A Note on How to Internalize Aviation's Climate Impact of Non-CO_2 Effects

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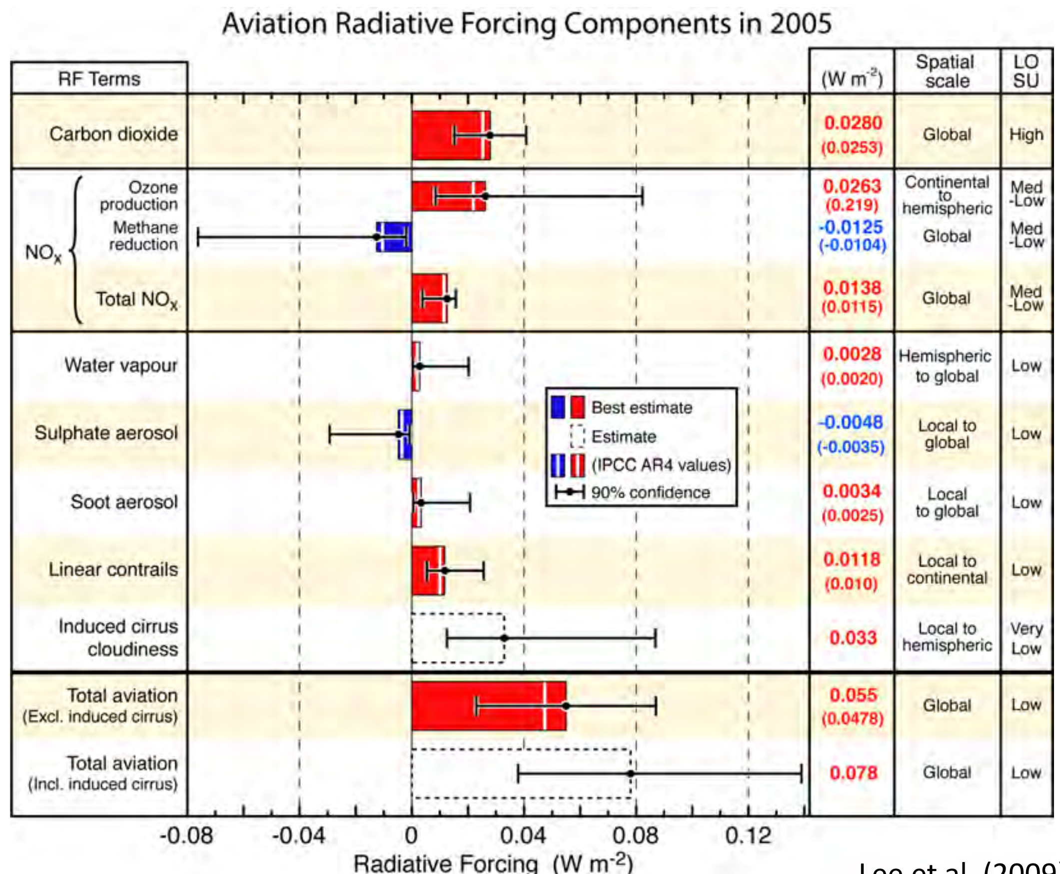
CO_2 is not equivalent to climate impact

Climate impact depends on :

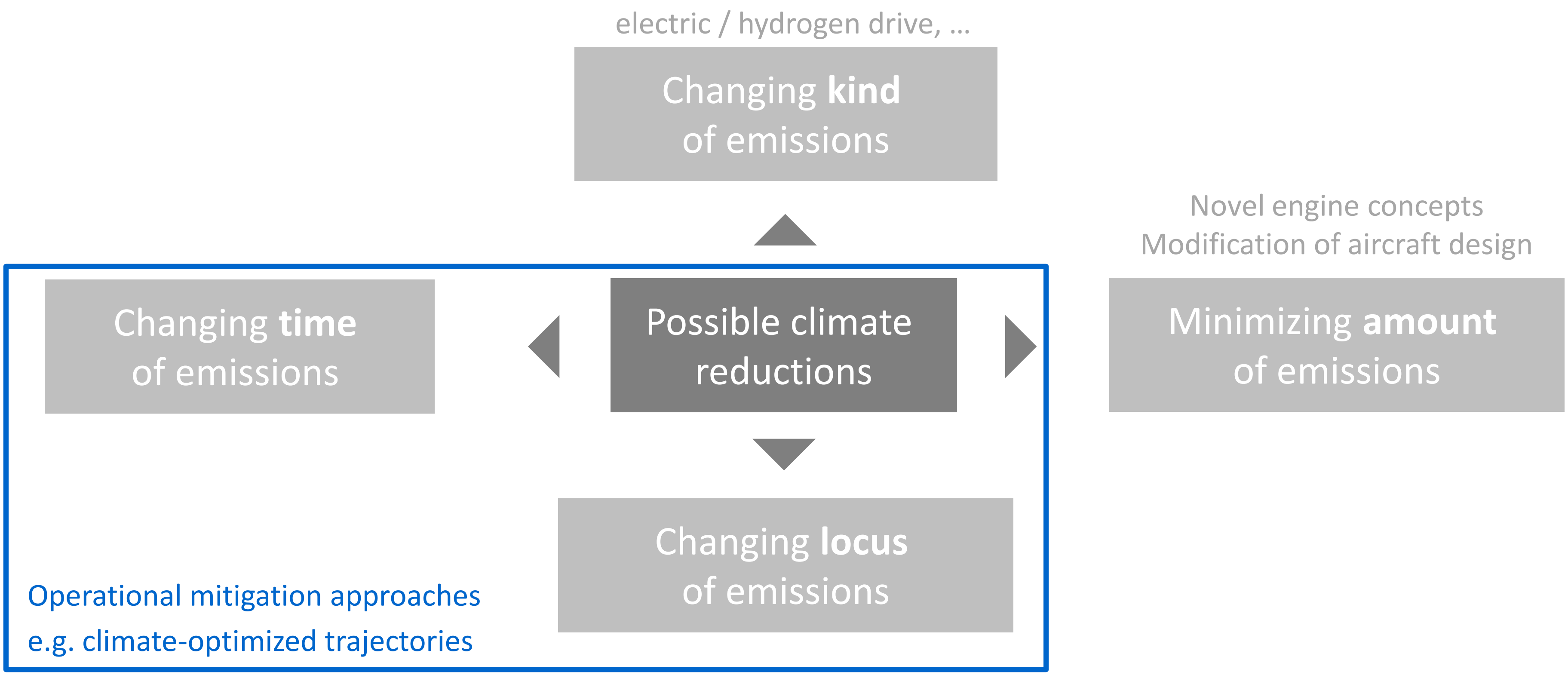
- **Species** of emission
- **Amount** of emission
- **Locus** of emission
- **Time** of emission
- **Weather** conditions



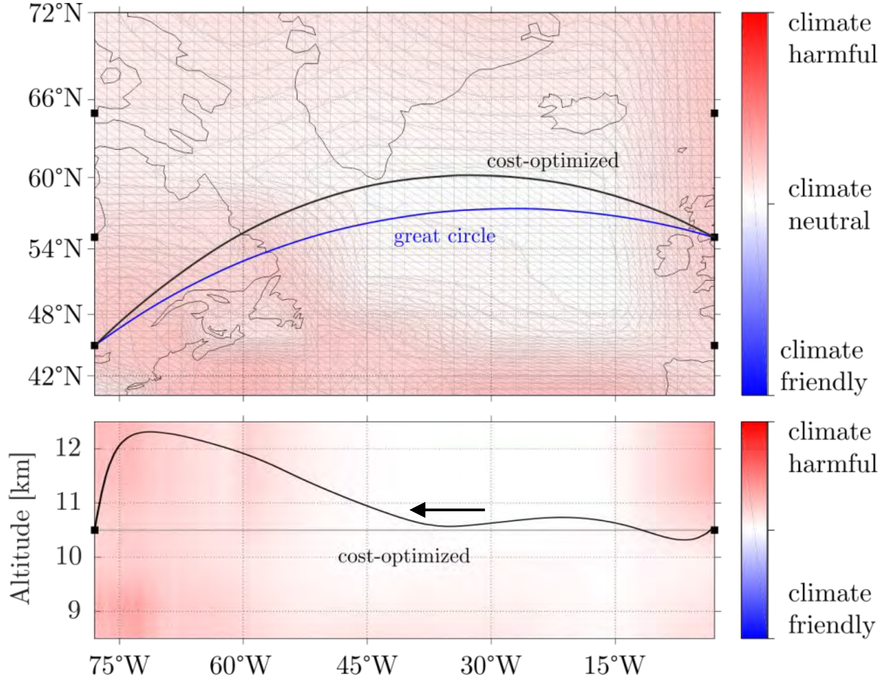
Lee et al. (2009)

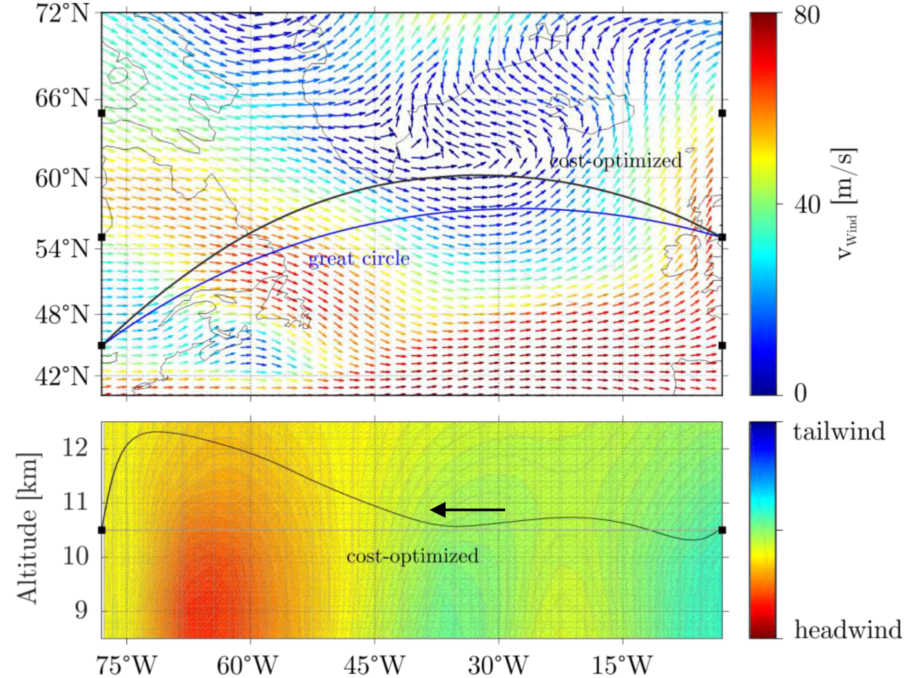
Aviation responsible for approximately 3.5 % of all anthropogenic radiative forcing in 2005

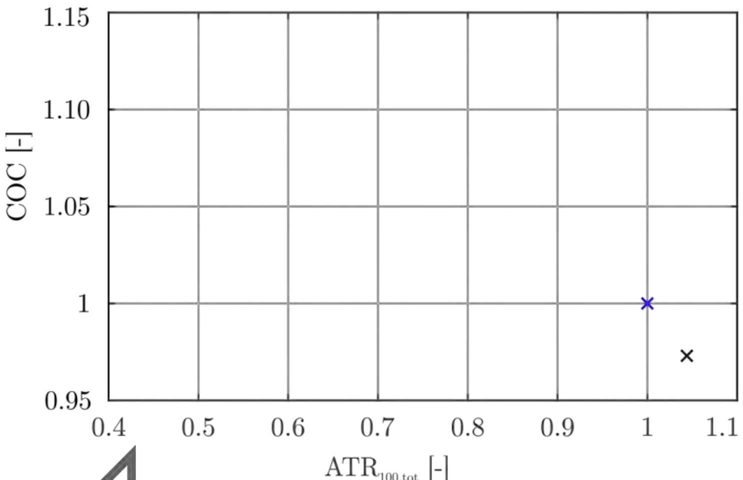
Overview of Climate Impact Mitigation Options



