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Advancing Sustainable Aviation & Urban Air Mobility

Smart Use of Sustainable Aviation Fuels and Climate-Optimized Routing Toward Mitigating Contrail-Induced Environmental Impacts

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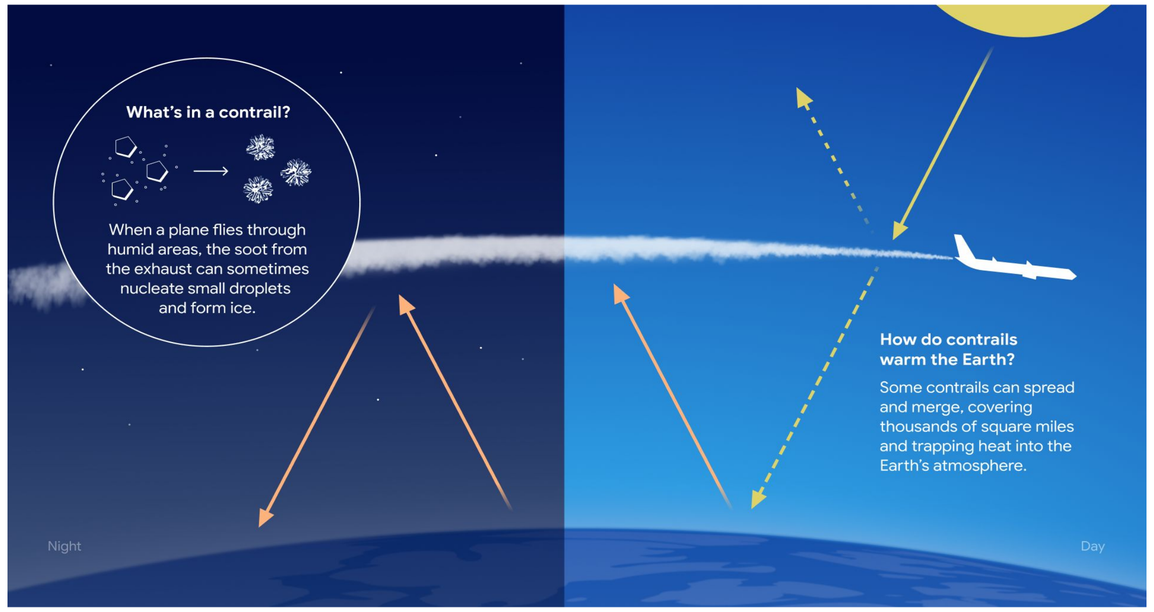
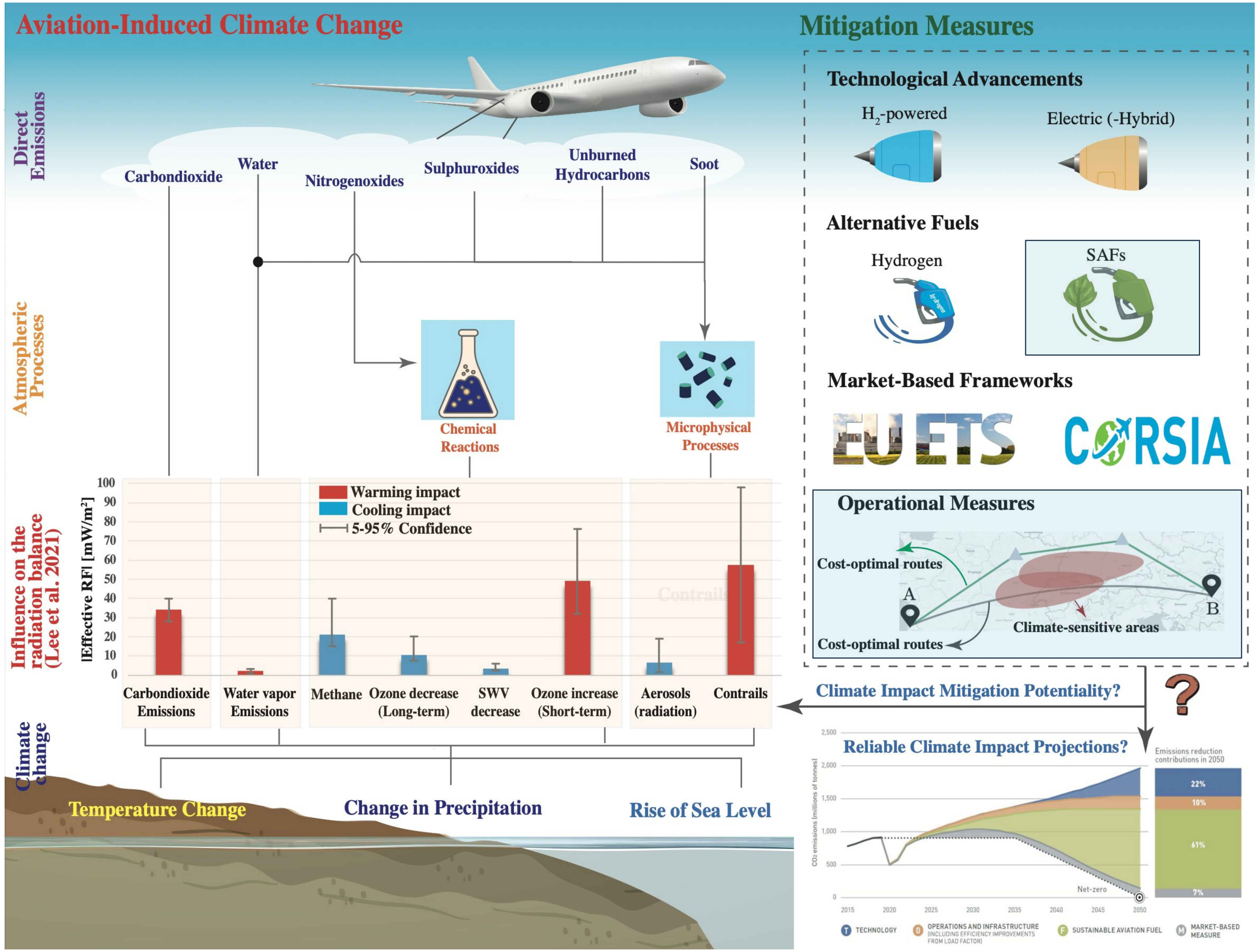
Climate Change, Aviation’s Contribution & Mitigation Measures

