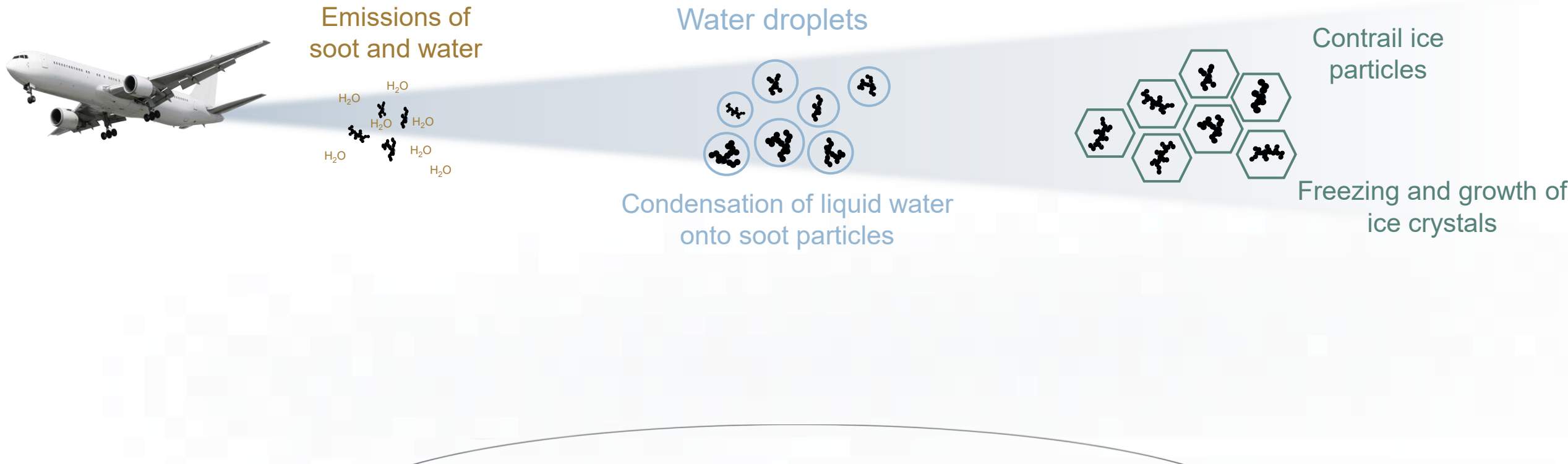


Implementation of Contrail Avoidance in Commercial Flight Planning

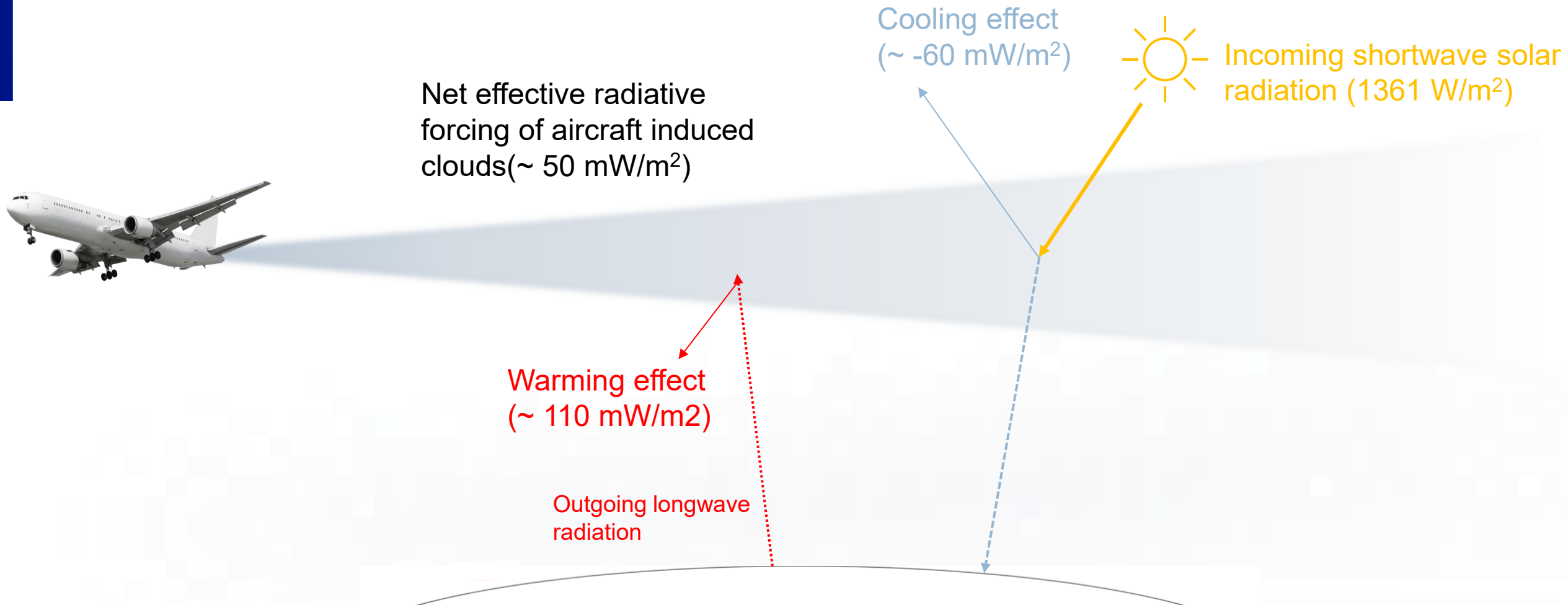
PhD Student: Alejandra Martin Frias
Supervisor/s: Manuel Soler

