11:35-12:15 Presentation:

How can low-aromatic fuels mitigate contrails

COPENHAGEN CONTRAILS CONFERENCE
25-26 March 2025 • Scandic Copenhagen

Christiane Voigt
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HOW CAN LOW-AROMATIC FUELS MITIGATE CONTRAILS?

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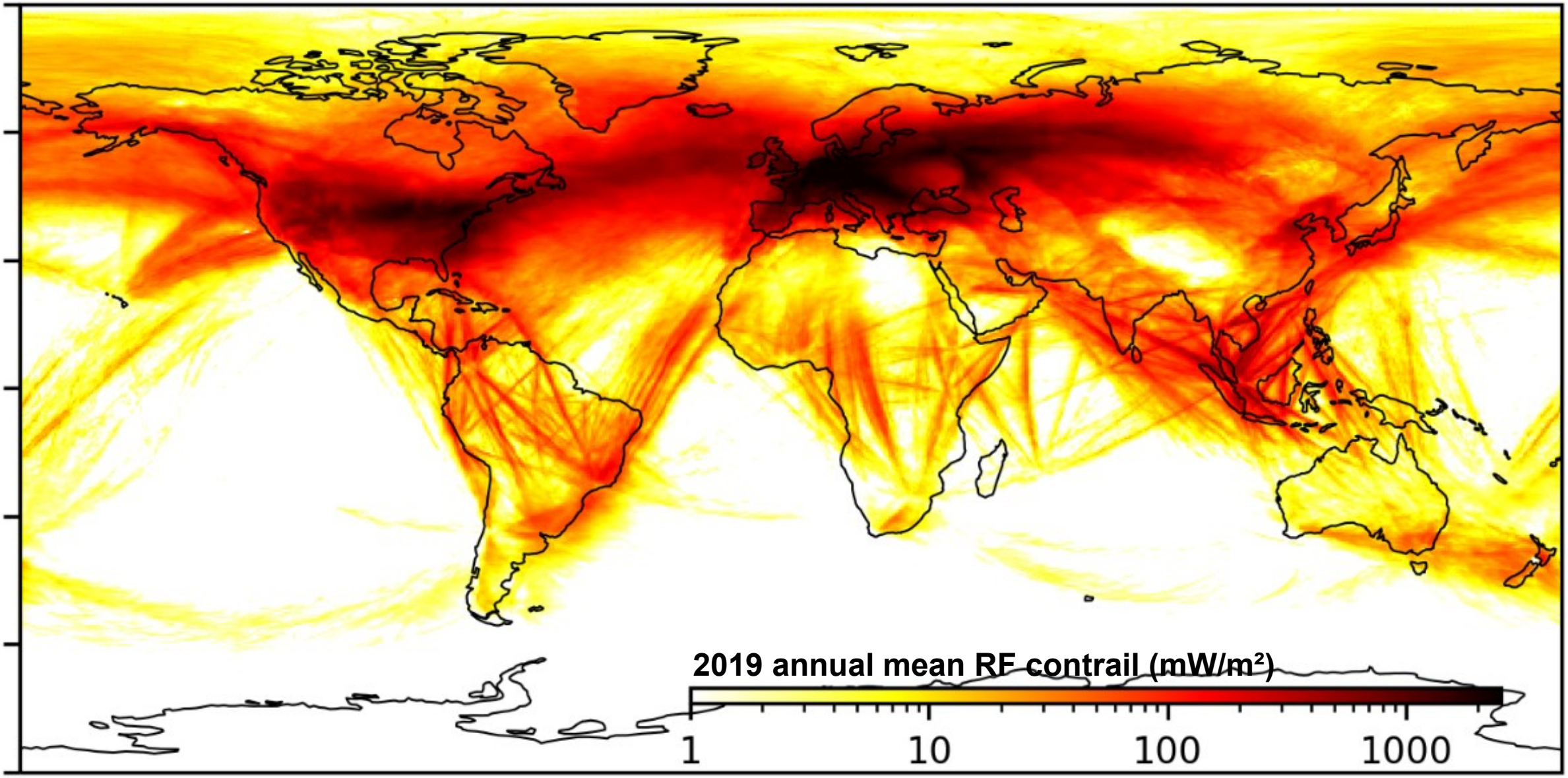
Stefan Kaufmann, Daniel Sauer, Tina Jurkat-Witschas, Gregor Neumann, Deniz Menekay, Magdalena Pühl, Monika Scheibe, Simon Braun, Mara Montag, Elisabeth Horst, Andreas Dörnbrack, Georg Dietz, Stefan Schröder, Marina Schimpf, Nina Gaiser, Tobias Grein, Simon Kirschler, Dennis Piontek, Luca Bugliaro, Vanessa Santos-Gabriel, Marlin Juchem, Sigrun Matthes, Kai Widmaier, Alexander Lau, Julian Solzer, Zarah Zengerling

DA: Regina Pouzolz

TUlfly: Devaiah Nalianda, Christoph Todt

The challenge – the contrails climate effect



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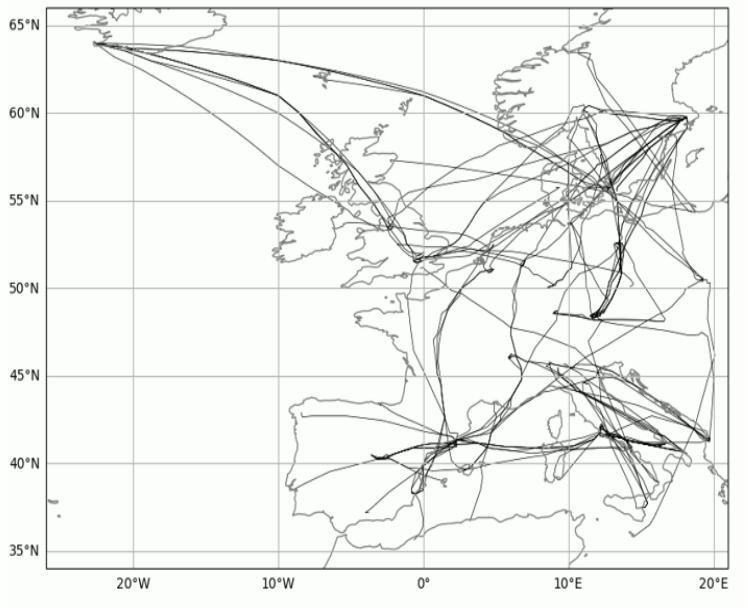
Teoh, Engberg, Schumann, Voigt, Rohs, Shapiro, Stettler, ACP, 2024

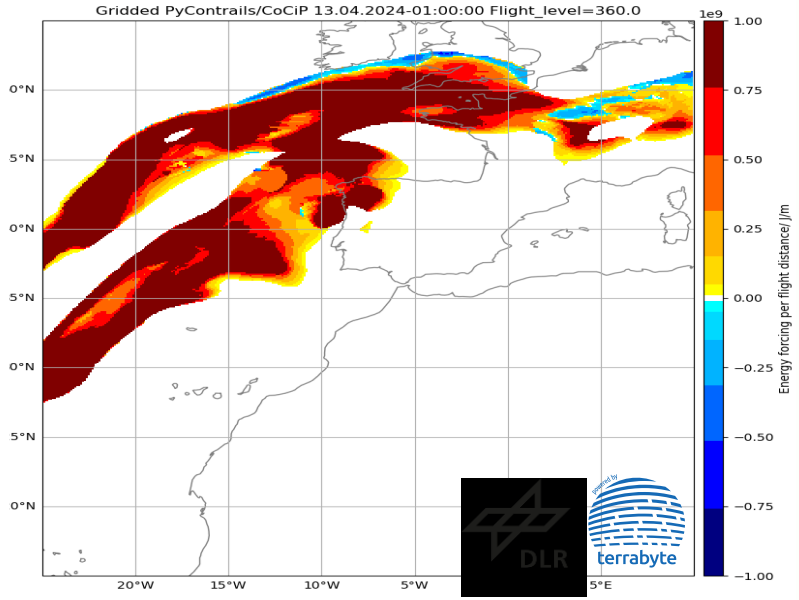
The Contrail Model COCIP (Contrail Cirrus Prediction Tool)