Climate-Optimized Trajectories





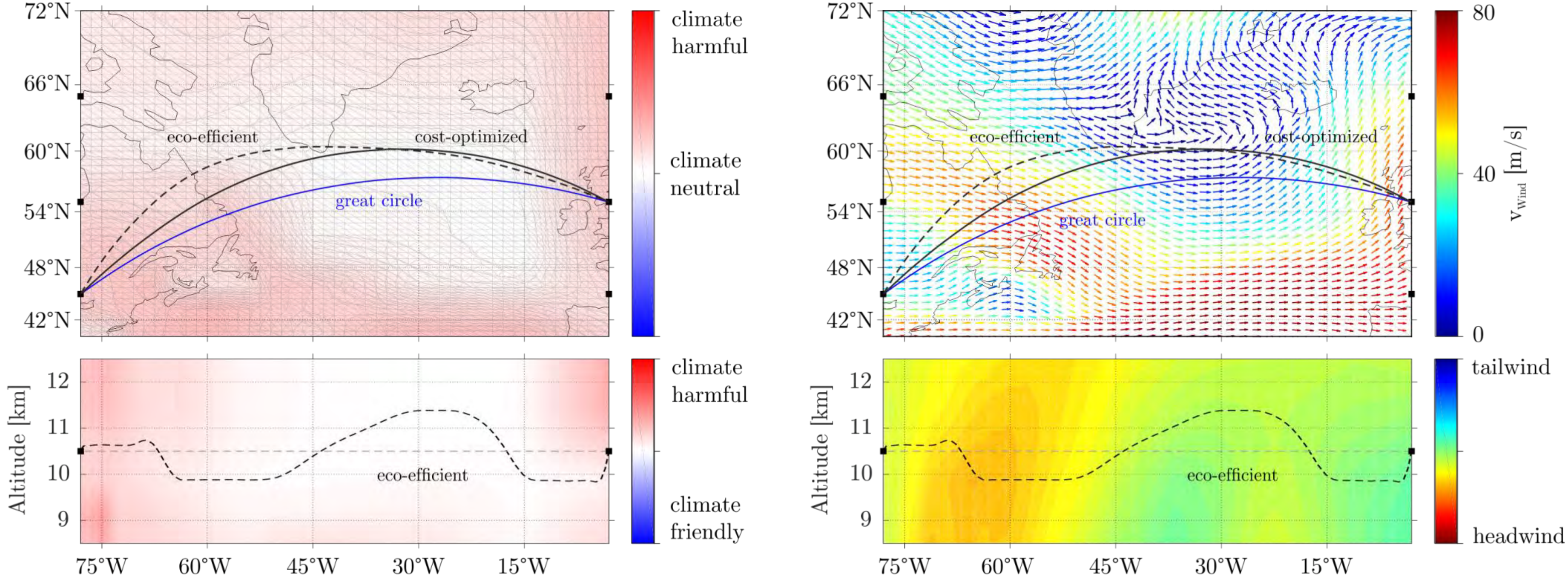


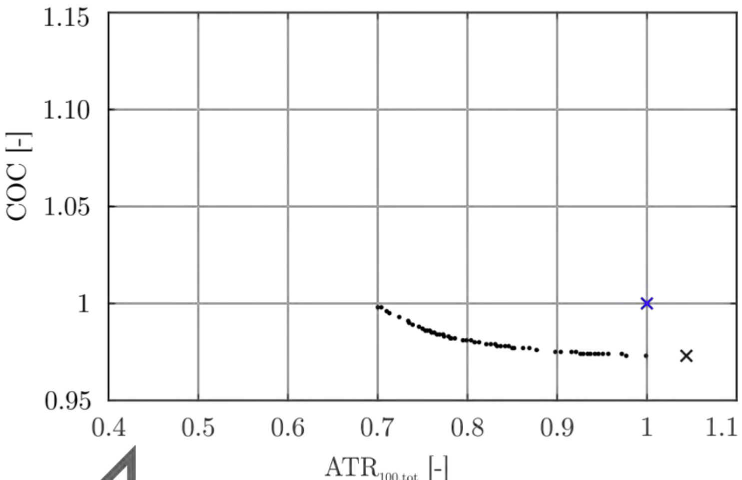
3D

monetary weighting	1.000
climate weighting	0.000
COC	0.973
ATR	1.044
fuel	0.960
flight time	0.979
mean altitude	11,252 m

Lührs et al. (2016)

Climate-Optimized Trajectories



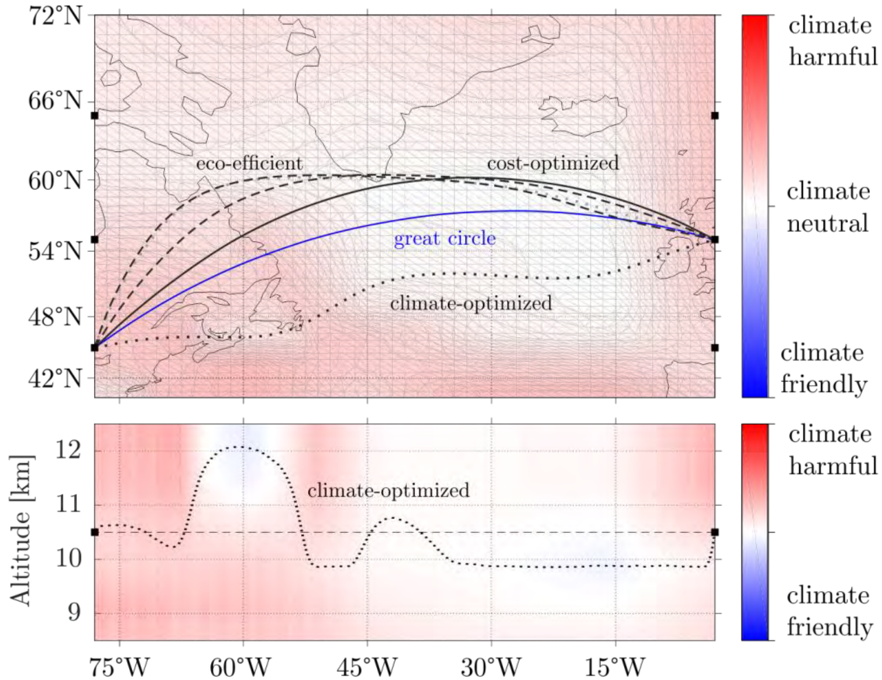


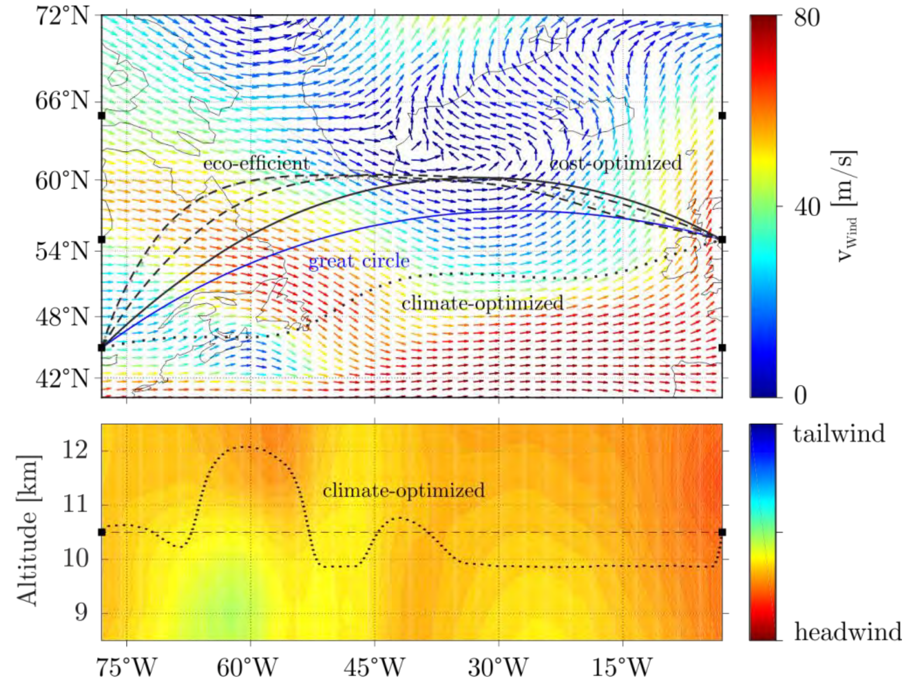
3D

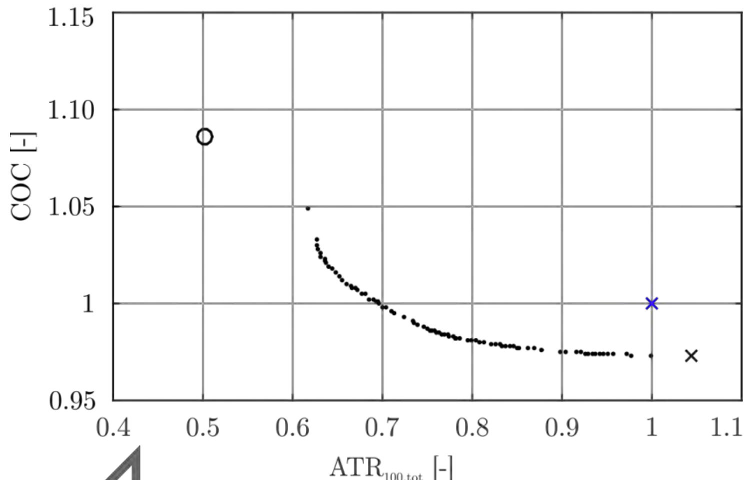
monetary weighting	0.736
climate weighting	0.264
COC	0.998
ATR	0.700
fuel	1.002
flight time	0.994
mean altitude	10,461 m

Lührs et al. (2016)

Climate-Optimized Trajectories





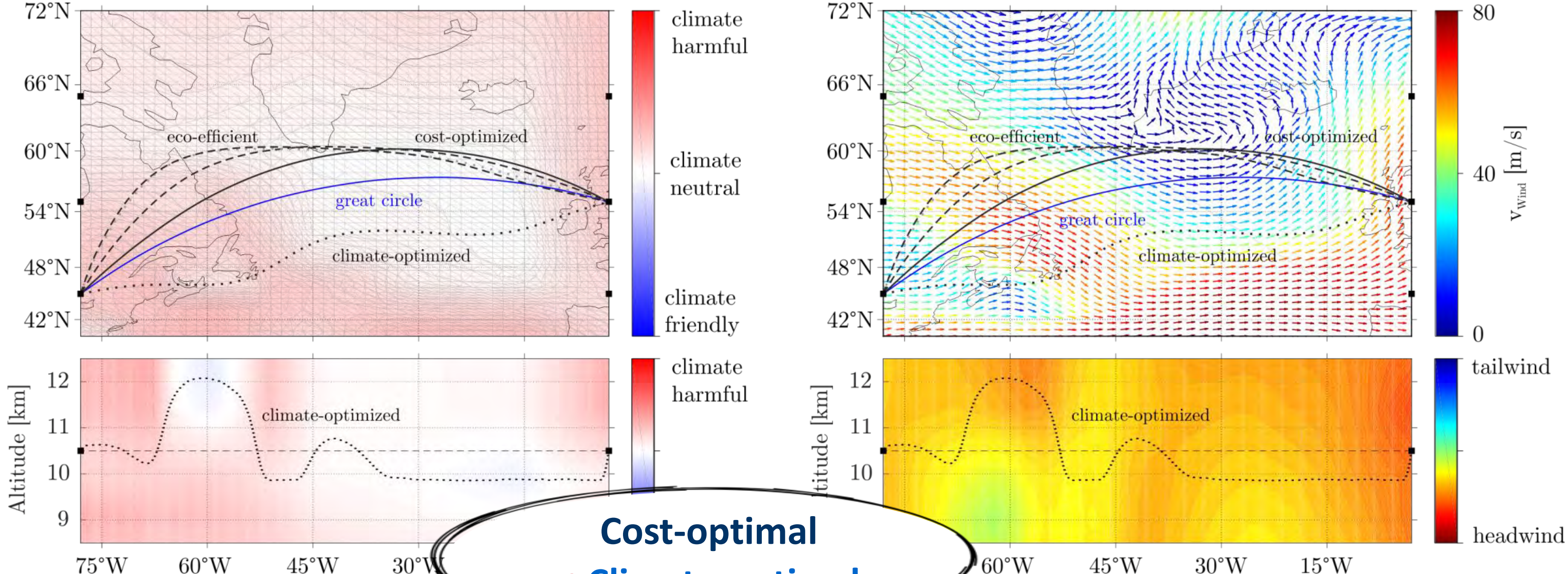


3D

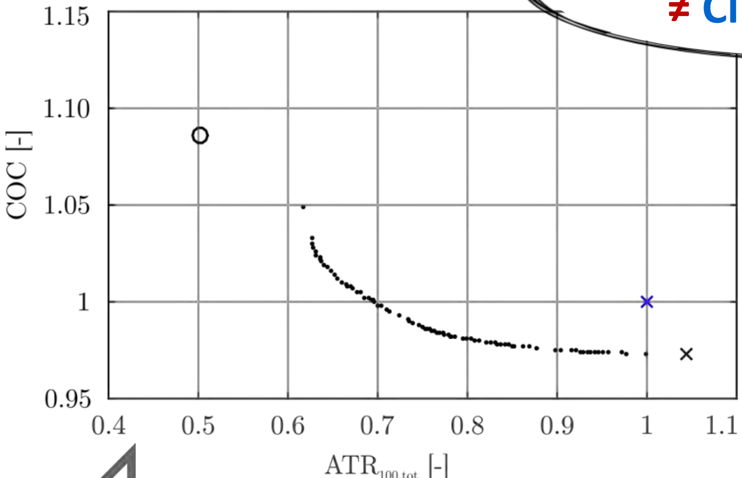
monetary weighting	0.000
climate weighting	1.000
COC	1.086
ATR	0.502
fuel	1.106
flight time	0.982
mean altitude	10,430 m

Lührs et al. (2016)

Climate-Optimized Trajectories



Cost-optimal
≠ Climate-optimal



3D

monetary weighting	0.000
climate weighting	1.000
COC	**1.086**
ATR	**0.502**
fuel	1.106
flight time	0.982
mean altitude	10,430 m

Lührs et al. (2016)

Key Findings

Climate Impact

- **Climate impact of non-CO_2 effects is highly dependent of locus and time of emission**
- **Climate-optimal operation $\neq$ cost-optimal operation**

Aviation Industry

Airlines are exclusively driven by economy

Environmental economics

→ **Monetization of external effects are necessary**

→ **Climate optimal operation $\stackrel{!}{=}$ cost optimal operation**

Research Questions

(i) How to include aviation's climate impact of non-CO_2 effects adequately into an environmental policy measure?

