Mitigation potential of optimized aircraft trajectories and its dependency on weather patterns

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OBJECTIVE

OBJECTIVE : To investigate how **atmospheric natural variability** affects the potential of **contrail avoidance** and the properties of optimized aircraft trajectories.

MODEL OVERVIEW

- We employ the ECHAM/MESSy **Atmospheric Chemistry (EMAC) model** to simulate a large number of atmospheric conditions, coupled with the air traffic simulator AirTraf, as described in [2].
- The CONTRAIL submodel computes the **potential contrail coverage**, i.e., the fraction of the model grid-box where contrails can form and persist [3].
- The air traffic simulator AirTraf includes the SolFinder module to select a single Pareto-optimal solution, according to the **preference of the decision-maker**.

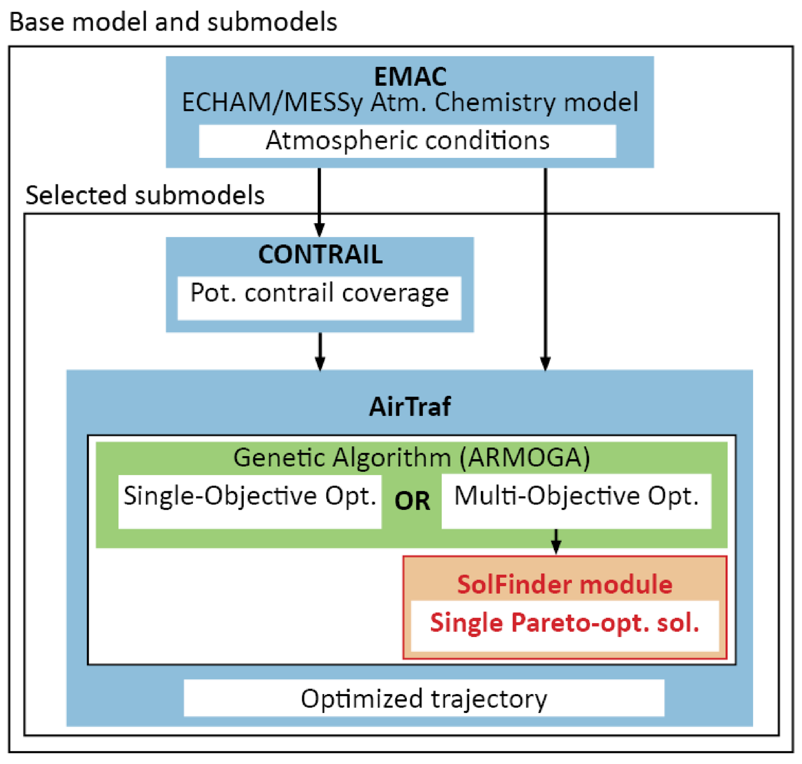
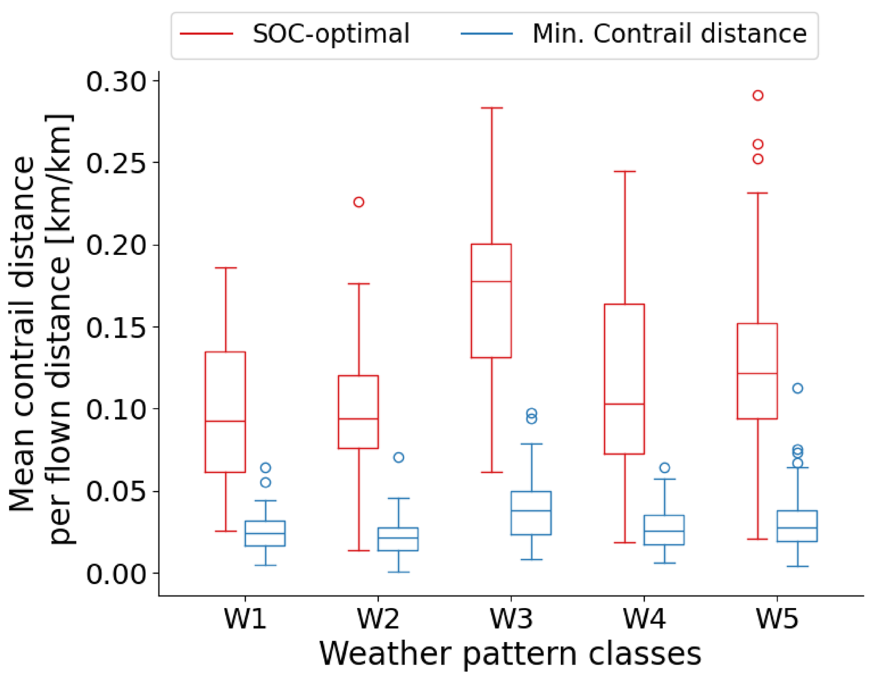
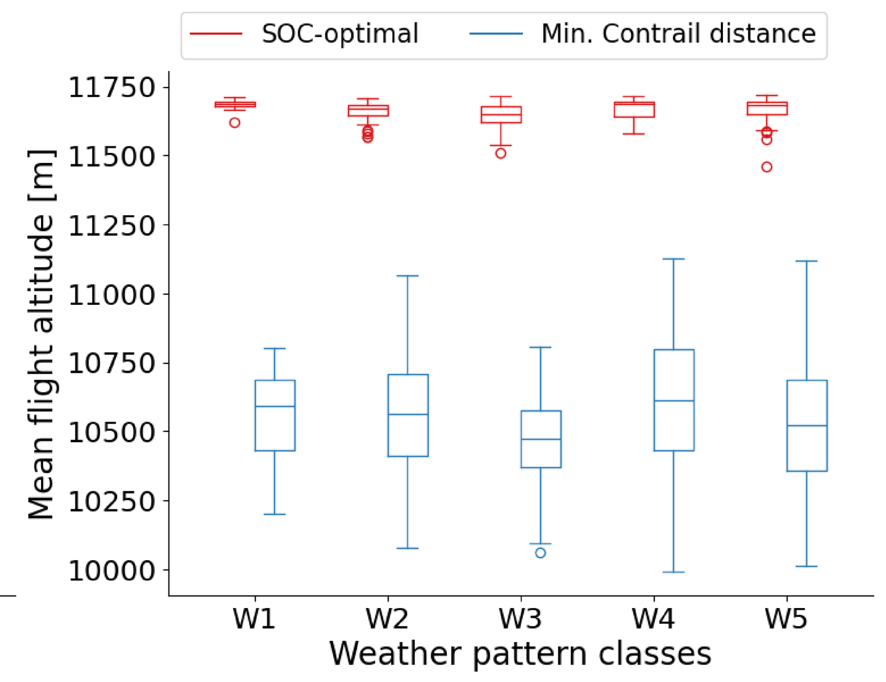