- 2024 was the first year exceeding 1.5°C above pre-industrial levels.
- Latest studies estimate 3-5% responsibility of aviation:
  - CO_2 emissions (34%)
  - Non-CO_2 effects (66%) (e.g., contrails)



- As aviation grows rapidly, its climate impact is expected to rise significantly, necessitating urgent actions.
- Most immediate measures:
  - Sustainable aviation fuels (SAFs)
  - Climate-friendly operations



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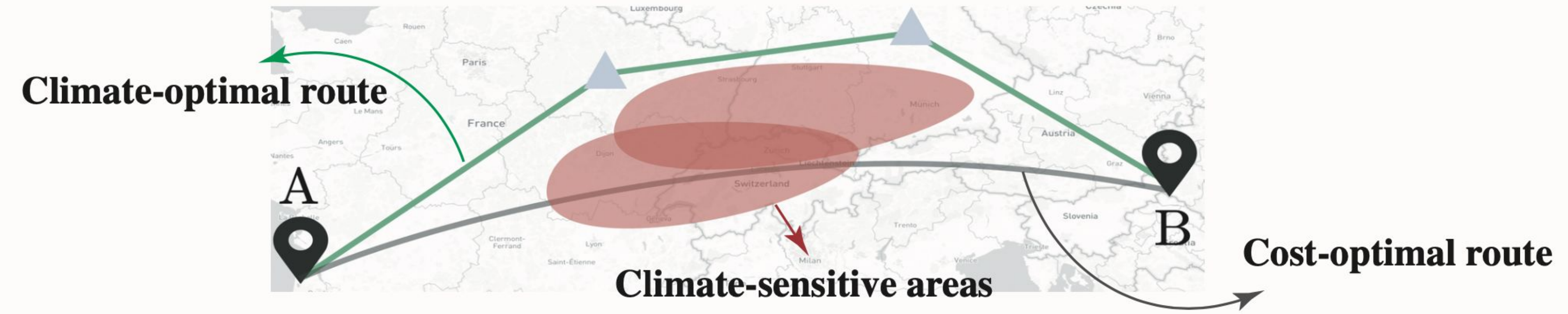
Climate-optimized flight planning and sustainable aviation fuels

I) Climate-optimized routing to mitigate aviation-induced non-CO_2 climate effects



Climate-Optimized Flight Planning

+ Mitigation of non-CO_2 climate effects
  - NO_x-induced ozone (O_3) and methane (CH_4)
  - Contrails

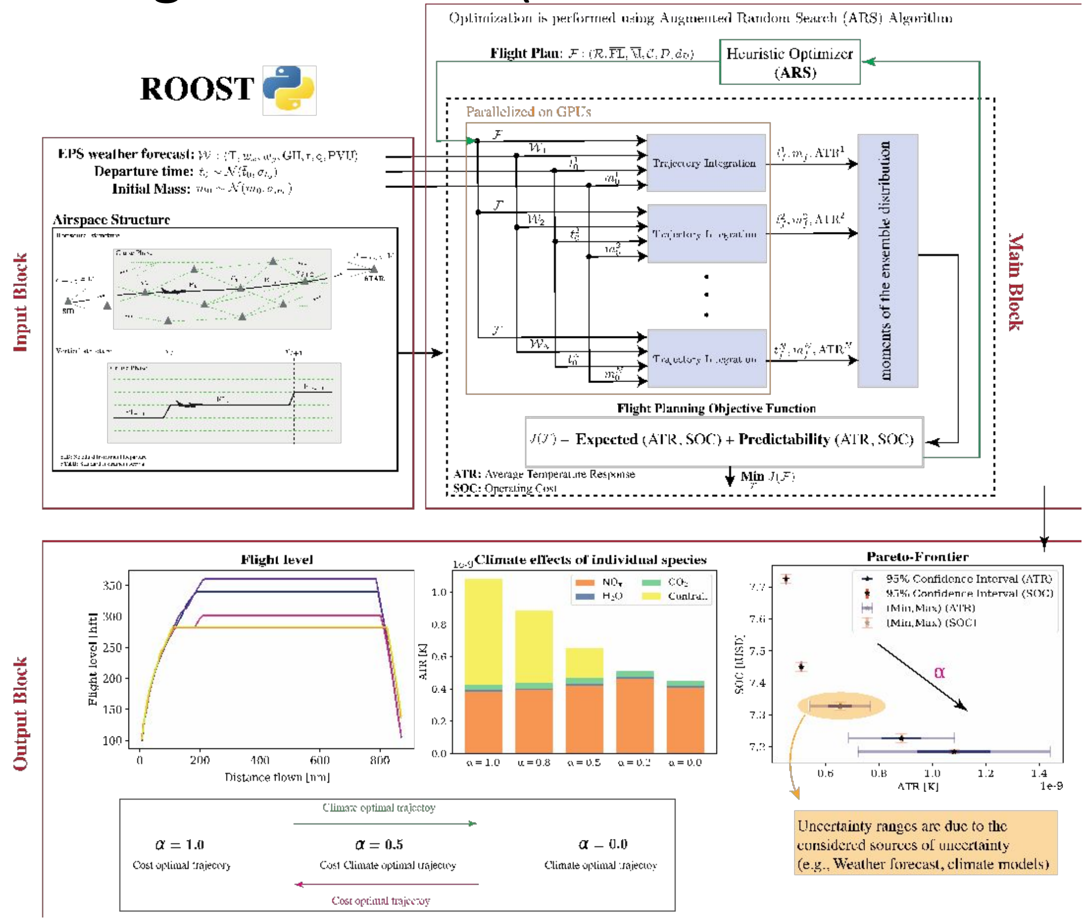
Sustainable Aviation Fuels:

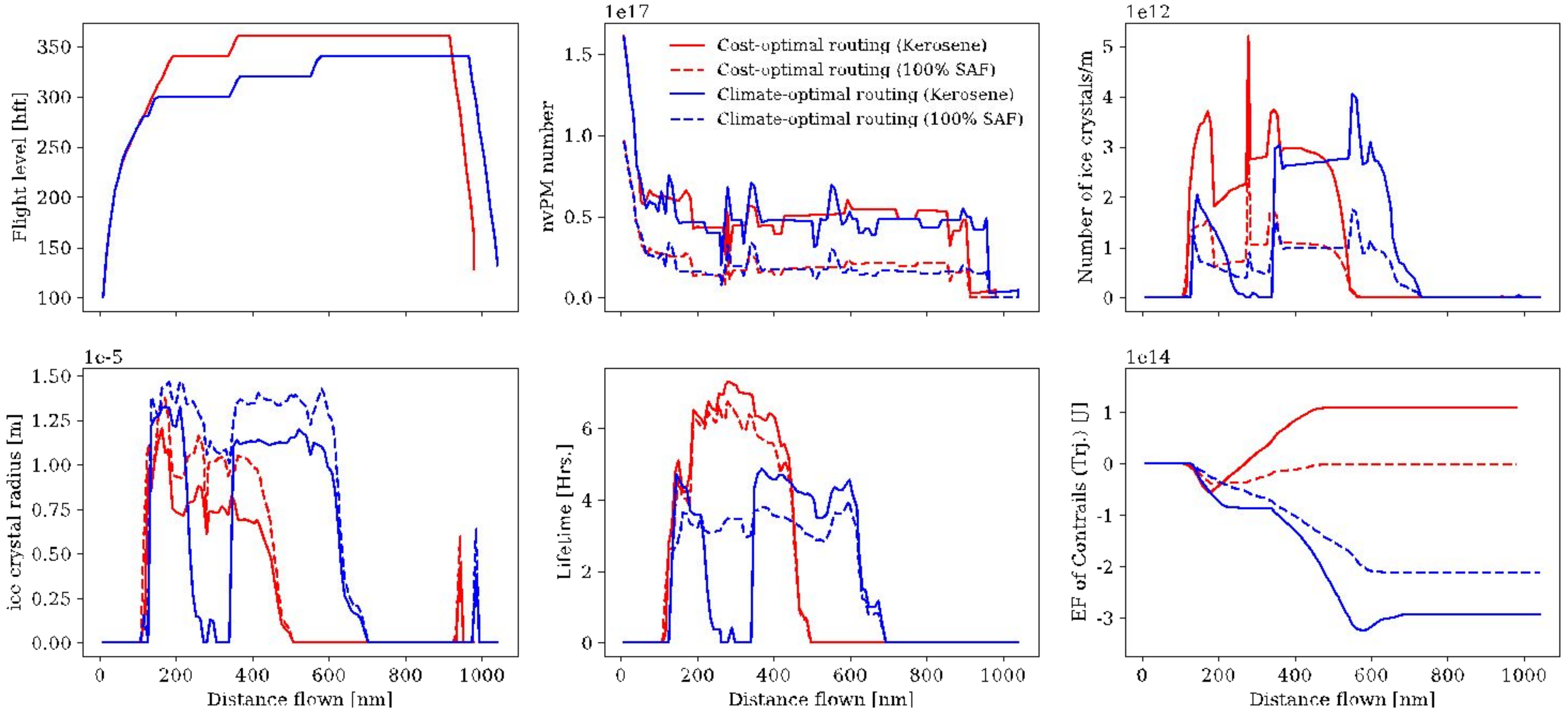
+ WTW CO_2-eq. emissions by up to 94%
+ reduce fuel flow by up to 2.5% (thus, CO_2 emissions)
+ mitigate non-CO2 effects, most notably contrails.