(ii) What is a reasonable „shadow price“ for global warming?

Overview of Instruments of Environmental Policy

Instruments of Environmental Policy

Voluntary Approaches
- Contractual Arrangements (Coase Theorem)
- Personal Interest
- Social Standards
- Helpfulness

Market-based Approaches
- Price-based Instruments i.a. subsidies, environmental taxes and charges.
- Quantity-based Instruments i.a. tradeable permits.

Regulatory Approaches
- Restrictive Instruments i.a. environmental limits and standards
- Coordinating Instruments i.a single European sky

Create financial incentive for airlines for climate impact mitigation

Types of Market-based Measures (MBMs)

In the aviation context, three types of MBMs have been considered

- Levies
- Emission Trading
- Offsetting

Focus on **CO_2 emissions reduction** only instead of **climate impact mitigation**

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Concept of Climate Charged Airspaces (CCA)

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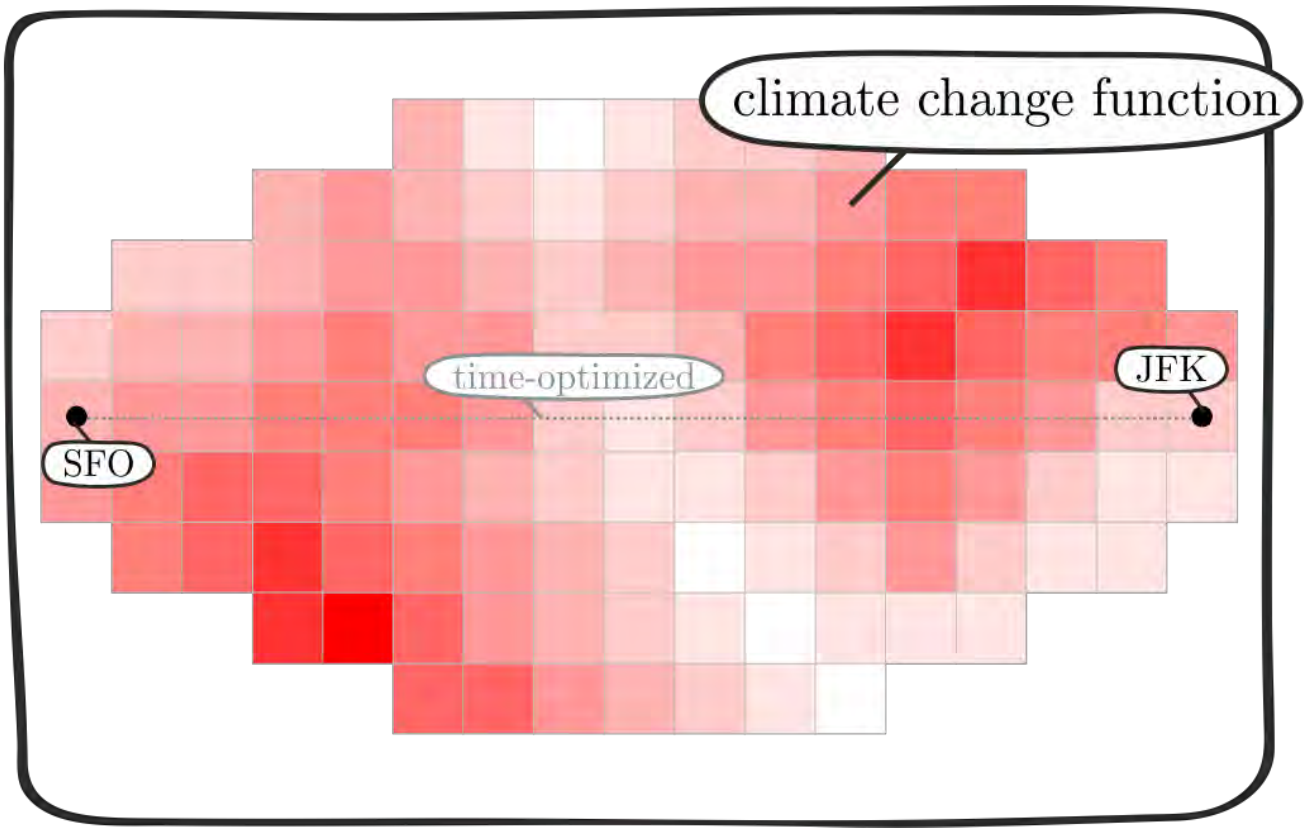
Concept of **Climate Charged Airspaces (CCA)**



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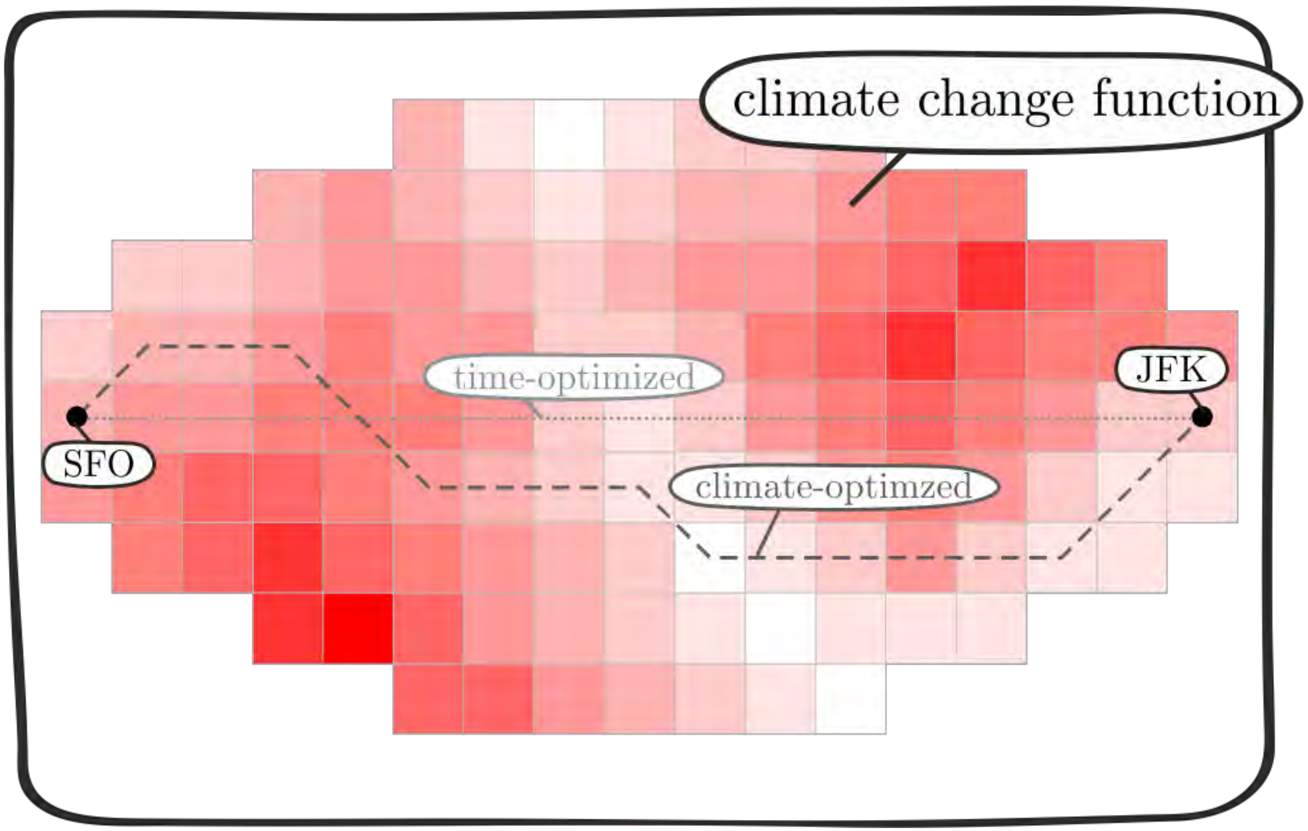

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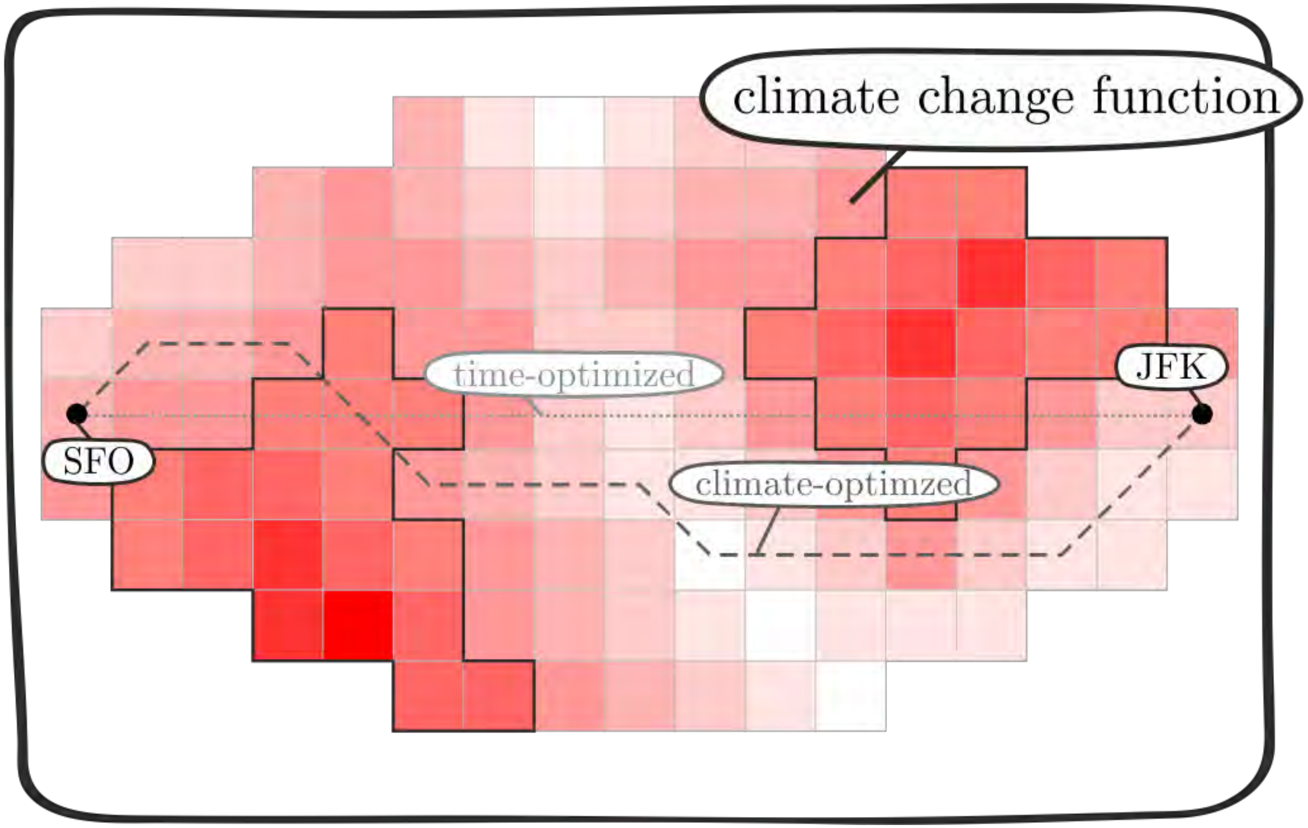
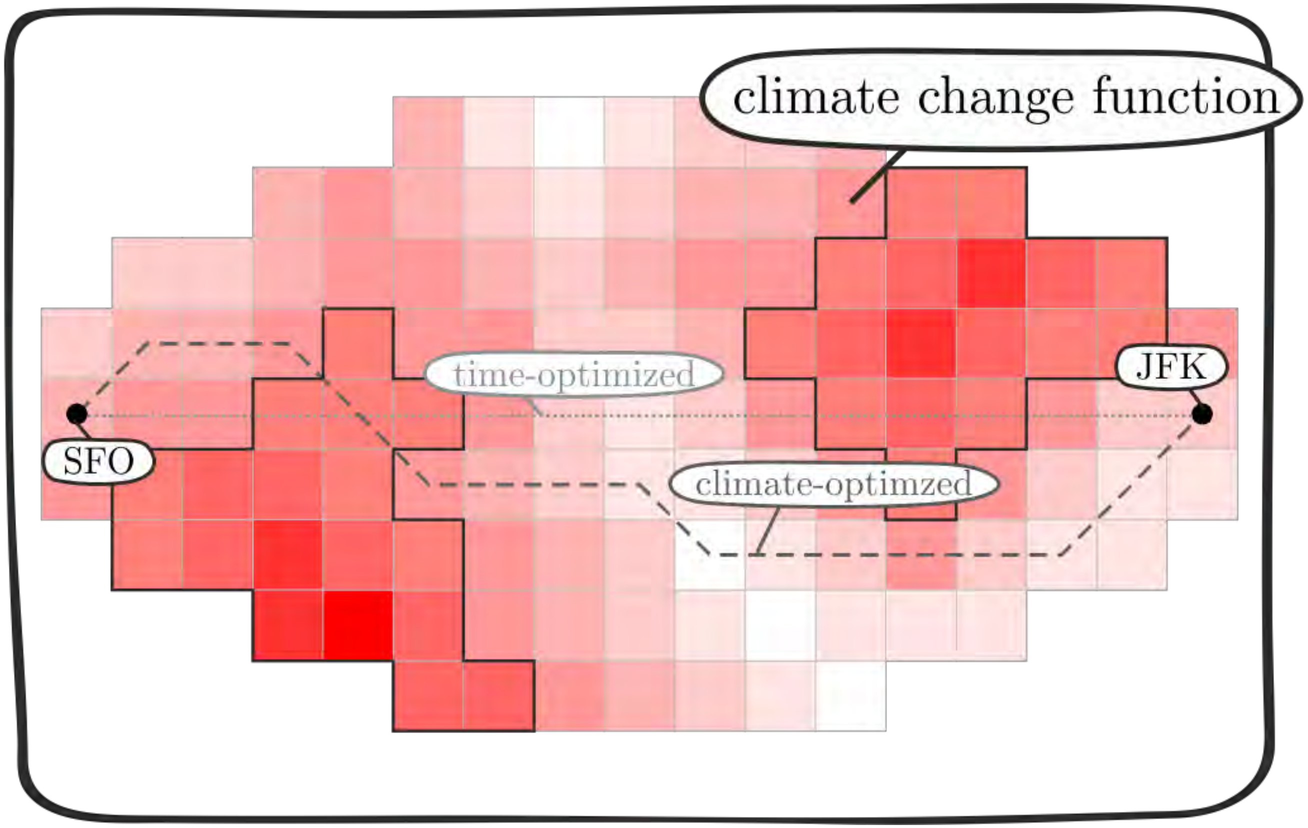


