Climate change and the role of ATM

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DLR FlyATM4E SESAR JOINT UNDERTAKING

Climate change and the role of ATM - Outline

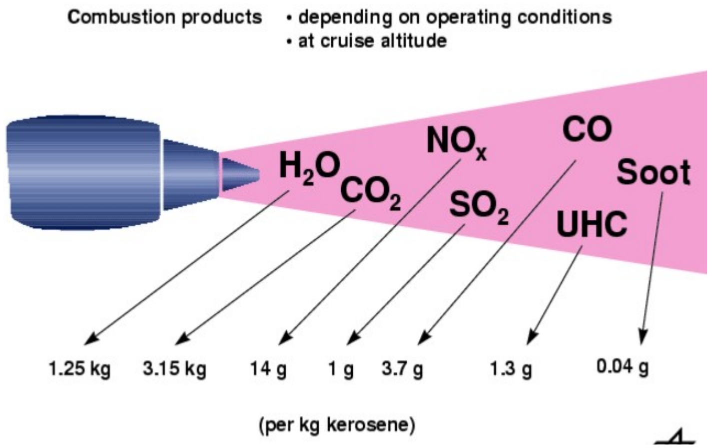
- Assessment of total climate impact of aviation – CO_2 and non-CO_2 effects

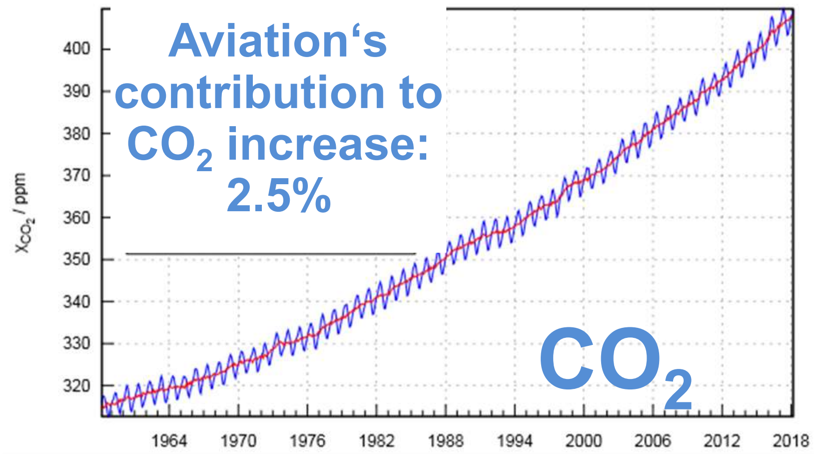
- Sensitivity of non-CO_2 effects when flying at alternative flight altitudes
- Concept to describe variation (spatially, temporally) of aviation non-CO_2 climate impacts
- Case studies on exploring mitigation potential by climate-optimized trajectories

- Towards implementation of MET services on aviation climate impact
- Towards integration of non-CO_2 effects in emission schemes, e.g. CORSIA

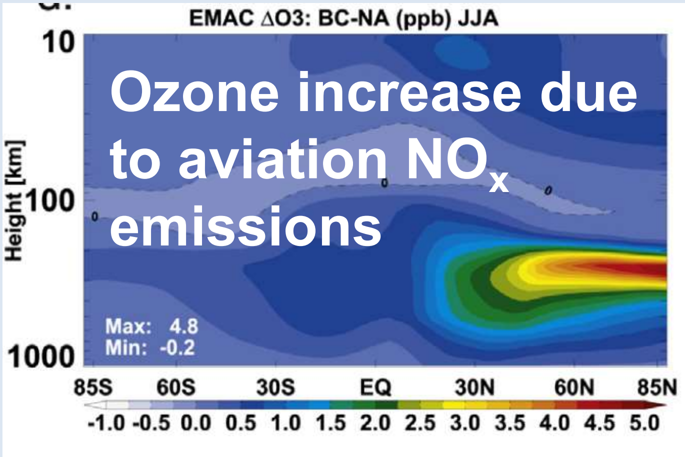
- Summary

Aviation emission and climate impact



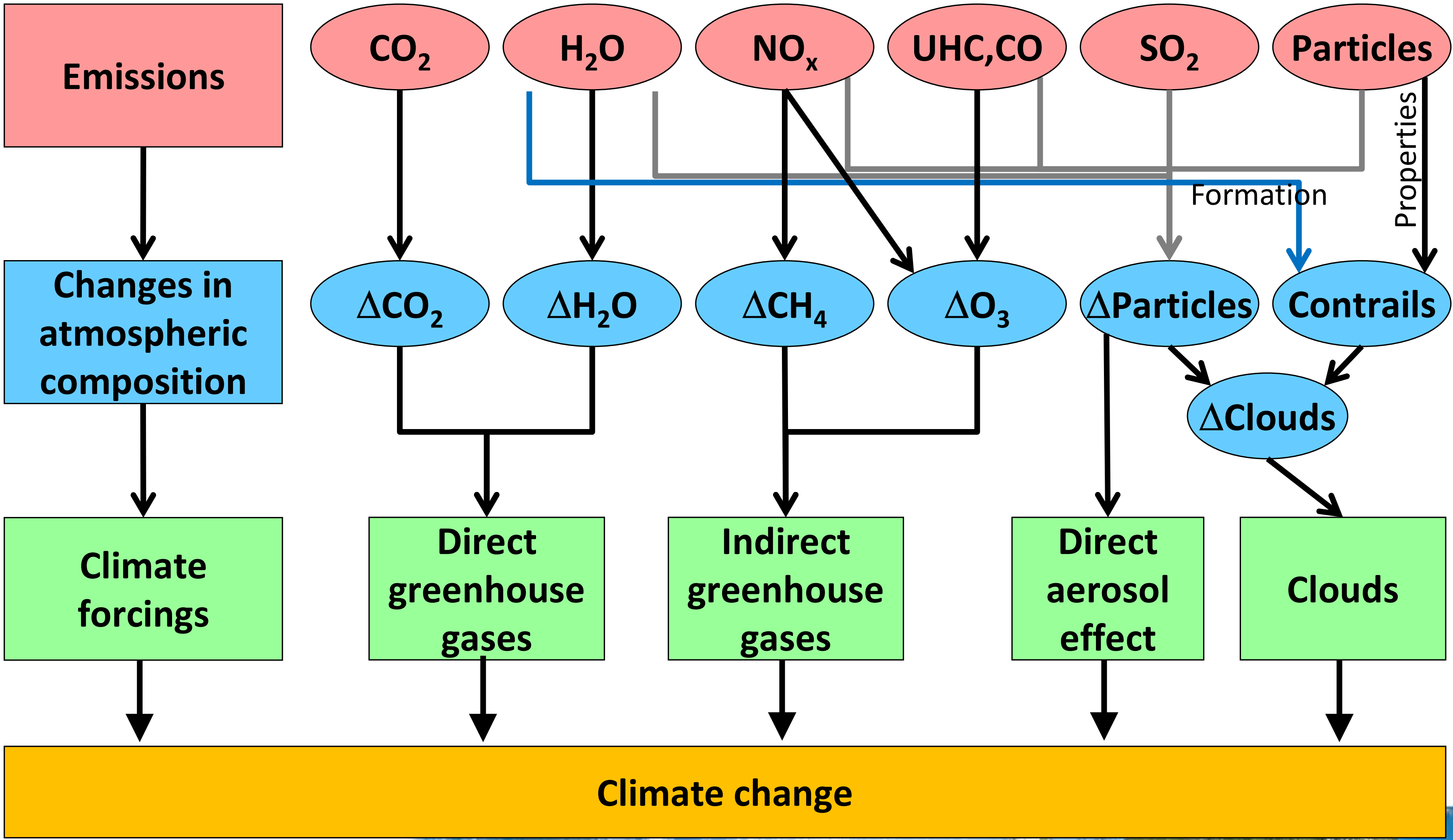


Climate impact of non-CO_2-Effects



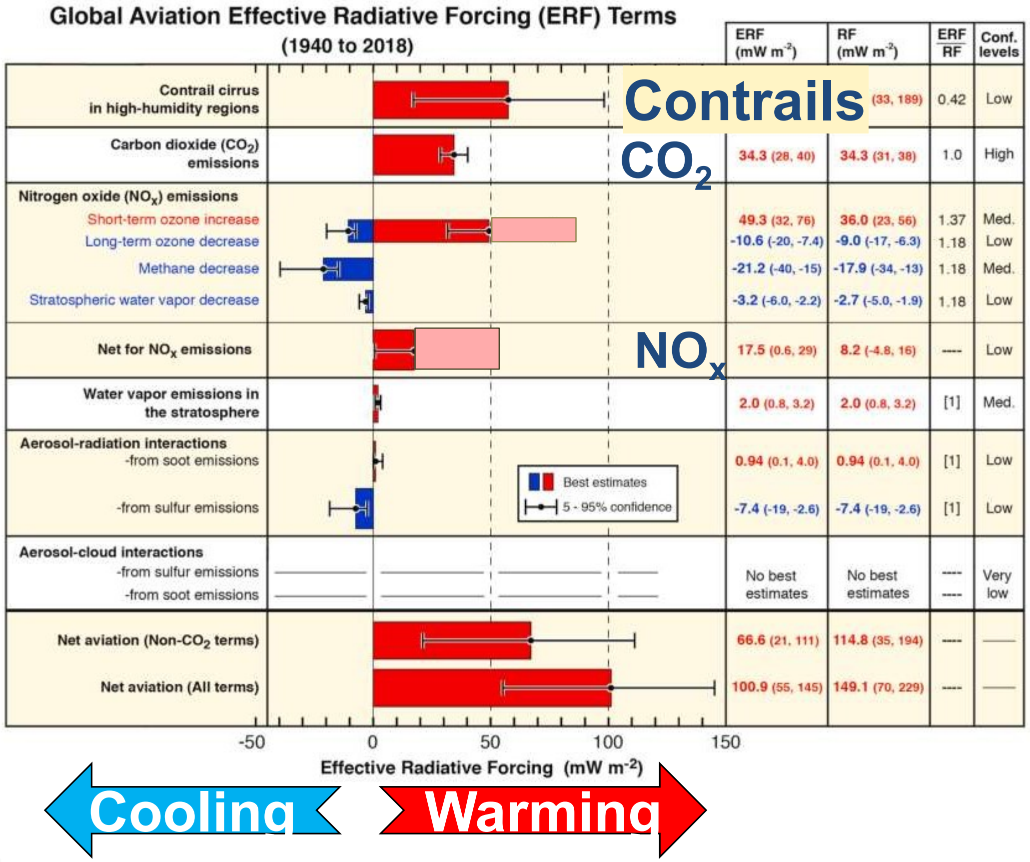
Søvde et al. (2014)

Overview: Climate impact of aviation



How important are the aviation non-CO_2-effects?

