<u>12:00-12:30</u> Presentation:

Tracking aviation's worldwide emissions – with a special focus on Denmark





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Tracking aviation's worldwide emissions: Denmark in Focus

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International Council on Clean Transportation

Perform and translate research into science-based policy recommendations



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Key Takeaways from this presentation

2023 saw 33% lower contrail impact than in 2019

75% of contrail warming in 2023 came from high-income countries

Aviation (CO₂ + contrails) represents **one-third** of Denmark's transport-related emissions

Day-to-day variation in fuel burn far exceeds expected fuel burn penalty from contrail avoidance



Methods

How did we do this analysis?



~38M commercial flight trajectories are analyzed

Commercial Trajectories



Multiple datasets are fused together for this analysis

ERA 5 Weather data

Spire ADS-B data

BADA 3 aircraft performance model

Payload data



Model Validation

Why should we trust these results?



Fuel consumption validation datasets: ANAC & CORSIA

ANAC Dataset

Scope: Brazilian airlinesSpecificity: Fuel burn per flight

Median error by flight: 3.7% Total percent difference: 3.2%

CORSIA

Scope: All international flights **Specificity:** CO₂ emissions per state-pair

Median error per region pair: -5.5% Total percent difference: -3.4%





What do we learn from this analysis?



Gridded total 2023 contrail energy forcing (1°x1° resolution)



THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Global flight and emissions comparison to Teoh et al. 2024

Annual Statistics	Units	2019	2023	2019 vs. 2023	
Number of flights	-	40,220,293	37,897,743	-6%	Covid recovery is
Annual flight distance flown	10º km	60.94	57.74	-5%	not complete
Annual fuel burn	10 ⁹ kg	280	255	-9%	Aviation operations
Fuel burn per flight distance	kg/km	4.596	4.414	-4%	have become more efficient
Flight distance forming persistent contrails	%	4.95	5%	+1%	Contrail incidence rate was similar
Annual mean contrail cirrus net RF	mW m ⁻²	62.1	41.5	-33%	Global contrail
GWP 20		1.23	0.82	-33%	impact in 2023 was two-thirds of 2019
GWP 100		0.33	0.22	-33%	levels





Contrail warming is primarily a High Income country problem

	Contrail warming (% of global impact)	Country with highest impact in each group
High income	76%	USA
Upper-middle income	19%	China
Lower–middle	5%	India
by the Worl	d Bank based on gross na	tional income
Low income	0.5%	Ethiopia



Denmark in focus



Denmark's contrail impact relative to CO₂ emissions is higher than the EU average



Denmark's aviation industry in 2023

Annual Statistics	Units	EU	Denmark	Denmark vs. EU
Number of flights	-	6,374,970	171,031	2.3%
Annual CO2 emissions	10 ⁹ kg	130	2.5	1.9%
Energy Forcing from contrails	10 18 J	146	3.1	2.3%
Contrail GWP 20		1.19	1.38	+15%
Contrail GWP 100		0.32	0.37	+15%

27% of all flights departing Denmark formed contrails in 2023 The Copenhagen – Bangkok route contributed the most contrail warming and CO_2 emissions in 2023



Denmark's Aviation impact in context

Aviation (CO₂ + contrails) represents **one-third** of Denmark's transport-related emissions

Being in higher latitudes increases the incidence of contrails on flights departing Denmark

Denmark's contribution to contrail warming is higher than the European average



Danish Energy Agency, "Denmark's Global Climate Impact", 2024, Link

What can we do about it?



Fuel burn penalty should not a barrier to contrail avoidance

Fuel consumption on a route varies day-today based on wind, payload, and trajectory.

AA trials achieved 64% reduction in contrails with a fuel burn penalty of 2%

Looking at JFK-CDG, nearly 40% of flights used 2% more fuel than the mean.



Mean fuel burn = 43 tonnes σ = 3.8 tonnes (8.6%)



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Aviation (CO₂ + contrails) represents **one-third** of Denmark's transportrelated emissions

Day-to-day variation in fuel burn exceeds expected fuel burn penalty from contrail avoidance



Questions?



Model structure



ANAC and BADA fuel burn are highly correlated, but not perfect for all aircraft



Median error by flight: 3.7% Total percent difference: 3.2%

Our methods underestimate CORSIA CO₂

- Covers only international aviation
- Country airport assignment is affected by territorial disputes
- Mix of reported and modeled data
- Some data is marked confidential and not included in state-pair totals

CORSIA International total = 511 Mt BADA International total = 495 Mt (-3.4%)





The US and EU are the biggest contributors to contrail warming



Contrails favor high latitude and equator, but not mid-latitude ~30° (Hadley cells)

The non-CO₂ multiplier for a flight *i* on route *j* is defined as:

 $x_i = \frac{EF_{contrail,100,i} \times \frac{ERF}{RF}}{EF_{CO_2,100,j}}$



Fuel burn seasonality closely follows the number of flights, EF_{contrail} peaks during N. hemispheric winter





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