Climate Optimal Trajectory Planning at Network-Scale

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Overview

- Introduction
  - Motivation & Problem statement
- Methodology and results
  - **Micro scale**: Trajectory optimization
  - **Network scale**: Assessment & Resolution
- Conclusion & future plans

Motivation

Challenges

- Aviation is responsible for about **3-5%** of total **global warming**
- Aviation-induced climate impact consists of
  - carbon dioxide (CO_2)
  - non-CO_2 species (e.g., No_x emission, formation of persistent contrails, water vapour emission, ...)
- An **increase** in global air traffic is foreseen in the coming decades (**4.4% yearly**)

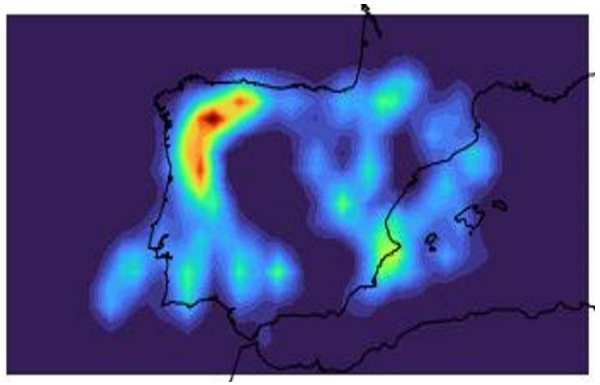
Critical **increase** in climate impact of **aviation** is expected

Solution

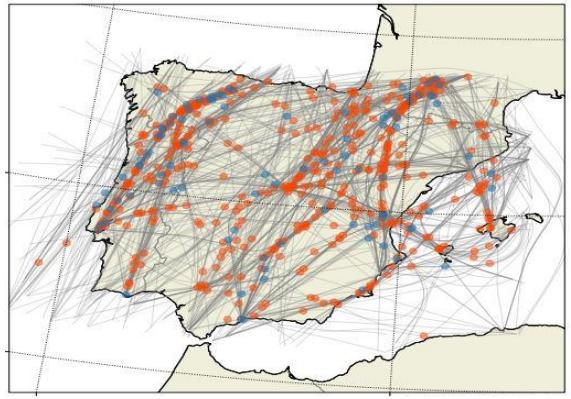
- The non-CO_2 climate impact mainly depends on geographic location, altitude and time of the emission.

Their effects can be **reduced** by efficient **trajectory planning**.

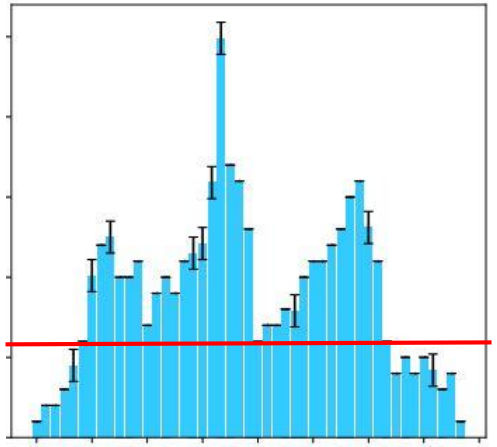
Motivation



Is adopting **independently** climate optimized trajectories operationally **feasible**?