Figure adapted from Fig. 6 in F. Castino et al., Geosci. Model Dev., 2024.

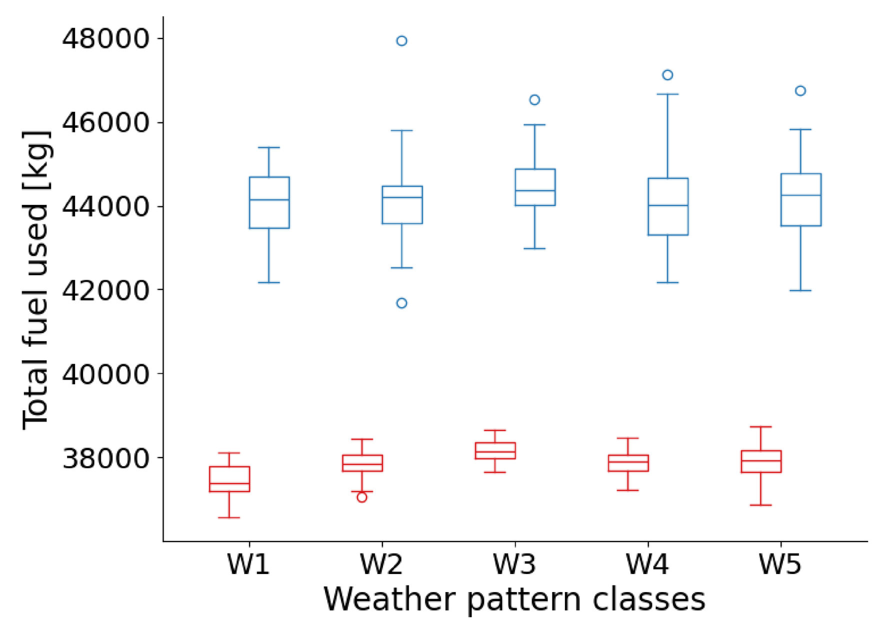
RESULTS - POTENTIAL OF REDUCING CONTRAILS FORMATION AND PROPERTIES OF TRAJECTORIES



