Eco-efficient aircraft routing and the weather uncertainty

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Aviation climate impact mitigation by 2030, 06/09/2023,
University of Bristol

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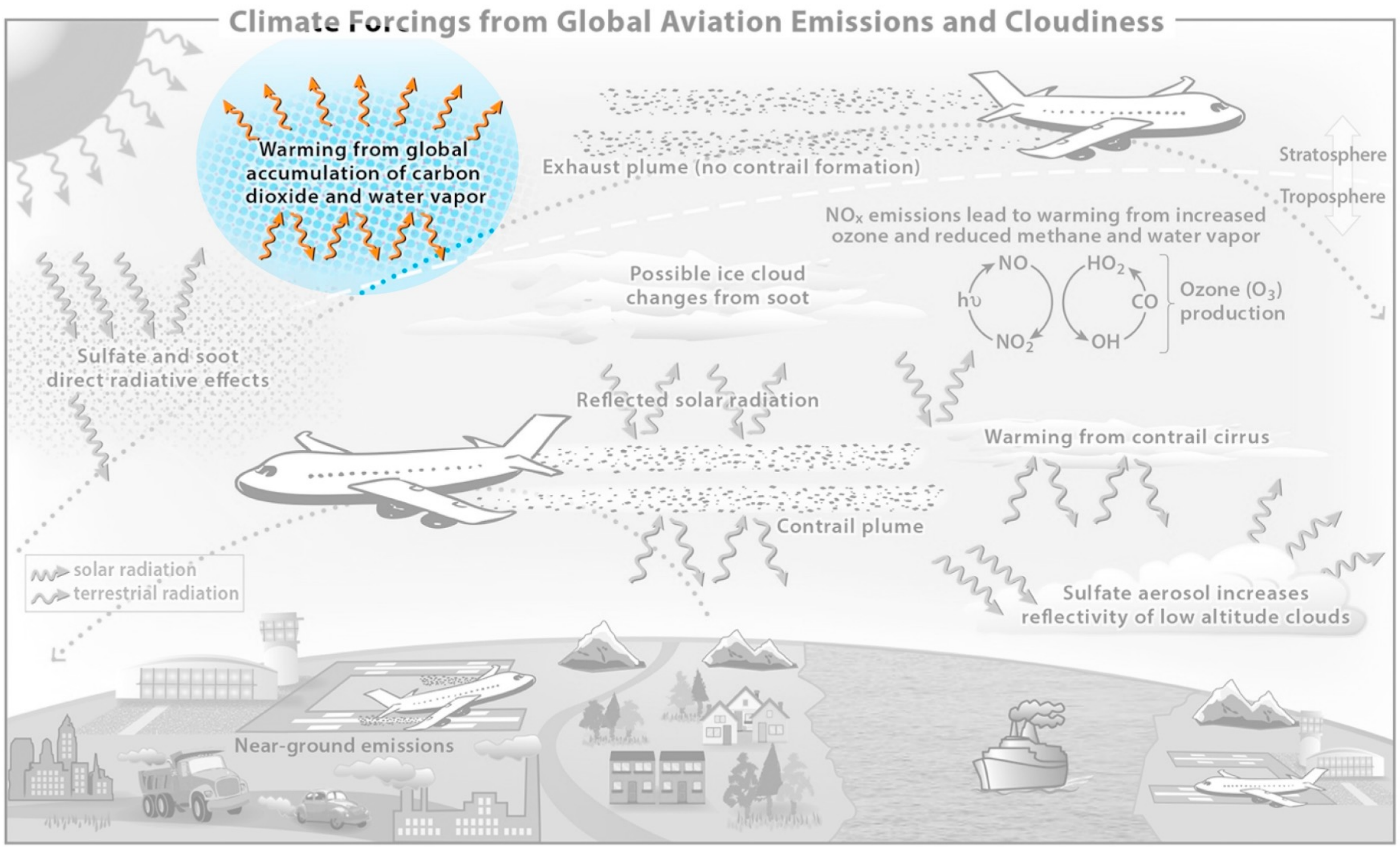
FlyATM4E

BeCoM

Aviation climate impact



- Aviation **emissions** perturb the atmosphere and affect the **climate**, for example **warming** the Earth surface.

- We distinguish:

  1. CO_2 effects
  2. Non-CO_2 effects

Figure adapted from Fig. 1 in D.S. Lee et al., 2021.

CO_2 and non-CO_2 effects

	CO_2 effects	Non-CO_2 effects
Time-scale	CO_2 emissions persist in the atmosphere for **decades**.	Shorter timescale (**hours** in the case of contrails, **months** in the case of ozone changes, and **years** in the case of methane changes)
Climate impact	It is only dependent on the amount of **fuel** used.	Strong dependency on geographic **position, altitude, weather** conditions and **time** of emission
Contribution	They account for ~**1/3** of the net aviation radiative forcing.	They account for ~**2/3** of the net aviation radiative forcing.
Confidence levels	High	Medium/Low

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Mitigation potential of climate-optimized trajectories

- Non-CO_2 effects of aviation are highly dependent on **time and location of emission**

  → potential of mitigating the climate impact of aviation by **optimizing the aircraft trajectories.**

- Previous projects results:
  - **REACT4C:** 25% reduction in the climate impact with 0.5% increase in the operational costs.
  - **ATM4E:** 75% - 85% of the overall climate impact mitigation potential can be achieved modifying 25% of the routes.