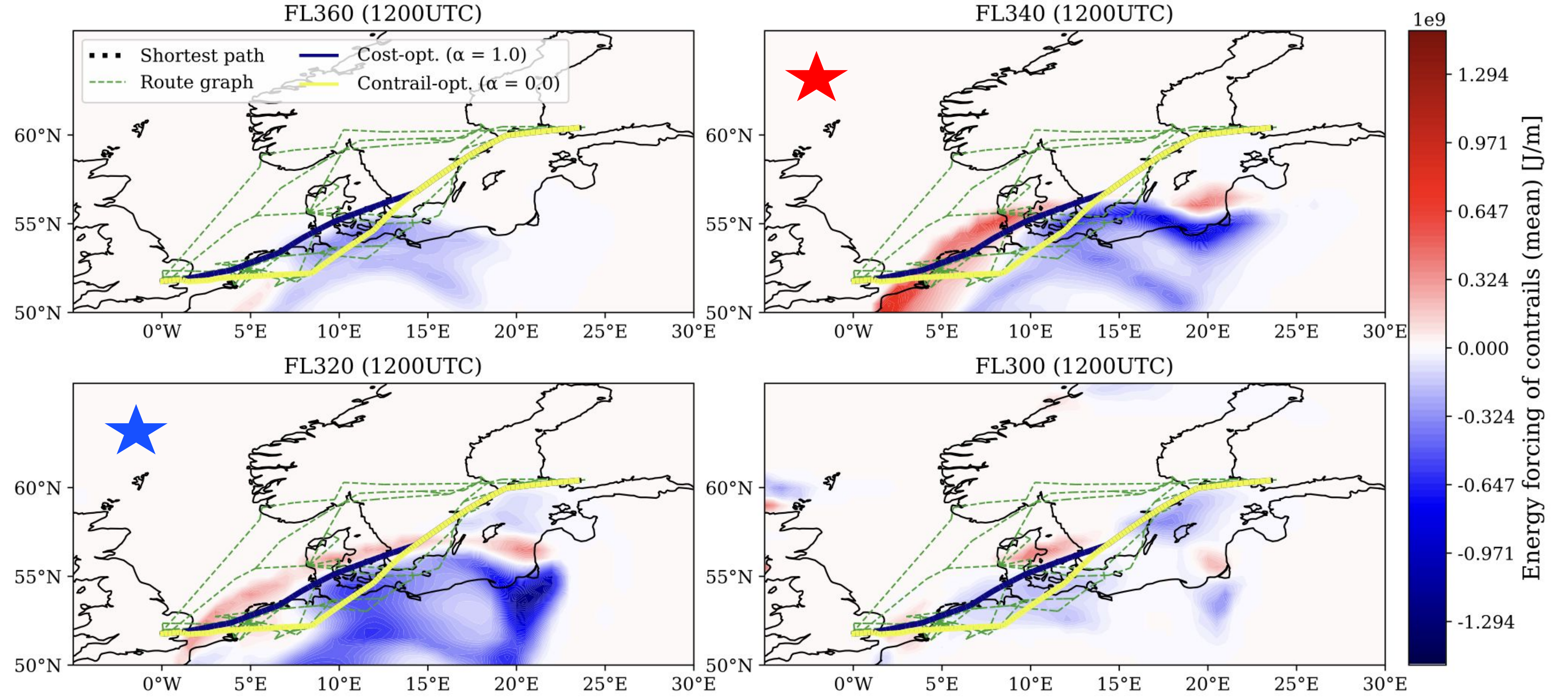
REF *A. Simorgh and M. Soler, "Climate-optimized flight planning can effectively reduce the environmental footprint of aviation in Europe at low operational costs," Nature Communications Earth & Environment, 2025.*

An Example

- **Date:** 17th of March 2023, 1200UTC.
- **Flights:** London-Helsinki
- **Uncertainties:** Ensemble Weather Data (ERA5)
- **Climate impact estimation model:** CoCiP (through pycontrails)
- **Flight planning tool:** ROOST (available on GitHub)







REF *A. Simorgh and M. Soler, "A. Simorgh, M. Soler, D. González-Arribas, F. Linke, B. Lührs, M. M. Meuser, et al., "Robust 4D climate-optimal flight planning in structured airspace using parallelized simulation on GPUs: ROOST V1.0," Geoscientific Model Development, vol. 16, no. 13, pp. 3723–3748, 2023.*

SAF has benefits only for flights that form warming contrails.

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Climate-optimized flight planning and sustainable aviation fuels: Challenges

Climate-Optimized Flight Planning

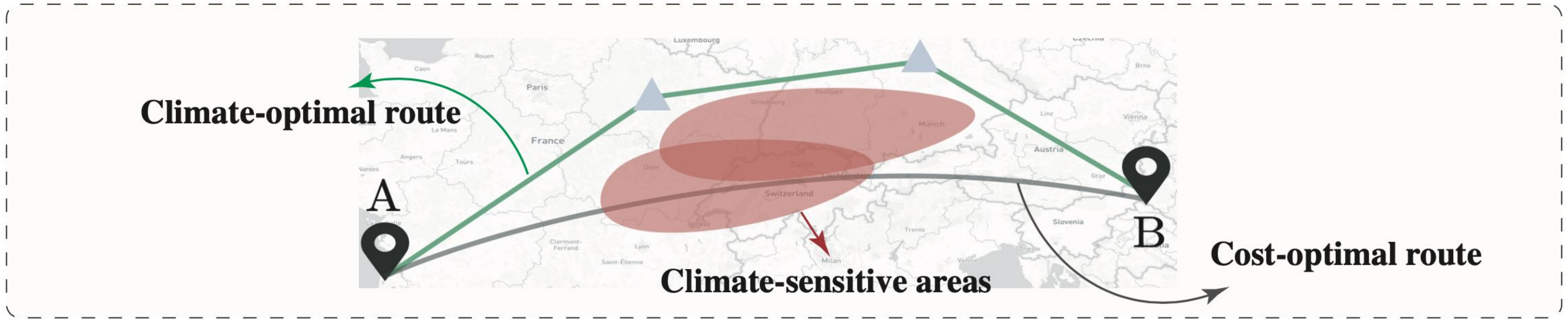
+ Mitigation of non-CO_2 climate effects
    - NO_x-induced ozone (O_3) and methane (CH_4)
    - Contrails
- Degradation of operational manageability (Baneshi et al. 2023-2025)