- Original CoCiP fortran version by Schumann, 2012
- Pycontrails/CoCiP platform by Breakthrough, Imperial
- Pycontrails/CoCiP science application platform now on DLR terabyte cluster

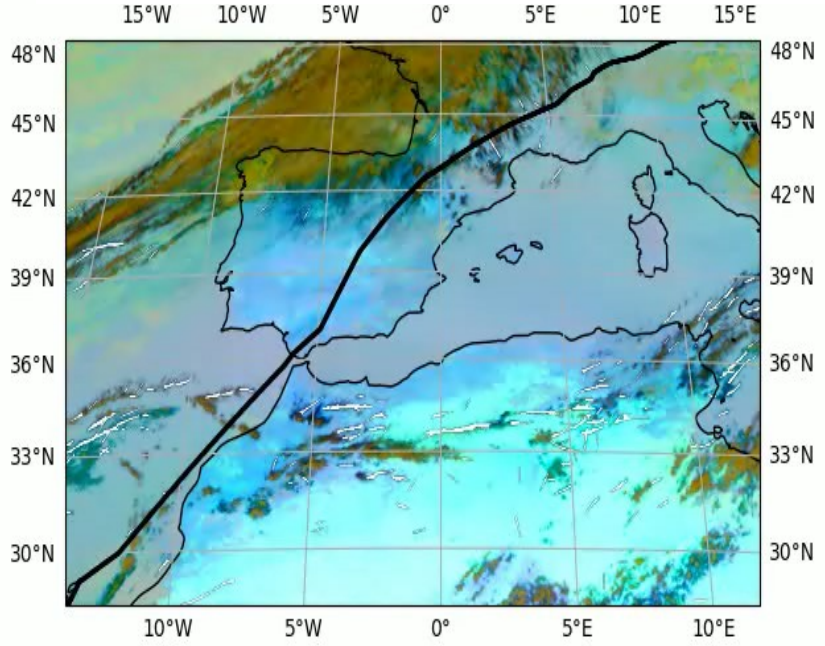
COCIP trajectory mode



COCIP grid mode



MSG/MTG Satellite data evaluation



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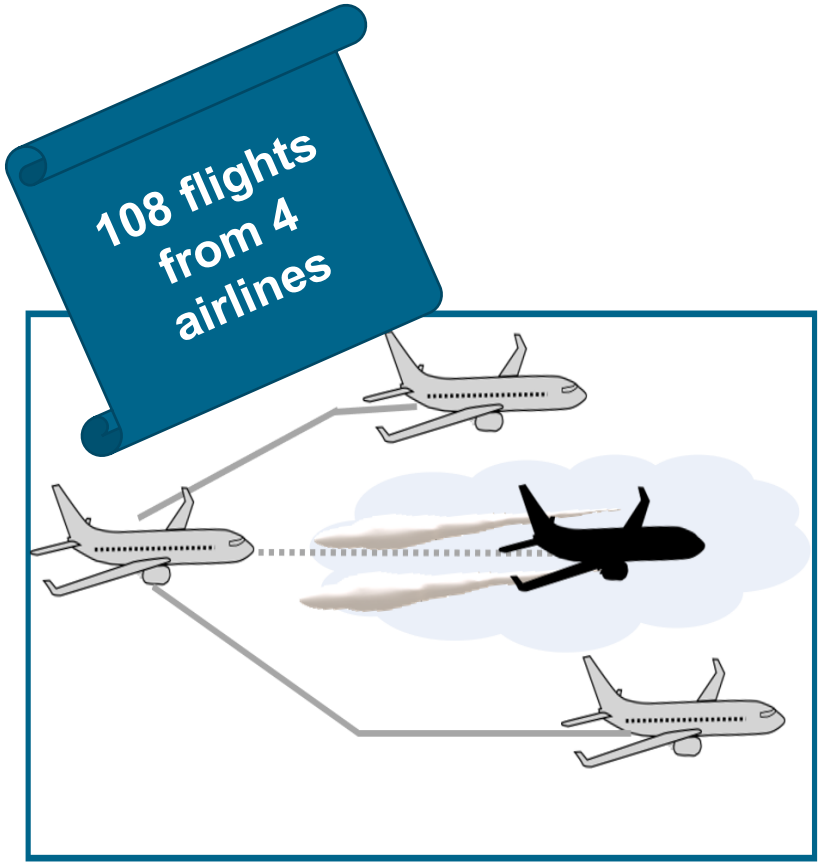
German AKKL 100-flights programme to test feasibility of contrail avoidance

Partner



108 contrail avoidance flights				
	TUI fly	Lufthansa	condor	Deutsche Post DHL
Avoidance	25	43	23	17
Observation	11	42	0	8
61 observation flights				