PhD Aerospace Engineering UC3M
Doctoral Meetings 2026
2nd and 3rd June 2026

Motivation: why contrails matter



Motivation: why contrails matter

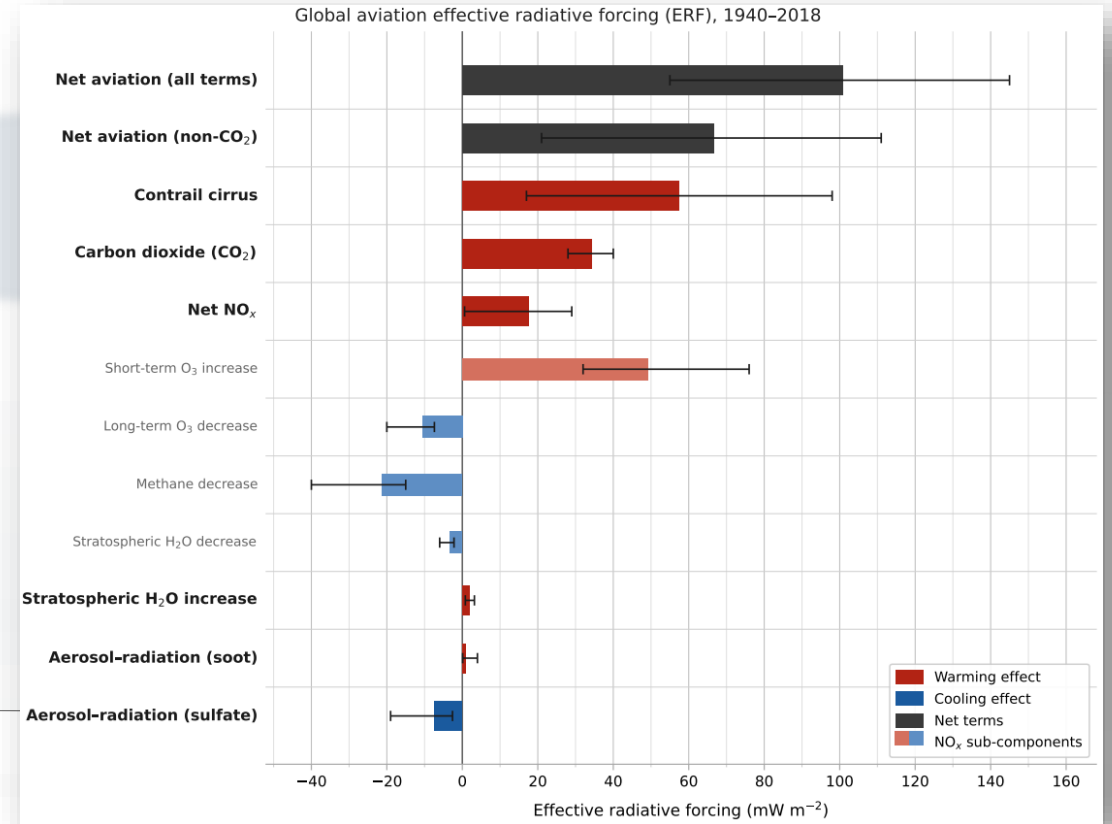




Net effective radiative forcing of aircraft induced clouds (~ 110 mW/m²)

Warming effect
(~ 110 mW/m²)

Outgoing longwave radiation



Flight Operation Strategies for Contrail Avoidance

01

Simulations and analytical approaches

They demonstrated the feasibility of ISSRs avoidance through altitude restrictions

Williams 2002 · Fichter 2005 · Mannstein 2005 · Gierens 2008

03

Development of contrail warming models

Trajectory optimization that targets warming impact, not formation: CCFs, aCCFs, CoCiP & the EF metric

Schumann 2011–12 · Grewe 2014 · Lührs 2021 · Vitali 2021

05

Operational Implementation

Large-scale and multi year analysis • uncertainty quantification • real-world trials • ATM network integration

Teoh 2024 · Dean/Platt/Simorgh 2024–25 · Baneshi 2025 · Sausen 2023 · AAL 2024

Trajectory Optimization Methods

02

Introduction of ISSR forecasts in formal optimisation techniques

