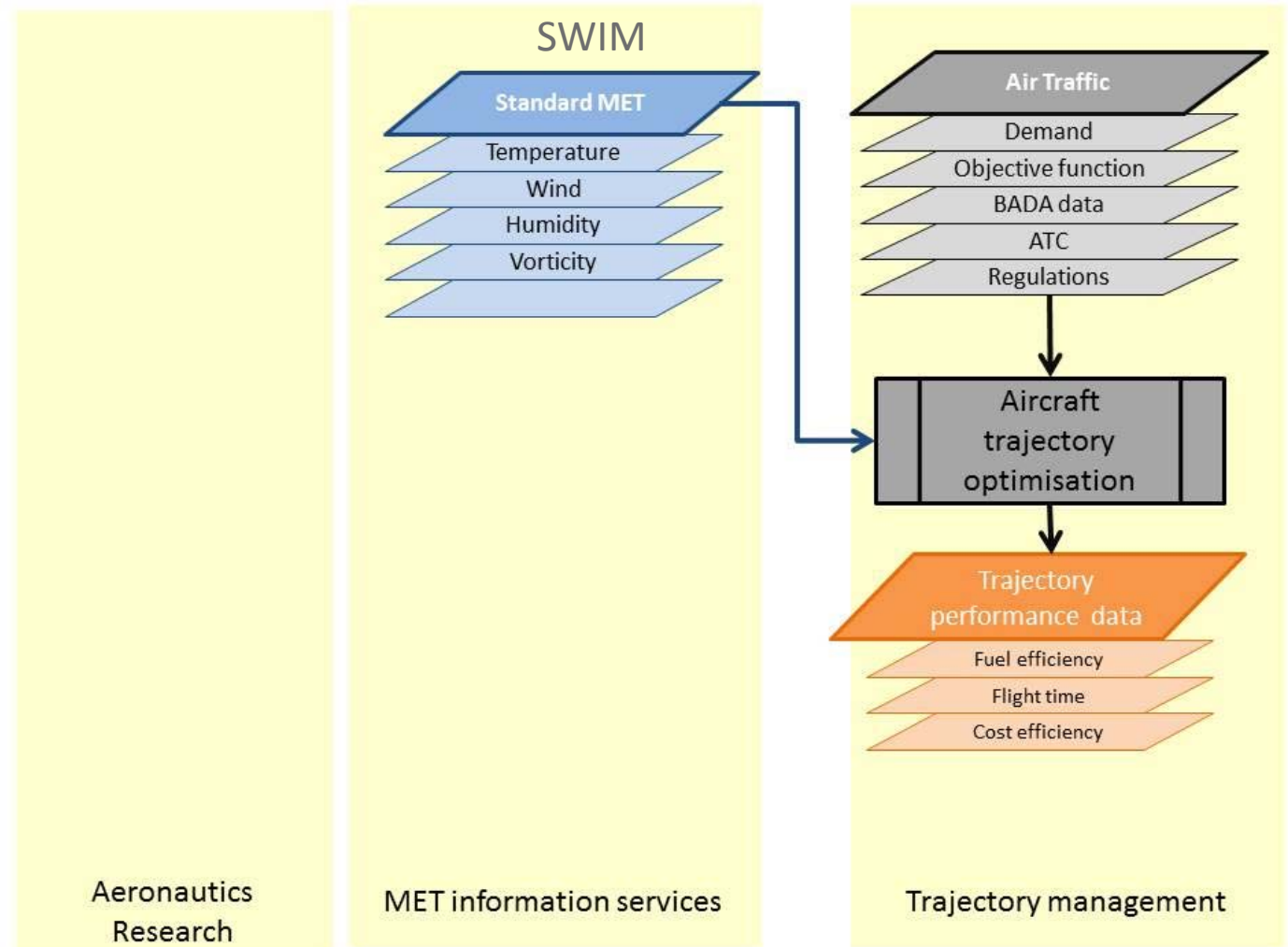
Frömming et al., 2017



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

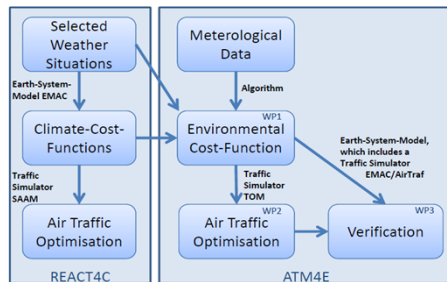


## Current situation

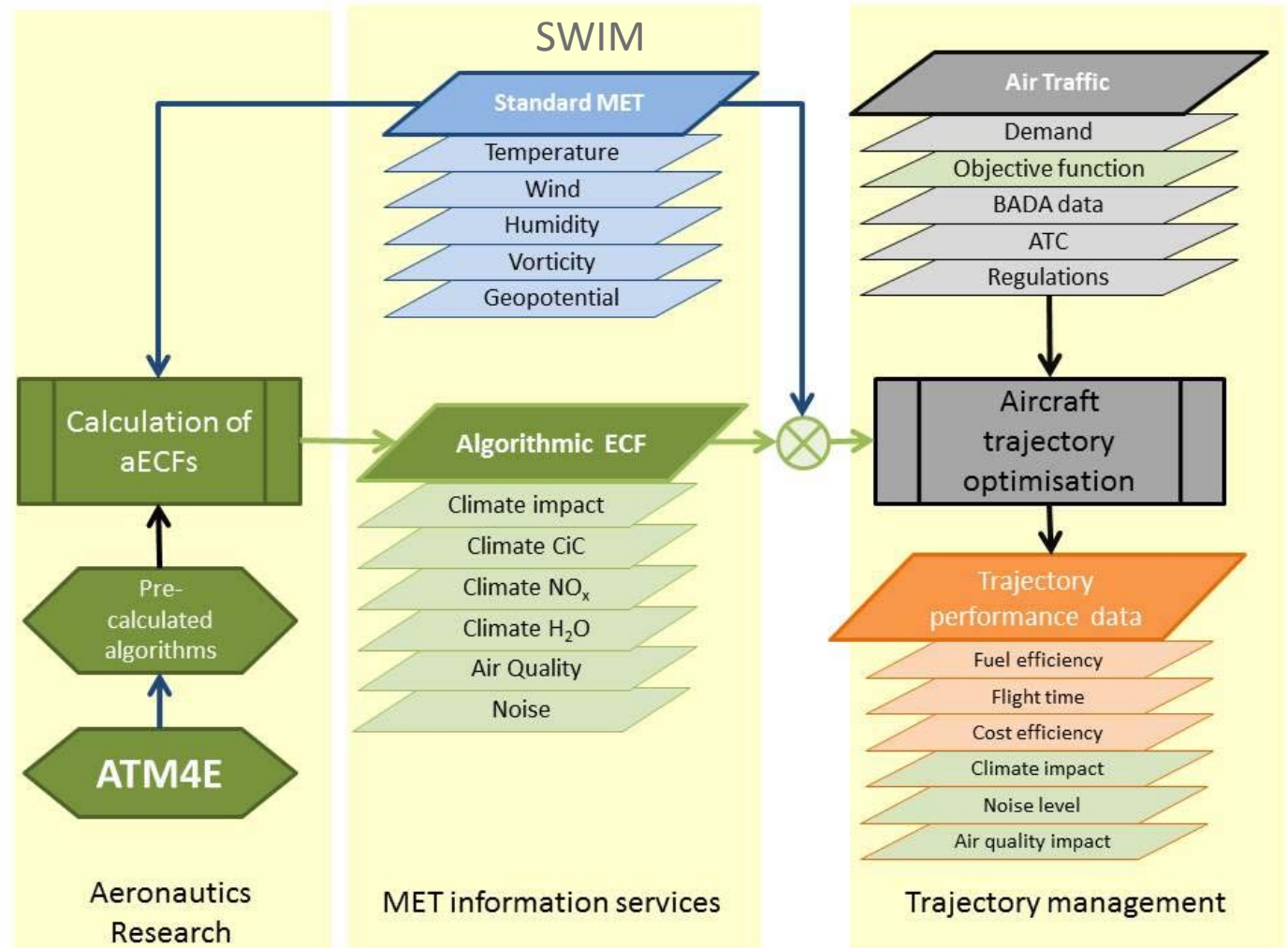


# Air traffic management for environment: SESAR/H2020-Project ATM4E

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## Contribution of ATM4E





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