Sustainable Aviation Fuels:

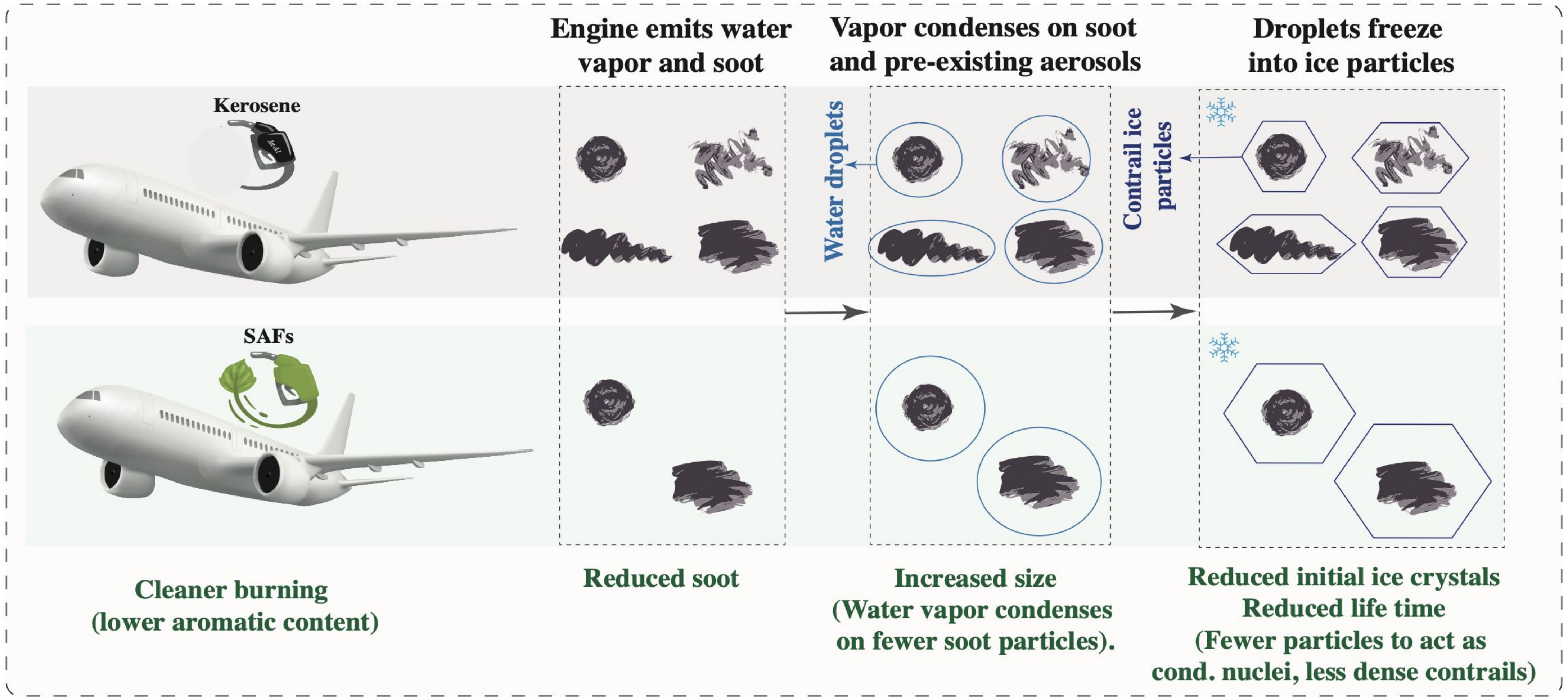
+ WTW CO_2-eq. emissions by up to 94%
+ reduce fuel flow by up to 2.5% (thus, CO_2 emissions)
+ mitigate non-CO2 effects, most notably contrails.
- More production-intensive and costly than kerosene, leading to limited availability in the short term.

Research Question: How can we maximize their environmental benefits while accounting for operational manageability and current SAF limitations?

I) Climate-optimized routing to mitigate aviation-induced non-CO_2 climate effects