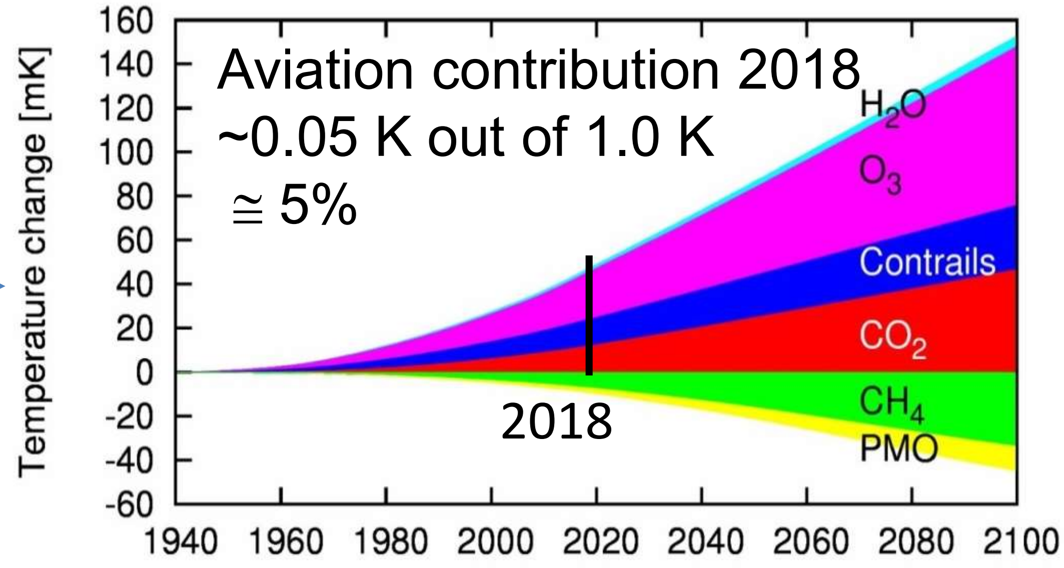
Radiation change



Lee et al. 2021

Grewe et al. (2019)

Temperature change



More than 50% of the aviation's climate impact results from non-CO_2 effects

Grewe et al. (2020)

DLR

Basic relation between inbalance in radiation budget (RF) and temperature change (dT)

$$dT = \lambda * RF$$

Temperature change — dT

Climate Sensitivity Parameter — λ

Radiative Forcing — RF

Radiative Forcing (RF), Effective Radiative Forcing (ERF) and Temperature change (dT)

Steady-state temp. change

Climate Sensitivity Parameter

Efficacy

Radiative Forcing

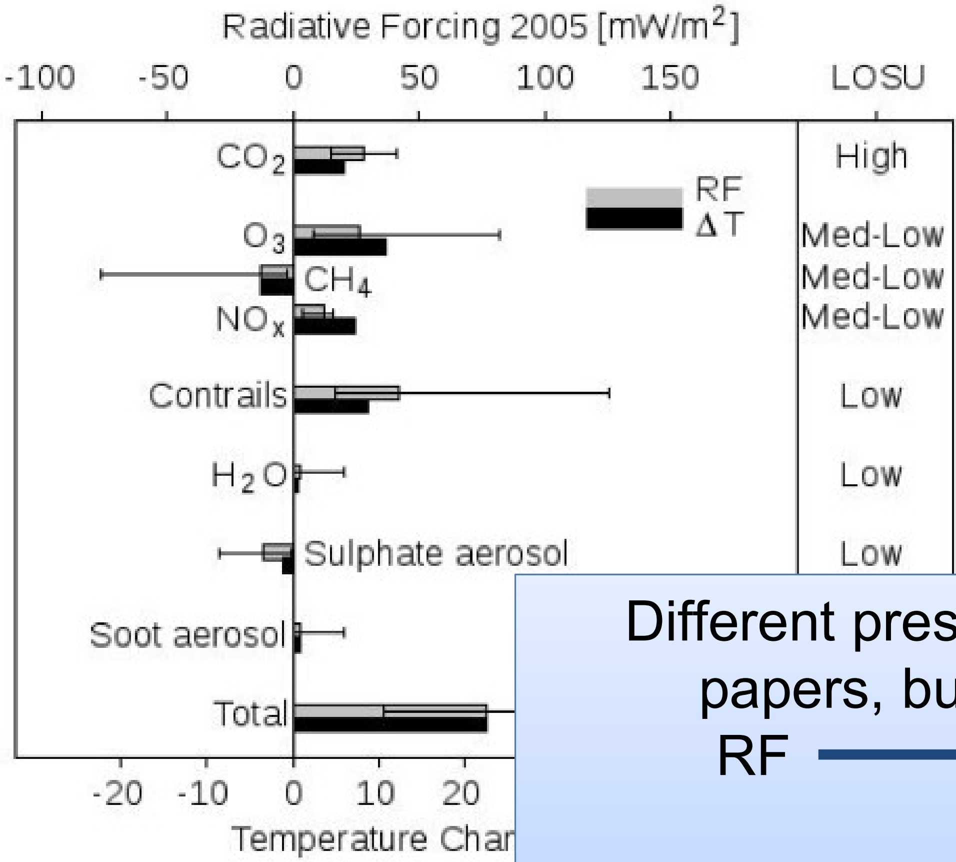
$$dT_{specie}(t=\infty) = \lambda_{CO2} * eff_{specie} * RF_{specie}(t=t_0)$$

Roughly equal

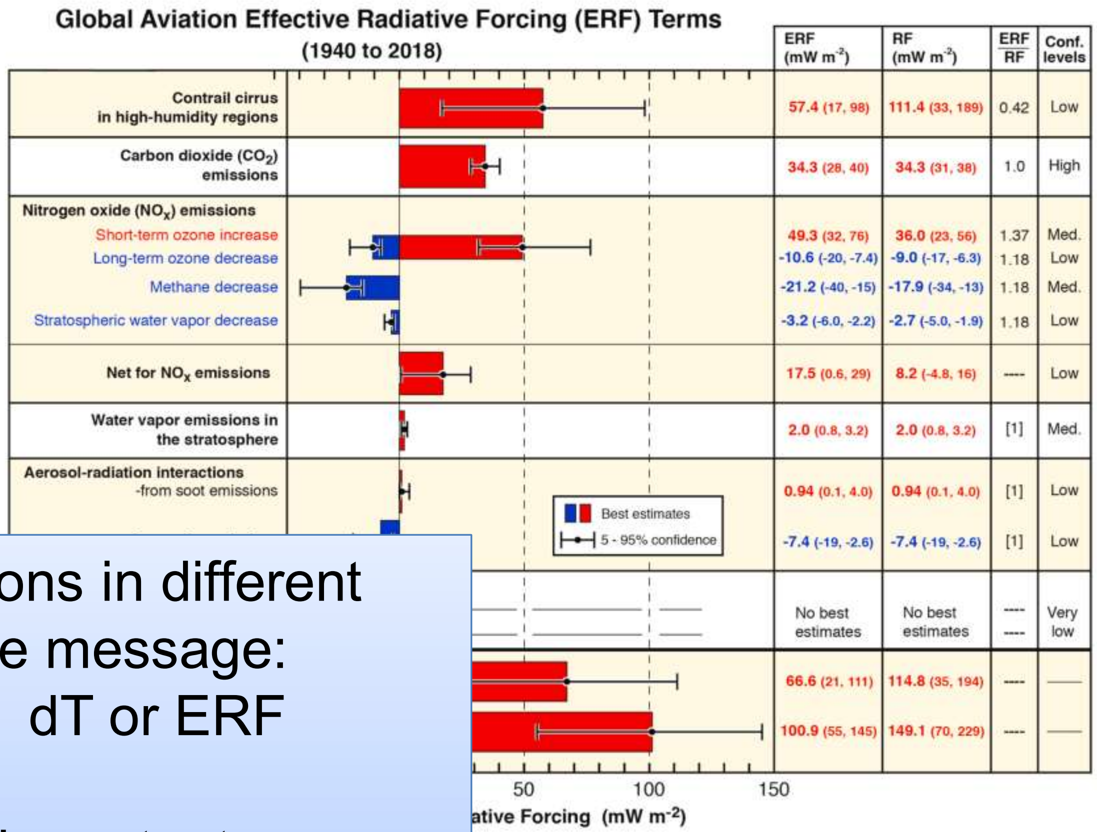
$$= \lambda_{CO2} * ERF_{specie}(t=t_0)$$

Effective Radiative Forcing

Radiative Forcing (RF), Effective Radiative Forcing (ERF) and Temperature change (dT)



Grewe, 2020



Lee et al., 2021

Different presentations in different papers, but same message:

RF → dT or ERF

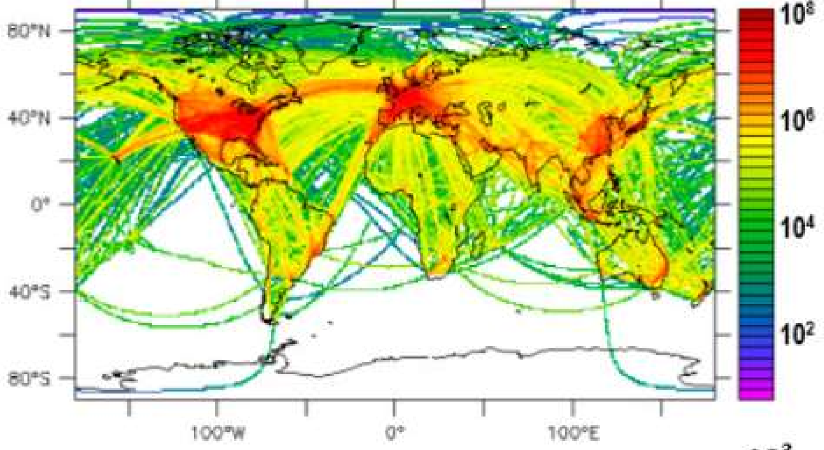
Contrails become less important

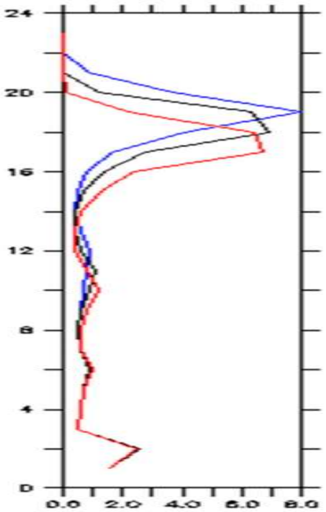
NO_x-Ozone becomes more important

CO_2, Contrails and NO_x all all important

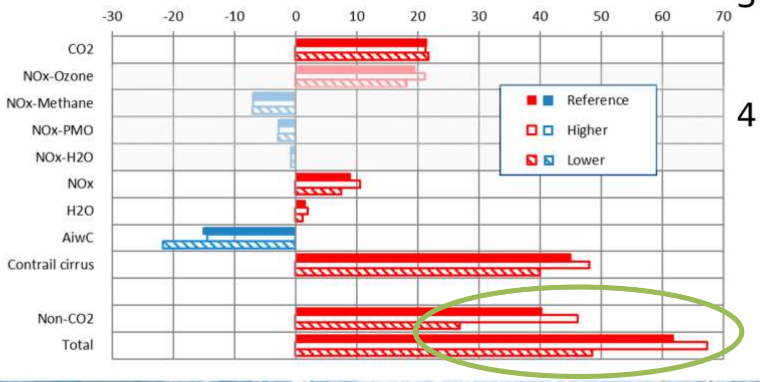
Altitude dependence of non-CO_2 climate impacts

Aviation NO_x emissions

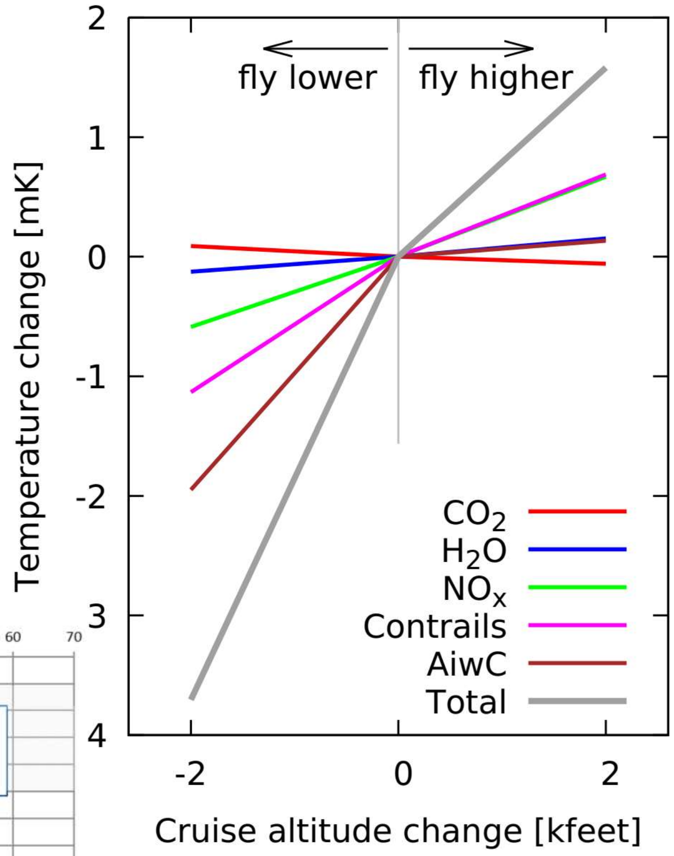




Parametric study to investigate **vertical dependence** of non-CO_2 impacts.
If aircraft **fly lower** aviation climate impact of **non-CO_2 effects** - water vapour, contrails, and aviation induced effects on warm clouds - **decreases**, while **CO_2** emission and impacts **increase** slightly.



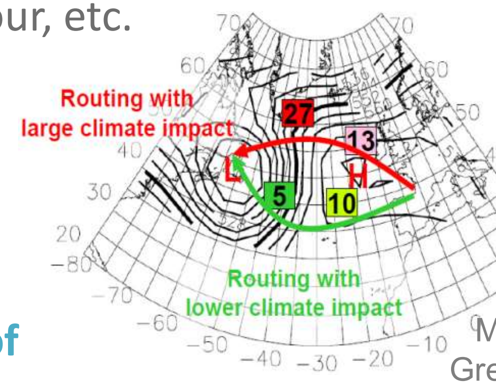
Impacts



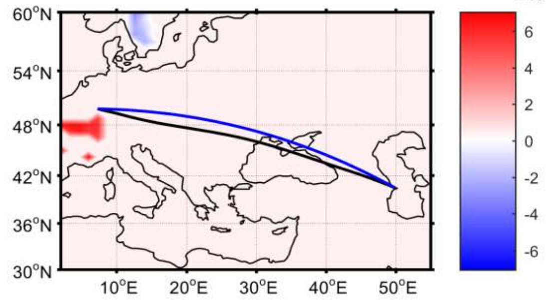
Matthes et al. 2021

ATM4E Environmental-optimised trajectories

- Aviation is concerned by environmental impact of its operations, comprising **air quality**, **noise** and climate impact. **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** linked to the emitted amount is available along the trajectory.
- **ATM4E**, Exploratory Research project **SESAR 2020** (2016-2018)
- **Main objective** of the ATM4E project was 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.
- Explore a **multi-dimensional** and **multi-criteria** optimization.



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



Matthes et al., 2020

ATM4E

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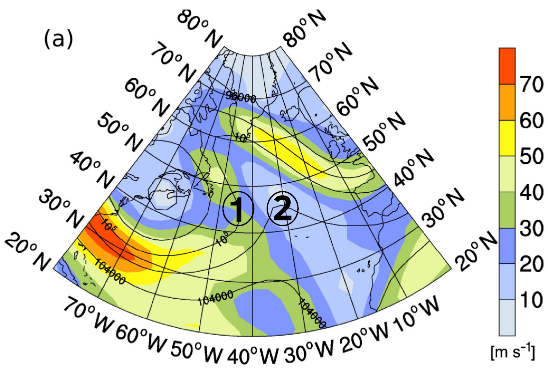
What is the relation between weather and aviation NO_x climate impact?

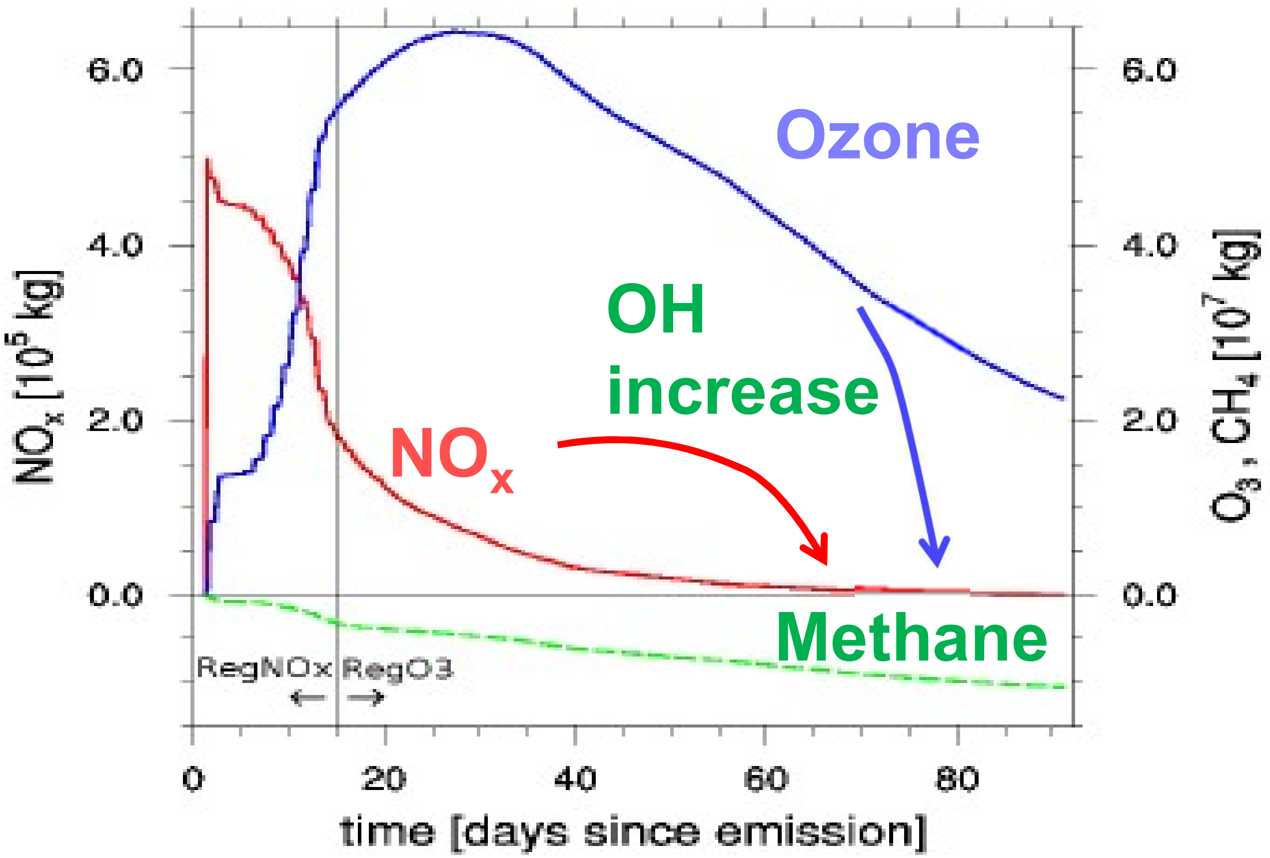
Weather



Aviation NOx - RF

Well established relation between NO_x-ozone-methane (typical situation)