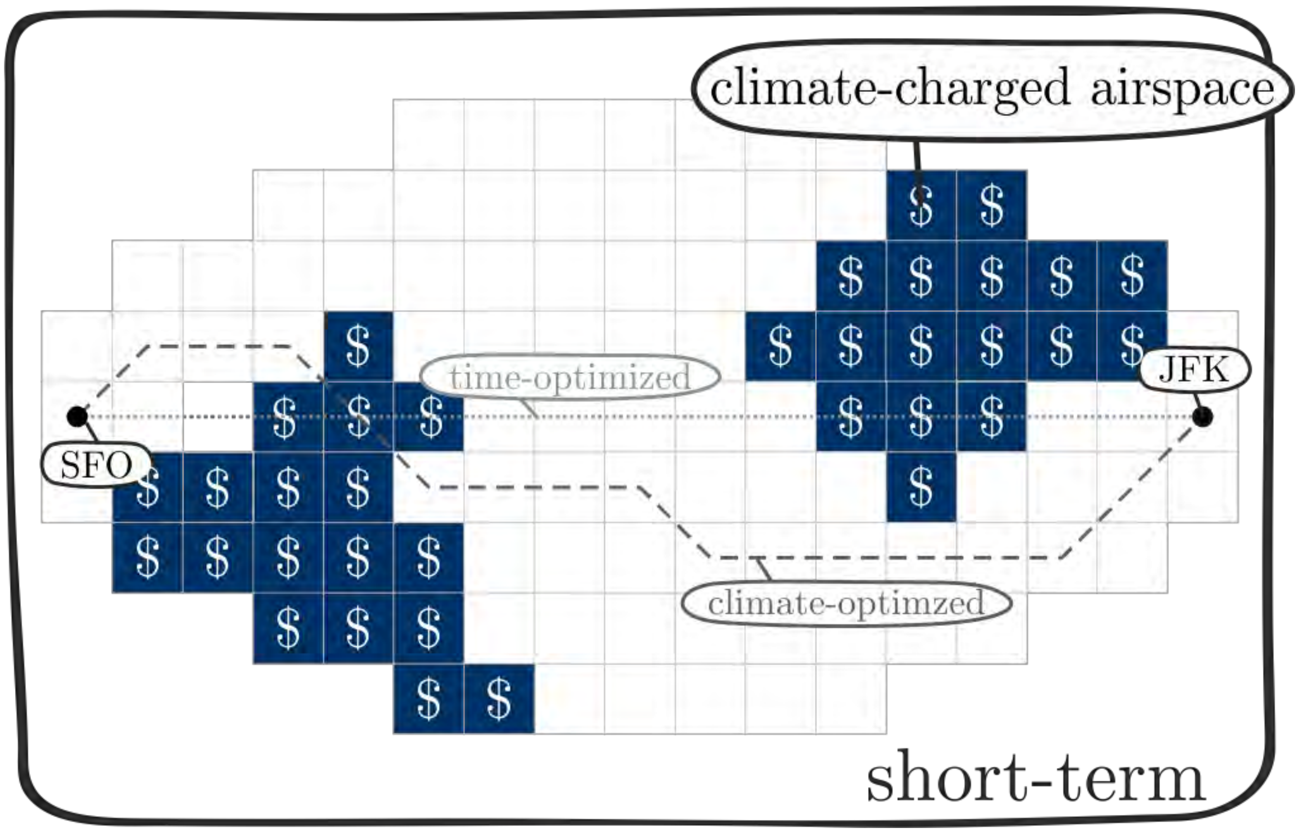
CONCEPT **FOCUSSES** ON **MOST SENSITIVE** AIRSPACES
WITH RESPECT TO CLIMATE CHANGE

Concept of **Climate Charged Airspaces (CCA)**



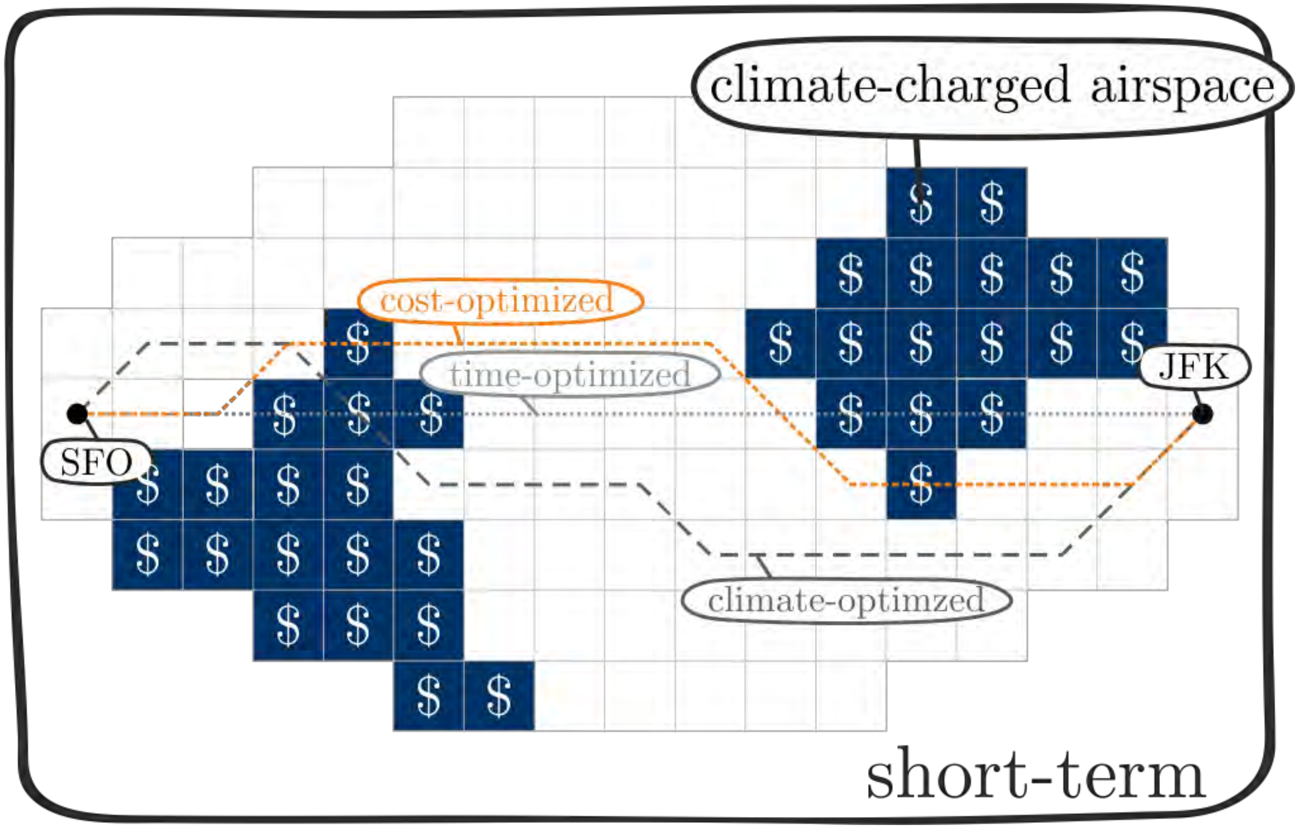
CONCEPT FOCUSES ON **LOCATION** AND **TIME DEPENDENY**
OF **NON-CO2 EFFECTS** INSTEAD OF EMISSION REDUCTION ONLY

Concept of **Climate Charged Airspaces (CCA)**



INTRODUCITON OF **CLIMATE CHARGES** FOR OPERATORS THAT FLY IN HIGHLY CLIMATE SENSITIVE AREAS

Concept of **Climate Charged Airspaces (CCA)**



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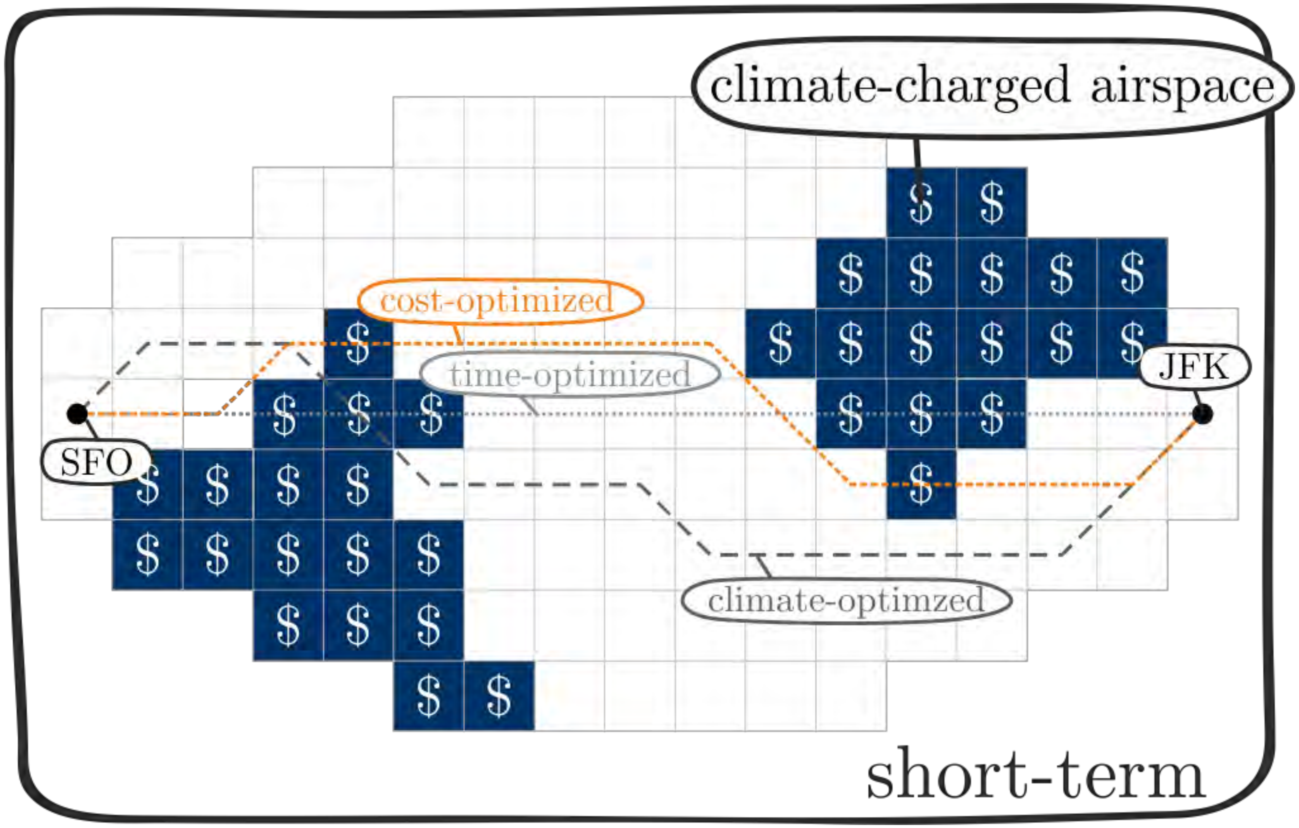
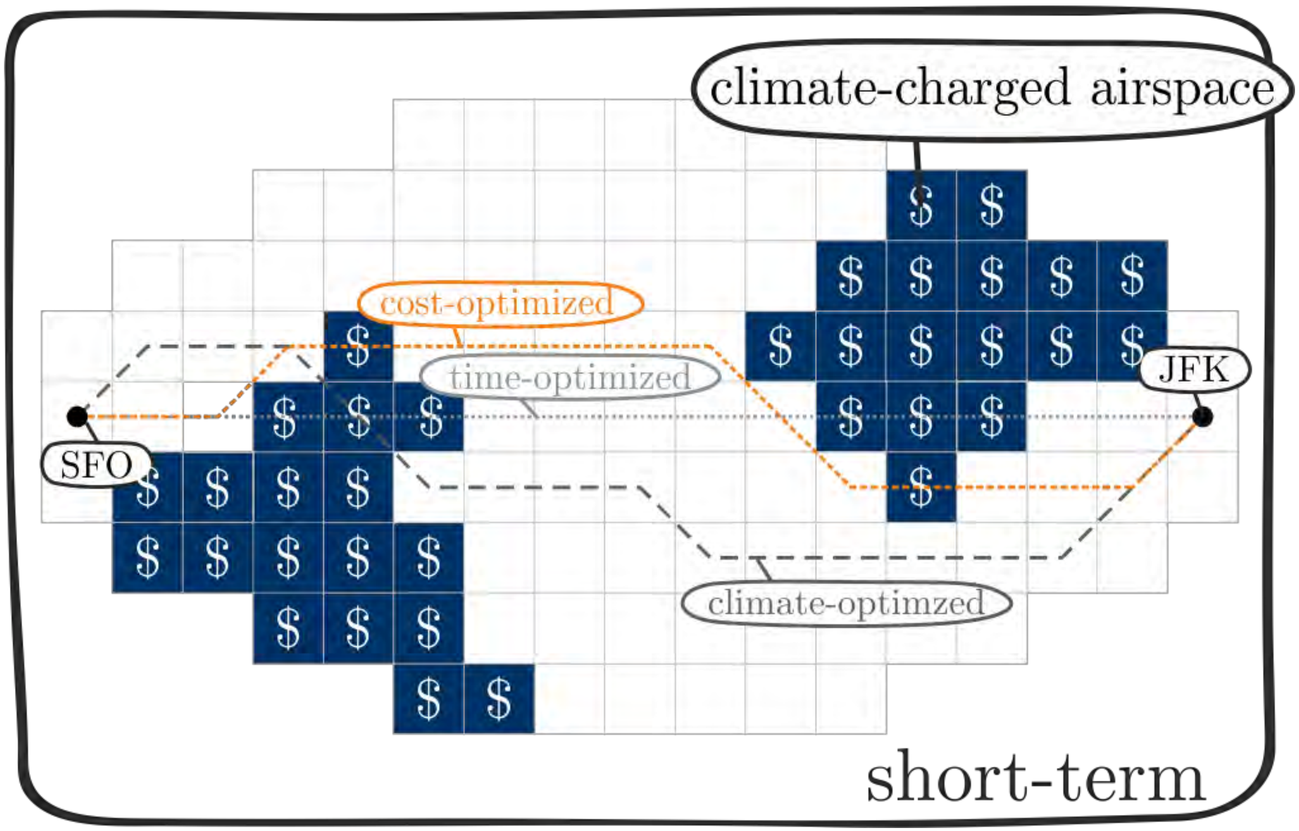