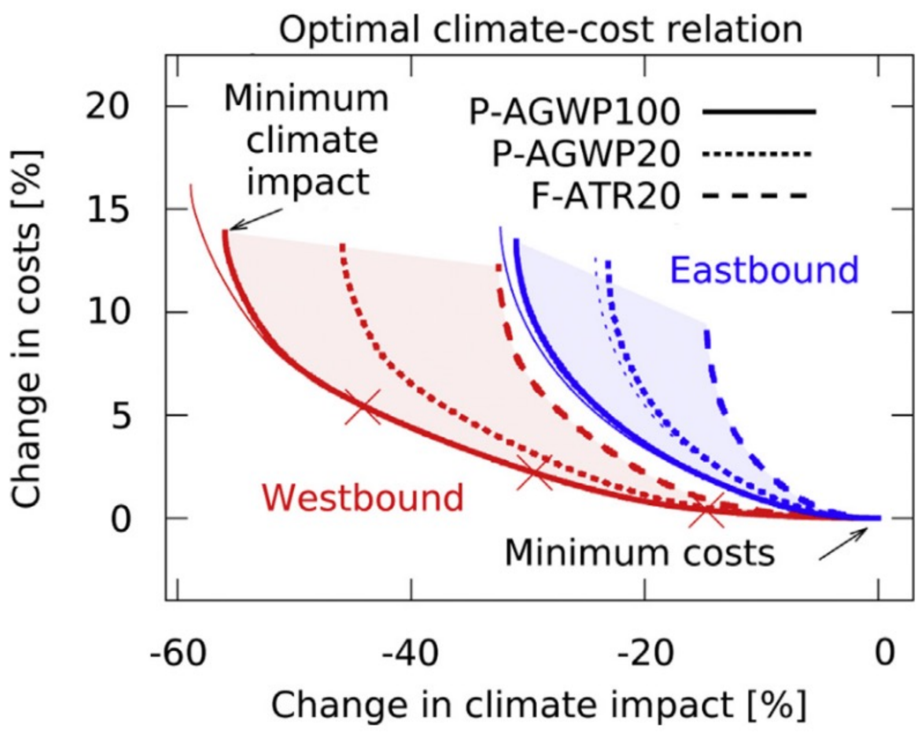

Figure from Grewe et al. (2014). Matthes, et al., (2017)

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Objective of this work

PhD project of Federica Castino

To identify **aircraft trajectories:**

- which allows a substantial reduction in aviation climate impact, leaving costs nearly unchanged ("**eco-efficient**")
- under various **weather patterns**.

- What is their **mitigation potential**?
- How do they change due to atmospheric **natural variability**?

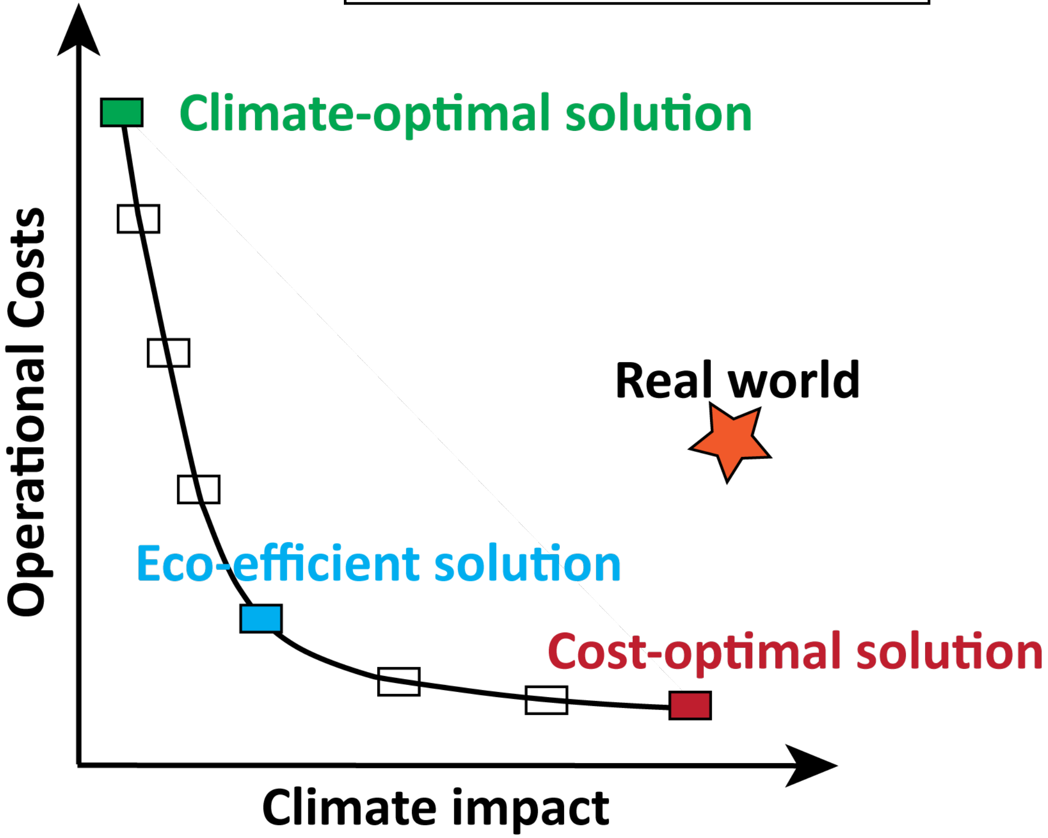

Figure adapted from FlyATM4E Deliverable 4.4.

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Modelling chain

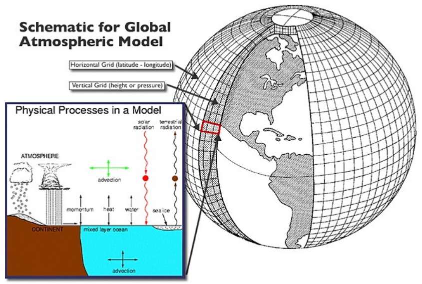


Figure from NOAA.