(e.g. Fuglestvedt et al 1999)



Different time scales for NO_x, ozone, and methane

Grewe et al. (2017a)

$O_3 + H_2O \rightarrow 2\ OH$

$NO + HO_2 \rightarrow NO_2 + OH$

Methane Loss

$CH_4 + OH \rightarrow CH_3 + H_2O$

Less Background Ozone Production = Primary Mode Ozone
PMO

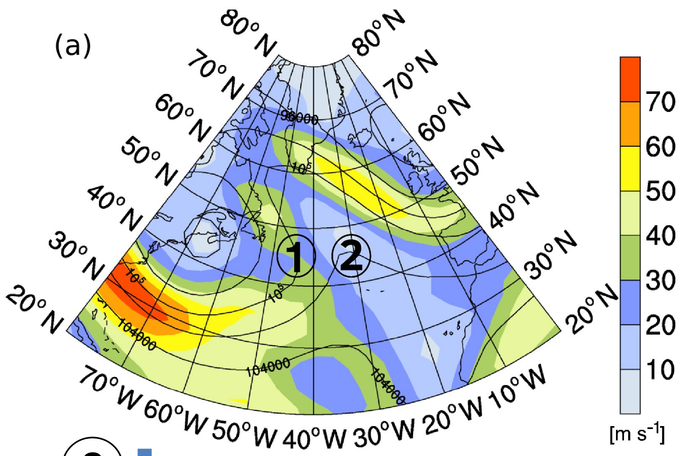
Less Stratospheric Water Vapour
SWV

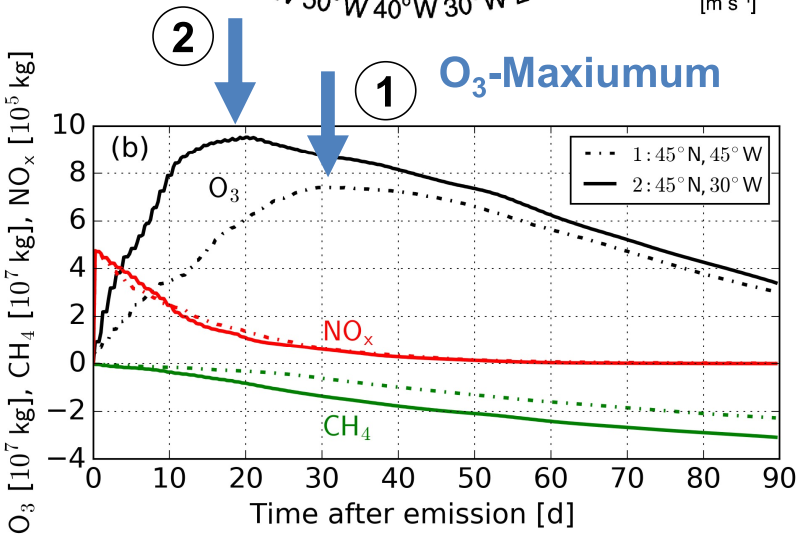
The role of the emission location

Different emission locations

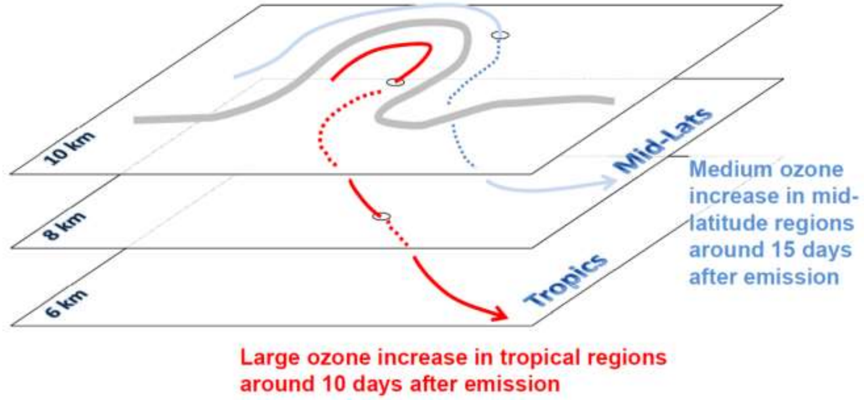
Different transport pathways

Different contributions to O_3 / CH_4





Rosanka et al. (2020)

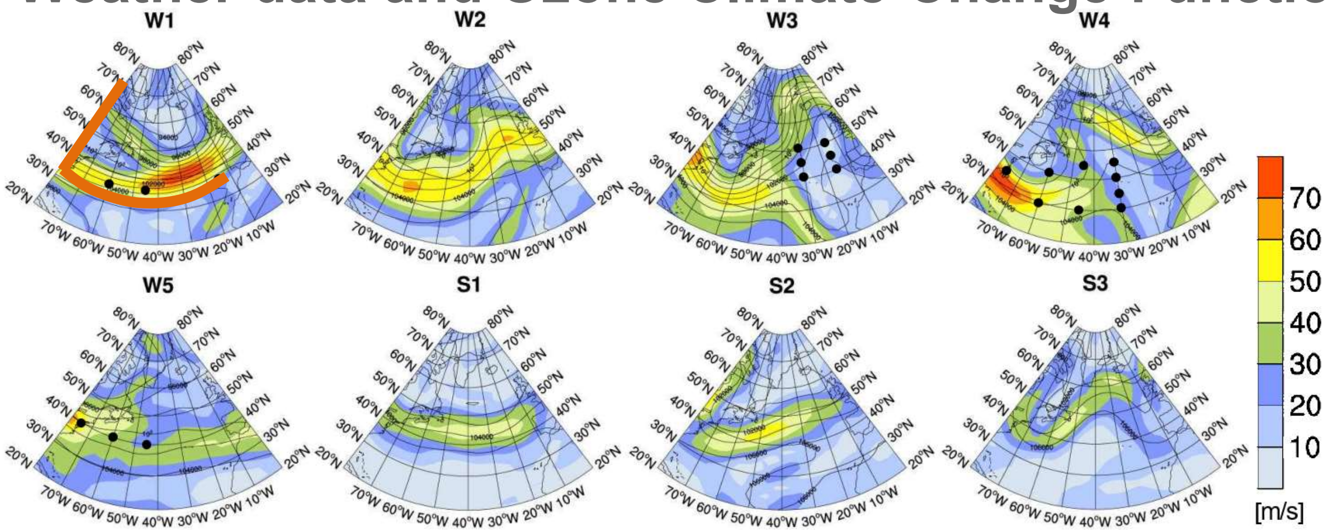


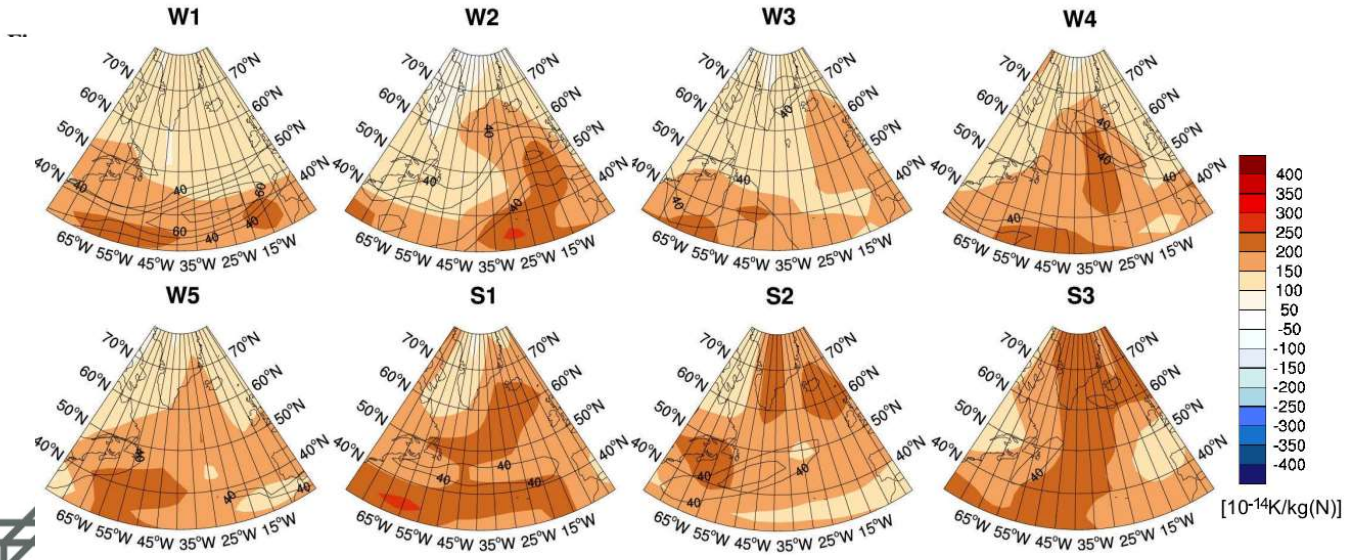
Grewe et al. (2017b)