THE CONCEPT GENERATES A **FINANCIAL INCENTIVE**
TO **REDUCE EMISSIONS** WITHIN THESE AREAS

Concept of **Climate Charged Airspaces (CCA)**



CLIMATE CHARGES ARE LEVIED FOR OPERATORS
PER KILOMETER FLOWN WITHIN THESE AREAS

Concept of **Climate Charged Airspaces (CCA)**

Introduction of climate charges (C_{cj}) for flights through CCA_j:

Charge as function of maximum take-off weight

Incentive factor for green technologies

$$C_{cj} = U_{cj} \cdot \left(\frac{\mathrm{MTOW}}{k_1}\right)^{k_2} \cdot d_j \cdot I_{AC}$$

Unit cost per km flown $[\$/km]$

Distance flown in CCA_j $[km]$

in analogy to en-route charges (C_{ei}):

$$C_{ei} = U_{ei} \cdot \left(\frac{\mathrm{MTOW}}{k_1}\right)^{k_2} \cdot d_i$$

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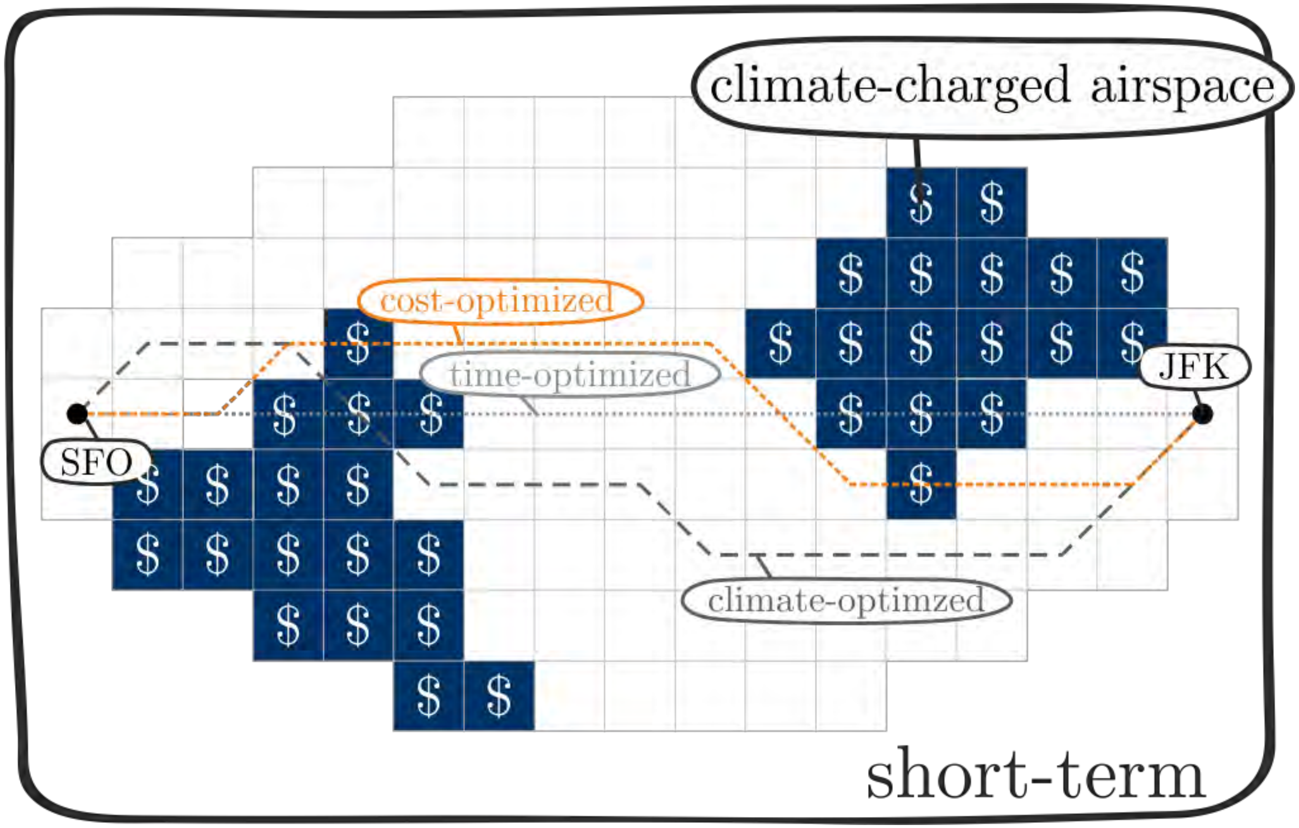
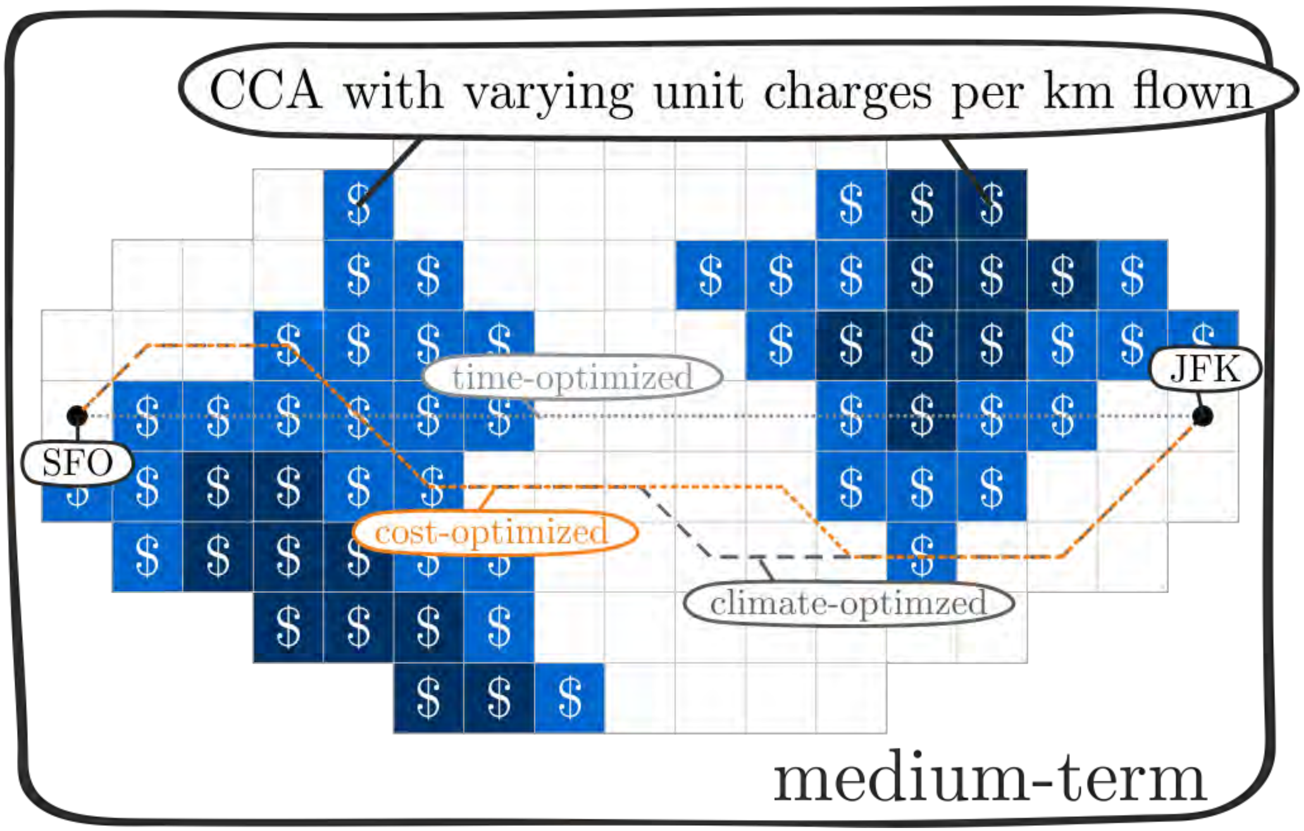
Concept of **Climate Charged Airspaces (CCA)**



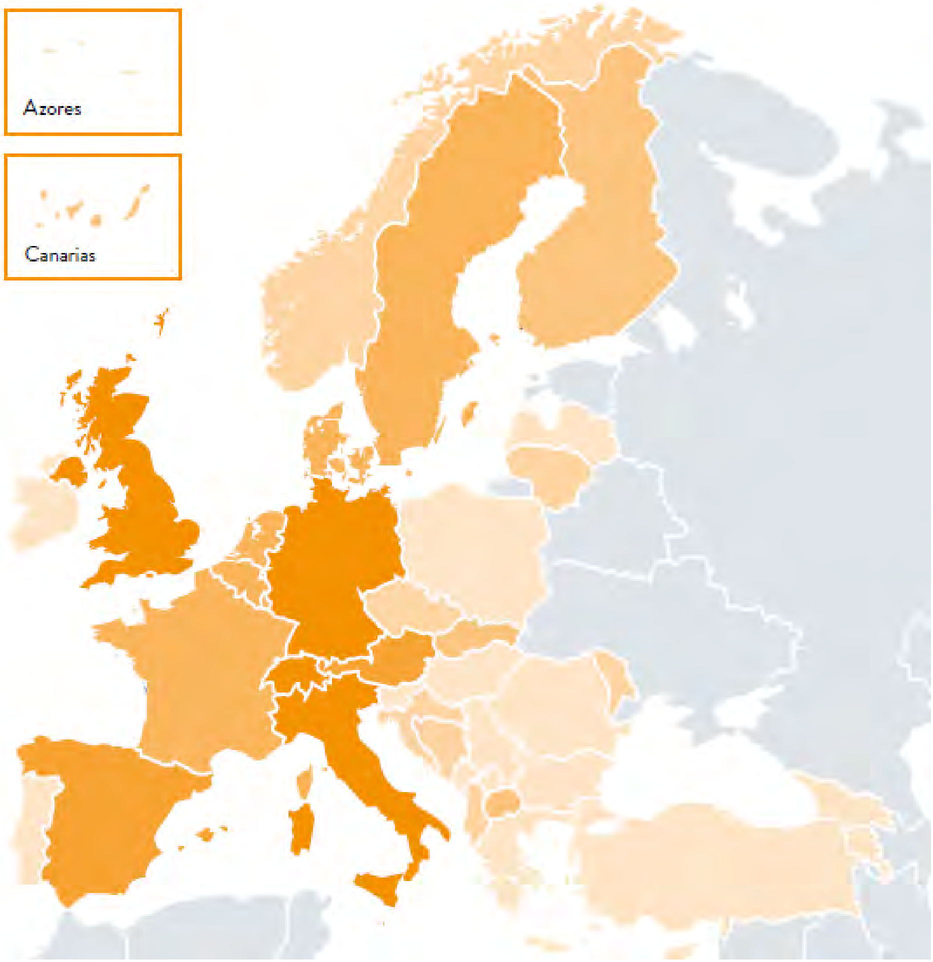
CONCEPT **FOCUSSES FIRST** ON **MOST SENSITIVE** AIRSPACES
WITH RESPECT TO CLIMATE CHANGE

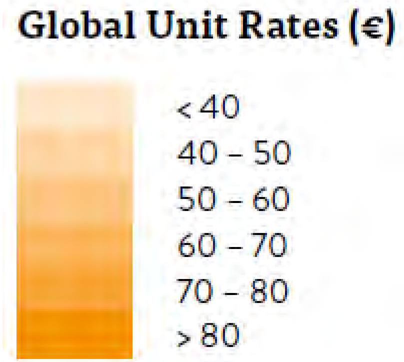
Concept of **Climate Charged Airspaces (CCA)**



CONCEPT CAN BE ADAPTED TO CURRENT
LEVEL OF SCIENTIFIC UNDERSTANDING (LOSU) ANY TIME

How *navigation* **charges** can **influence traffic patterns**





$$C_{ei} = U_{ei} \cdot \left(\frac{\mathrm{MTOW}}{k_1}\right)^{k_2} \cdot d_i$$

"If an airline chooses to fly a longer route around an expensive airspace, it's relatively cheap these days, in terms of additional fuel burn, to do this."