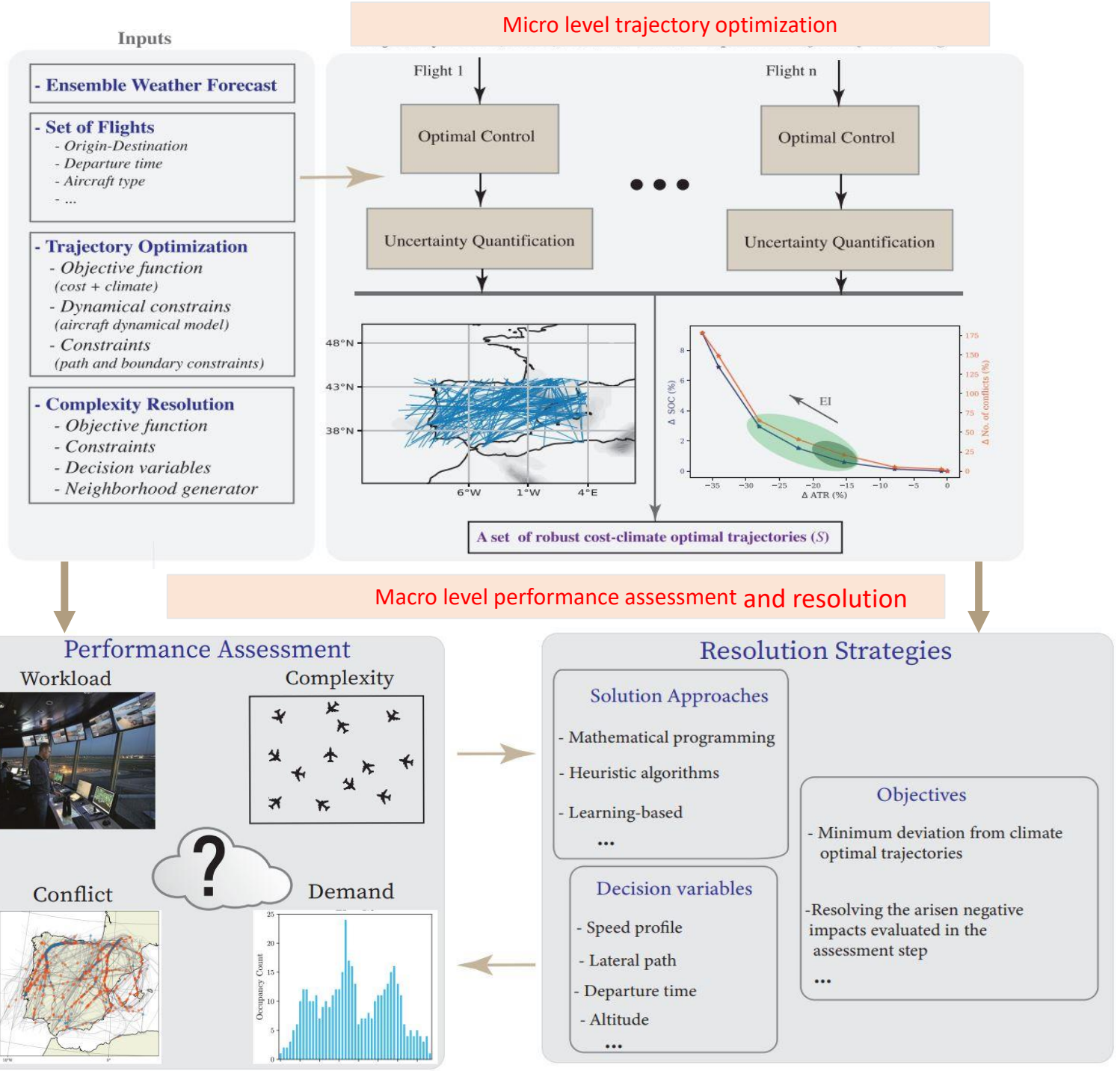
- The ATM is a **multi agent** system and cannot be characterized by individual elements.
- Optimizing each aircraft trajectory to avoid climate hotspots may result in more congested areas around climate hotspot.
- Raising challenges, particularly **capacity-demand imbalance**, and increasing **workload**, **complexity**, etc.



True mitigation potential of climate impact needs to be analyzed at the **network level**

Problem statement

- Performing trajectory optimization for individual flights.
- Assessment of the fostered effects of considering climate impact on the network performance.
- Proposing resolution strategies to compensate for the arisen negative impacts due to the consideration of climate impact.



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Trajectory Optimization

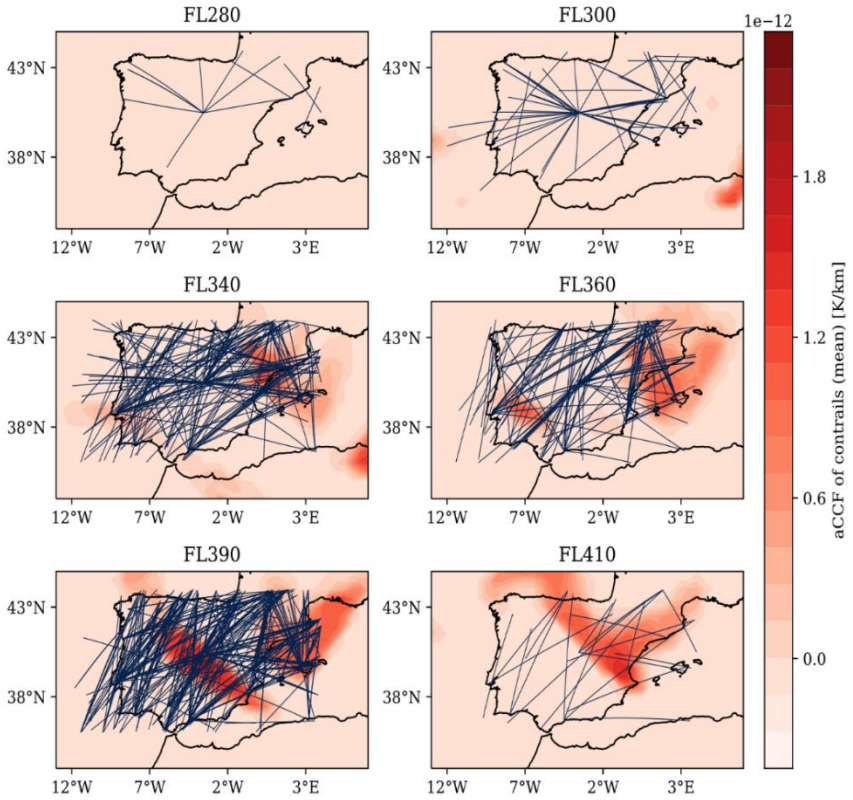
Considered network scale scenario:

- 1000 flights on May 6-th 2018 from 12:00 to 16:00 covering Spain and Portugal airspace
- The aircraft models are all considered to be A330-341
- Objective function :
  Operational Cost + ***EI*** * Climate impact
- Trajectory optimization
  - Direct optimal control
- Uncertainty quantification
  - **Ensemble trajectory prediction**

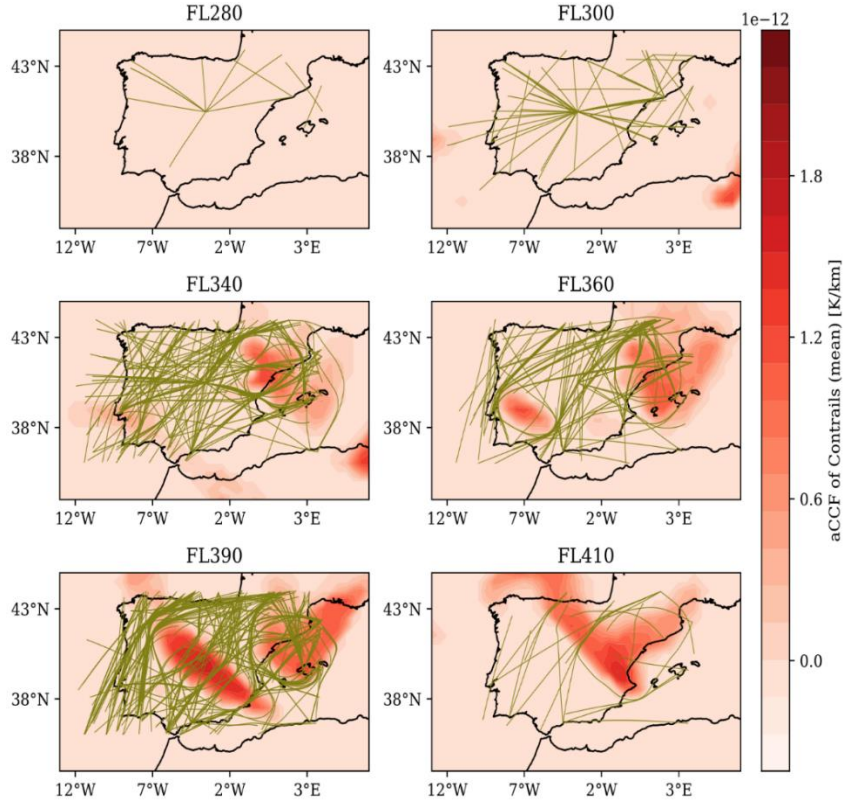
By **increasing EI**(weighting parameter penalizing climate impact) :

- The **climate hotspot** areas are mostly **avoided**.

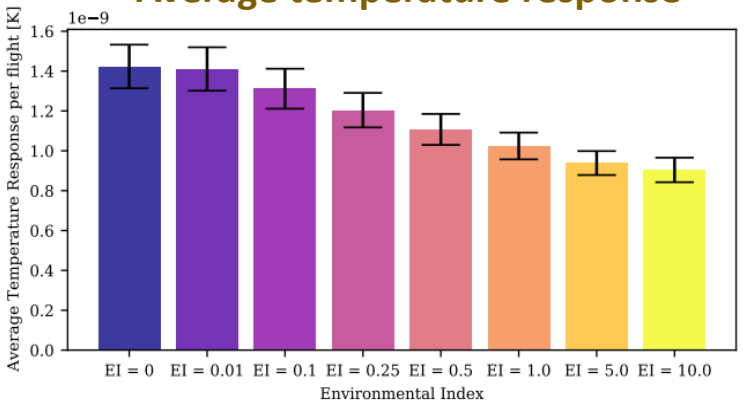
Cost optimal (EI = 0.0)



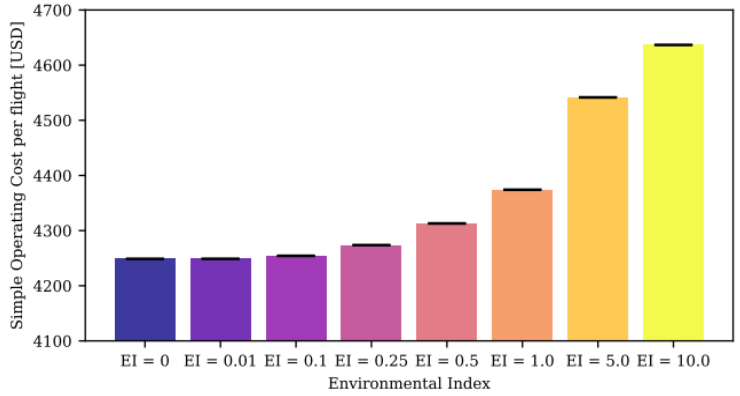
Climate optimal (EI = 10.0)