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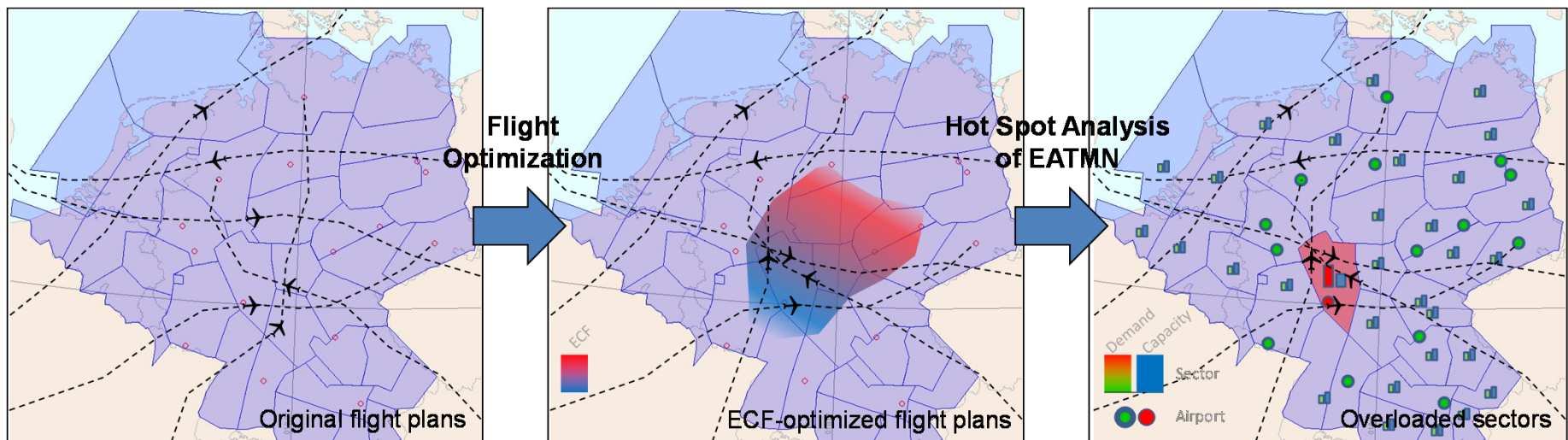


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# Environmental-optimized routing impact on ATM changes in air traffic flows

- 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



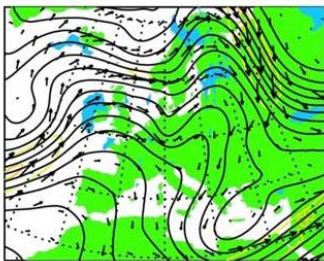
# Using ECFs for flight planning

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