Same NO_x evolution (generally not the case)

But different O_3 and CH_4 evolution

Weather data and Ozone Climate-Change-Functions





Frömming et al. 2021

Climatology of aviation weather situations:

Winter W1-W5

Summer S1-S3

University Reading

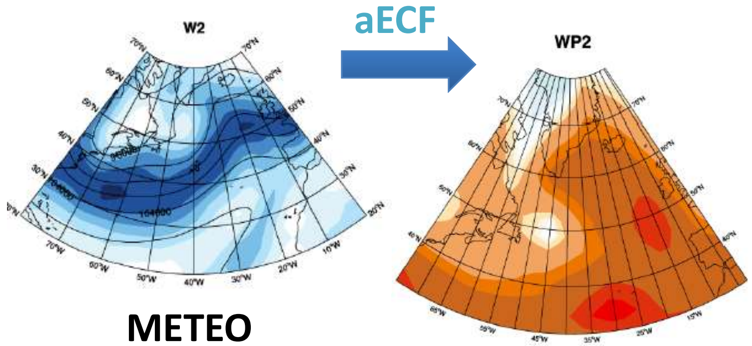
Irvine et al. 2013

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

Clear relationship between weather and CCFs

Step towards algorithmic Environmental Change Functions ECFs
From climate change function to aCCFs

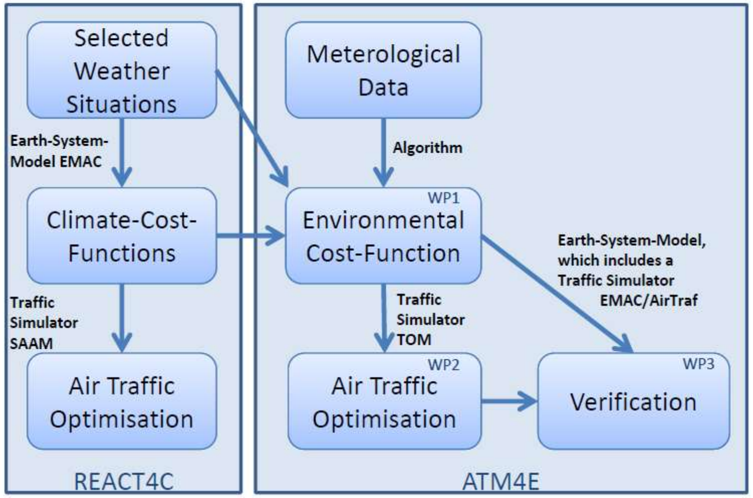
ATM4E



Frömming et al., 2020

- The key step in ATM4E was 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 a meteorological interface, e.g. to **SWIM infrastructure** (format, architecture) to make it available during flight planning.



Matthes et al., Aerospace, 2017.

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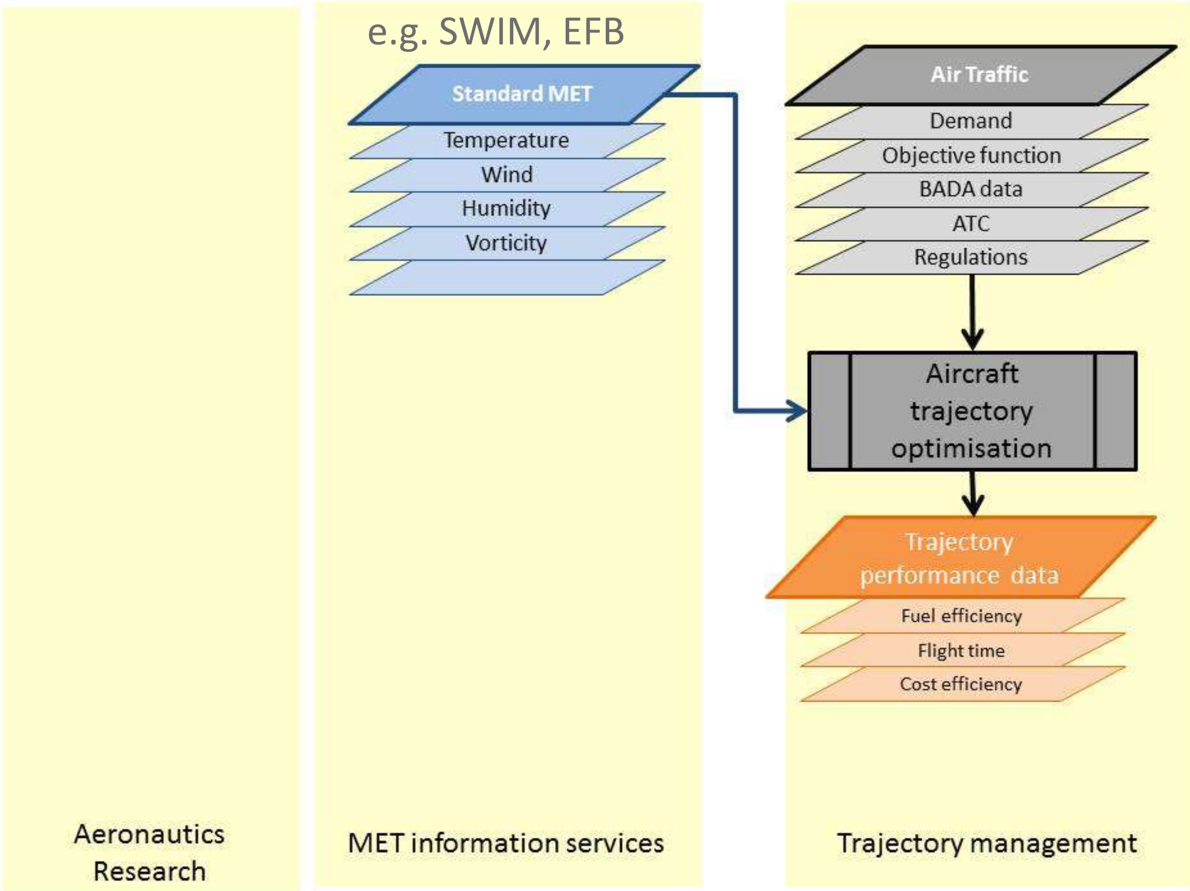
Air traffic management for environment: SESAR/H2020-Project ATM4E

ATM system



ATM4E

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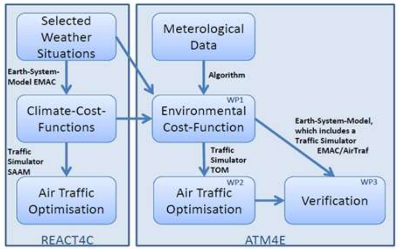
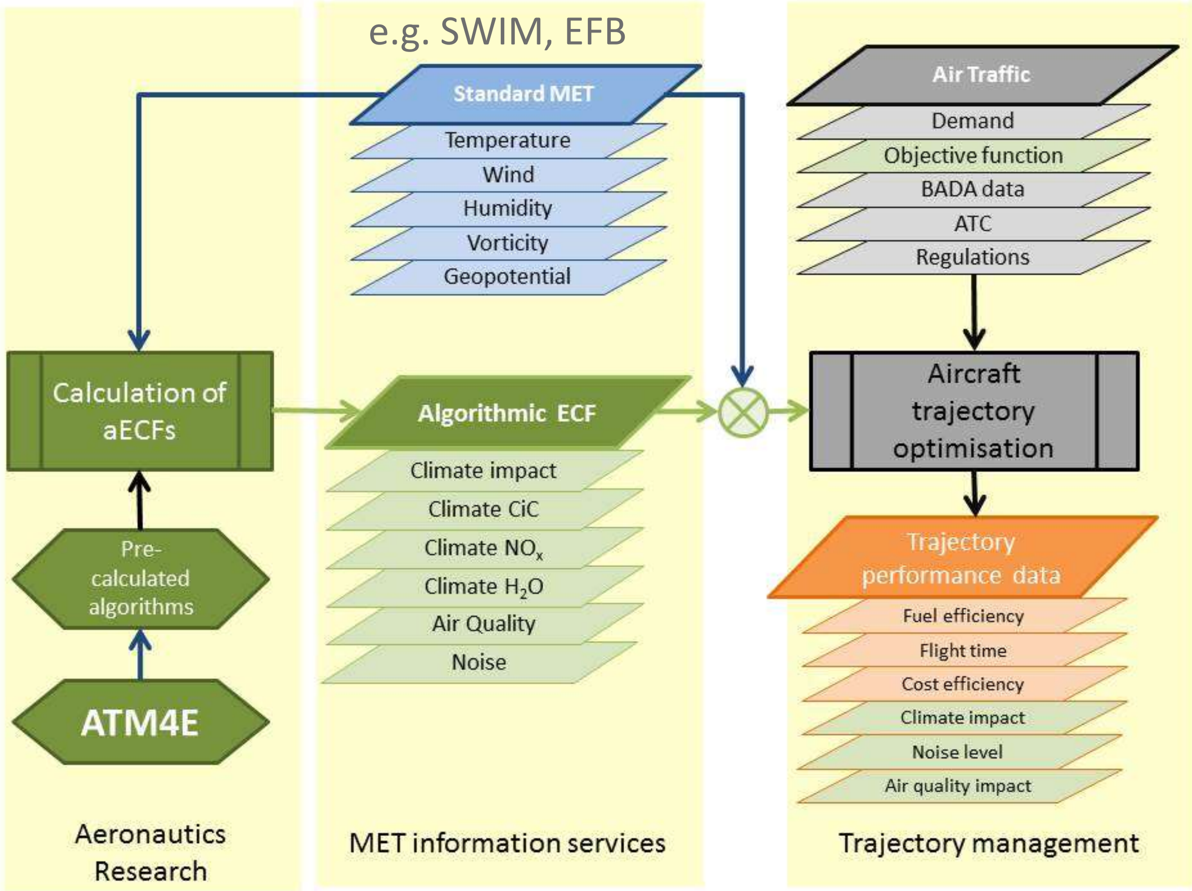
Air traffic management for environment: SESAR/H2020-Project ATM4E