Flemming Nyrup,
Performance Manager at MUAC

Global Unit Rates applicable from 01/01/2016 according to Eurocontrol (2016)

First Results

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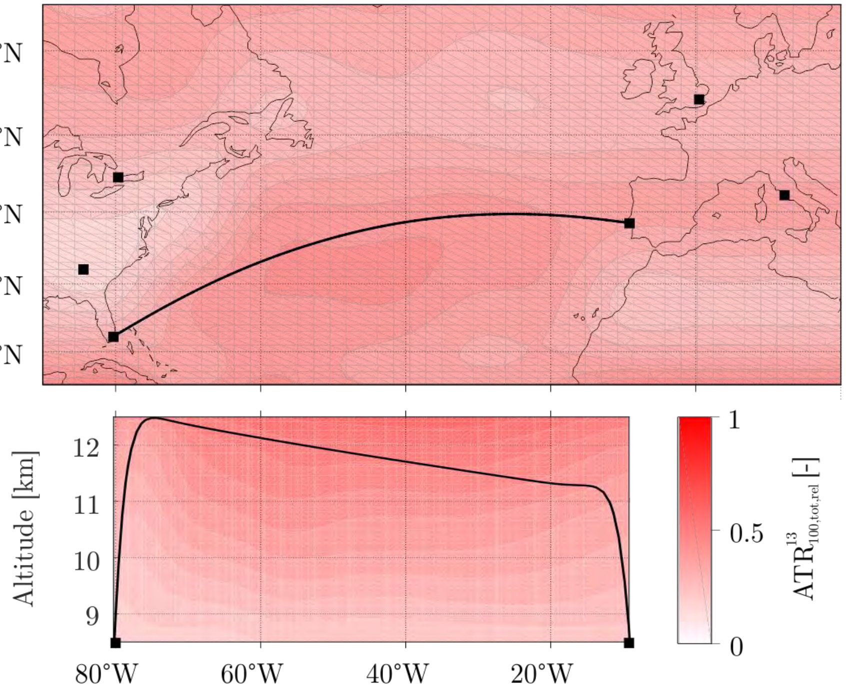
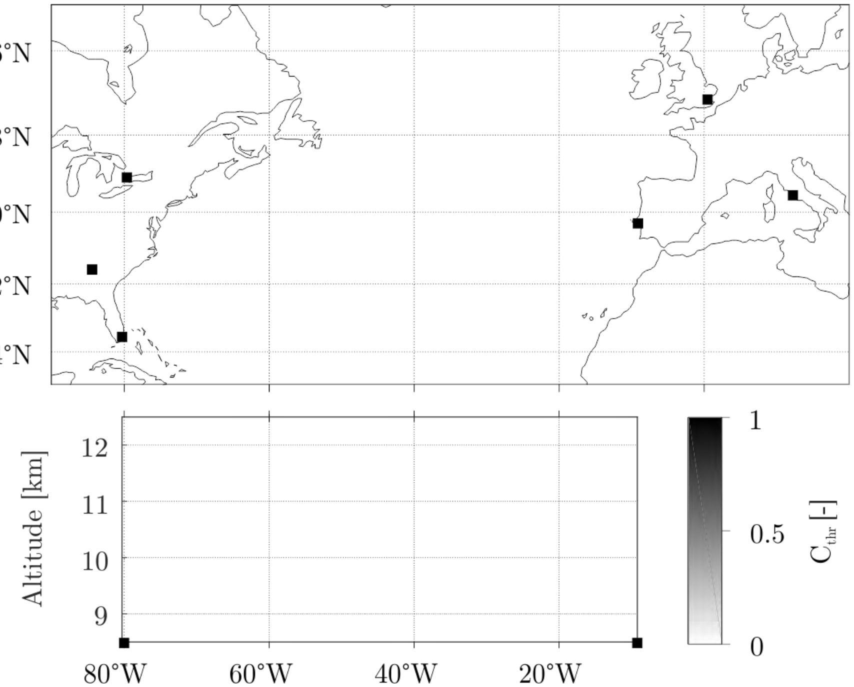
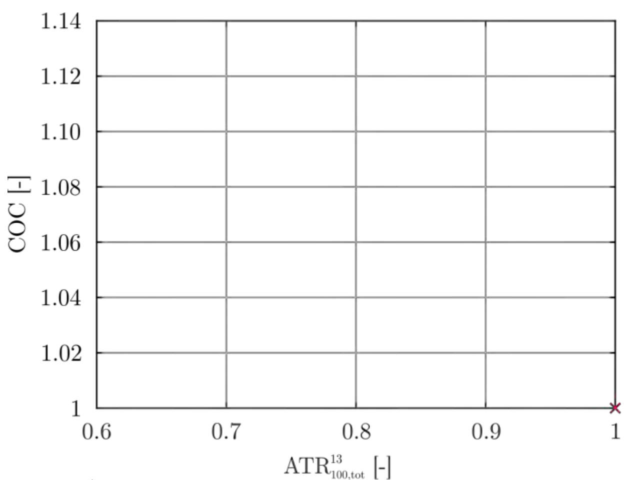
> Climate Optimized Trajectories > Benchmark

> Cost Optimized Trajectories for CCA Concept







Climate Weighting	**0.0**	**%**
Climate charge	0.000	$/km
COC	1.000	
ATR	1.000	
fuel	1.000	
flight time	1.000	
mean altitude	11,645	m

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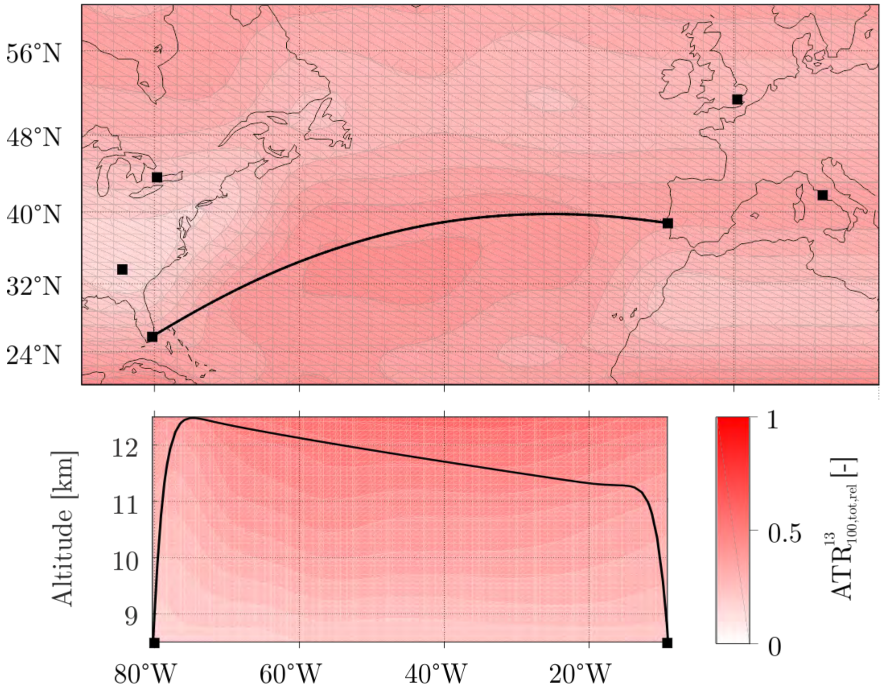
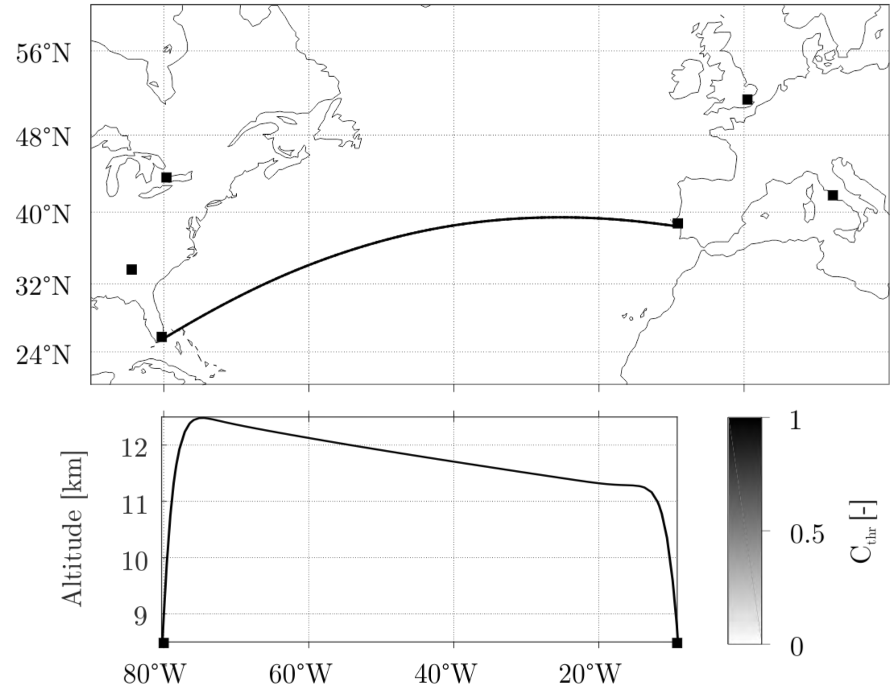
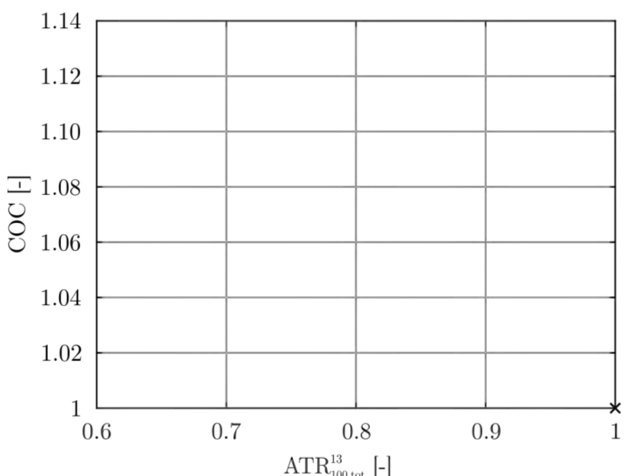
> Climate Optimized Trajectories > Benchmark

> Cost Optimized Trajectories for CCA Concept







variables

Charged Volume Fraction	**0.0**	**%**
Climate charge	∞	$/km
COC	1.000	
ATR	1.000	
fuel	1.000	
flight time	1.000	
mean altitude	11,645	m