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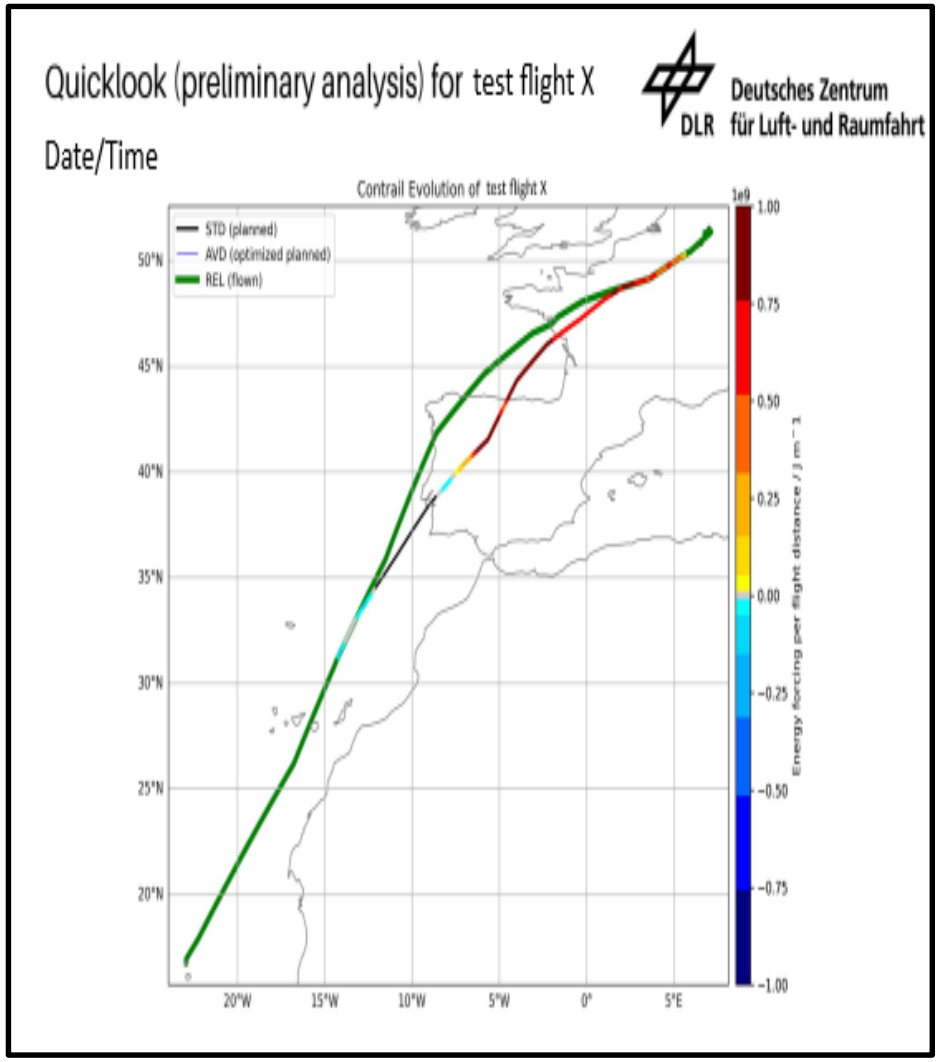
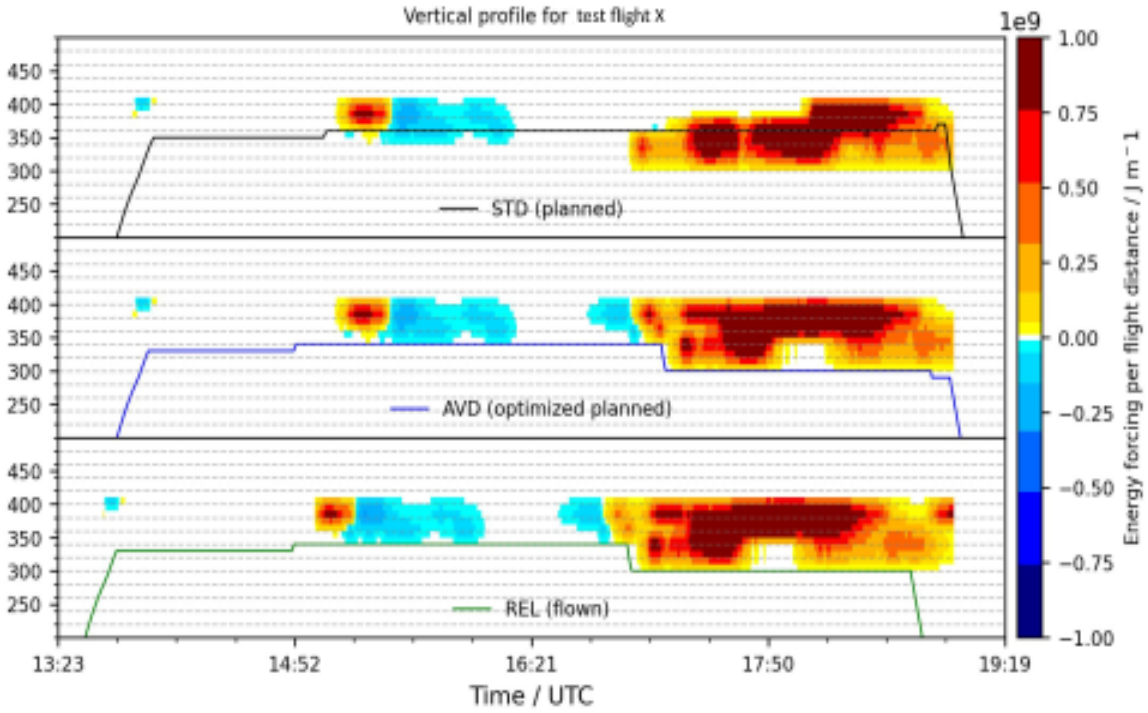
Single flight analysis





	planned	optimized	flown	optimized - planned	%	flown - optimized	%
Flight time / minutes	344.4	343.4	341.1	-1.0	-0.3	-2.3	-0.7
Total emitted CO_2 / t	$4.7 \cdot 10^1$	$4.9 \cdot 10^1$	$4.8 \cdot 10^1$	$1.9 \cdot 10^0$	4.1	$-3.0 \cdot 10^{-1}$	-0.6
CO_2 + CO_2eq for GWP20 / t	$3.1 \cdot 10^3$	$4.9 \cdot 10^1$	$4.8 \cdot 10^1$	$-3.1 \cdot 10^3$	-98.5	$-3.0 \cdot 10^{-1}$	-0.6
CO_2 + CO_2eq for GWP50 / t	$1.5 \cdot 10^3$	$4.9 \cdot 10^1$	$4.8 \cdot 10^1$	$-1.5 \cdot 10^3$	-96.8	$-3.0 \cdot 10^{-1}$	-0.6
CO_2 + CO_2eq for GWP100 / t	$8.9 \cdot 10^2$	$4.9 \cdot 10^1$	$4.8 \cdot 10^1$	$-8.4 \cdot 10^2$	-94.6	$-3.0 \cdot 10^{-1}$	-0.6
CO_2 + CO_2eq for rATR20 / t	$5.0 \cdot 10^3$	$4.9 \cdot 10^1$	$4.8 \cdot 10^1$	$-5.0 \cdot 10^3$	-99.0	$-3.0 \cdot 10^{-1}$	-0.6
Energy forcing / J	$1.3 \cdot 10^{15}$	$0.0 \cdot 10^0$	$0.0 \cdot 10^0$	$-1.3 \cdot 10^{15}$	-100.0	$0.0 \cdot 10^0$	nan

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Fleet statistics from TUIfly 17 flights, preliminary

	Planned	Optimized	Flown	Optimized – Planned	%	Flown – Optimized	%
Flight time per flight / min	225.3	228.0	224.3	2.7	1.2	-3.8	-1.7
CO_2 per flight / t	$3.0 \cdot 10^1$	$3.1 \cdot 10^1$	$3.0 \cdot 10^1$	$7.5 \cdot 10^{-1}$	2.5	$-4.8 \cdot 10^{-1}$	-1.6
CO_{2e} GWP20 per flight / t (CO_2+GWP20contrail)	$5.6 \cdot 10^2$	$1.7 \cdot 10^2$	$1.6 \cdot 10^2$	$-3.9 \cdot 10^2$	-70.0	$-4.5 \cdot 10^0$	-2.7
CO_{2e} GWP100 per flight / t (CO_2+GWP100contrail)	$1.7 \cdot 10^2$	$6.8 \cdot 10^1$	$6.6 \cdot 10^1$	$-1.1 \cdot 10^2$	-60.8	$-1.6 \cdot 10^0$	-2.3

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Preliminary 100-flights demo trial assessment
– What have we learned so far?

- **108 contrail avoidance + 61 observation flights by 4 German Airlines (TUIfly, LH, CONDOR, DHL)**
- **Here, single flight/fleet evaluation for one airline (TUIfly) with one model (CoCiP)**
- **On average, 60-70% estimated reduction in total climate effect (CO_{2e}=CO_2+contrails, 17 flights)**
- **1-2% change in flight time or direct CO_2 emissions, within range of normal operations**

→ **Feasibility of operational contrail avoidance with positive climate effect documented** (see also Sonabend et al., Nature Eng., 2025)

→ **Additional CO_2 is not the problem for climate** (see also Martin Frias et al., 2024)

→ **The choice of the metric does not prevent the start of measures (affects climate costs)** (Borella, 2024)

→ **High quality data improves the analysis**

→ **400 more flights planned within EU project A4CLIMATE**

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DLR Expertise Ground & In-Flight Emission and Contrail Campaigns

2008 CONCERT

2011 CONCERT-II

2014 ACCESS

2017 WeCare

2018 NDMAX/ECLIF-II

1994 SULFUR

Falcon & ATTAS

Figure 1. The contrail forming aircraft at FL 299, 1024 UTC (digitized photo). The sun is about 40° to the left, giving higher contrast for the left than for the right contrail.