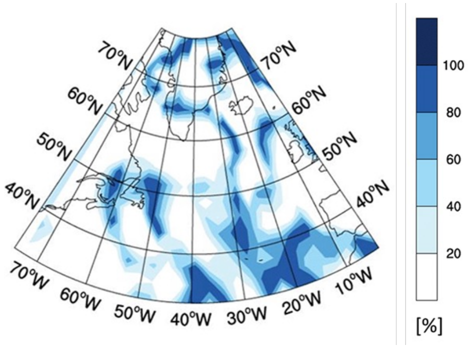
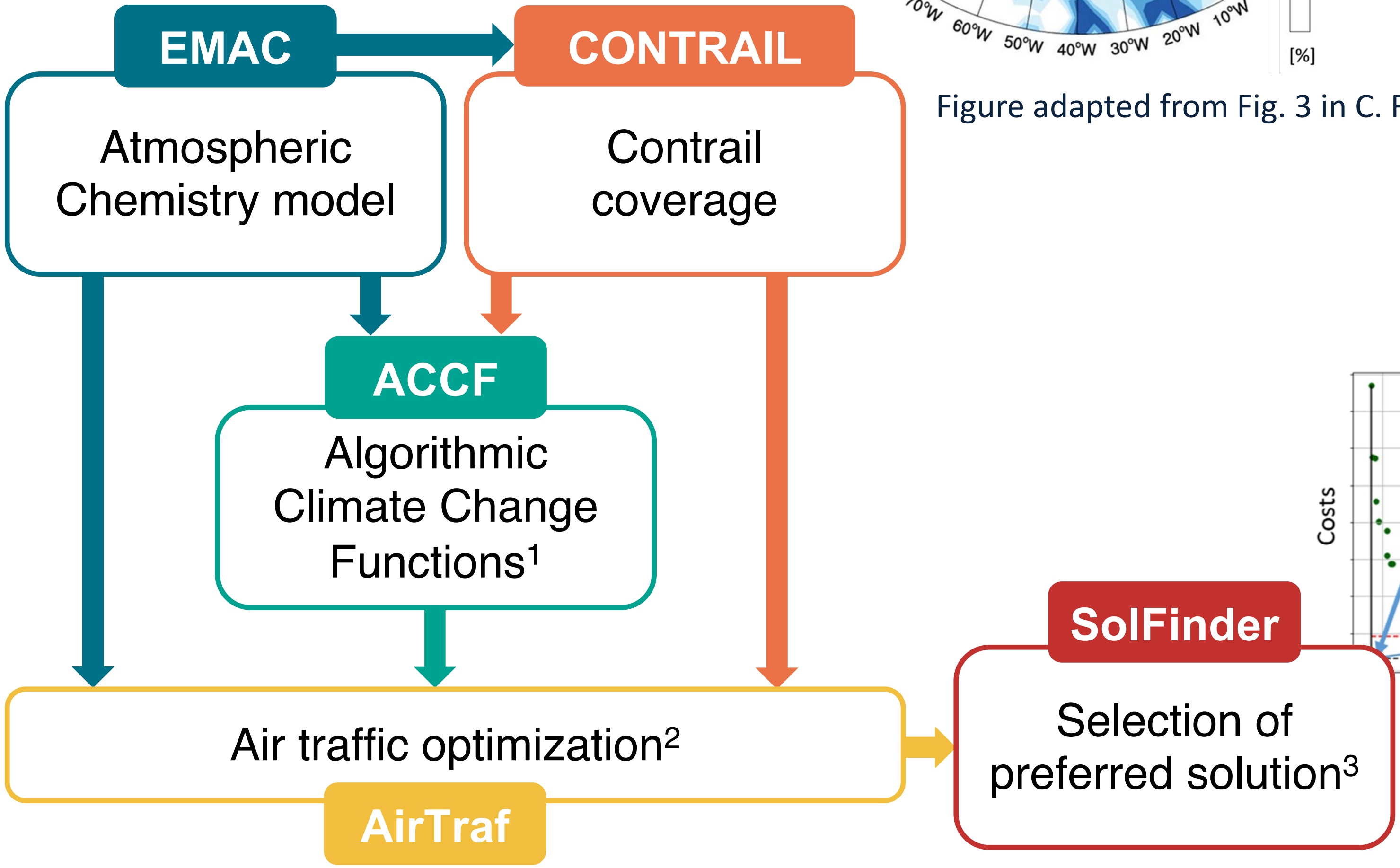
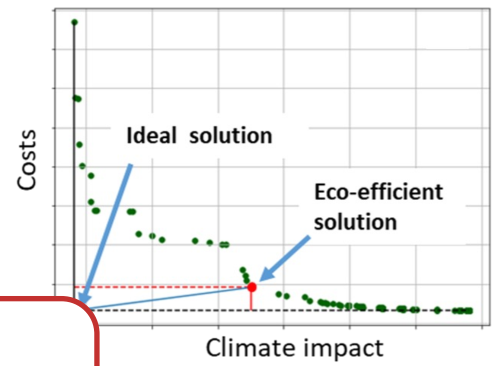


Figure adapted from Fig. 3 in C. Frömming et al., 2021.