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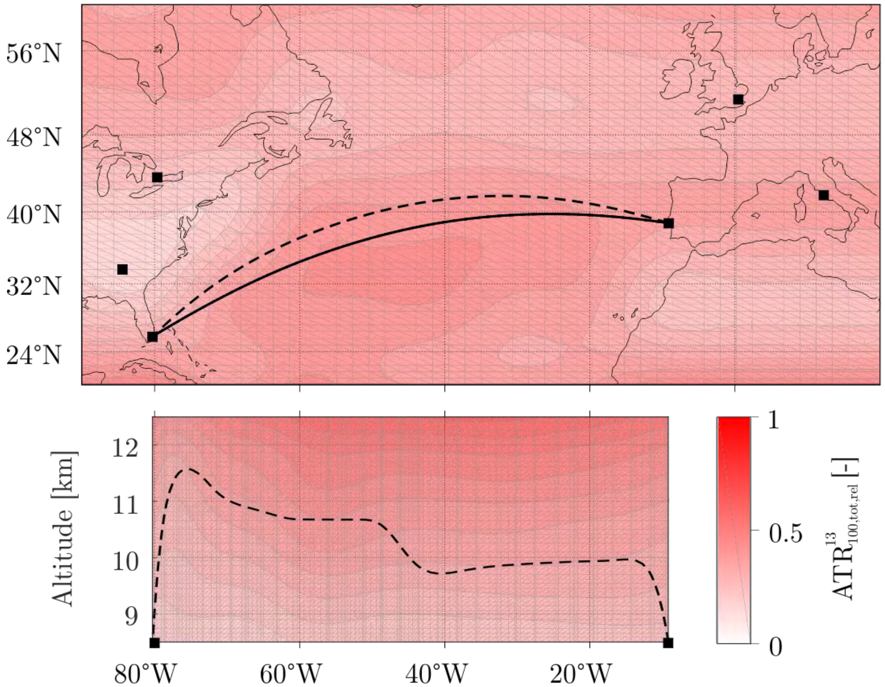
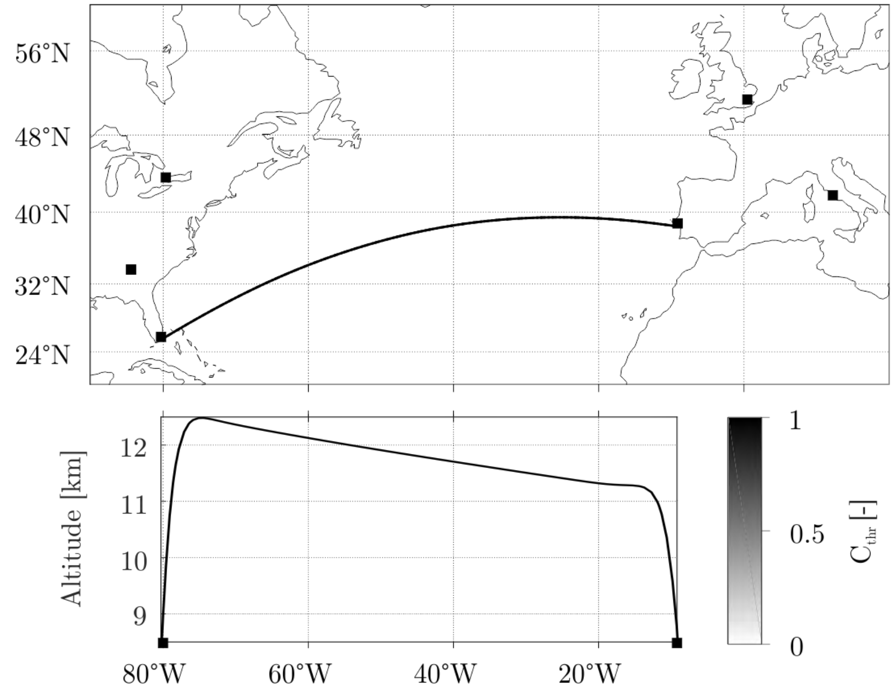
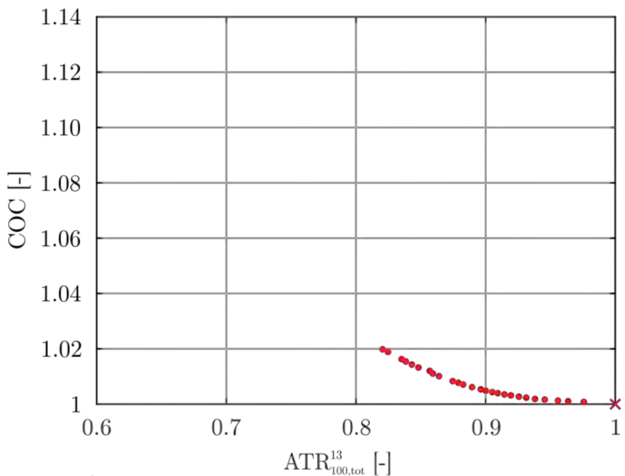
> Climate Optimized Trajectories > Benchmark



> Cost Optimized Trajectories for CCA Concept





Climate Weighting	**30.0**	**%**
Climate charge	0.000	$/km
COC	1.020	
ATR	0.821	
fuel	1.051	
flight time	0.994	
mean altitude	10,374	m

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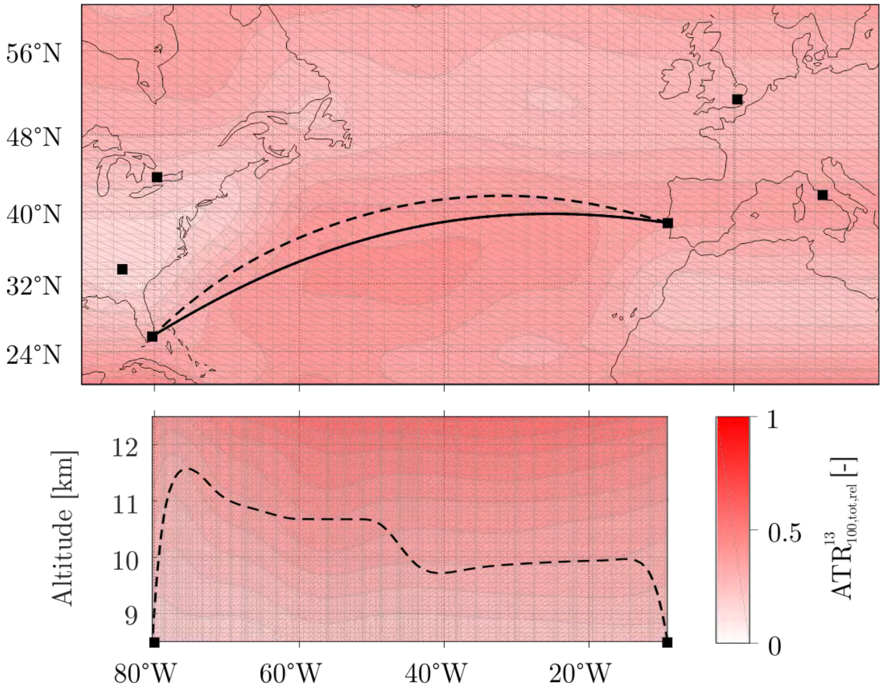
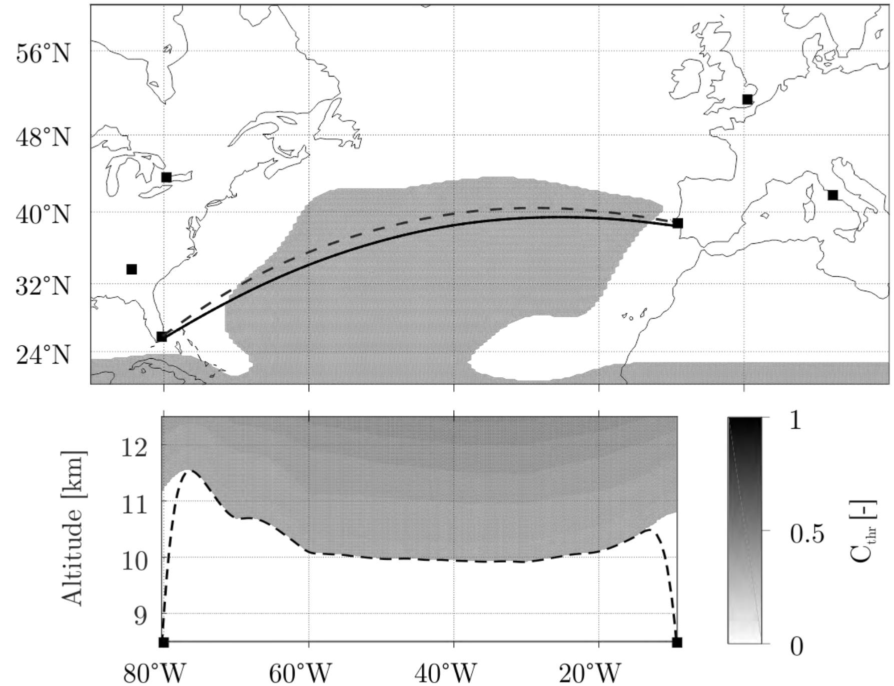
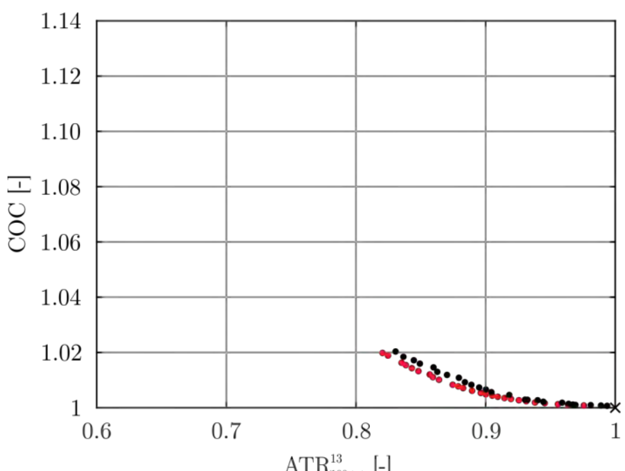
> Climate Optimized Trajectories > Benchmark

> Cost Optimized Trajectories for CCA Concept







Charged Volume Fraction	**41.5**	**%**
Climate charge	∞	\$/km
COC	1.020	
ATR	0.834	
fuel	1.055	
flight time	0.990	
mean altitude	11,012	m

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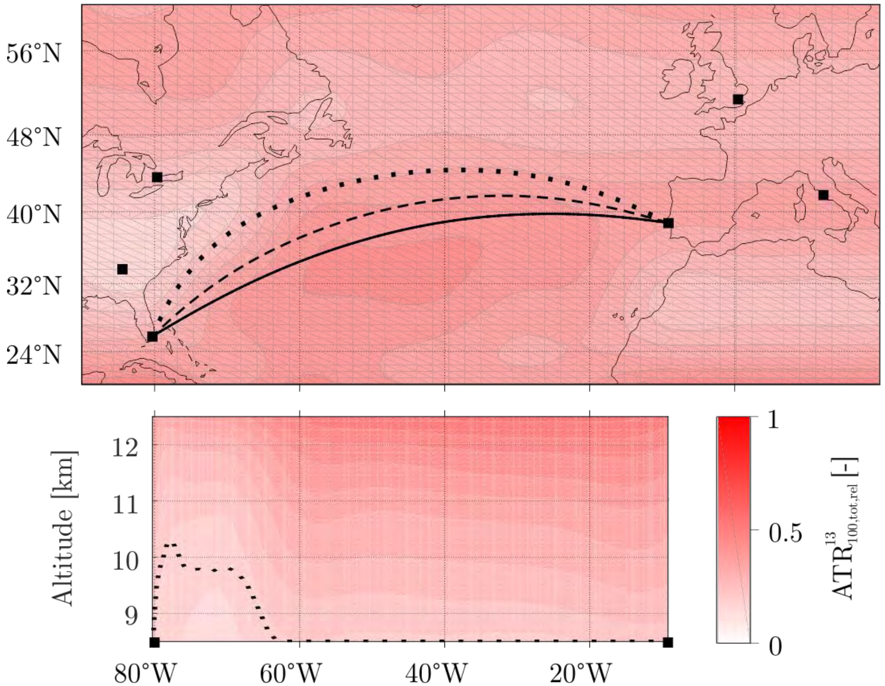
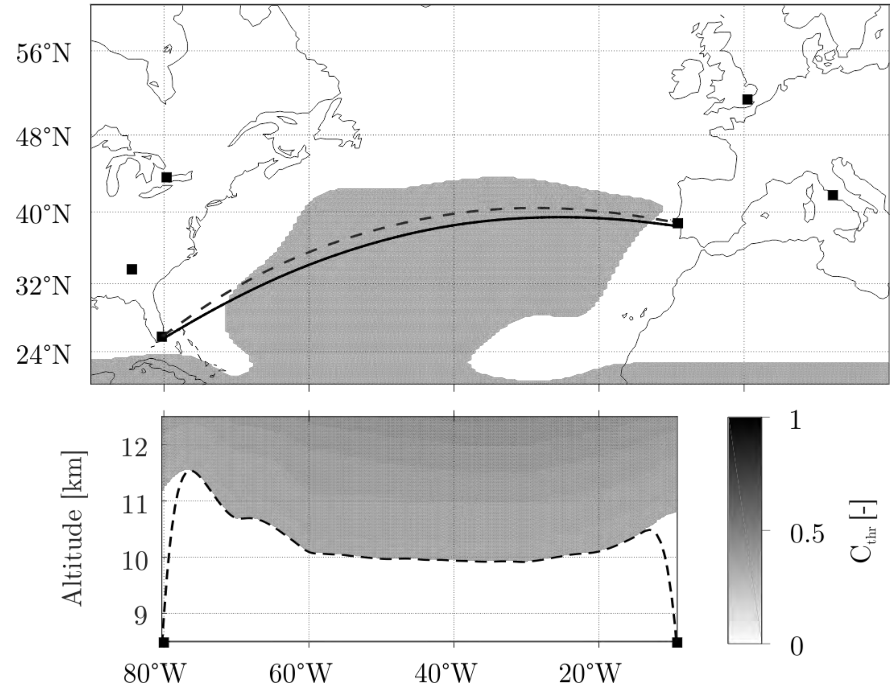
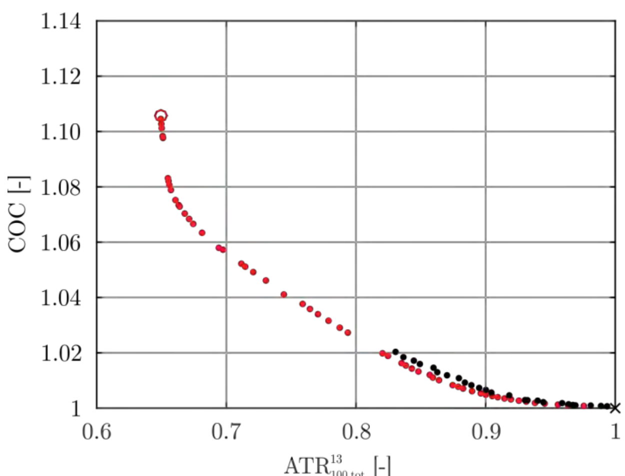
> Climate Optimized Trajectories > Benchmark