First tests of fuels with different sulfur content

Busen & Schumann, 1995
Schumann et al., 1998, Voigt et al., 2010;2011

2015 ECLIF

DLR/Sasol
Falcon & ATRA

Emission measurements behind DLR ATRA with semi synthetic fuels

Voigt et al., 2021, Kleine et al., 2019
Moore et al., 2017;
Bräuer et al., 2021a&b

2021 ECLIF3

DLR/AIRBUS/Rolls-Royce/
NRC/Neste
Falcon & A350

First emission measurements behind Airbus A350 with RR Trent-XWB engines and 100% SAF (HEFA)

Märkl et al., 2024; Dischl et al., 2024; Harlass et al., 2024
Yue et al., 2024

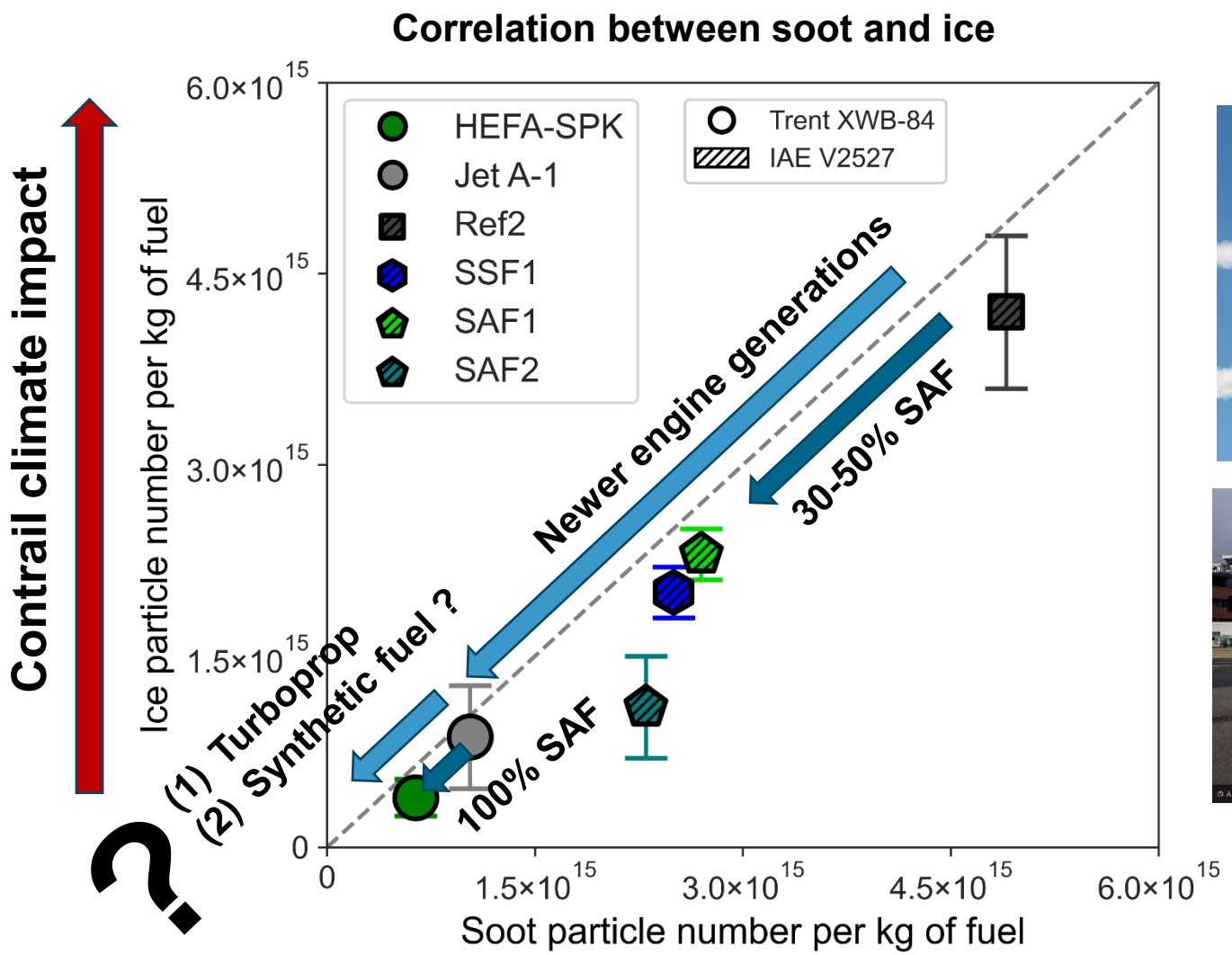
2021 & 2023 VOLCAN
2023 ECO-D

DLR/AIRBUS/Safran/Dassault/ONERA
Falcon & A319neo, A321neo
NASA/BOEING/UNITED/FAA/MS&T/CNR/MIT
DC8 B737MAX

Emission measurements behind A321neo and B737max with Leap1A/ new Leap 1B engines and 100% SAF (HEFA), low sulfur Jet A-1

Ms in prep

Low aromatic fuels reduce particle emissions & contrails



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Voigt et al., Nat. Comm. Earth Env. 2021; Bräuer et al., ACP, 2021; Märkl et al., ACP, 2024; Dischl et al., ACP, 2024

SAF: The LUFO UPLIFT CLIM0ART campaign

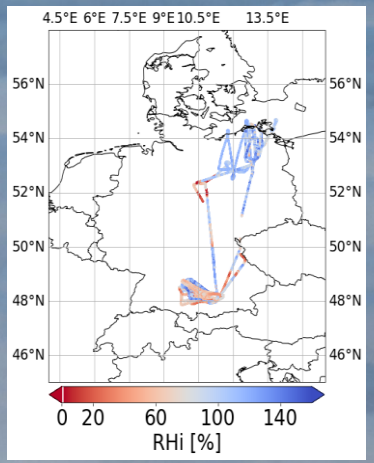
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages
DLR
DEUTSCHE AIRCRAFT

sasol

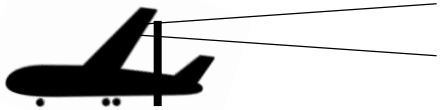
→ How much does a turboprop engine emit at cruise altitudes?

→ Reference for short/mid range turboprop aircraft

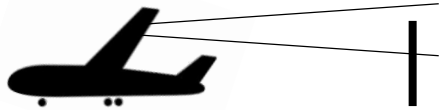
→ How much does 100% synthetic e-fuel (PtL proxy) change emissions and contrails?