Campbell 2008–13 · Sridhar 2011 · Ng 2011 · Wei/Chen 2012 · Lim 2017

Energy Forcing Selective Diversion

04

~2% of flights cause ~ 80% of the warming: we should focus on re-routing only the “big hits”

Teoh 2020 (mitigating & beyond) · Niklaß 2021 (climate charge areas)

Objective 1

Implementation of contrail avoidance in a commercial Flight Planning Software

In the last PhD meetings....

01



Load contrail weather data

Introduction of contrail areas using GRIB data, as a separate weather layer (J/m).

02



Cost based avoidance

$$\min_T \sum_{s \in S(T)} C_{\text{Total}}(s) = \min_T \sum_{s \in S(T)} \left(c_{\text{fuel}}(s) + c_{\text{time}}(s) + c_{\text{delay}}(s) + c_{\text{routeCharges}}(s) + c_{\text{engineCycleCost}}(s) + c_{\text{contrail}}(s) \right)$$

03



Flight trials

They try to stick to the filed flight plan or can adjust if there is contrail data in EFB

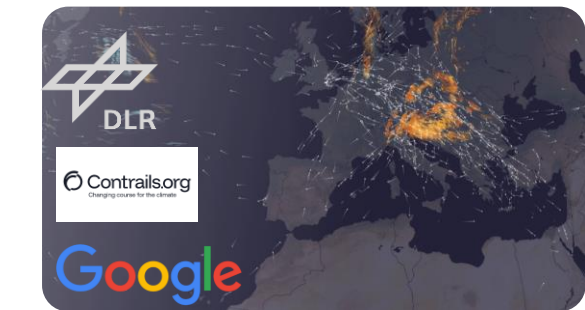
04



Validation and verification

In coordination with Contrails.org, DLR and Google, to improve the prediction models.