Average temperature response



Simple operating cost



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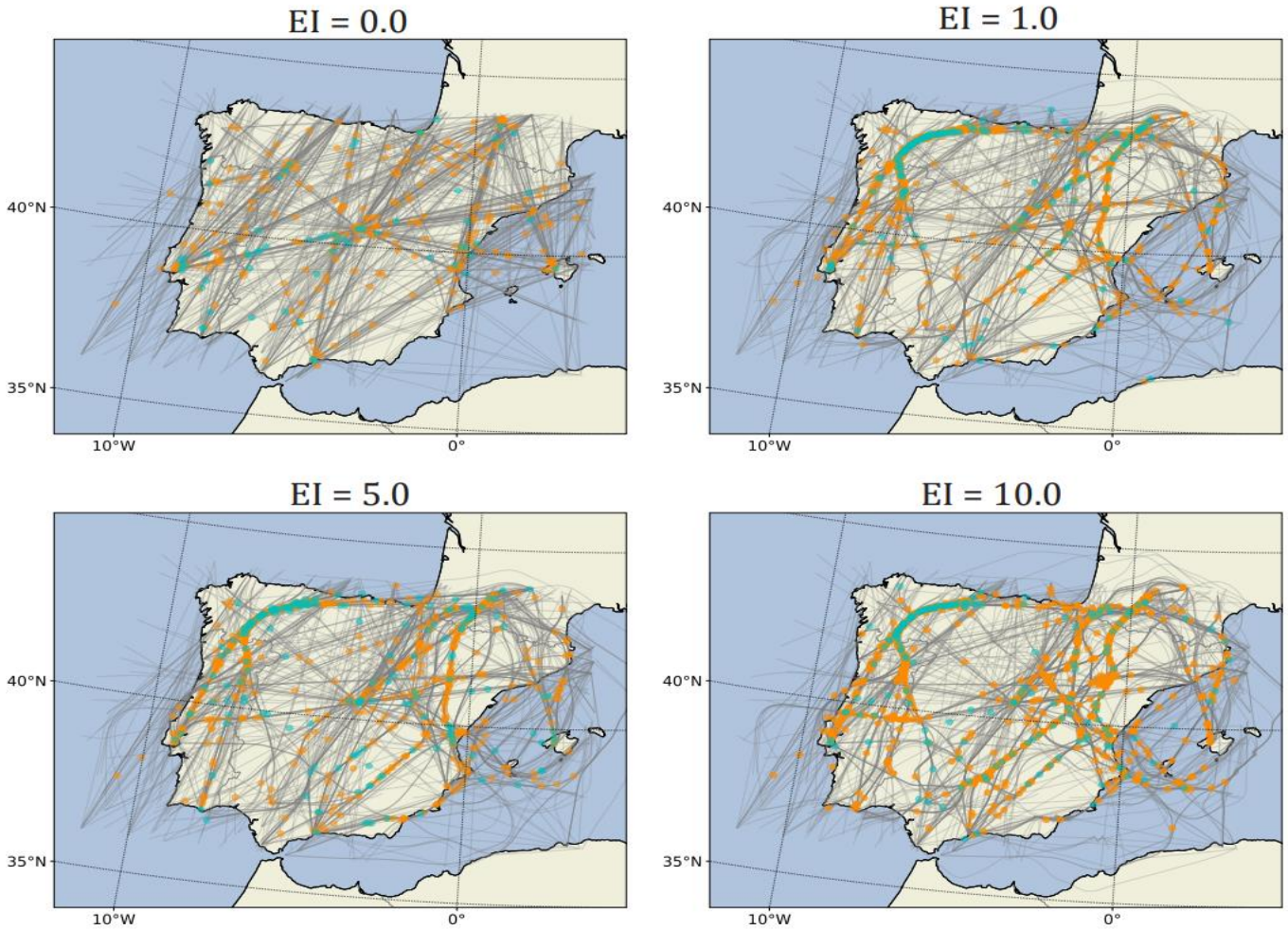
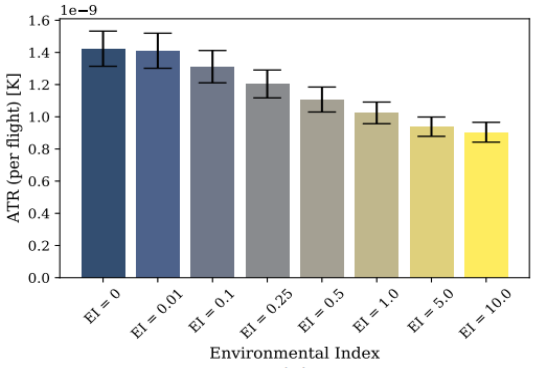
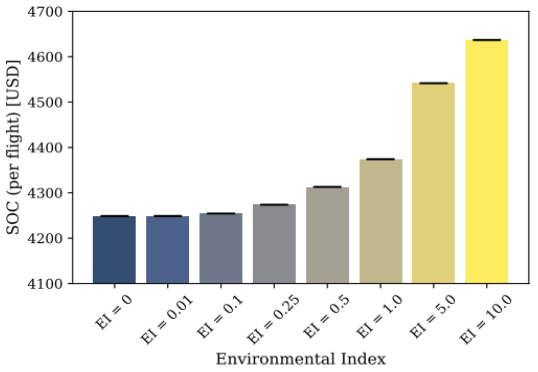
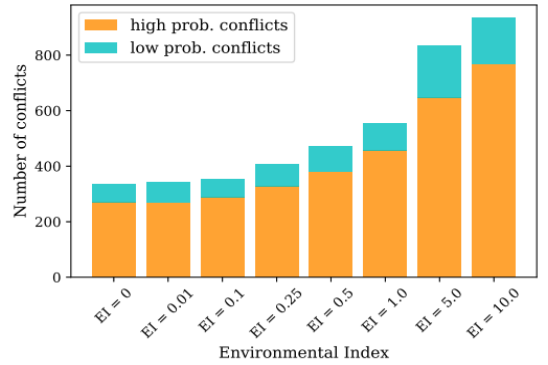
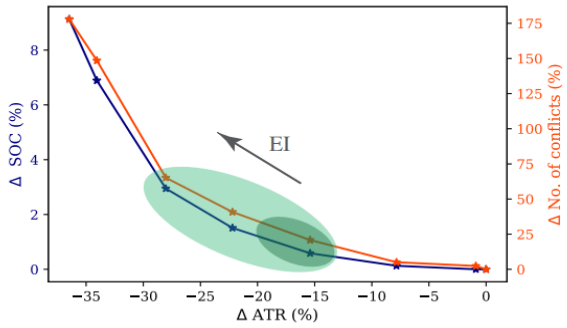
Probabilistic Conflict Assessment