II) Sustainable aviation fuels to reduce warming impact of contrails



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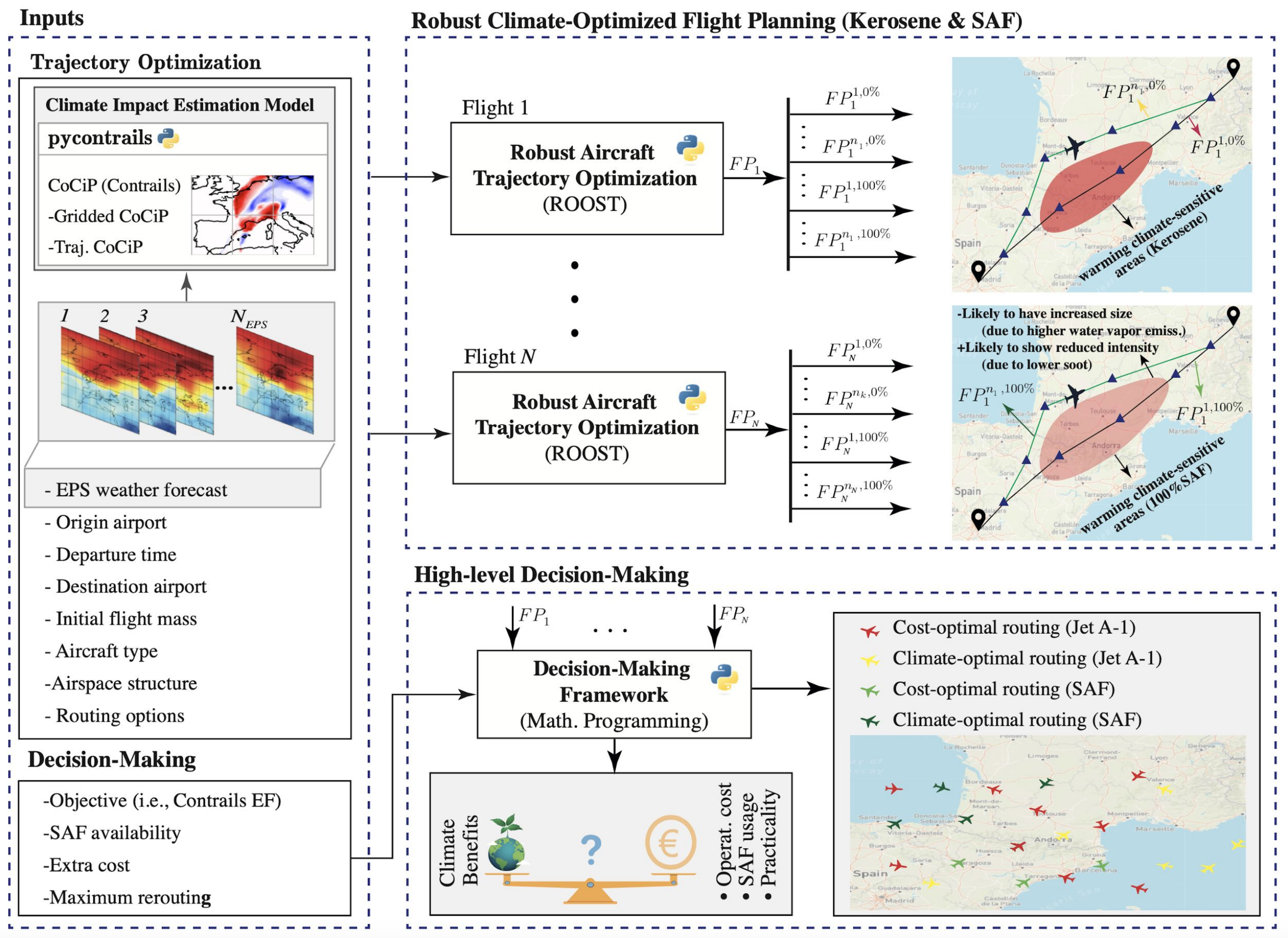
Introduced Concept: Smart Use of SAF and Climate-Optimal Routing

Smart (or targeted) application of measures:

- **Minimal disruption to current BAU operations**
  - e.g., limited rerouting by focusing on high-impact flights
- **Targeted SAF deployment**
  - Using it on flights that generate strongly warming contrails (Teoh et al. 2022)

Objective function of flight planning:

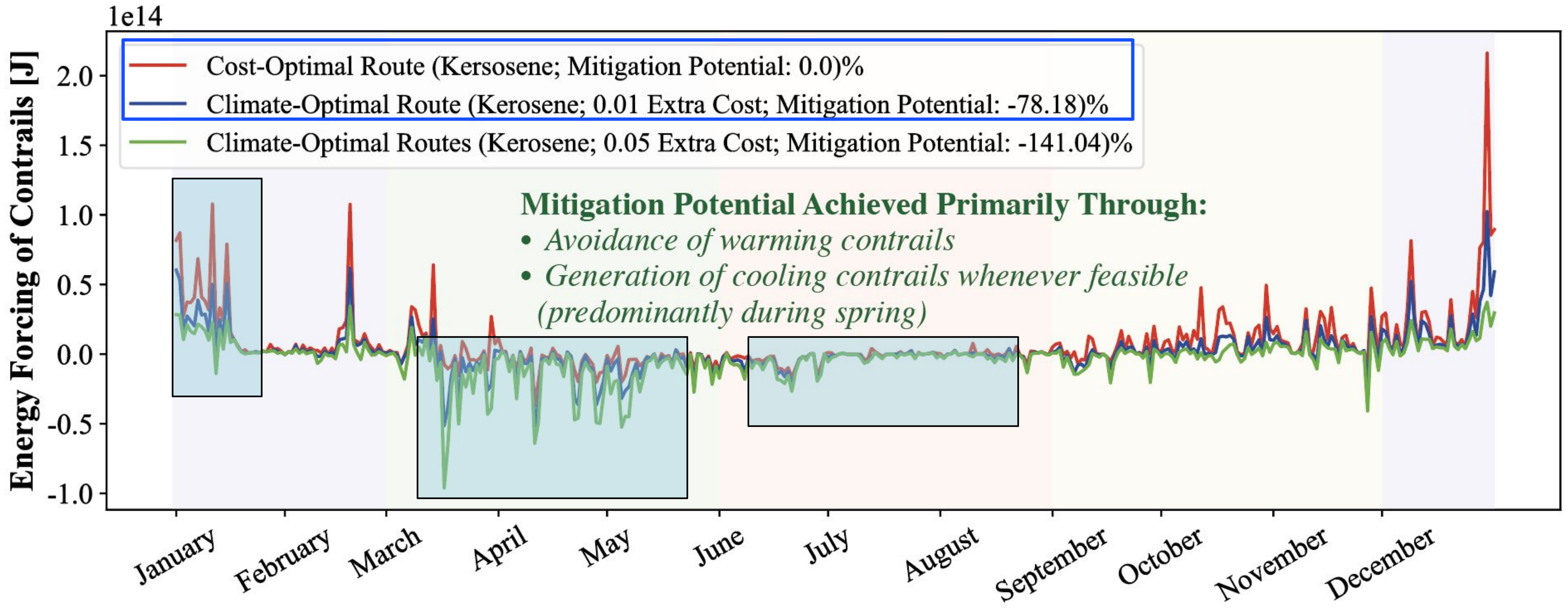
J = Operational Cost + EI * Climate Impact