Publications: <https://iopscience.iop.org/article/10.1088/2634-4505/ad310c>
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=6341458

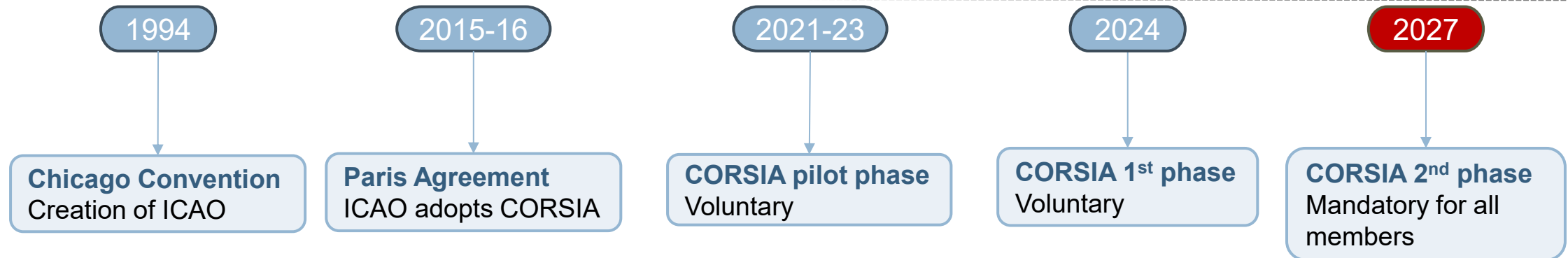


Aviation Climate Regulation: International



ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

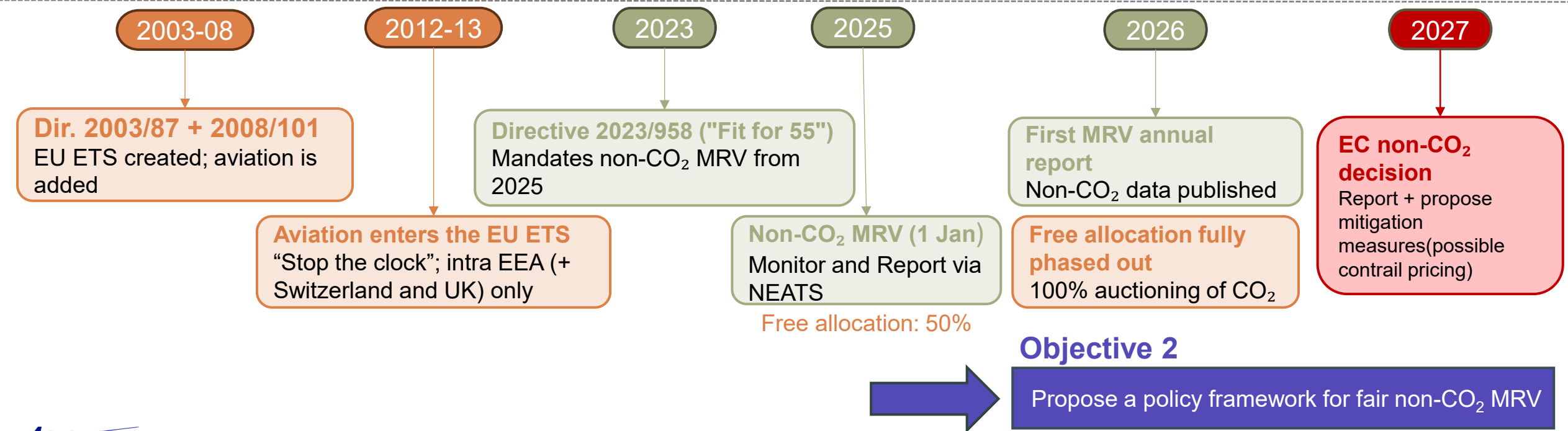
A global ICAO scheme that requires airlines to offset CO₂ emissions growth on international flights by buying carbon credits.