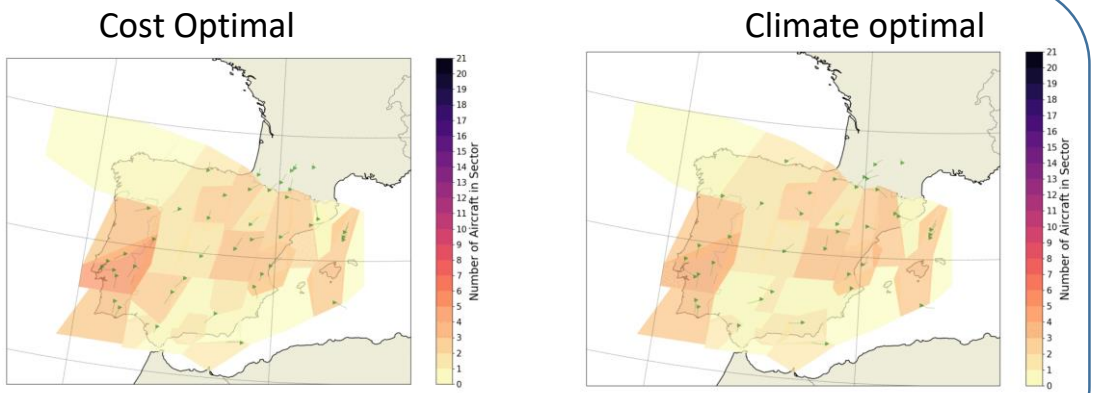


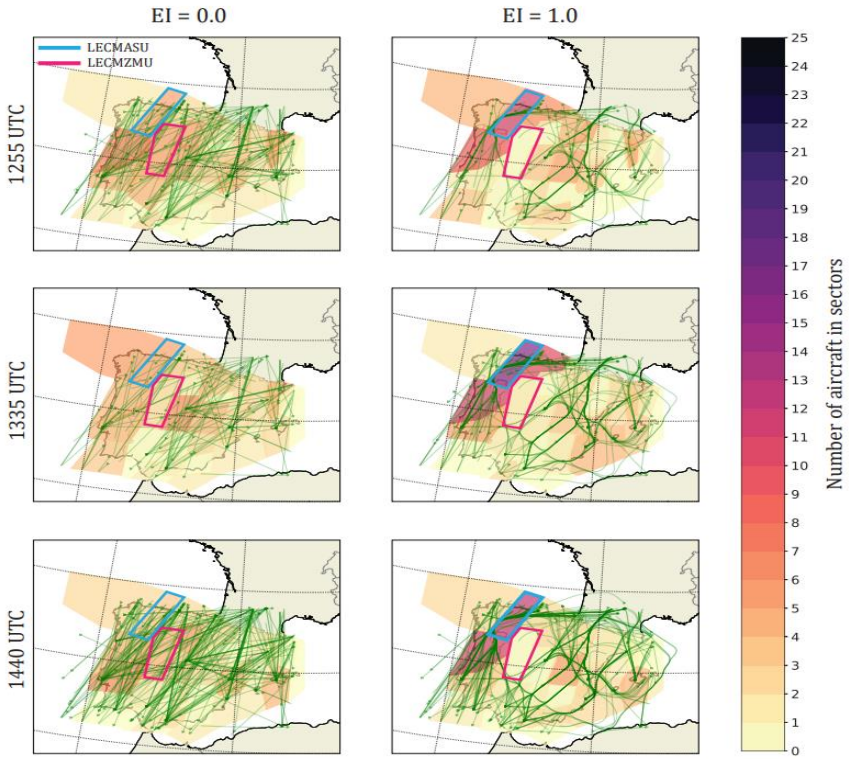
By **increasing EI** (weighting parameter penalizing climate impact) :