Ground & In-Flight Measurements for complete overview

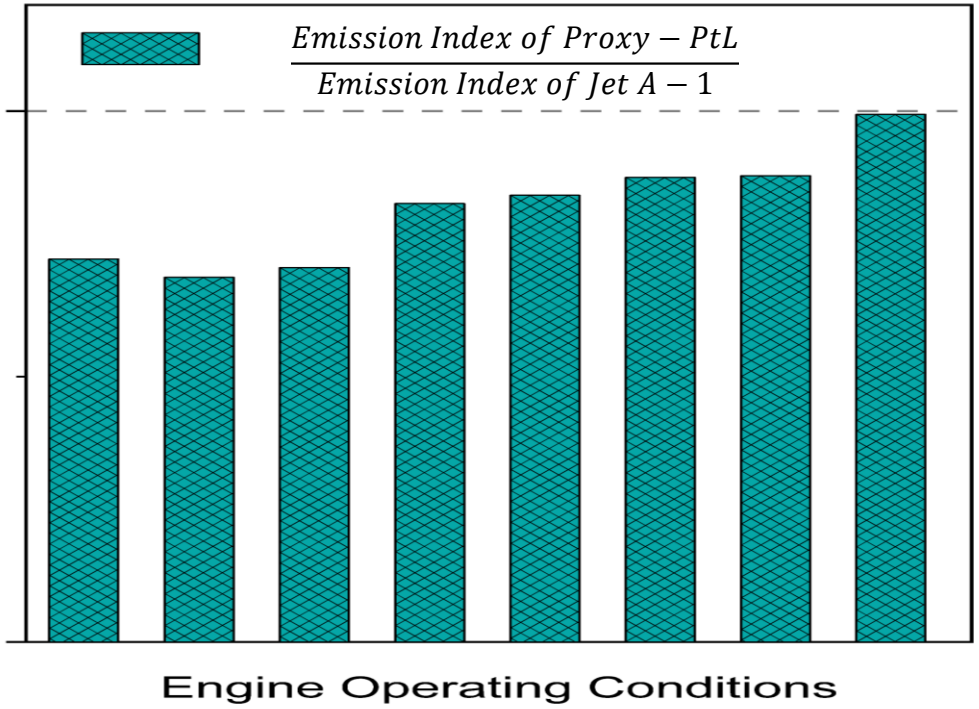


Engine Exit (0 – 50 cm)
Combustion emissions



Far-field (< 30 m)
aged emissions

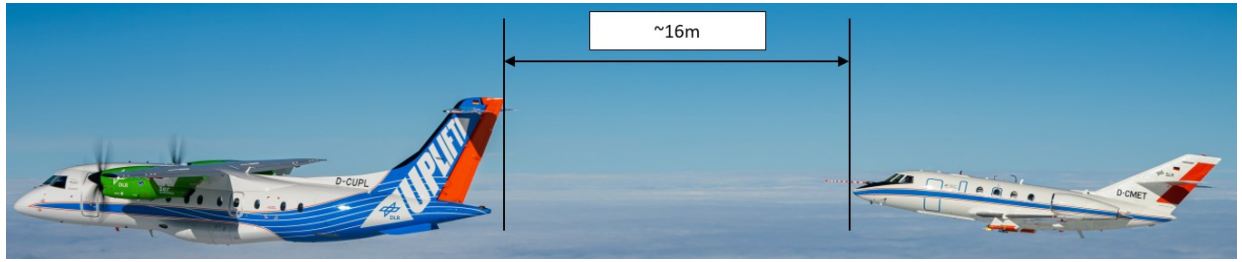
3 weeks of ground measurements at different thrust settings

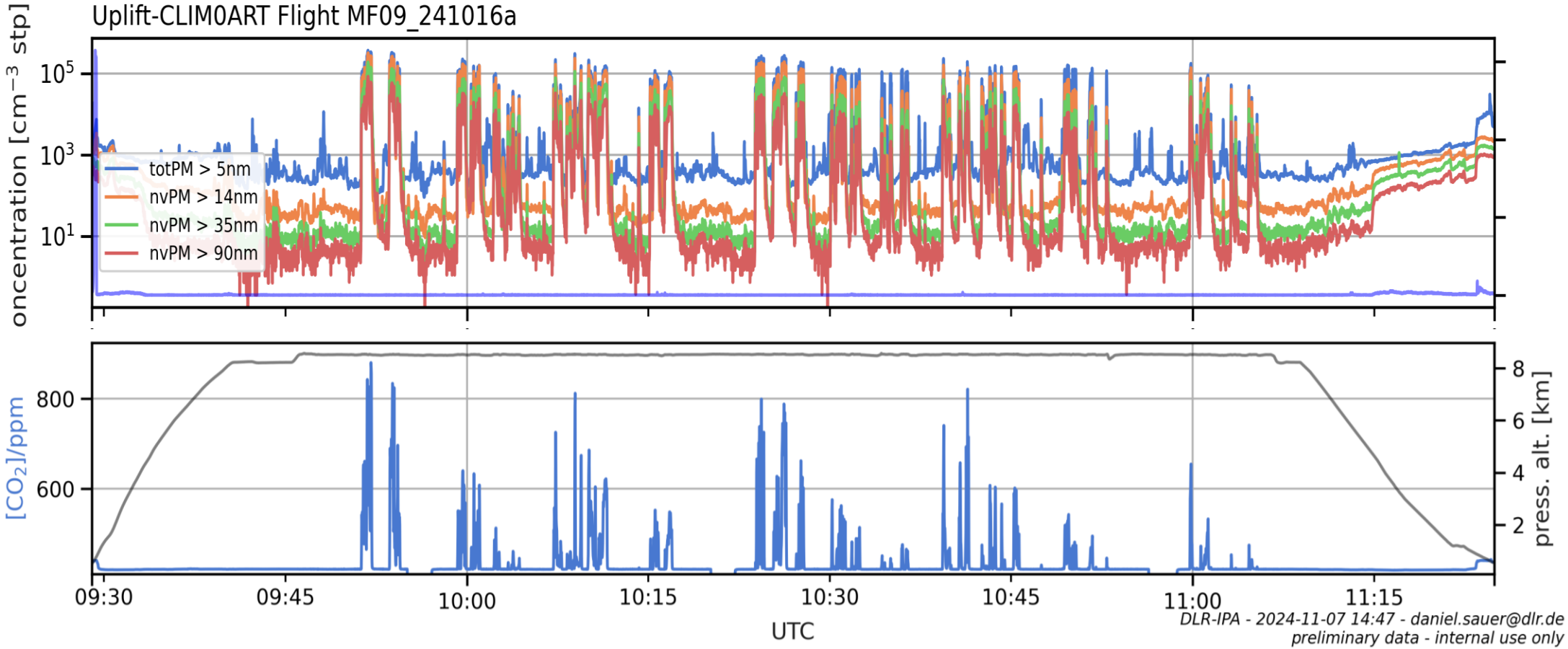


nvPM Emission index/kg-fuel burned for different engine operation conditions

T. Grein, N. Gaiser, DLR, Institute of Combustion Technology

Emission measurements behind turboprop with e-fuels





Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

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Contrail measurement behind turboprop with e-fuel

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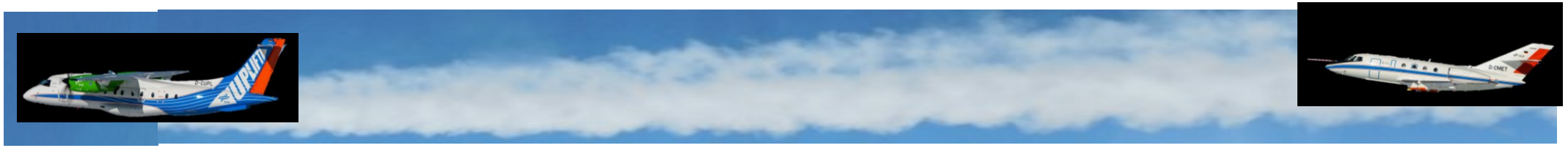