Aviation Climate Regulation: European Union



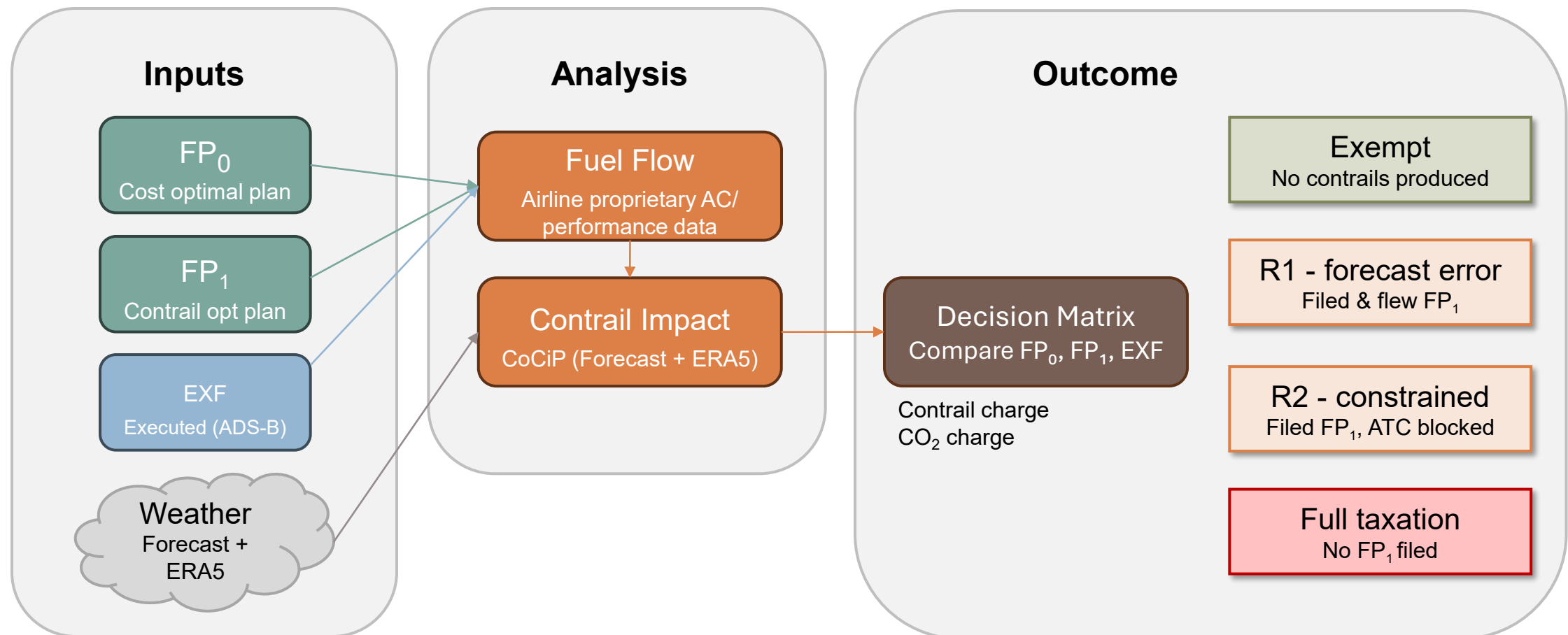
A European cap-and-trade system that makes airlines buy and surrender allowances for the CO₂ they emit on flights within Europe, with the cap shrinking every year



From 2027, airlines will be taxed:

- CO₂ → CORSIA (international) and EU ETS (EEA)
- Non-CO₂ → Potentially

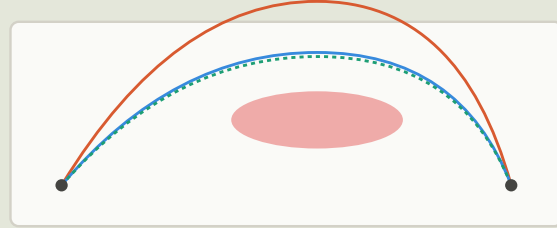
Assuming the MRV will follow the same structure as the CO₂ MRV, how can we make taxation fairer for airlines?



— FP_0 cost-optimal — FP_1 contrail-optimal — EXF executed — Warming ISSR

Flight 1 — LEPA → EDDV

Filed and flew FP_1 · contrails avoided



EFcontrail (EXF): -26.9×10^{13} J (net cooling)