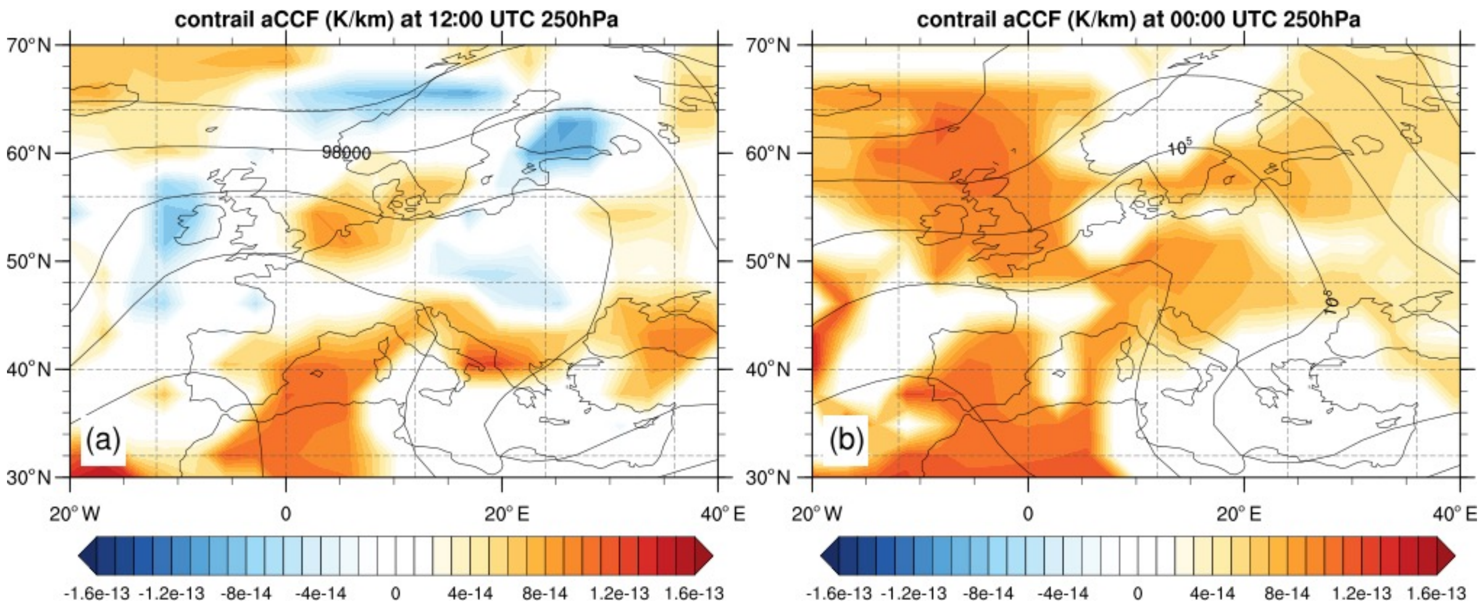




1. Yin, et al., GMD, 2023
2. Yamashita et al., GMD, 2019
3. Catino et al., GMDD [preprint], 2023

Algorithmic climate change functions

- A set of **prototype algorithmic Climate Change Functions (aCCFs)** estimate the flight climate impact in terms of Average Temperature Response over a time horizon of 20 years (ATR20) from contrail cirrus, NO_x-O_3, NO_x-methane, water vapor



Contrail-cirrus aCCFs (coloured contour) (in K km^{-1}) and geopotential height (black contour) (in m^2 s^{-2}) on 18 December 2015 at 250 hPa: (a) 12:00 UTC and (b) 00:00 UTC.

Yin et al., 2023

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Analysis of eco-efficient aircraft trajectories

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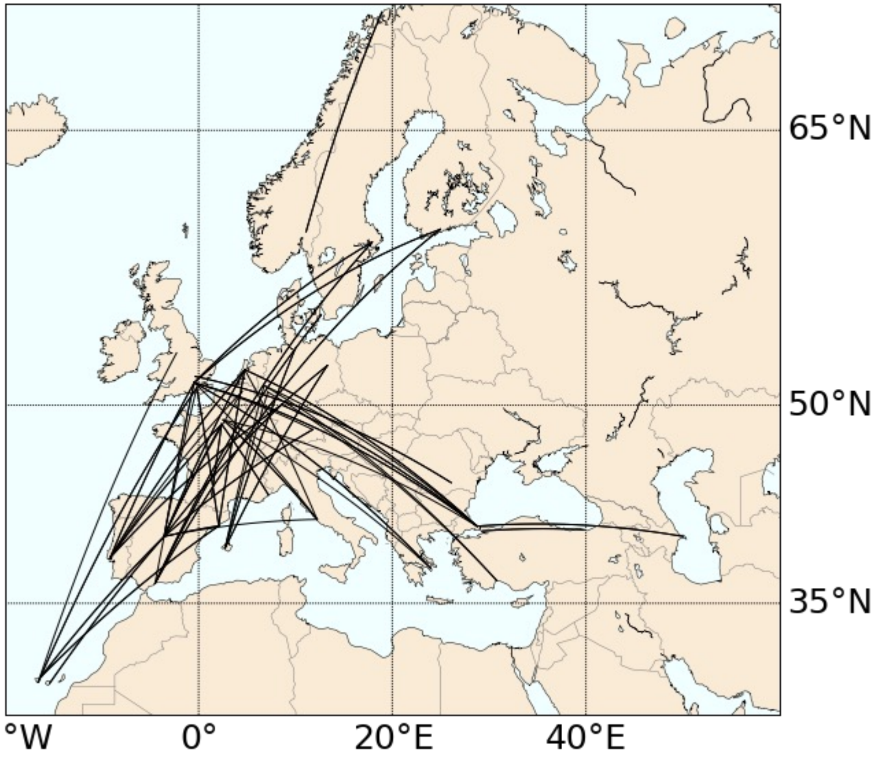
Simulations set-up:

- **Duration:** 1-31 Jan. 2018 (31 days)
- **Air Traffic Sample:** Top 100 routes by ASK for the ECAC area in 2018
- **Aircraft/Engine**: A320/CFM56-5B4
- **Departure time:** 00:00 UTC
- **Optimization objectives:**
  1. Simple Operating Costs (SOC) → fuel and flight time
  2. Average Temperature Response over 20 years (ATR20)

     → CO_2 and non-CO_2 effects



Castino, Yin, et al., Geoscientific Model Development Discussion, pre-print, 2023.