> Cost Optimized Trajectories for CCA Concept







Climate Weighting	**100.0**	**%**
Climate charge	0.000	$/km
COC	1.106	
ATR	0.652	
fuel	1.228	
flight time	1.010	
mean altitude	8,910	m

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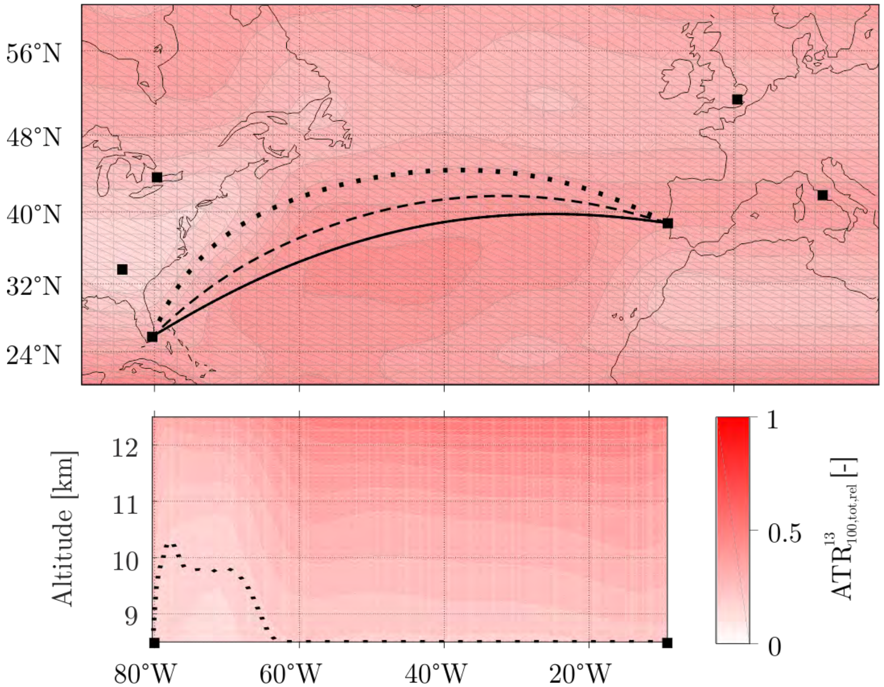

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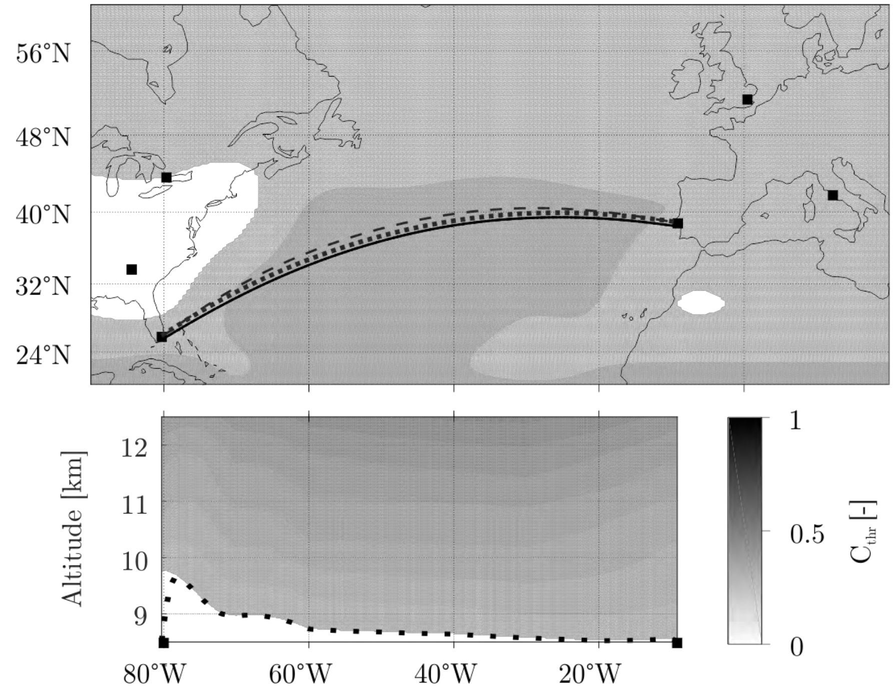

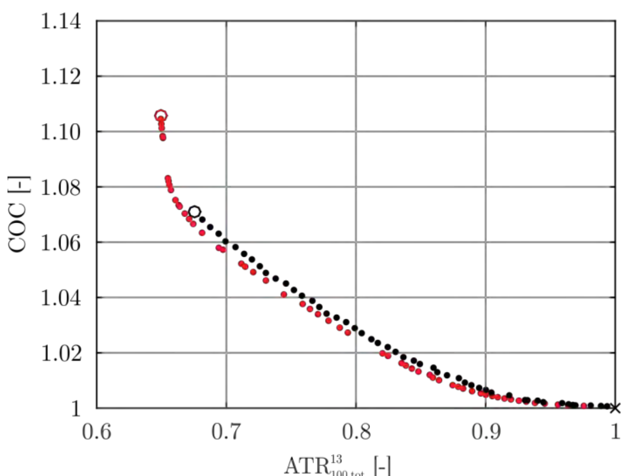

Charged Volume Fraction	**88.8**	**%**
Climate charge	∞	$/km
COC	1.071	
ATR	0.678	
fuel	1.191	
flight time	0,969	
mean altitude	8,932	m

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Conclusion & Outlook

Conclusion

- **Climate Charged Airspaces (CCA)** are a **policy instrument** to **operationalize** the eco-efficiency of **climate-optimized trajectories (COT)**
- CCA are introduced to generate a **financial incentive** to **minimize** the **total climate impact** of aviation
- First results of the CCA concept with infinite climate unit costs show large **climate impact reduction potentials** in the **same order of magnitude** as COT
- **Focusing** on highly climate sensitive areas seems to be **very effective**
- **High mitigation efficiencies** are reachable for small cost increments
- Optimizing for **maximum climate impact reduction** leads to **disproportional rise** in **monetary costs**

Outlook

Improvement of Environmental Economics

Add variations of climate unit costs

▼

Replacement of hard restriction

▼

Improvement of flight simulations

Add constraints to optimization

▼

More realistic results

▼

Trade-off studies

▼

Recommendations for Policy Planning

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Annex

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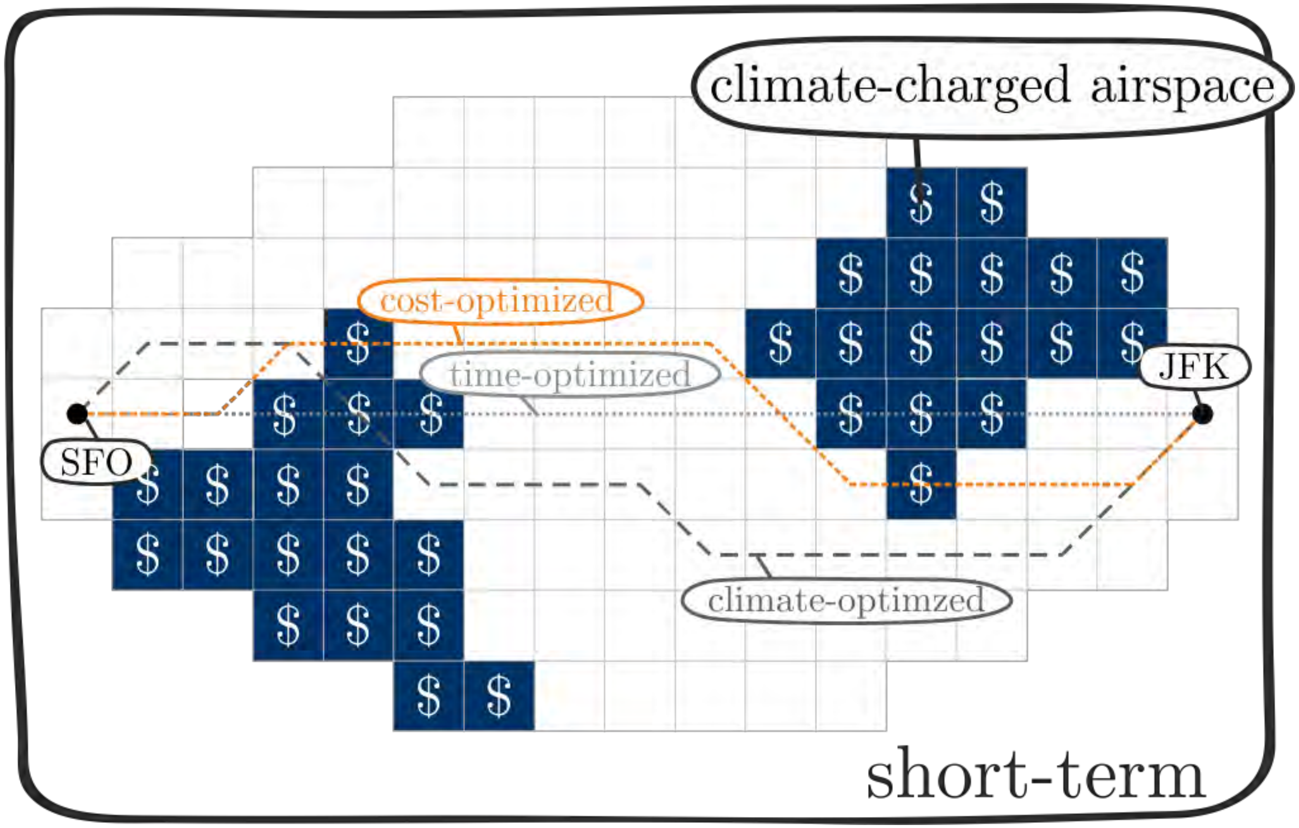
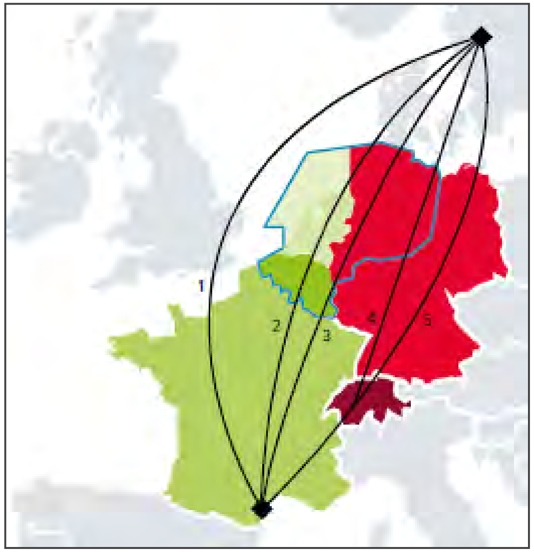
Concept of **Climate Charged Airspaces (CCA)**



$$\mathrm{CCA}_j(\boldsymbol{x}) = \begin{cases} U_{cj} & \text{if } \mathrm{CCF}_{\mathrm{tot}}(\boldsymbol{x}) \geq c_{\mathrm{thr}} \\ 0 & \text{if } \mathrm{CCF}_{\mathrm{tot}}(\boldsymbol{x}) < c_{\mathrm{thr}} \end{cases}$$

How *navigation* **charges** can **influence traffic patterns**



Route charges	2012	2013	2014	2015
Belgium	€ 74	€ 68	€ 72	€ 71
Netherlands	€ 66	€ 66	€ 67	€ 67
Germany	€ 74	€ 77	€ 77	€ 90
France	€ 65	€ 65	€ 66	€ 70
Switzerland	€ 99	€ 97	€ 100	€ 111
UK	€ 85	€ 85	€ 87	€ 100
Jet fuel (gallons) average price	€ 2.38	€ 2.20	€ 2.03	€ 1.47

% distribution of traffic on available routes		2012	2013	2014	2015[1]	Total 2012-2015
1	UK-France	4%	4%	4%	3%	-1%
2	Germany-Netherlands-Belgium-France	61%	64%	65%	70%	+9%
3	Germany-Belgium-France	14%	14%	13%	11%	-3%
4	Germany (MUAC)-Switzerland-France	17%	14%	12%	12%	-5%
5	Germany-Switzerland-France	3%	4%	3%	2%	-1%
Other	Germany-Hannover-Belgium-France	1%	1%	2%	2%	+1%

Eurocontrol (2016)