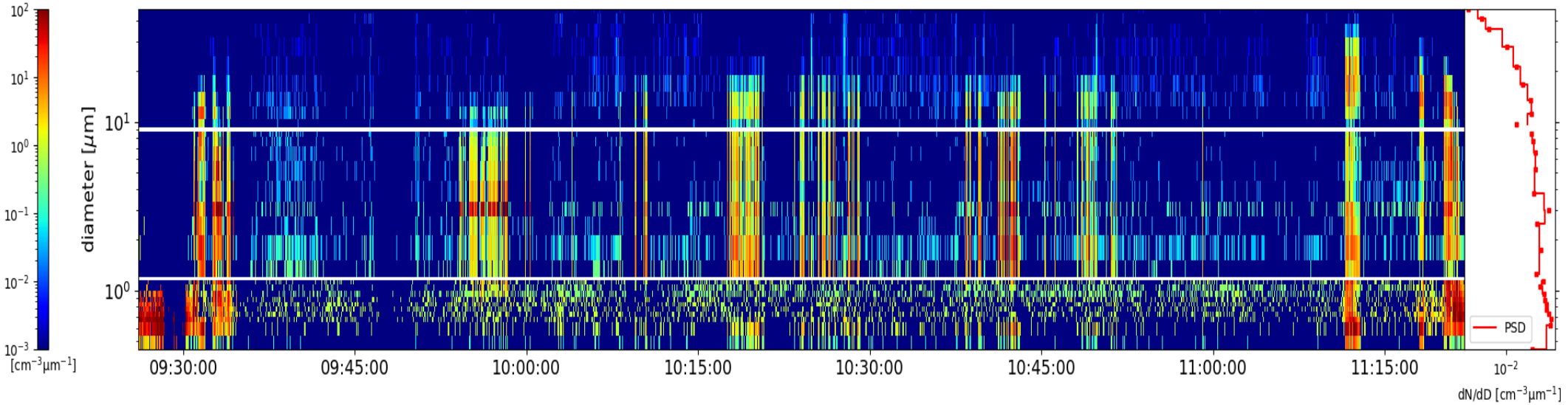

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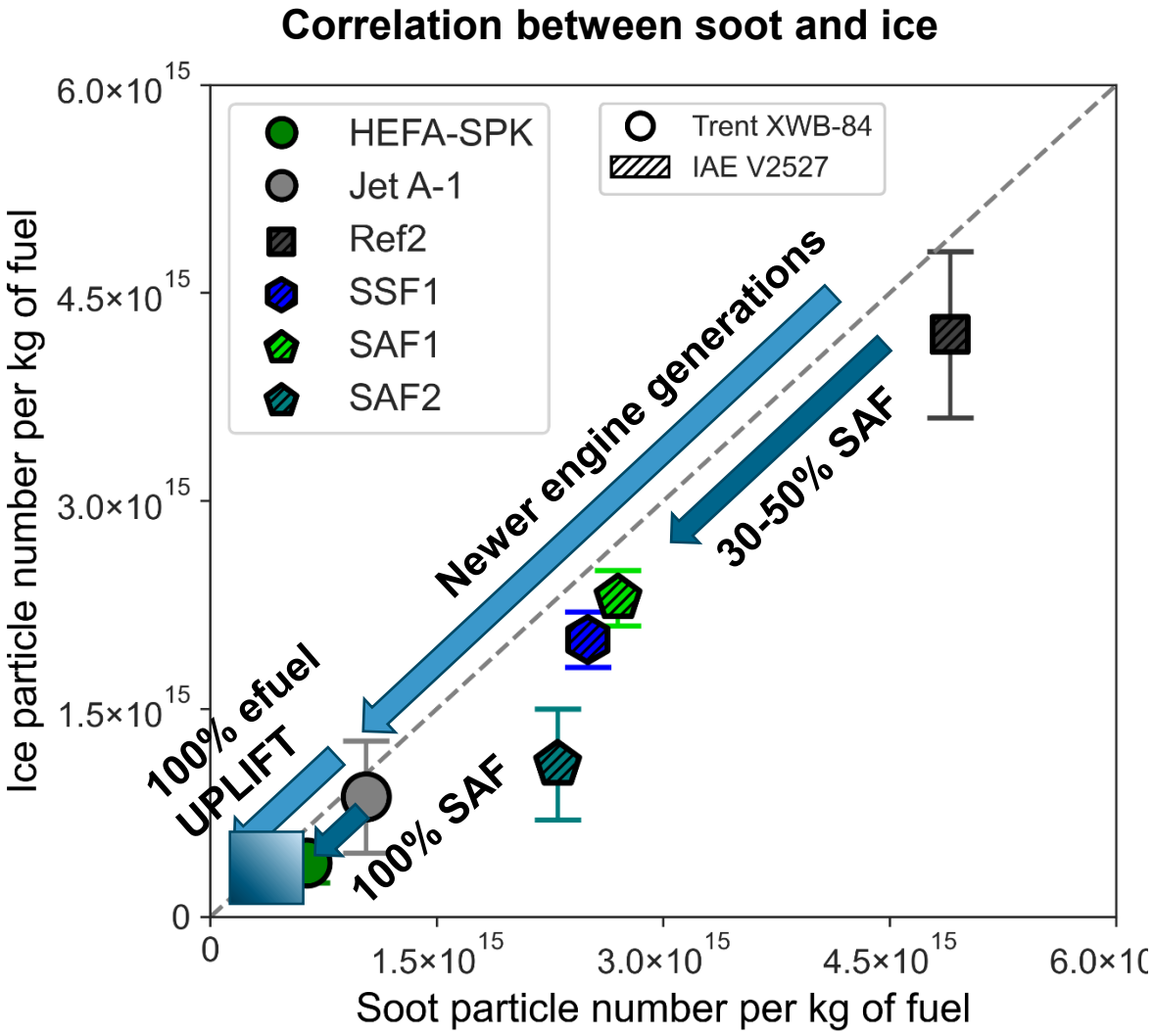
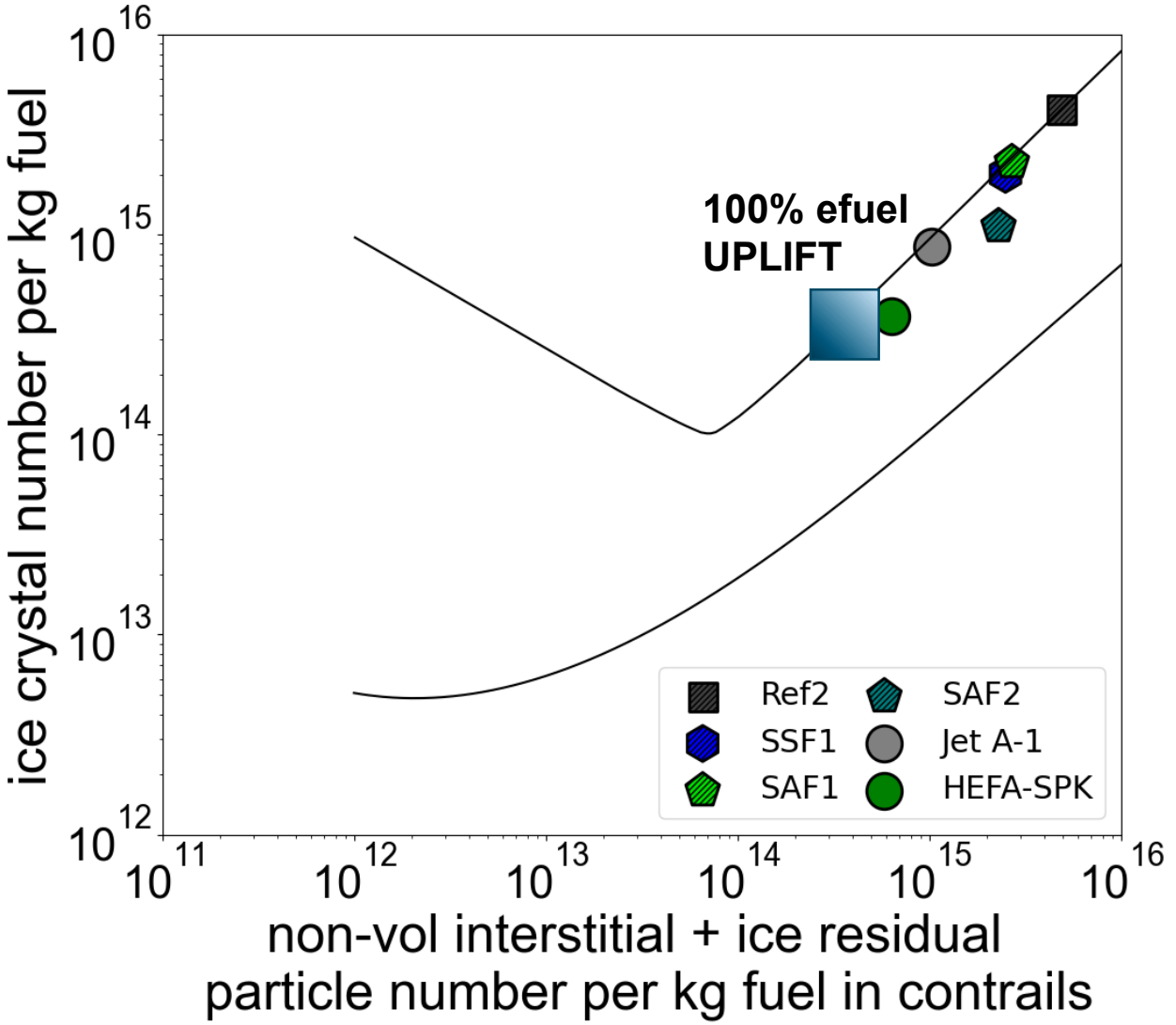
Low aromatic fuels reduce particle emissions & contrails