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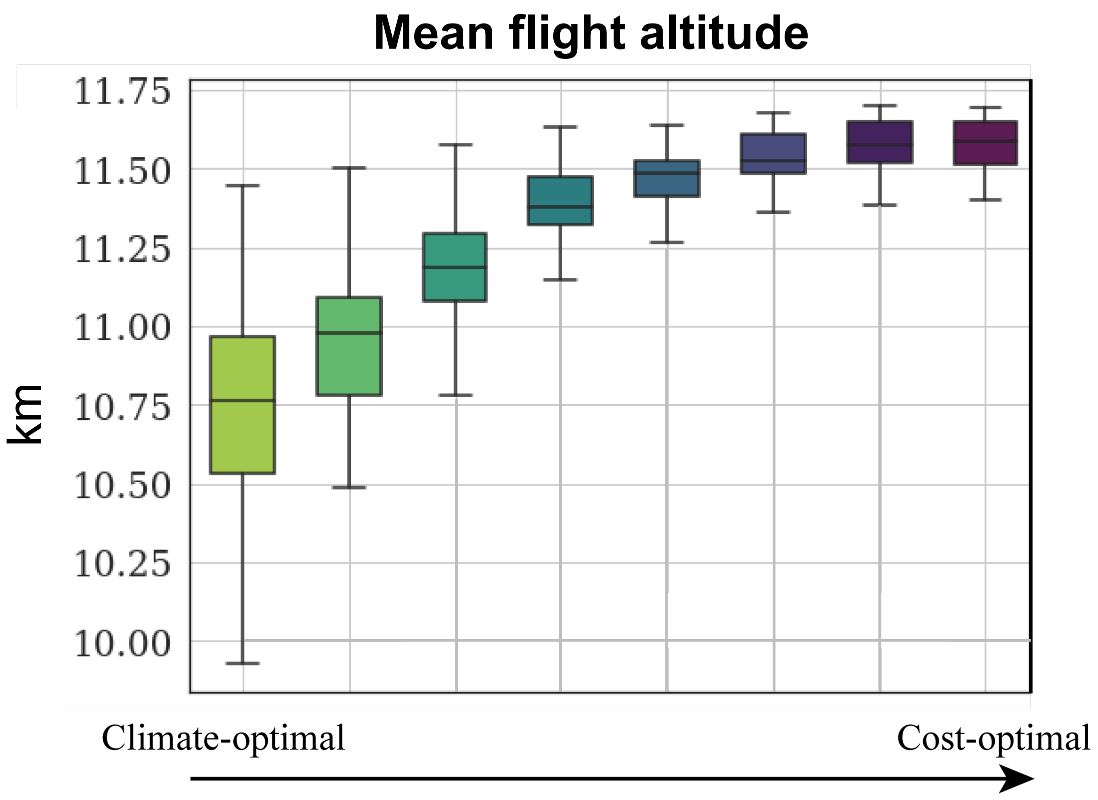
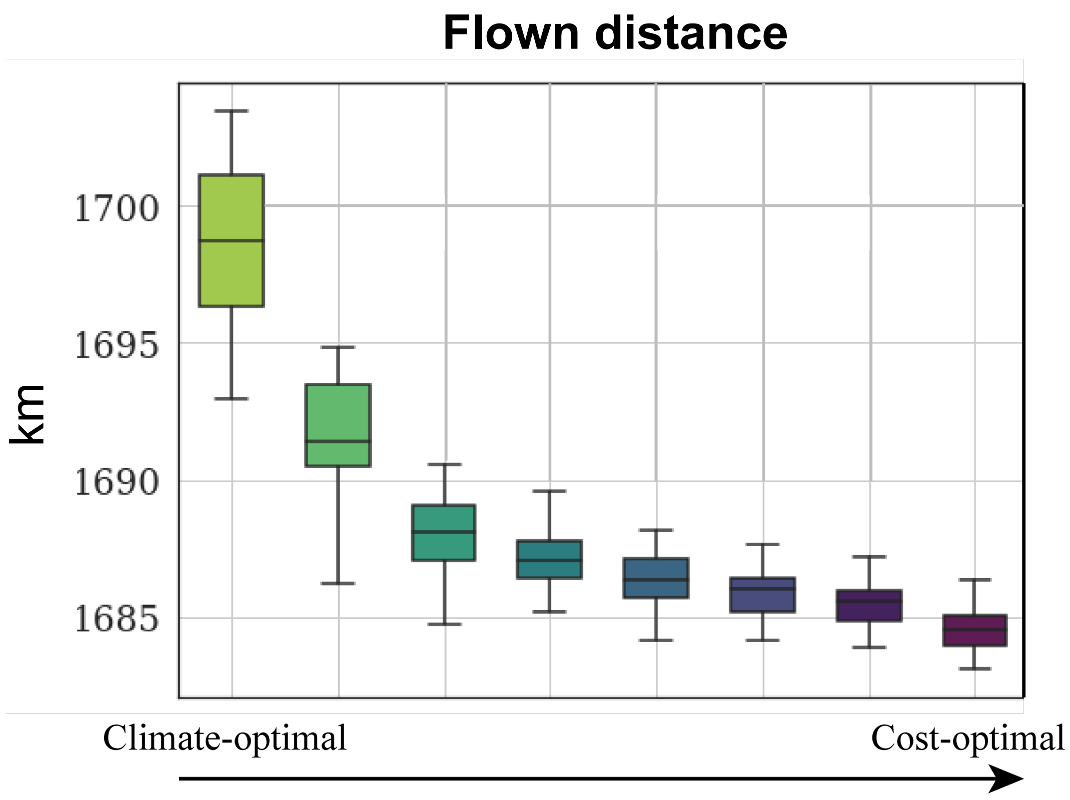
Flights properties along Pareto fronts





Castino, Yin, et al., Geoscientific Model Development Discussion, pre-print, 2023.

Monthly mean changes in CO_2 and non- CO_2 effects

- Figure: Monthly mean absolute differences in ATR20 components.
- The increase in CO_2 emissions is compensated by the reduction in non-CO_2 effects.
- The non-CO_2 effects reduction are largely affected by contrails impact.