Large-scale analysis: climate-optimized flight planning with kerosene

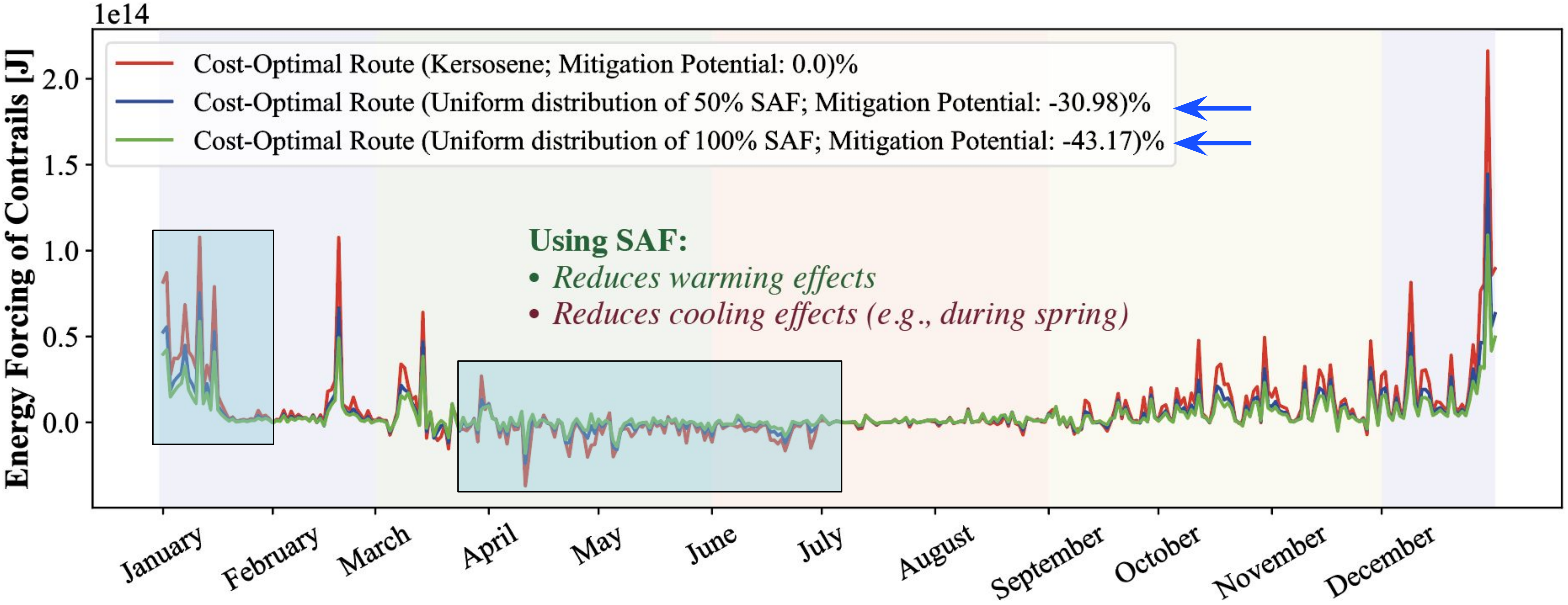
Scenario

- **Date:** All days in 2023 (0000UTC and 1200UTC)
- **Flights:** Top 150 routes in 2018 ranked using ASK
- **Uncertainties:** Ensemble Weather Data (ERA5)
- **Climate impact estimation model:** CoCiP v0.51 (Grid/trajectory-based)