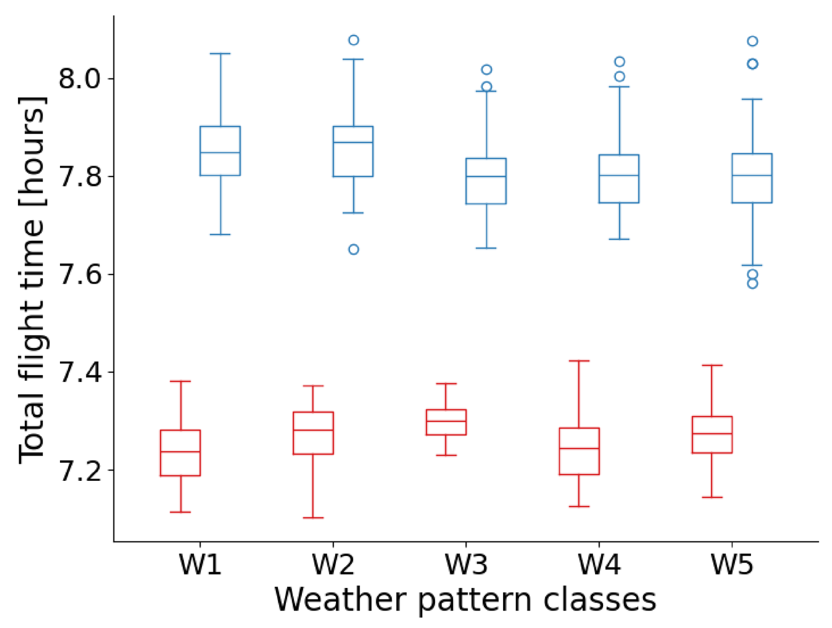
- The highest absolute reduction in contrail distance by changing optimization strategy is found under W3.



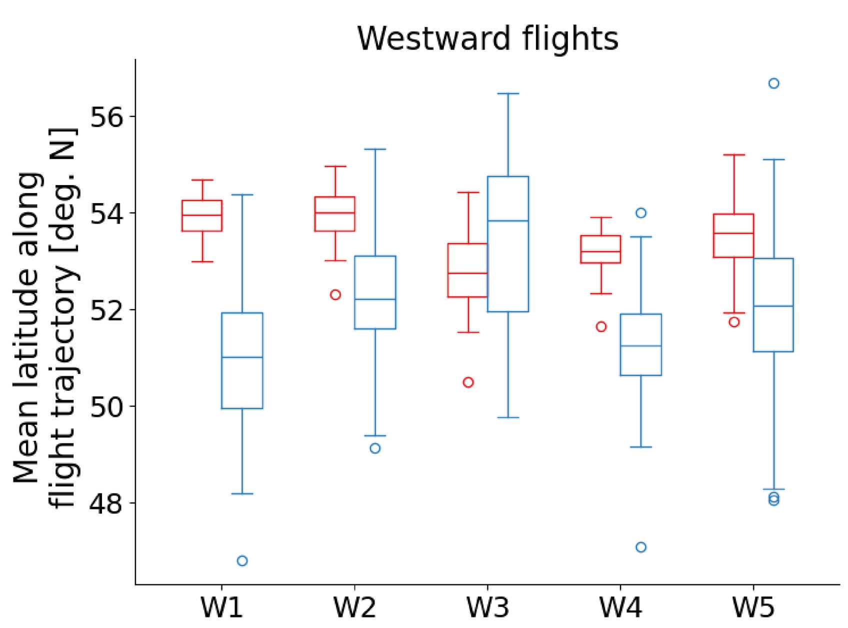
- The lowest aerodynamic drag is found at higher altitudes.
- Minimal contrail distance is achieved flying lower and in a wider range of flight altitudes.