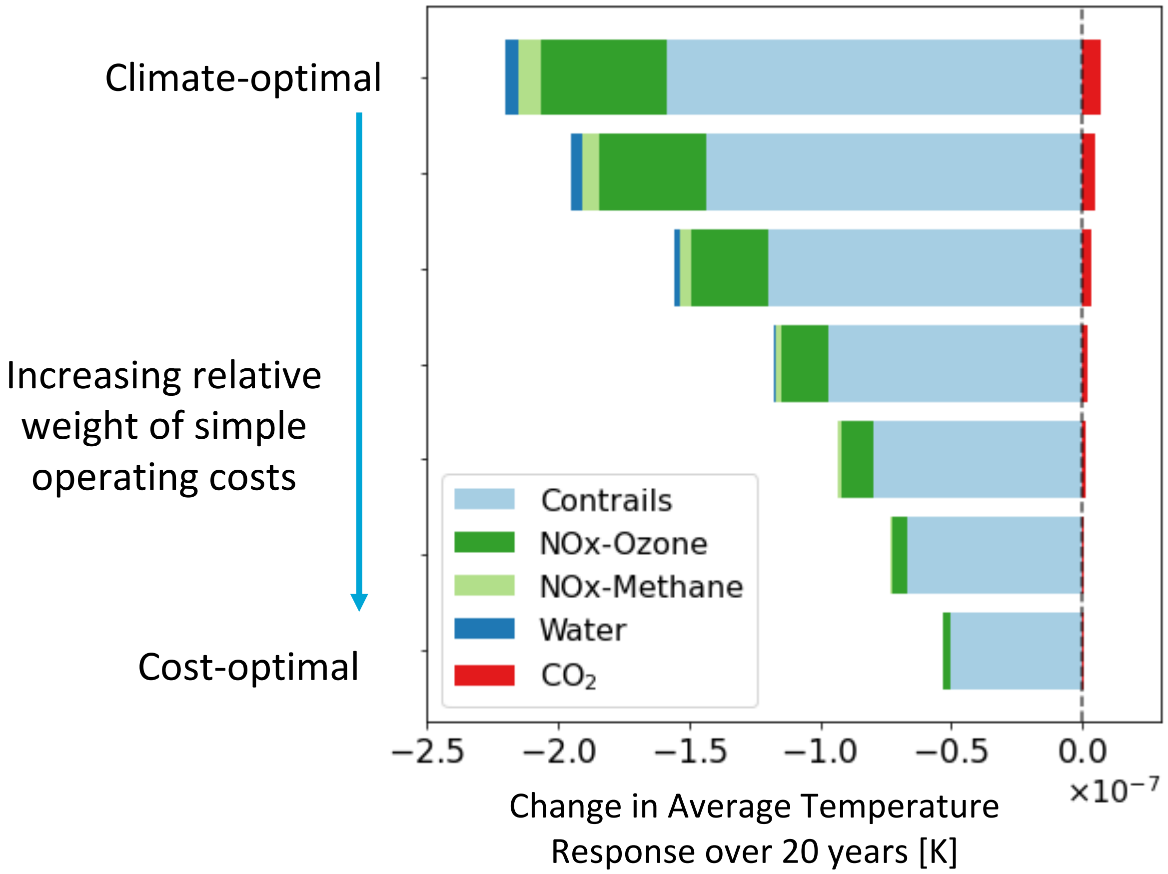
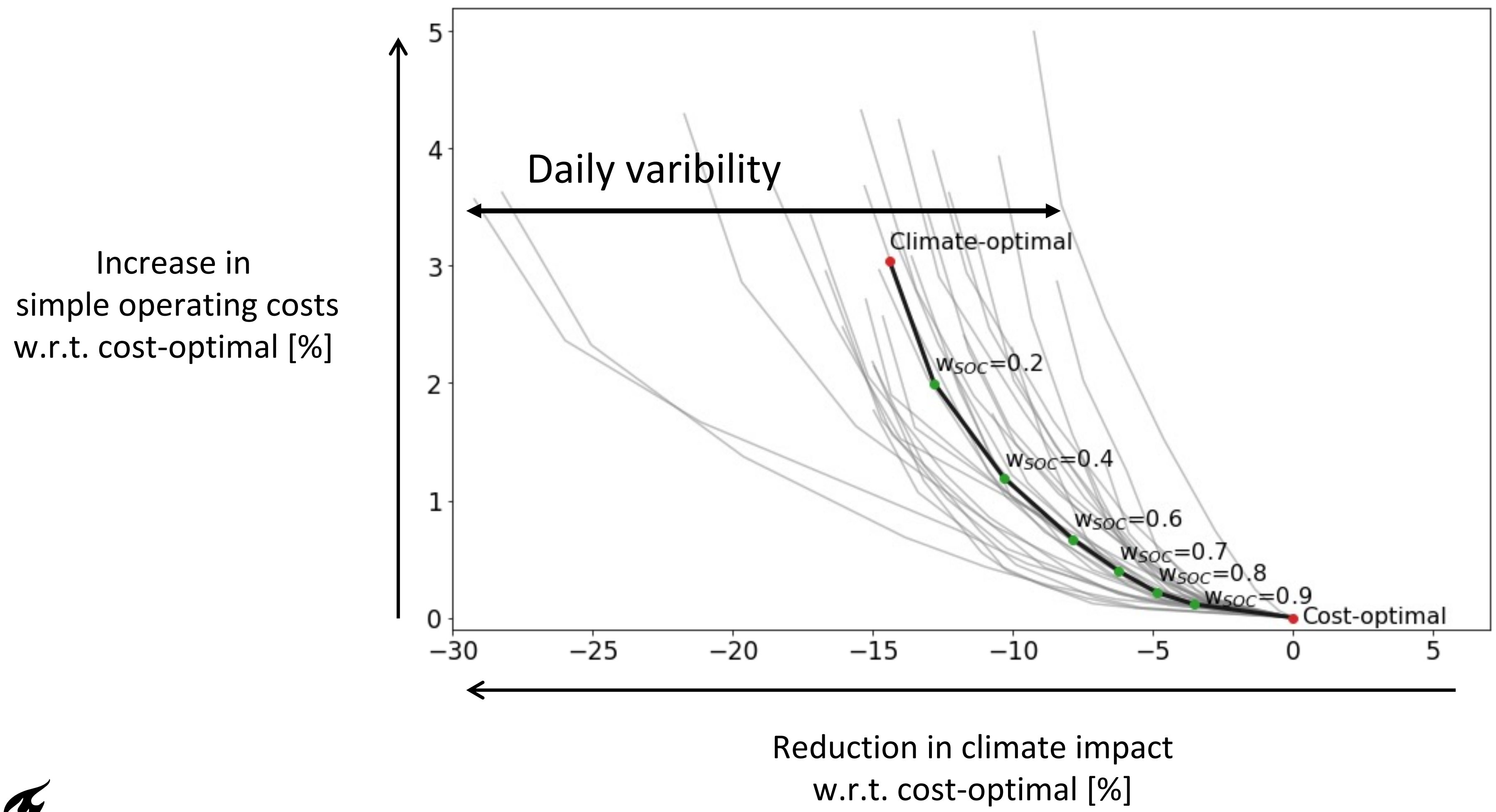


Figure adapted from Fig. 12 in Castino, Yin, et al., Geoscientific Model Development Discussion, pre-print, 2023.

Daily variability of Pareto front



Castino, Yin et al., Geoscientific Model Development Discussion, pre-print, 2023.