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

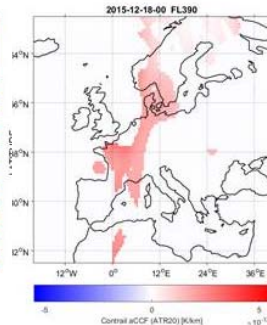
**Synoptical situation**

*GpH, wind*



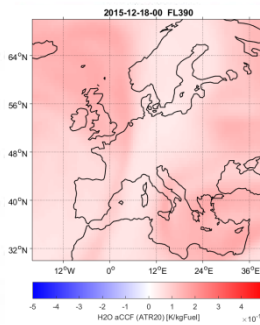
**Contrail**

*T, RH, OLR*



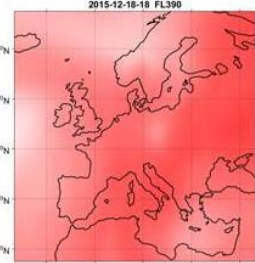
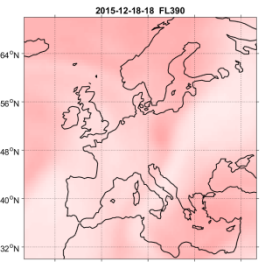
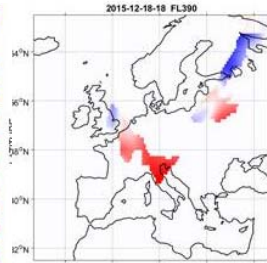
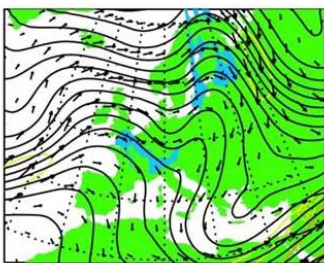
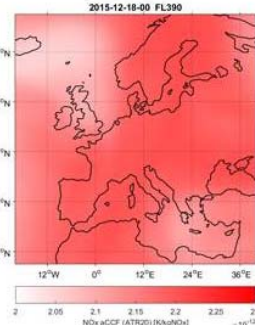
**H<sub>2</sub>O**