Contribution of ATM4E

ATM4E

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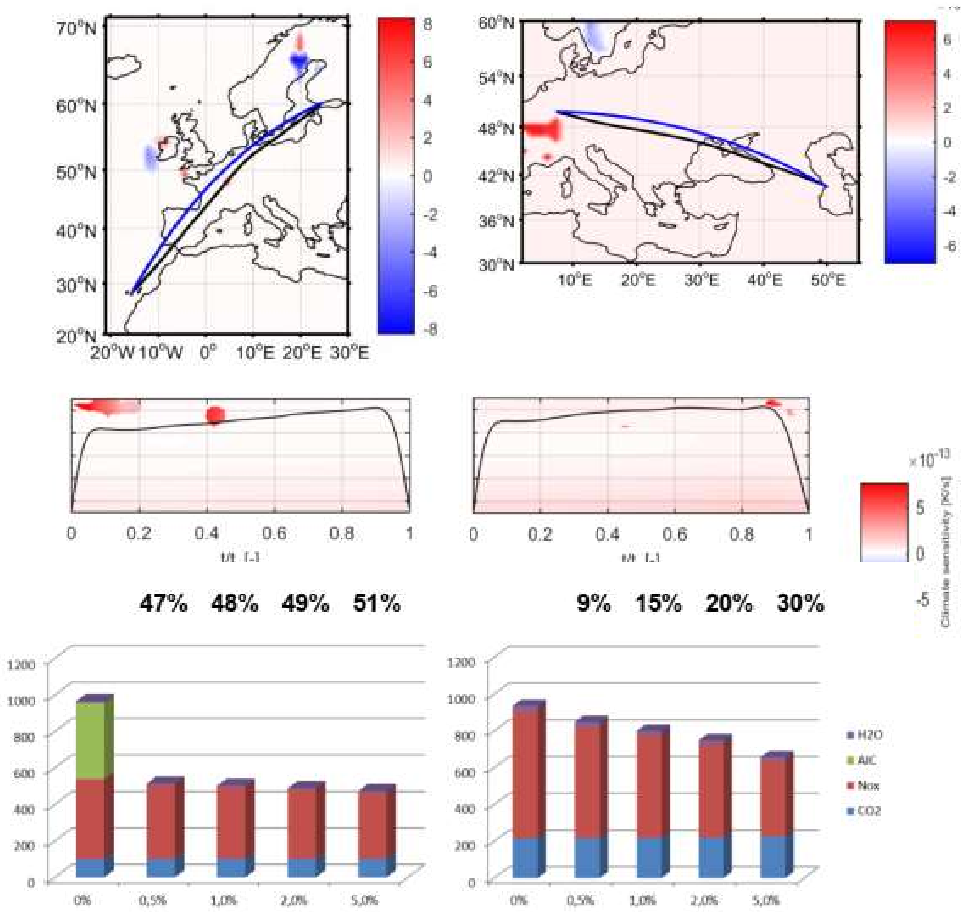
Step towards algorithmic Environmental Change Functions aECFs

ATM4E

- Results from **ATM4E case study** – real day was selected with high potential impact due to aviation induced contrail and contrail cirrus.
- Case study for a winter situation in 2018 relying on **prototype aCCFs**.
- **Mitigation potential** due to contrail avoidance (*left*) and NO_x-induced climate impacts (*right*) quantified.

FlyATM4E



Matthes et al. 2020

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Identified research needs in ATM4E on Environmental Change functions

1. **Enhancing the technological readiness of the algorithmic environmental change functions (aECF):** these need to cover all aircraft starting and landing in European airspace and represent uncertainties
2. **Expand the aECF concept from a case-study approach to a full European-scale application including performance indicators:** this would also need to consider expanding the aECFs (e.g. for air quality, other pollutants; for noise, the impact of airframe; for climate, additional non-CO_2 effects)
3. **Expand the aECF concept to include a robustness measure to minimize the risk of wrong decisions:** this would need to account for uncertainties in weather forecasts, environmental impacts, and exact routing knowledge

→ FlyATM4E

ATM4E

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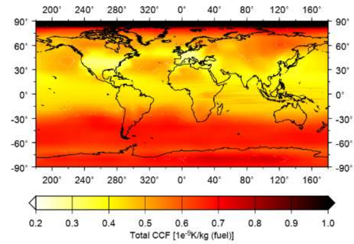
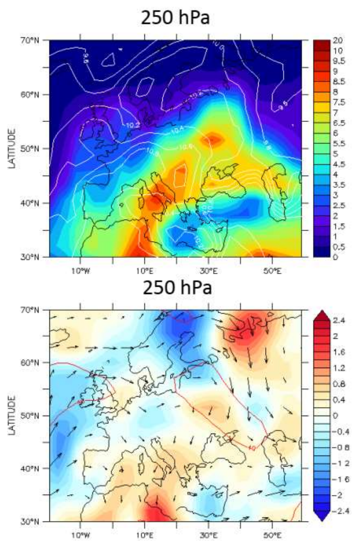
Step towards robustness of climate-optimized trajectories
Using algorithmic Environmental Change Functions ECFs (MET service)

ATM4E



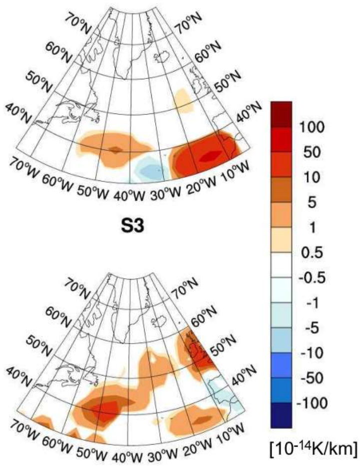
- Providing a technical description of **algorithmic climate change functions aCCFs** which represent **spatially and temporally resolved climate impact** of aviation emission to quantify CO_2 and non-CO_2 effects, comprising NO_x and contrail-cirrus.

Europe

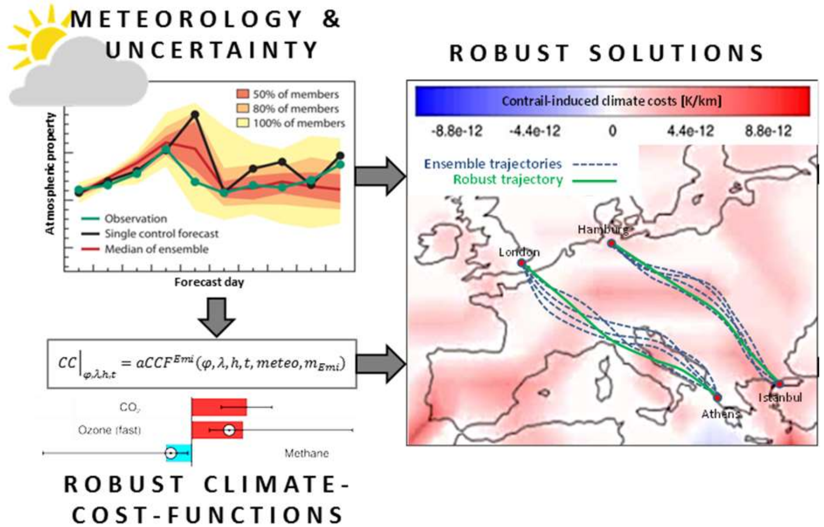


Matthes et al. 2017

NAFC



Frömming et al. 2020



FlyATM4E

DLR FlyATM4E SESAR JOINT UNDERTAKING

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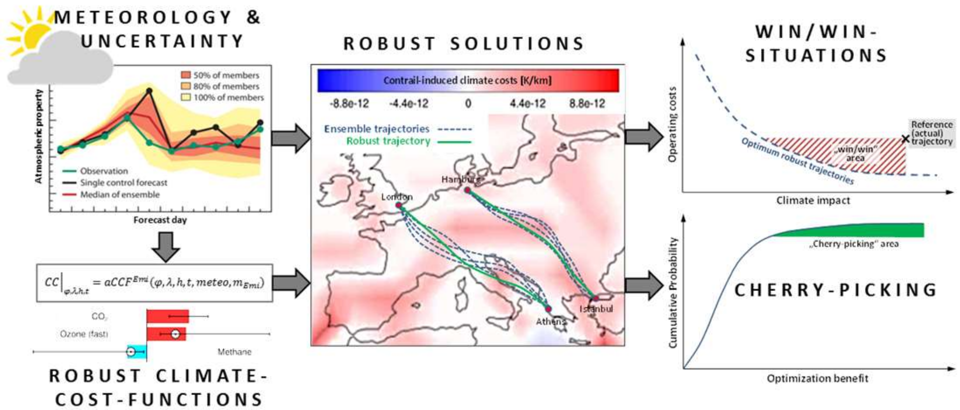
FlyATM4E: Flying ATM for Environment (2020-2022)
Project Objective

- FlyATM4E will develop a concept to identify climate-optimised aircraft trajectories which enable a robust and eco-efficient reduction in aviation’s climate impact.
- FlyATM4E will **identify those weather situations** and aircraft trajectories, which lead to a **robust climate impact reduction** despite **uncertainties** in atmospheric science that can be characterised by ensemble probabilistic forecasts. This will improve the assessment of aviation’s climate impact.
- It will further identify those situations where there is 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**”).

- As a summary, FlyATM4E will **formulate recommendations** how to implement these **strategies in meteorological (MET) products** and enable not only the understanding of ATM possibilities to reduce aviation’s climate impact, but moreover how to implement such eco-efficient routing.