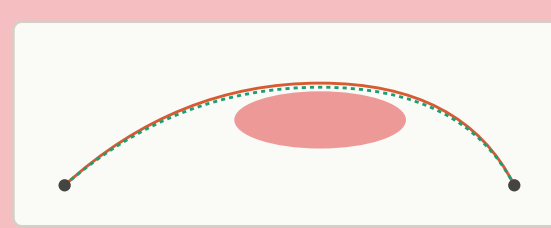
Contrail charge: none

CO₂ charge: Δ CO₂ exempt

→ **Net saving: €505 (-30%)**

Flight 2 — GMAD → EDDL

No FP_1 filed · flew through ISSR



EFcontrail (EXF): $+46.7 \times 10^{13}$ J

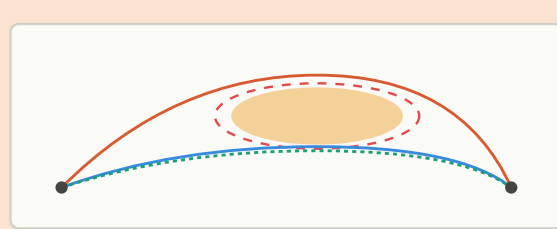
Contrail charge: full (131.8 t CO₂e)

CO₂ charge: full

→ **Penalty of inaction: €2,626**

Flight 3 — LPMA → EDDS

Filed & flew FP_1 · forecast missed an ISSR



EFcontrail (EXF): $+0.025 \times 10^{13}$ J (99.9% ↓)

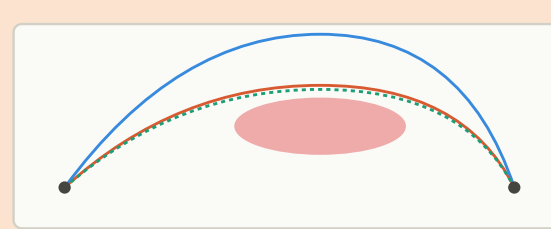
Contrail charge: R1 reduction (80% off)

CO₂ charge: Δ CO₂ exempt

→ **Net saving: €1,349 (-38%)**

Flight 4 — EDDL → GCLP

Filed FP_1 · ATC forced FL350 instead of FL370



EFcontrail (EXF): $+0.067 \times 10^{13}$ J

Contrail charge: R2 reduction (40% off)

CO₂ charge: Δ CO₂ exempt · extra fuel from ATC

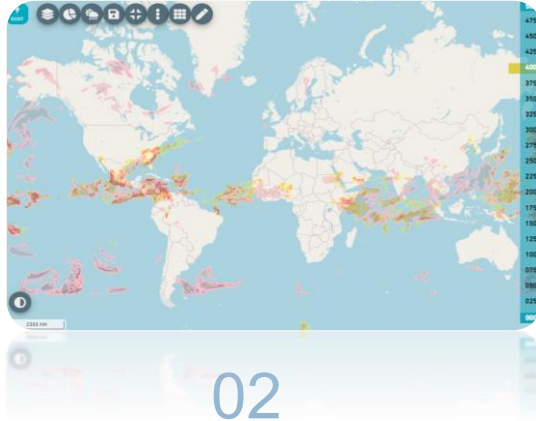
→ **Net cost: +€215 (vs full charge)**

In comparison to NEATS:

- Uses real airline performance data, not generic models
- Recognises mitigation intent, not only contrail outcomes
- Credits ATC constraints instead of treating them as inaction
- Applies reductions for model and forecast uncertainty
- Exempts extra CO₂ burned during avoidance attempts

Implementation of the CoCiP and Google

Implementation in commercial flight planning system



It is possible to do contrail avoidance in real life?

- Operations
- Weather and
- Uncertainty

Flight Trials

Conferences

1. Scientific conferences
2. Aviation climate & policy forums
3. Industry & ATM forums
4. Technical working groups & workshops
5. Airline & Industry events

01



02

Flight simulations

Publication of first results

1. Conference paper: ATM Seminar 2023
2. A Martin Frias *et al* 2024 *Environ. Res.: Infrastruct. Sustain.*
3. A Martin Frias *et al* 2026 (preprint) *Journal of Air Traffic Management*

03

MRV policy proposal

how can we make taxation fairer for airlines?

1. A Martin Frias *et al* 2026 (preprint) *Transportation Research Part A: Policy and Practice*

04



05

PhD Thesis

Target end of June

Thank you!
Questions?

Implementation of Contrail Avoidance in Commercial Flight Planning

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