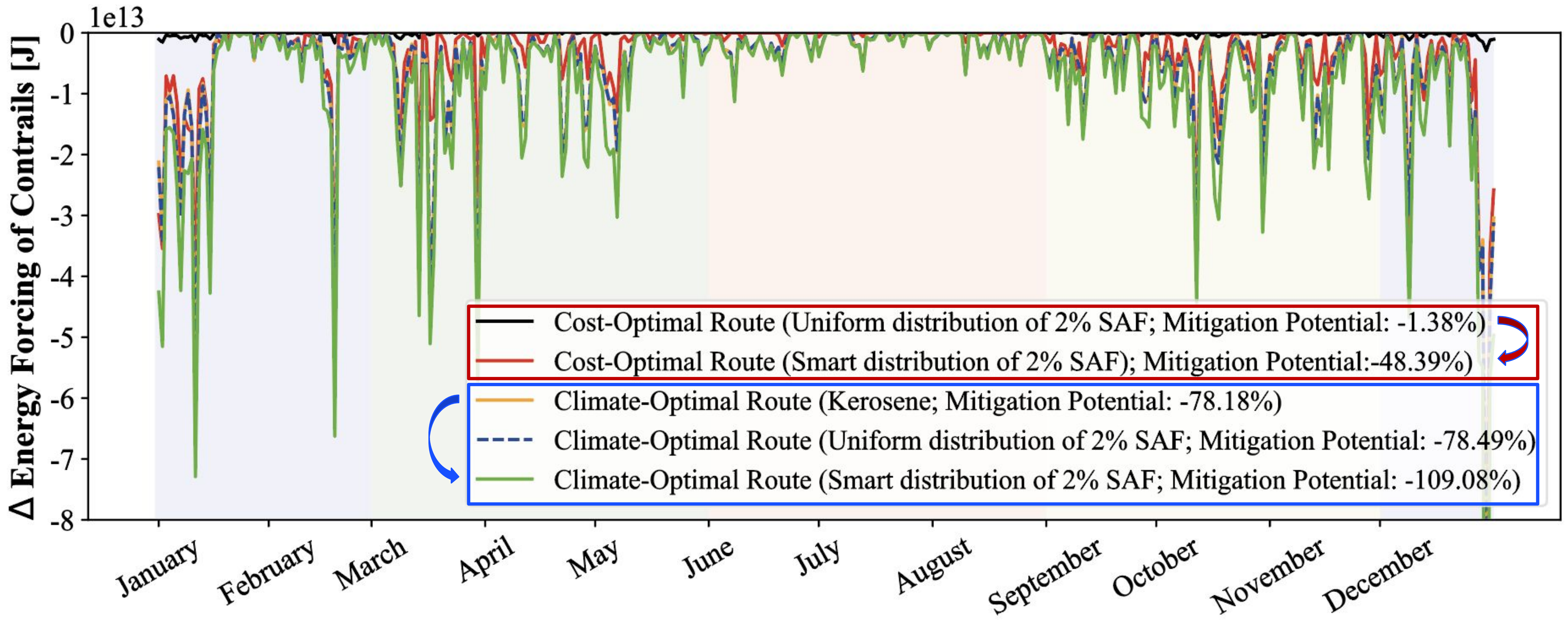
- Avoiding the formation of warming contrails during <u>winter</u>
- Favoring the formation of cooling contrails during <u>spring</u>
- No or Limited mitigation potential during <u>summer</u>

Uniform SAF distribution (for cost-optimal routing option)



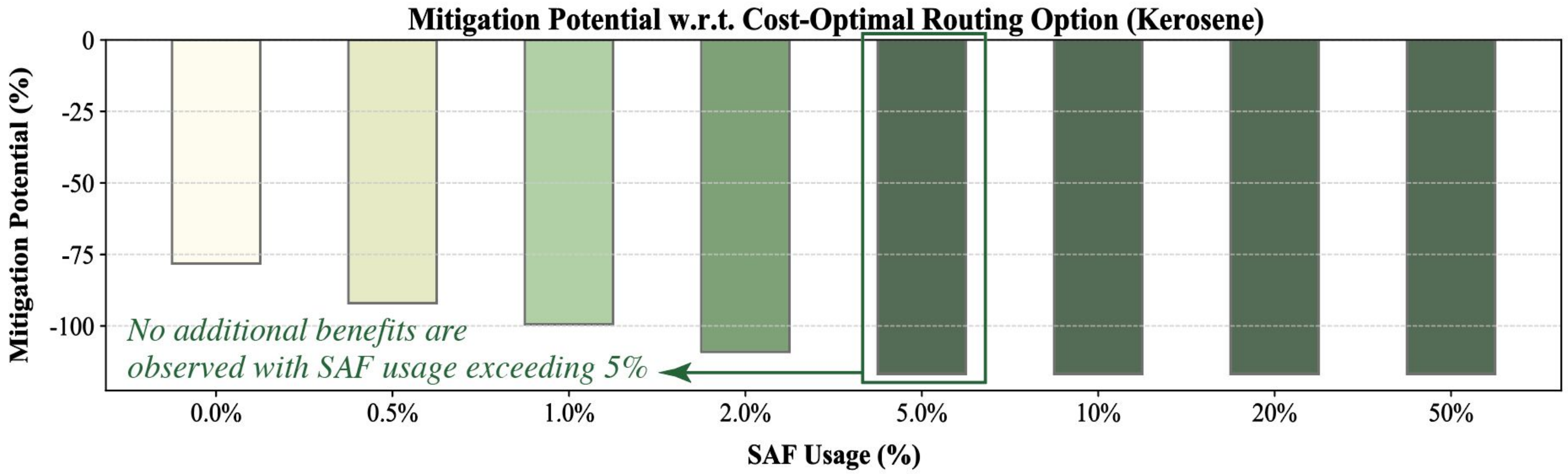
- On average, SAF reduces contrail-related climate impact (though the assumed usage levels are not yet realistic).
- <u>In winter</u>, SAF is beneficial when used on flights generating warming contrails.
- <u>In spring</u>, SAF can increase climate impact by reducing cooling potential.

Smart SAF usage and climate-optimized flight planning (2% SAF, +0.01 Cost)



- Smart usage of limited SAF can provide substantial climate benefits (even higher than 100% uniform SAF usage)
- This is achieved by allocating SAF to flights that form strongly warming contrails.
- Overall, using SAF can lead to a 30-40% reduction in the climate effects of contrails for both cost-optimal and climate-optimal routing options.

Case Study: Mitigation Potential for Varying Percentages of SAF Usage



- In terms of the climate effects of contrails, more SAF does not necessarily provide considerable mitigation:
  - Many flights do not form contrails
  - Some flights generate cooling contrails during daylight hours

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thank you
for your attention!

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Q&A / Closing

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Aviation-Induced Climate Change & Mitigation Measures

- 2024 was the first year exceeding 1.5°C above pre-industrial levels.
- Aviation contributes 3.5–5% to climate change.
- Aviation needs urgent action to meet climate goals.