Daily variability of climate impact reduction

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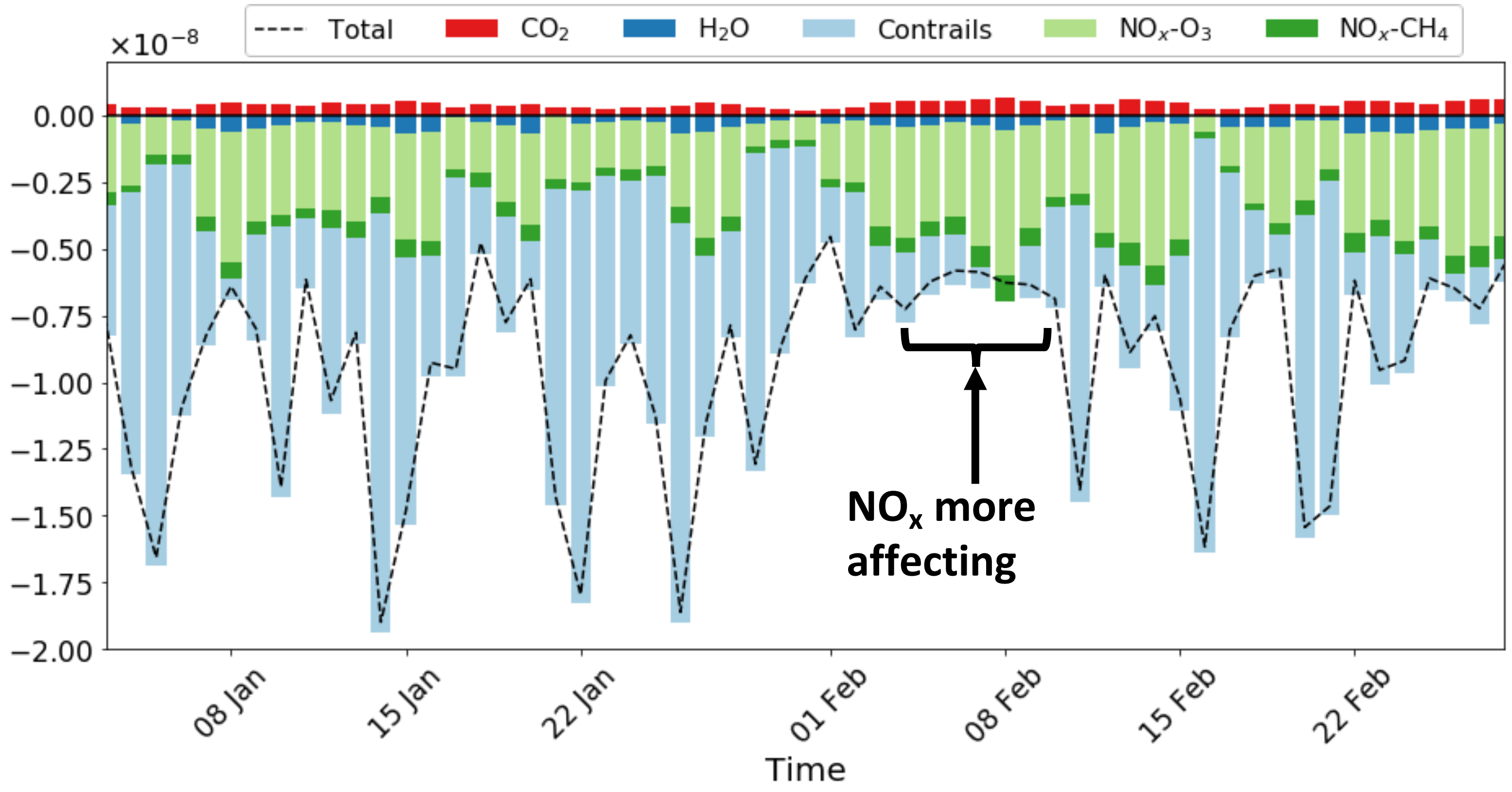
Change in Average Temperature Response over 20 years [K]

(difference between climate-optimal and cost-optimal solutions)



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Summary and ongoing work

- The analysis showed that **-10%** climate impact (ATR20) can be achieved with **+1%** in the operating costs (SOC).
- Daily variability exists for the climate mitigation potentials.
- Contrails and NO_x play different importance on different days, which requires further investigation.

Ongoing work

- Currently analysing **1-year simulations** to consider the variability of eco-efficient conditions due to atmospheric natural variability for the contrail-NO_x climate impact mitigation.

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Forecast of ice supersaturation

About 15% of all flight distances occur in ice-supersaturated regions (ISSRs, relative humidity with respect to ice (Rhi)>100%);

Unreliable forecast of persistent contrail formation[1], due to:

- A **lack of relative humidity measurements** at cruise levels;
- **Underestimation of ISSRs** in current Numerical Weather Prediction (NWP) models.

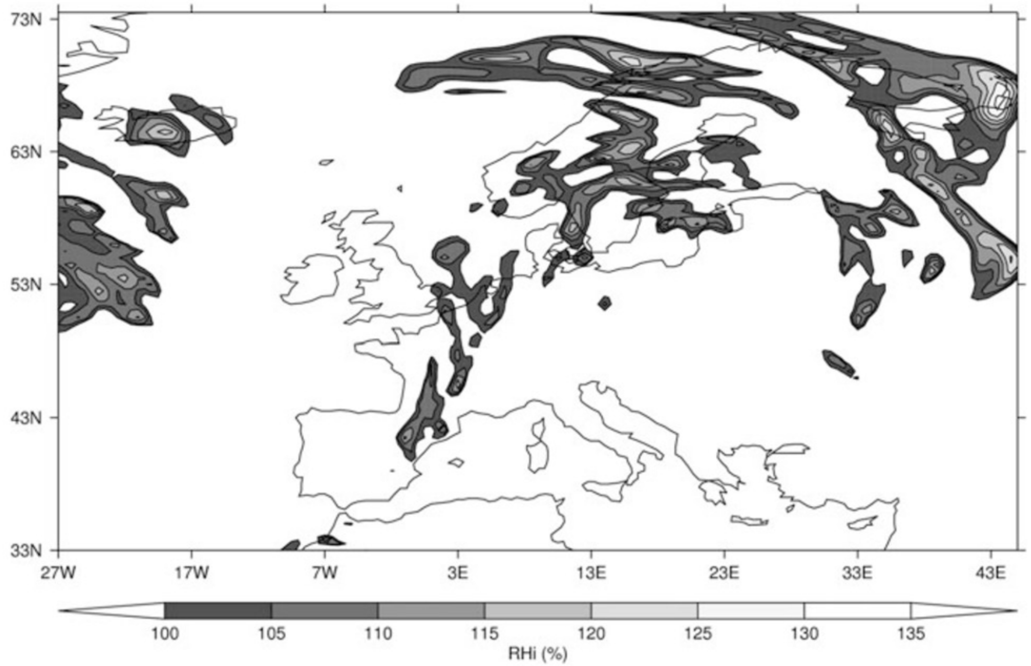

Figure taken from Gierens et al., 2012, ECMWF data
1. Sperber and Gierens, EGUsphere [preprint], 2023.