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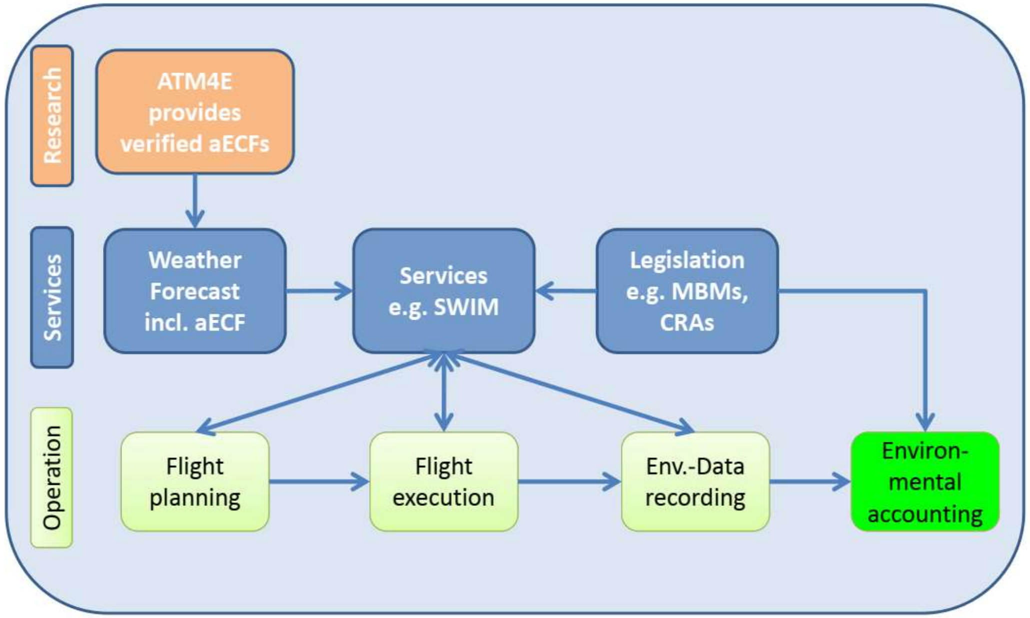
Towards implementation of climate optimized trajectories

- Implementation relies on **provision of climate change functions to ATM** (trajectory optimisation)
- Feasibility study performed on **infrastructure** comprising MET components – roadmap definition

- Options **on how to integrate** such novel MET products have been studied, e.g. ATM4E, SESAR ATM4E, PJ18
- Further options on how to expand current ATM and how to identify overall **mitigation potential by climate-optimized trajectories** are currently explored, e.g. SESAR FlyATM4E, ALARM, but also in Aeronautics projects ClimOP.



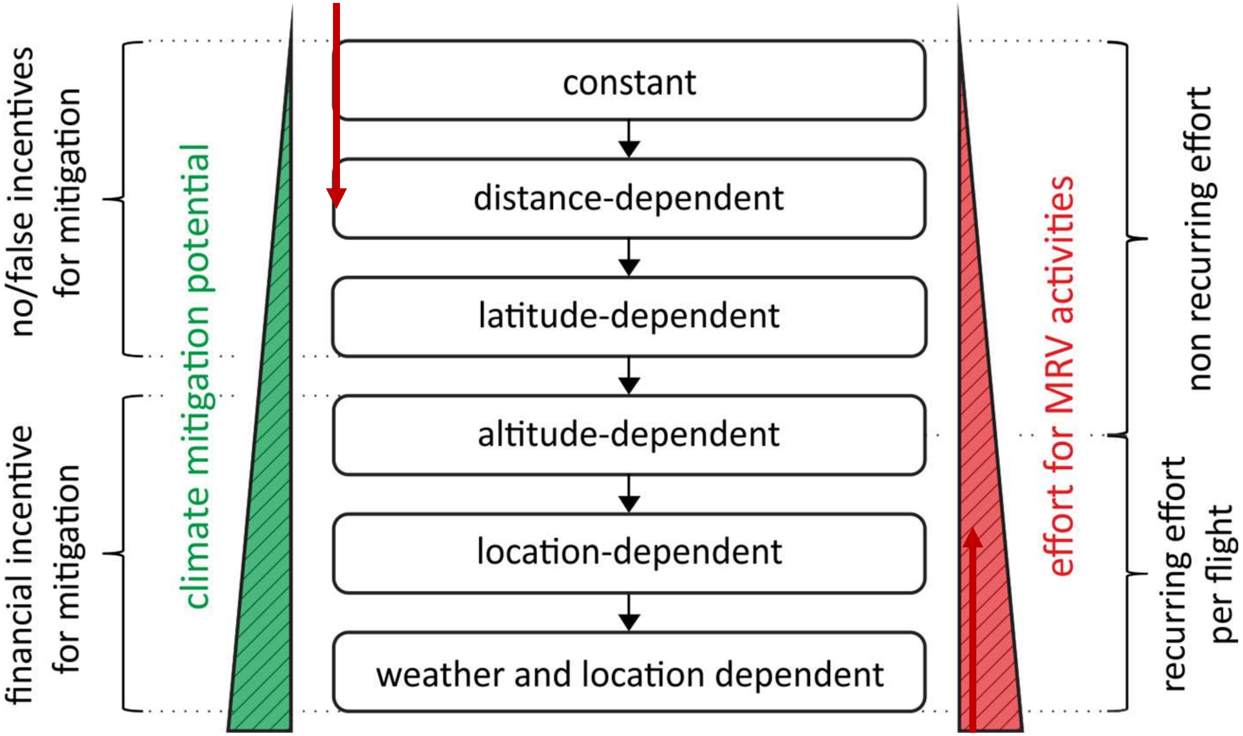
Matthes et al. 2017

ECATS DLR FlyATM4E SESAR JOINT UNDERTAKING

Towards integration of non-CO_2 effects in emission schemes

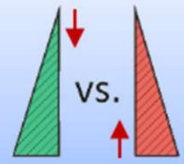
Need for market-based / policy measures for integrating non-CO_2 effects of aviation into EU ETS and under CORSIA

Integration based on CO_2 equivalents (CO2e)



- From research on **climate impact of aviation**, e.g. IPCC (EASA) with current level of confidence in climate impact estimates we suggest a **risk analysis** to **quantify robust mitigation** potentials.
- **Decision making** under uncertainty conditions.

Choosing a CO_2e method is a trade-off between high climate mitigation incentives and low efforts for MRV activities.



Key criteria for selecting a CO2e method
- CO2e factors must provide an incentive for mitigating non-CO_2 effects
- CO2e factors should be easy to calculate, predictable and transparent

Niklaß et al., 2020

MRV = Monitoring, Reporting, Verification

Ongoing research projects on sustainable aviation Focussing on topics related to ATM

- **FlyATM4E** investigates robustness criteria of **climate-optimized aircraft** trajectories and synoptical situations with large mitigation potential
  - Assessment strategies: Win-win situations and Cherry picking in the European Air Space
  - SESAR Exploratory Research Project, 06/2020-11/2022, coordinated by DLR Institute of Atmospheric Physics
- **ALARM** will to develop a prototype on global **multi-hazard monitoring** and Early Warning System (EWS).
  - Early warnings on volcanic ash, dust, severe weather, space weather as well as hot spots in terms of climate impact provided (nowcast, forecast)
  - SESAR Exploratory Research Project, 06/2020-11/2022, U3CM, DLR, BIRA, Satavia, UniPad, SymOpt
- **DYNCAT** will explore more **environmentally friendly** and more **predictable flight profiles** in the terminal manoeuvring area, or TMA. It will sup pilots in their configuration management during approach.
  - DYNCAT will have available data (real-world, simulation)
  - SESAR Exploratory Research Project, 07/2020-12/2022, coordinated by DLR Institute of Flight Systems
- **Contrail avoiding** trajectories planning and satellite verification for night time traffic
  - Exercise to avoid night-time contrails over Europe, 01/2021-12/2023, DLR Institute of Atmospheric Physics, DWD, MUAC
- **ACACIA** improves **scientific understanding** on mechanisms and processes causing **aviation climate impact** and provides an updated climate impact assessment
  - Investigate **non-CO_2 climate impacts of aviation** comprising indirect aerosol cloud interaction
  - Aeronautics Project (RIA), 01/2020-06/2023 coordinated by DLR Institute of Atmospheric Physics
- **ClimOP** assesses strategies for **operational improvements** in order to reduce climate impact of aviation comprising CO_2 and non-CO_2 impacts
  - Most promising mitigation strategies are identified and their mitigation potential assessed
  - Aeronautics Project (RIA), 01/2020-06/2023, DeepBlue, DLR, NLR, TU Delft et al.

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Climate change and the role of ATM - Summary

- **Total climate impact** of aviation is caused by CO_2 and non-CO_2 effects, with aviation contributing to anthropgenic climate change by 2.5% (only CO_2) and about 5 % (considering non-CO_2 effects as well).

- Non-CO_2 effects show a **strong spatially and temporally variation** which can be exploited by **alternative trajectories (climate-optimized)** in order to reduce climate impact of aviation.
- Climate change functions are a **concept to describe** these non-CO_2 climate impacts, and algorithms are currently under development which enable an direct linkage to weather forecast data.
- Using such **novel MET services** (prototypes) enables exploring **mitigation potential** by climate-optimized trajectories, e.g. in European traffic case study.

- **Towards implementation** of such novel MET services on aviation climate impact requires an expanded infrastructure, as well as concepts on **decision making under uncertainty conditions** (robustnest).
- Conceptual work on how to best integrate non-CO_2 effects in current emission schemes, e.g. CORSIA are delivering initial concepts with different levels of **complexity** and **accuracy** (Stakeholder dialogue).
- **Strategic partnership** between climate impacts research and air traffic management helps efficient integration.