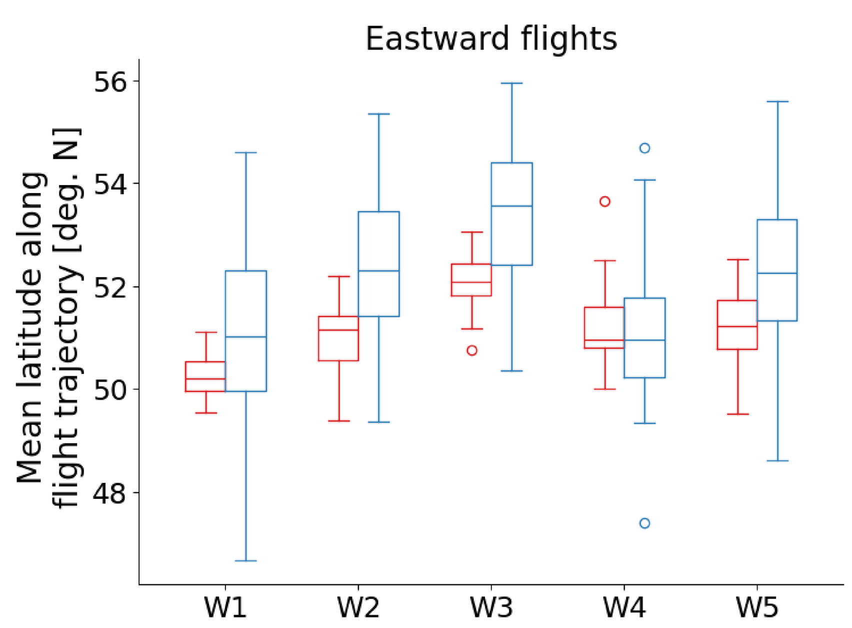
- The fuel used reaches a minimum with W1.
- Its standard deviation across different days almost doubles introducing contrail avoidance.



- The +7.7% change (average) in flight time can be mitigated selecting trade-off solutions using SolFinder [1, 2].



- Cost-optimal westwards flights tend to avoid the jet stream by flying at higher latitudes.
- To avoid contrails, lower latitudes may be selected.



- Eastwards flights show similar tendencies of flying at lower/higher latitudes under different weather types with both optimization strategies.

MOTIVATION

- The **non-CO_2 effects** of a flight on the climate depend on the background atmospheric conditions at the **time, location,** and **altitude** of its emissions.
- This is due to, for example, the possibility of forming persistent contrails, which are only supported within **ice-supersaturated regions** of the atmosphere.
- Therefore, **aircraft trajectories can be optimized** to reduce climate effects of aviation, by avoiding **climate sensitive regions**, e.g. minimizing the flight distance through regions where contrails form and persist [1].
- Aircraft trajectory optimization as operational **climate mitigation strategy** is affected by strong **daily variability** [2].