Representation of ice supersaturation in Numerical Weather Prediction models

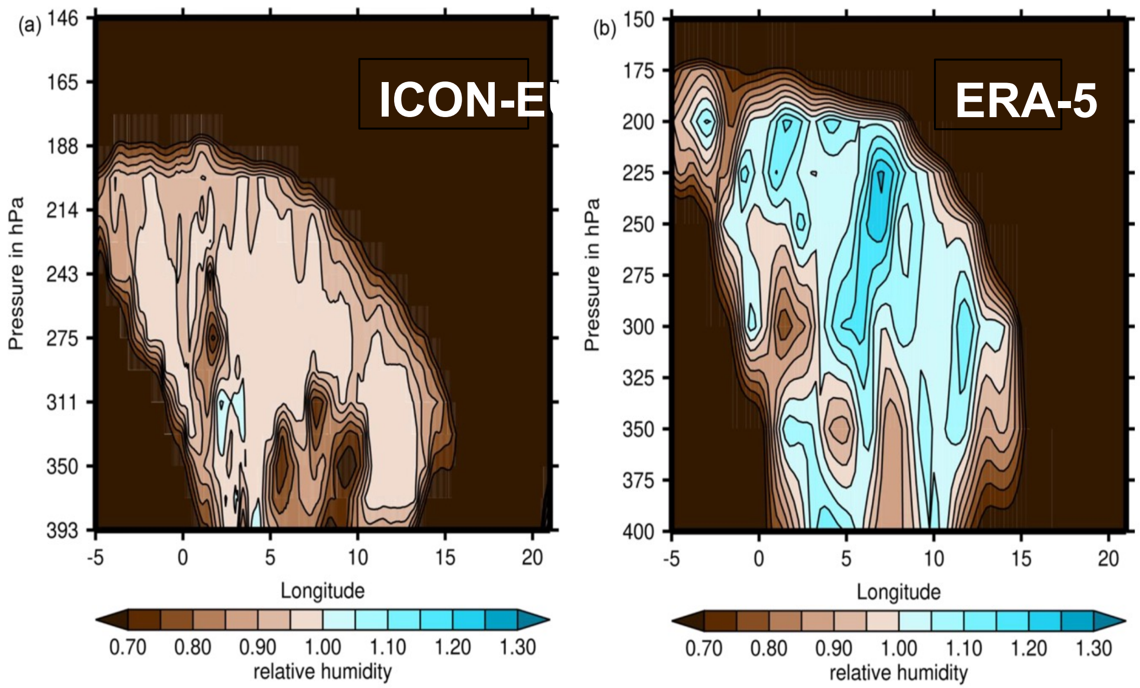

Figure taken from Gierens et al., ACP, 2022.

Significant differences in the representation of ice supersaturation between different NWP models (e.g., ICON-EU vs. ERA-5).

Forced consumption of all excess water vapour once an ice cloud forms (saturation adjustment).

A new concept to allow the decay of humidity is required.

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BeCoM methodology to improve ice supersaturation prediction

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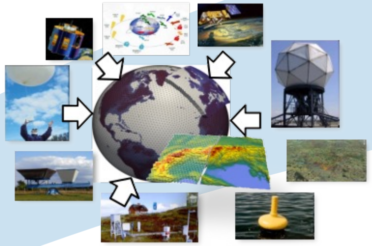
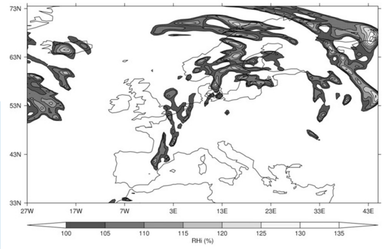
Assimilation of observational data and direct camera images using **artificial intelligence**





Better representation of ice supersaturation in NWP model (Sperber and Gierens, EGUsphere [preprint], 2023.)

Operational and new measurements of humidity & characterization

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Future work of trajectory optimization for contrail avoidance

- Assess the impact of improved forecast of ISSRs through trajectory calculations.
- Evaluate the climate impact reduction potential via trajectory optimization measure.

References

[1] Lee, D. S., et al.: The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, Atmospheric Environment, 244, https://doi.org/10.1016/j.atmosenv.2020.117834, 2021.

[2] Matthes, S., et al.: Climate-optimized trajectories and robust mitigation potential: Flying atm4e, Aerospace, 7, 1–15, https://doi.org/10.3390/aerospace7110156, 2020.

[3] Grewe, V., et al.: Reduction of the air traffic's contribution to climate change: A REACT4C case study, Atmospheric Environment, 94, 616-625, https://doi.org/10.1016/j.atmosenv.2014.05.059, 2014.

[4] Lührs, B., et al.: Climate impact mitigation potential of European air traffic in a weather situation with strong contrail formation, Aerospace, 8, 1–15, https://doi.org/10.3390/aerospace8020050, 2021.

[5] Frömming, C., et al.: Influence of weather situation on non-CO_2 aviation climate effects: The REACT4C climate change functions, Atmospheric Chemistry and Physics, 21, 9151–9172, https://doi.org/10.5194/acp-21-9151-2021, 2021.

[6] Yamashita, H., et al.: Air traffic simulation in chemistry-climate model EMAC 2.41: AirTraf 1.0, Geoscientific Model Development, 9, 3363–3392, https://doi.org/10.5194/gmd-9-3363-2016, 2016.

[7] Yin, F., et al.: Impact on flight trajectory characteristics when avoiding the formation of persistent contrails for transatlantic flights, 65, Transport Research Part D: Transport and Environment, https://doi.org/10.1016/j.trd.2018.09.017, 2018.

[8] Sperber and Gierens: Towards a more reliable forecast of ice supersaturation: Concept of a one-moment ice cloud scheme that avoids saturation adjustment, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-914, 2023.

[9] Castino, F., et al.: Decision-making strategies implemented in SolFinder 1.0 to identify eco-efficient aircraft trajectories: application study in AirTraf 3.0, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2023-88, 2023.

- Additional information can be found on the following project websites:
  - FlyATM4E: https://flyatm4e.eu/
  - BeCoM: https://www.becom-project.eu

Thank you for your attentions!