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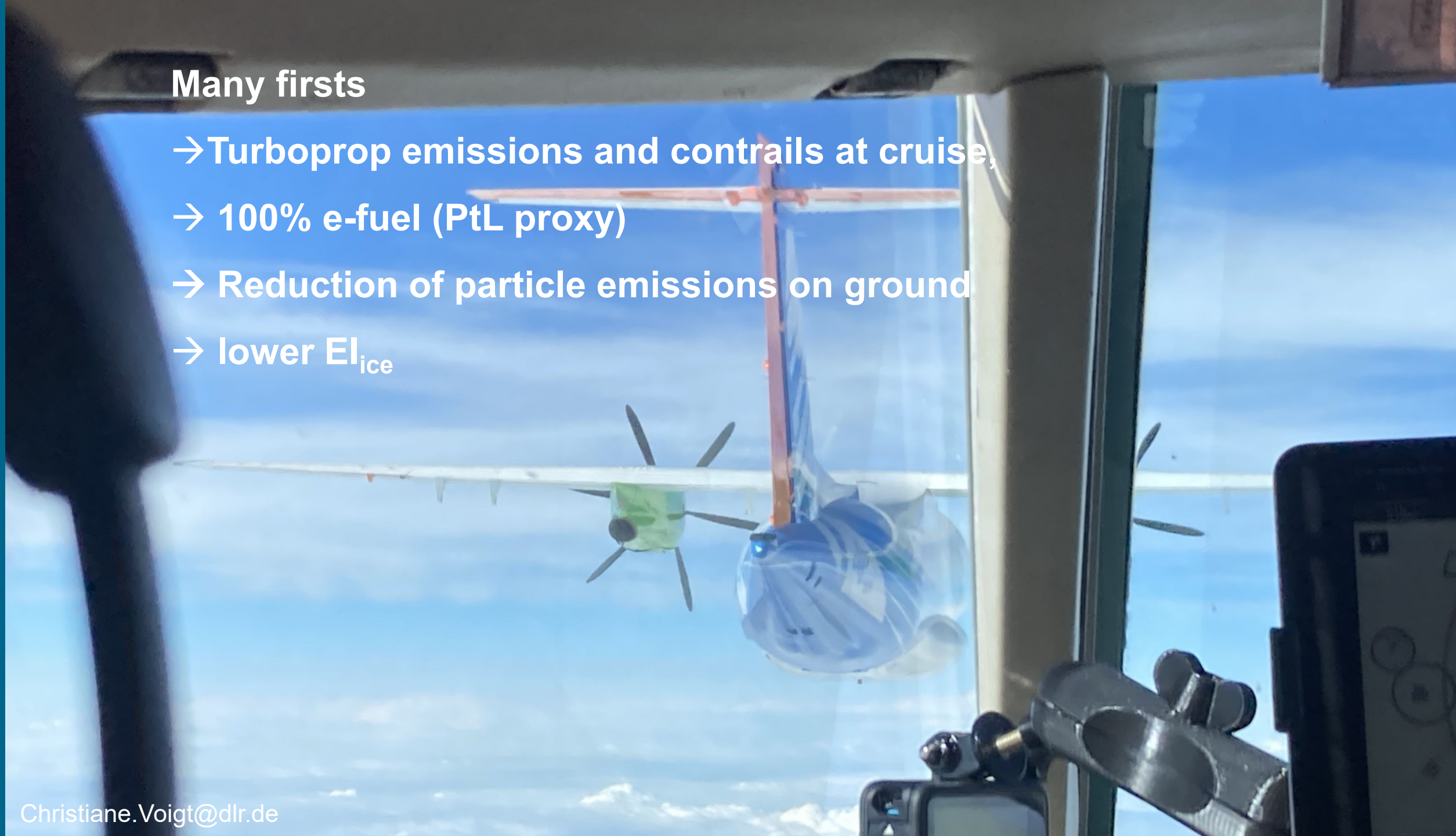
Many firsts

→Turboprop emissions and contrails at cruise,

→ 100% e-fuel (PtL proxy)