*Pot. Vort.*



**NO<sub>x</sub>**

*GpH, T*

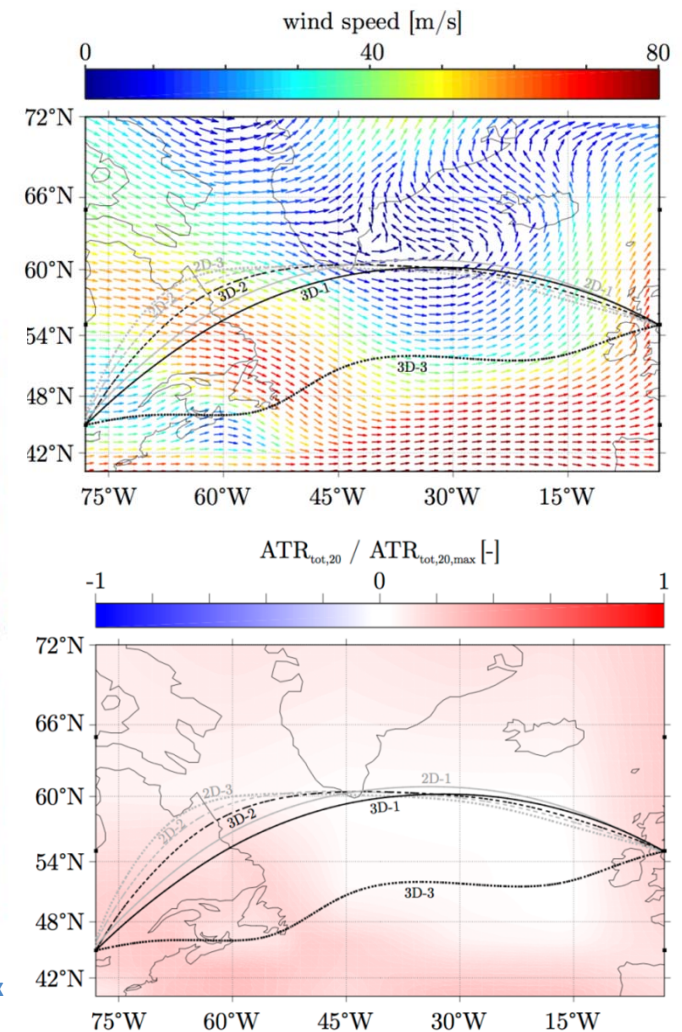


10<sup>-12</sup> K/km

10<sup>-15</sup> K/kg fuel

10<sup>-12</sup> K/kg NO<sub>x</sub>

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

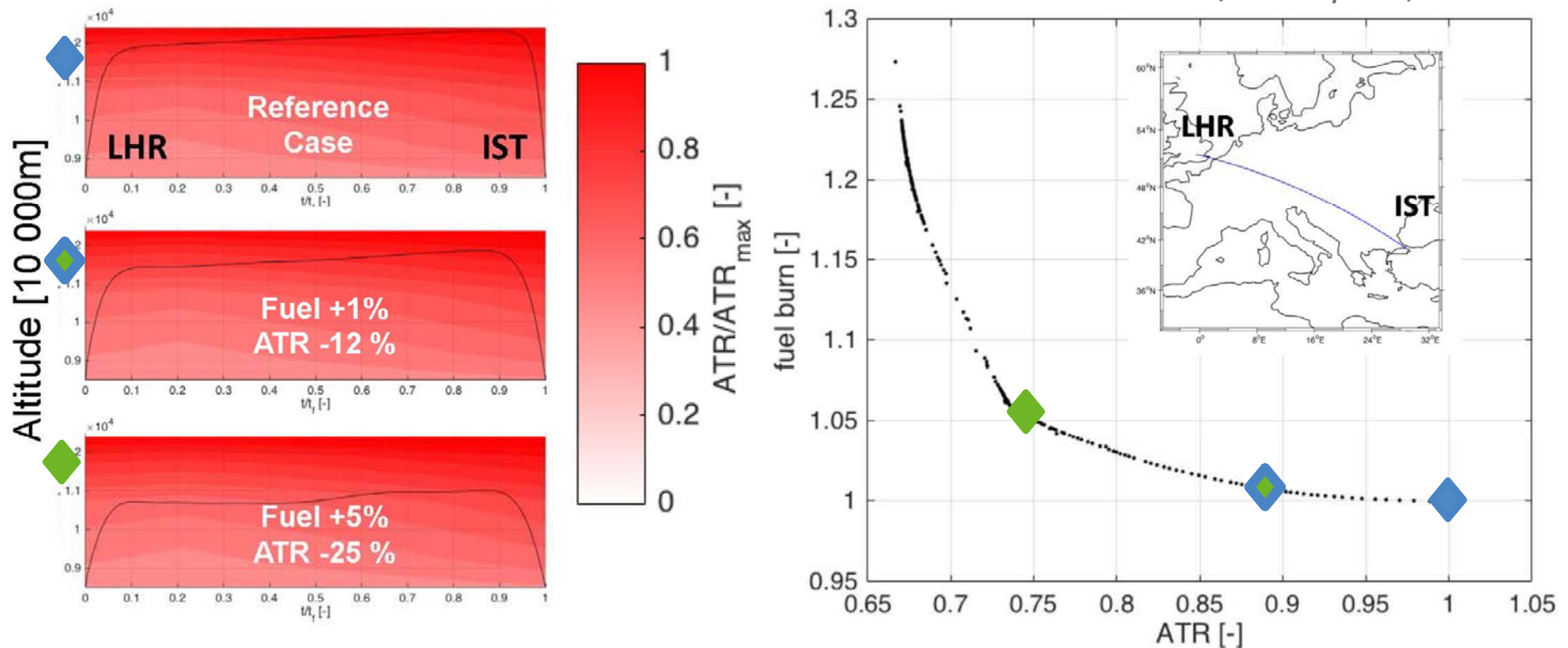


TOM work by Linke, Lührs, Niklaß