- The **climate impact** is **decreased** by 35%.
- The **operational cost** is **increased** by 8%.
- The **number of conflicts** is **increased** by 170%. ✖✖✖

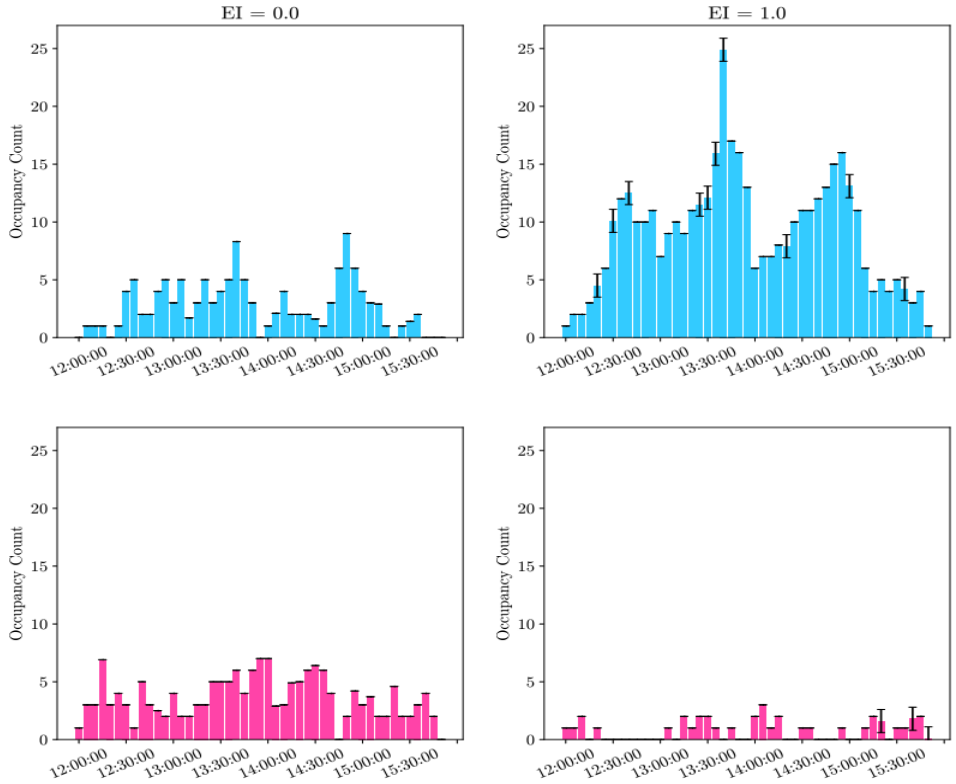
The errorbars show the ranges of uncertainty due to the ensemble forecast

Demand Assessment





By **increasing EI**, the demand for the **adjacent sector to climate hotspot** (e.g., blue polygon) **increases** considerably.



By **increasing EI**, sectors containing **climate hotspot** (e.g., Pink polygon), becomes almost **empty**.

EI: Weighting parameter penalizing climate impact

The errorbars show the ranges of uncertainty due to the ensemble forecast

Complexity Assessment

Com_Score= r_VDIF + r_HDIF + r_SDIF

r_VDIF: Relative Vertical Interactions

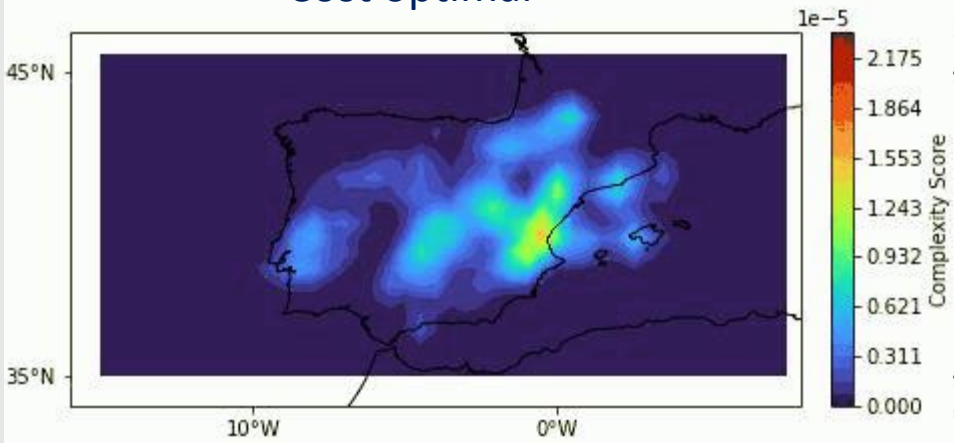
r_HDIF: Relative Horizontal Interactions