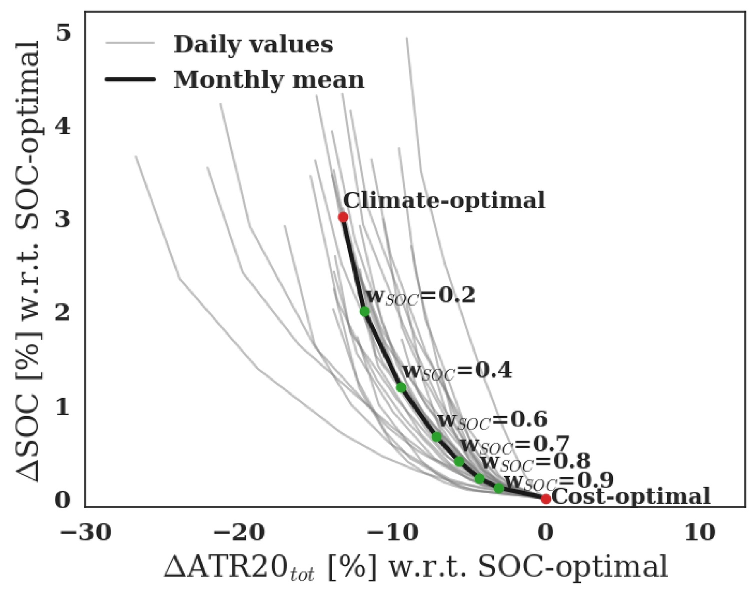


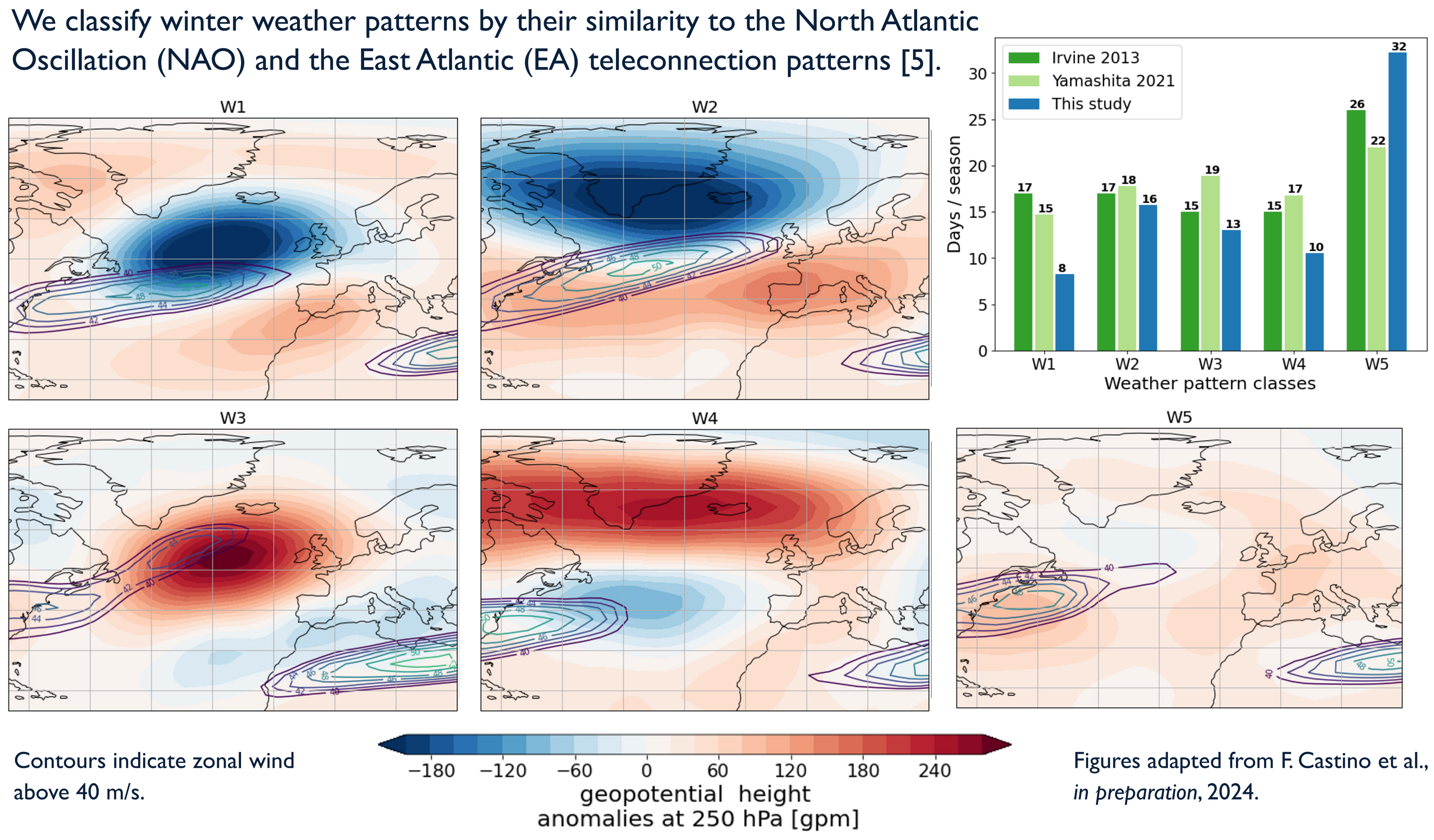
Figure adapted from Fig. 6 in F. Castino et al., Geosci. Model Dev., 2024.

SIMULATIONS SETUP

- Resolution: T42L31ECMWF (2.8° x 2.8°, 31 vertical levels)
- Time step: 12 minutes
- Time coverage: **winter months** from 2015 to 2019
- Air Traffic Sample: 103 routes over **North Atlantic**, A33x aircraft
- Optimization objectives:
  1. minimal **Simple Operating Costs** (SOC), defined as the weighted sum of **fuel used** and **flight time** (reference scenario);
  2. minimal **contrail distance**, defined as the distance flown through regions where contrails can form and persist.

WEATHER PATTERN CLASSIFICATION

We classify winter weather patterns by their similarity to the North Atlantic Oscillation (NAO) and the East Atlantic (EA) teleconnection patterns [5].



Contours indicate zonal wind above 40 m/s.

Figures adapted from F. Castino et al., *in preparation*, 2024.

CONCLUSIONS AND NEXT STEPS

- The **negative regime of the East Atlantic pattern** (W3) results to be linked to higher mitigation potential through contrail avoidance.
- The decision making tool SolFinder will be employed to explore how the weather patterns affect **trade-off solutions** between aircraft trajectories optimization strategies minimizing economic cost and contrail distance, which reduce penalties in terms of fuel used and flight time.
- In the next step, the results presented here will be tested over different scenarios and winter days, comparing our reference scenario with **actual air traffic**, and using data generated from **satellite observation** and **in-flight measurements**.
- Moreover, we will explore the interdependencies of the mitigation potential of different climate effects of aviation (**CO_2, contrails, and NO_x**).

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ACKNOWLEDGMENTS:

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