# Environmental Optimization of Aircraft Trajectories

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

*Matthes et al., Aerospace, 2017.*

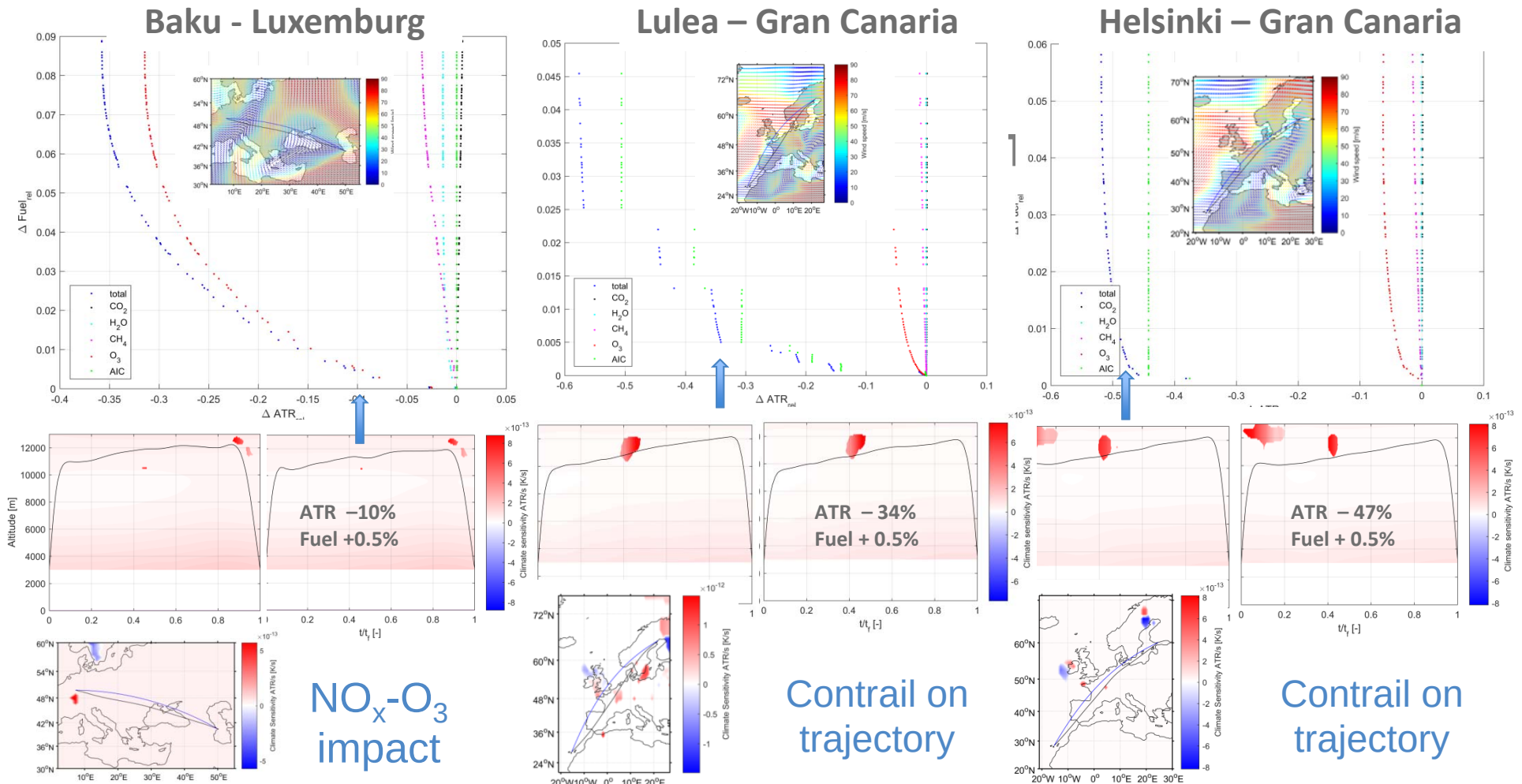


Trajectory optimisation assesses climate impact simultaneously with fuel burn.

**ATM delivers economic and environmental performance – Pareto Front**

# Case Study – Climate optimisation

Using advanced