r_SDIF : Relative Speed Interactions

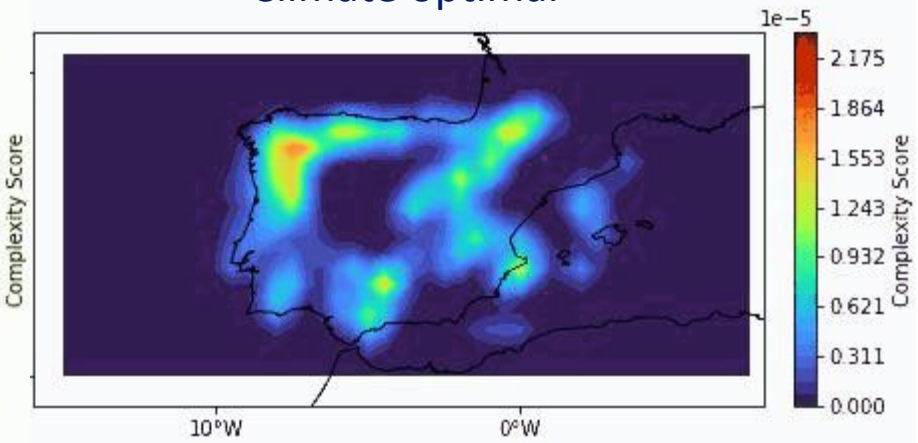
- There is a need for **strategic resolution** to mitigate the arisen negative impacts at the strategic level.