Literature and references

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Thank you

The role of the emission location

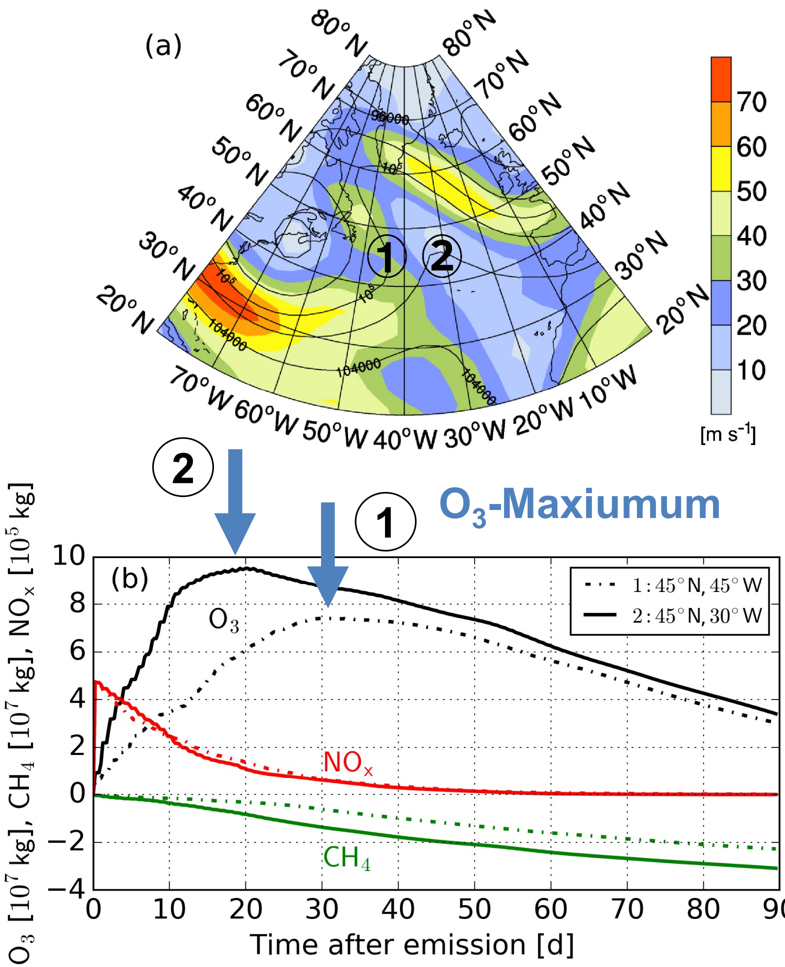
Different emission locations

↓

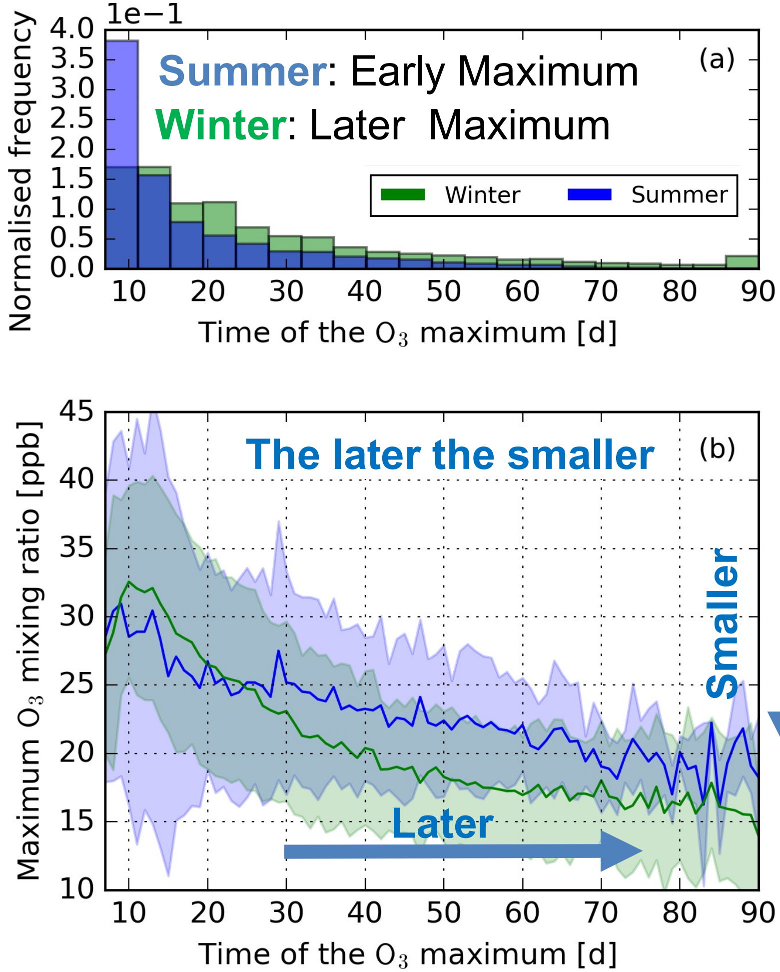
Different transport pathways

↓

Different contributions to O_3 / CH_4



Analysis of ozone maximum for ~50,000 trajectories



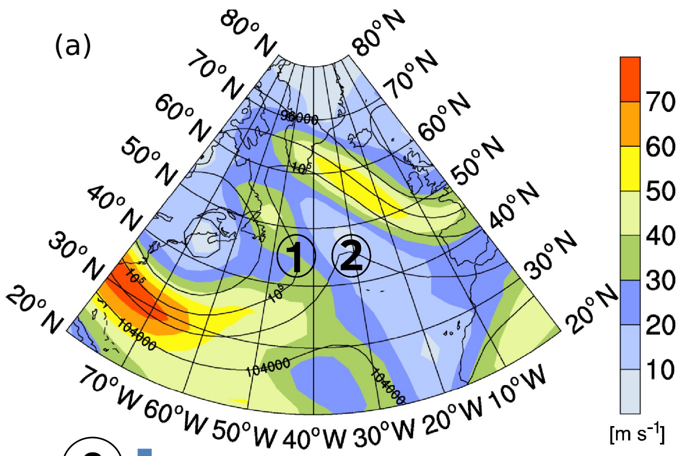
Rosanka et al. (2020)

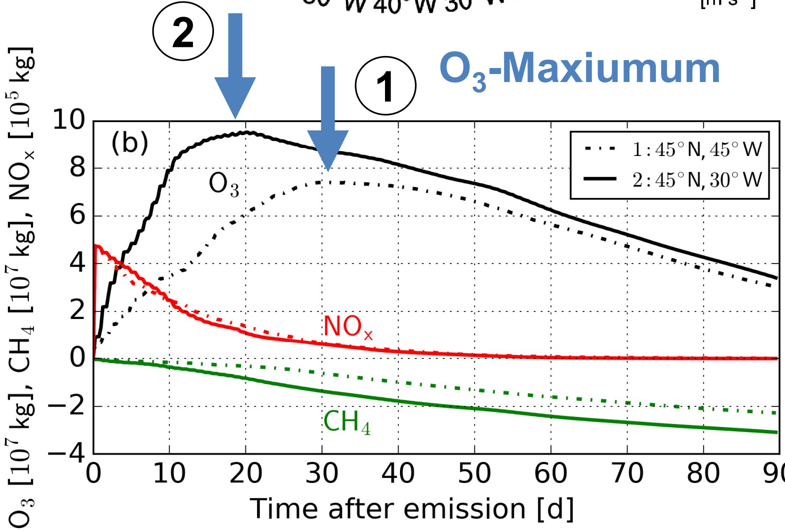
The role of the emission location

Different emission locations

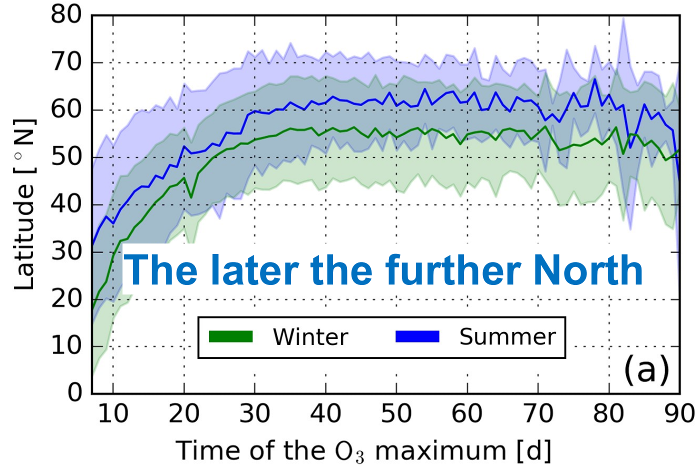
Different transport pathways

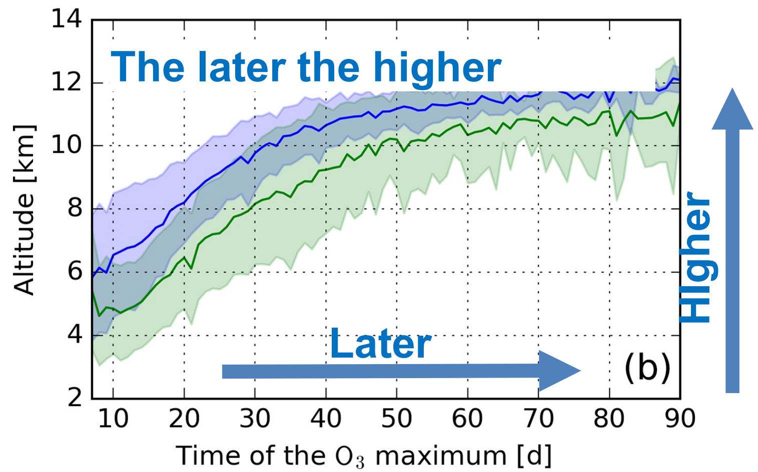
Different contributions to O_3 / CH_4





Analysis of ozone maximum for ~50,000 trajectories





Rosanka et al. (2020)