MET service as algorithmic ECFs 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 (Case study 19 Dec 2015)**



# Verification of environmental benefit by due to environmental-optimized flight planning



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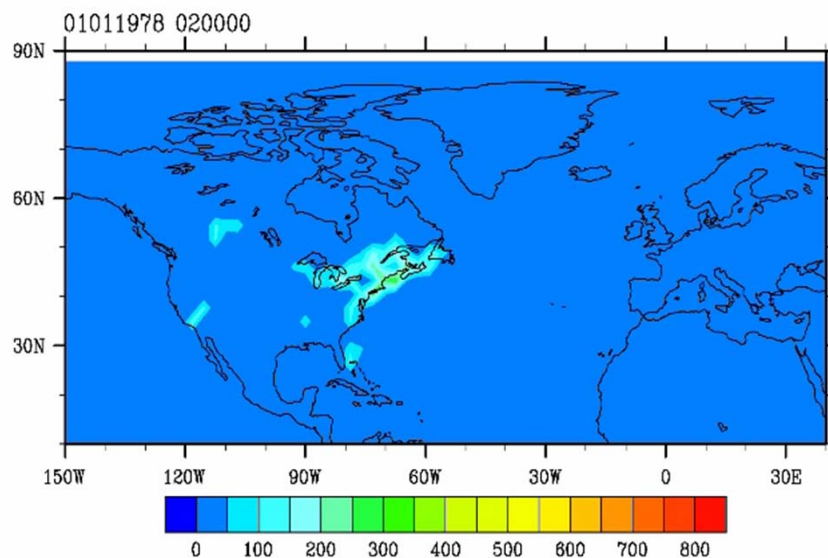
# Verification of Environmental Benefit