Complexity Score

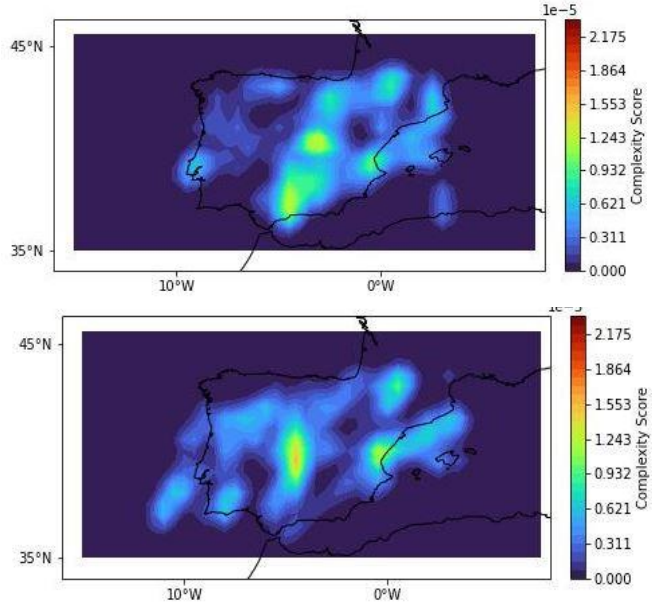
Cost optimal



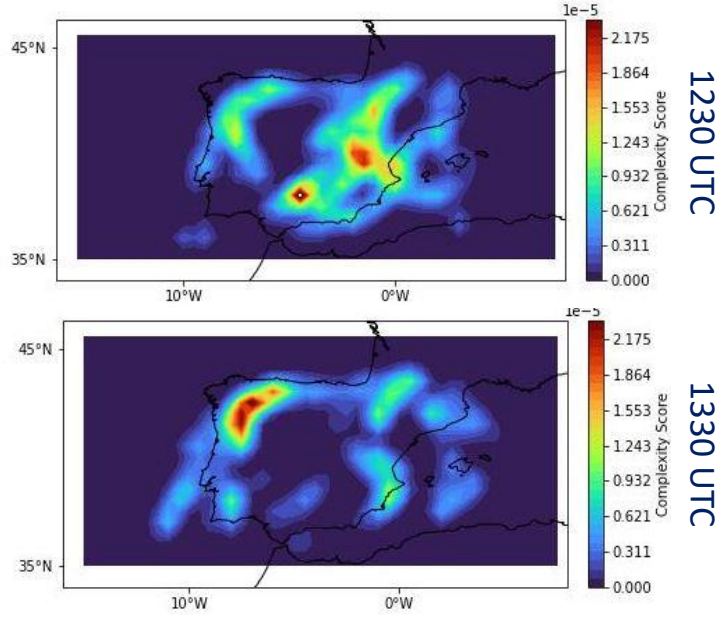
Climate optimal



EI = 0.0



EI = 1.0



1230 UTC

1330 UTC

Probabilistic Conflict Resolution

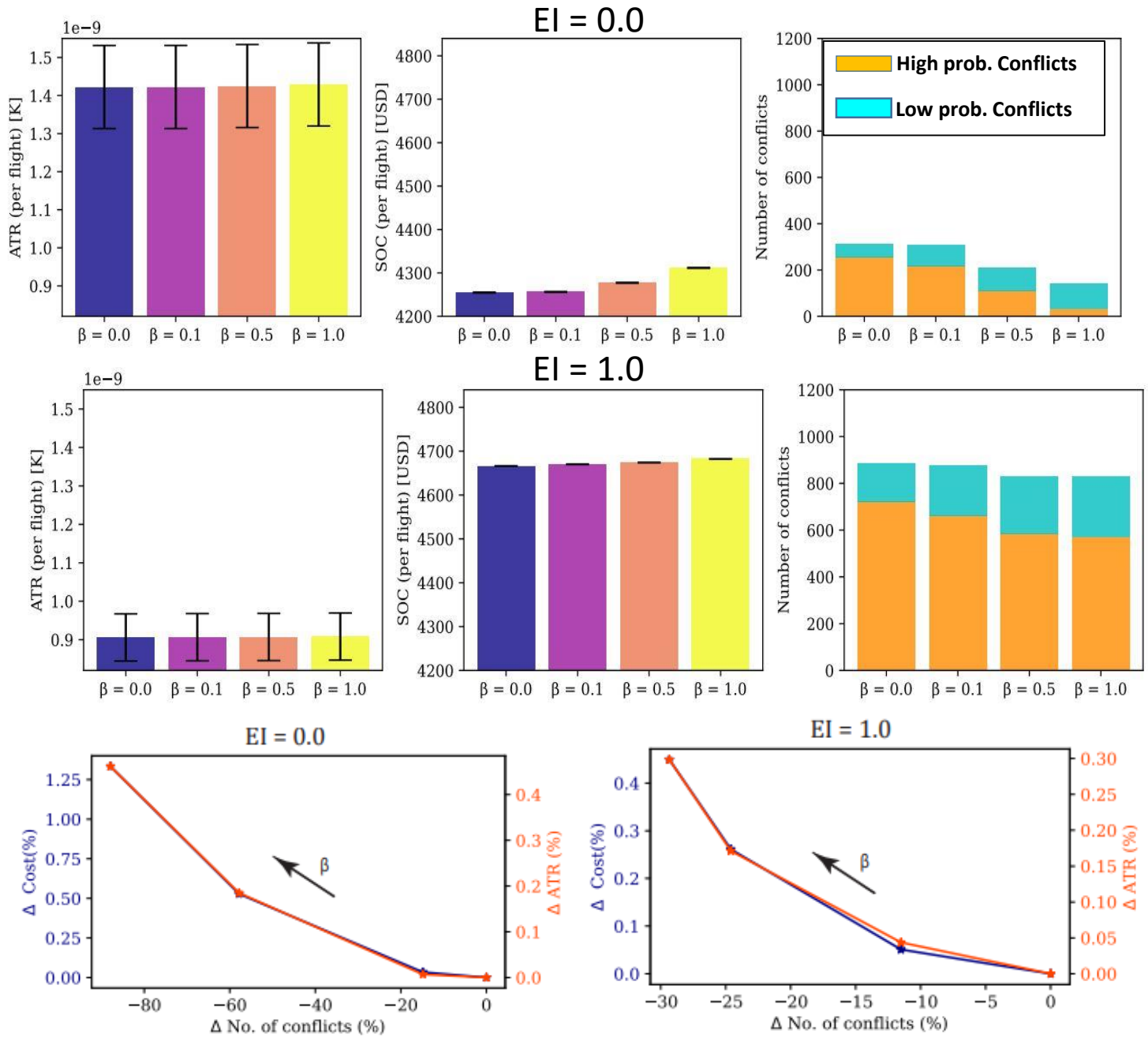
- Objective function:
  $$\beta * \text{conf} + (1 - \beta) * \text{dv}$$
- Decision variable: Speed profile
- Solution approaches: Simulated annealing
- Probability threshold = 0.5

conf: number of high probable conflicts
dv : deviation from climate optimal trajectories

By **increasing β** (weighting parameter penalizing conflict) :

- The **climate impact** is **slightly increases**.
- The **operational cost** is **slightly increases**.
- The **number of conflicts** is **reduced**.
- The **potential** to reduce conflicts is **reduced**.

Including other **decision variables** , such as departure time, and altitude may **increase** the potentiality to **reduce conflicts**.



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Conclusion

- The climate impact of non-CO2 can be reduced by employing trajectory optimization at the micro-level.
- Climate impact mitigation can be obtained at the expense of increasing operational cost, complexity, demand, and conflict.
- The resolution strategy can be employed to solve the arisen negative impacts at the strategic level.

Future works

Micro level:

- Consider the full 4D trajectory optimization in free route and structured airspace

Macro level:

- Employing different metrics to quantify the network-wide effects of adopting climate optimal trajectories
- Propose efficient resolution algorithms to reduce the effects of adopting climate optimal trajectories.
- Adding other decision variables to the resolution method


Thanks for your attention
Any Questions?
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