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

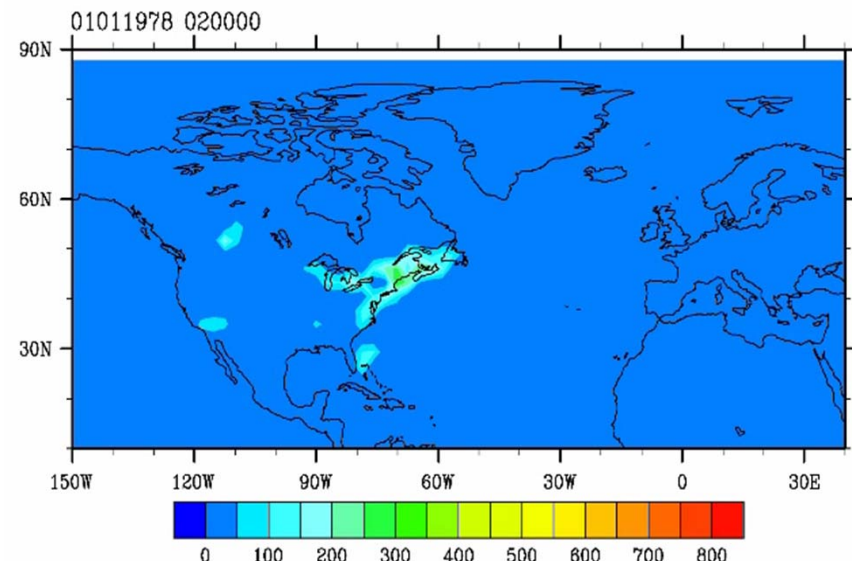
*Yamashita et al., GMD, 2016.*

## Great circle FL330



Kg(fuel)/box/s

## Time-optimal

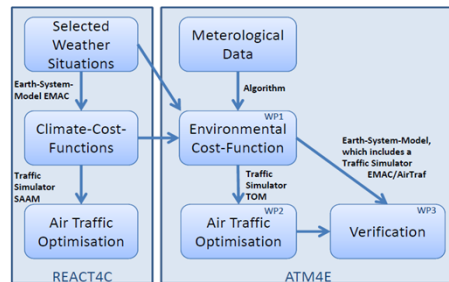


Kg(fuel)/box/s

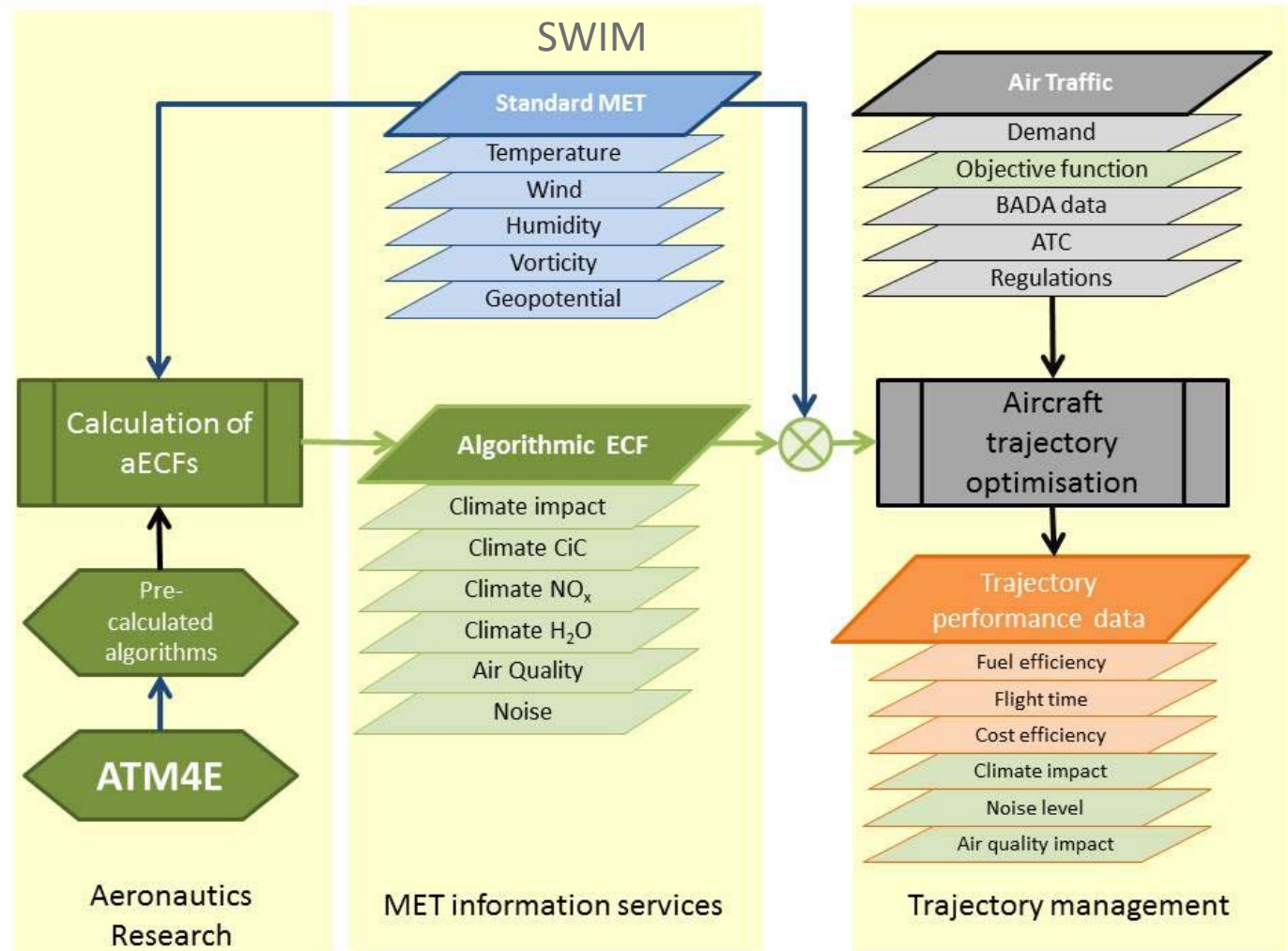
Atmospheric model uses algorithm based Environmental change functions.

**We will focus on the European Airspace in the ATM4E project**

# Air Traffic Management for Environment



## 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, Webinar, 26 Jan 18 / 1 Feb 18).
- **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 optimisation of aircraft trajectories  
Sigrun Matthes, DLR

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Thank you very much  
for your attention!



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Founding Members



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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]

# Environmental Optimization of Aircraft Trajectories

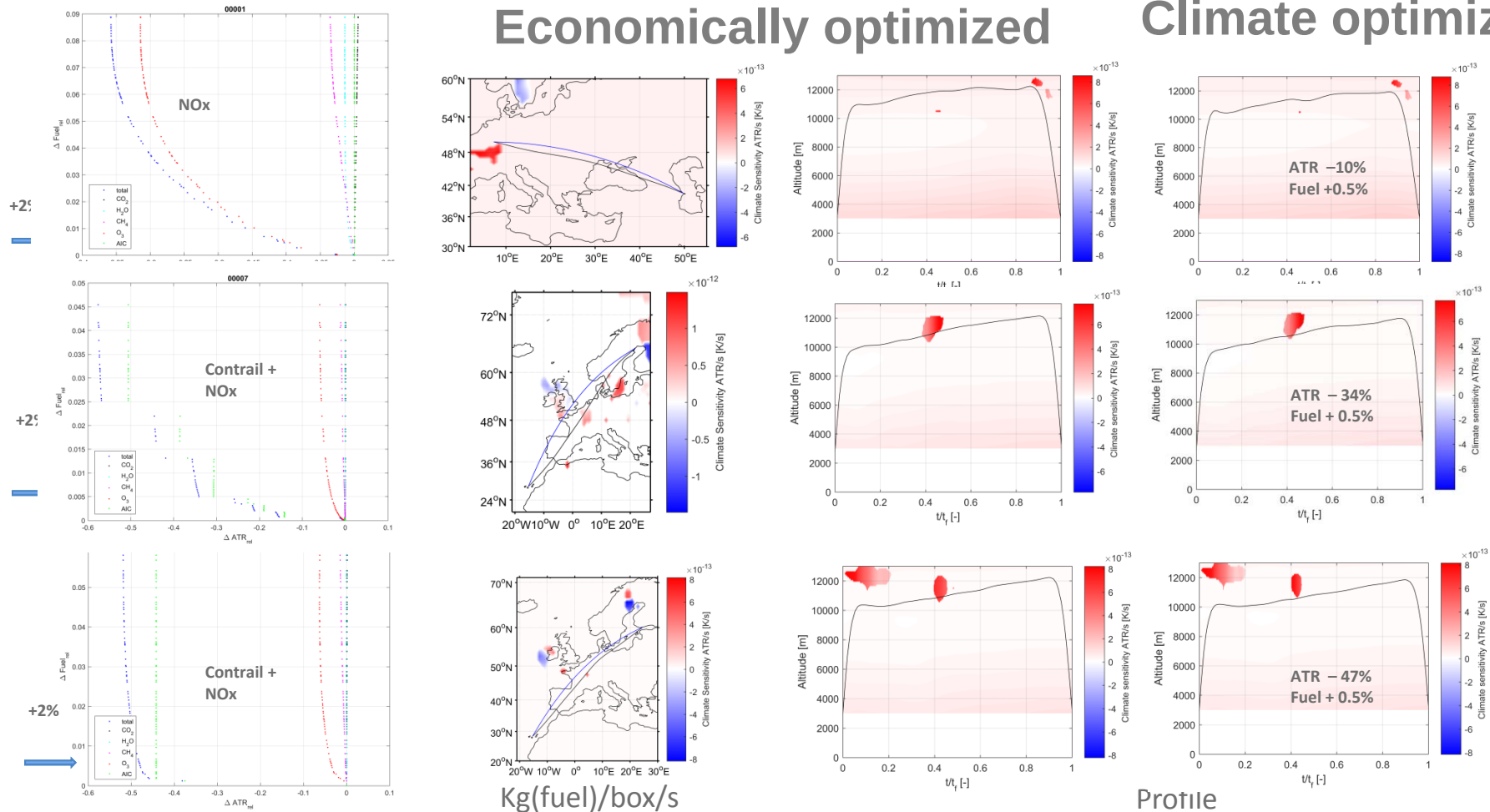
## Using advanced MET service as algorithmic ECFs to identify Pareto front for use case climate optimized trajectories

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### Economically optimized

### Climate optimized



Trajectory optimisation assesses climate impact simultaneously with fuel burn.

**ATM delivers economic and environmental performance – Pareto Front**