→ Reduction of particle emissions on ground

→ lower EI_{ice}



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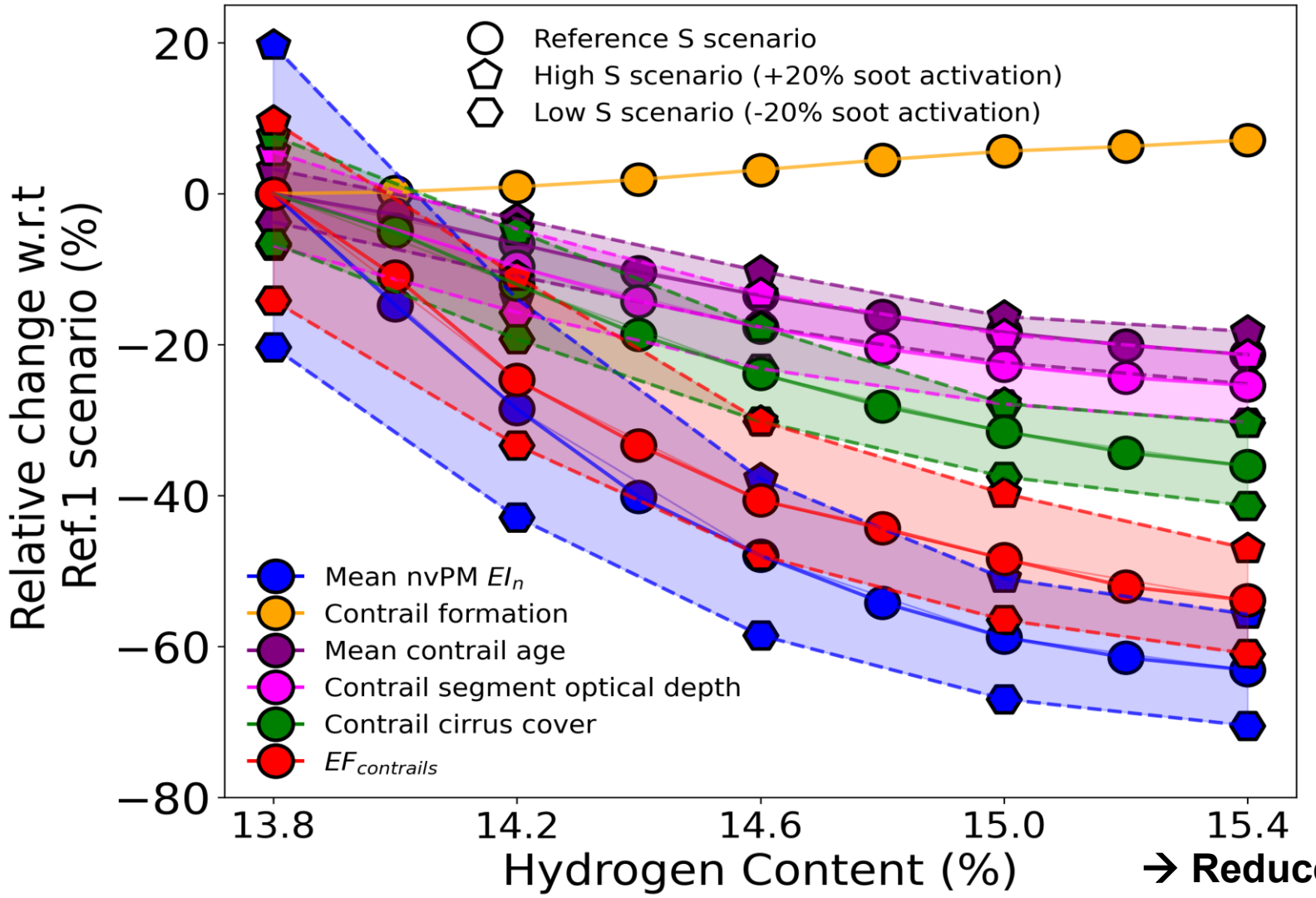
Contrail effects by low aromatic/high hydrogen content fuels



Energy Forcing from Contrails

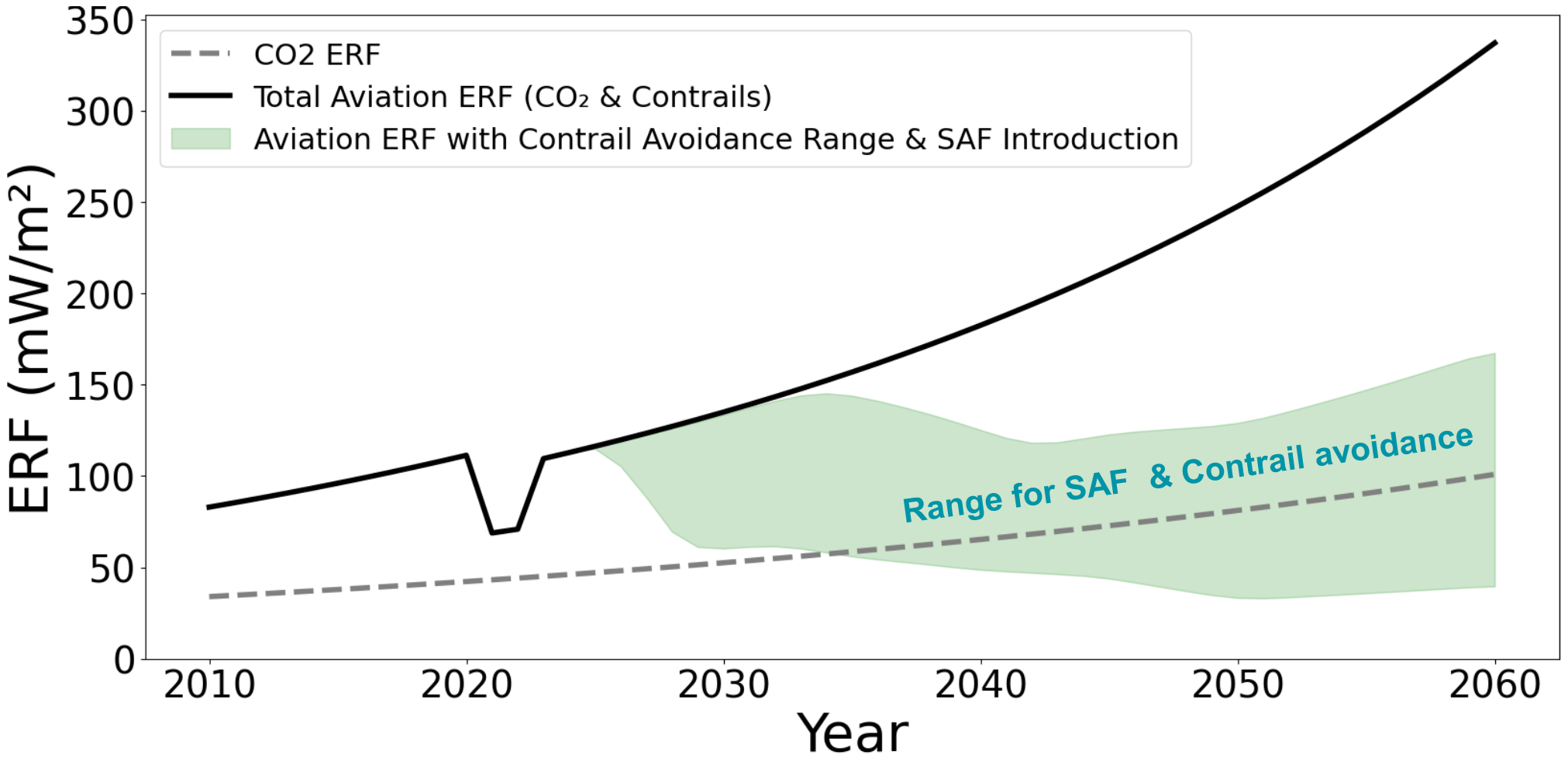
Soot

→ Reduced aromatic content

→ Increasing H content

Ziming Wang, Christiane Voigt

Potential for ERF reduction by SAF & contrail avoidance



The overlap of SAF effects on contrails and contrail avoidance measures is accounted for.
Less contrails to avoid due to SAF & ERF effect of remaining CO2

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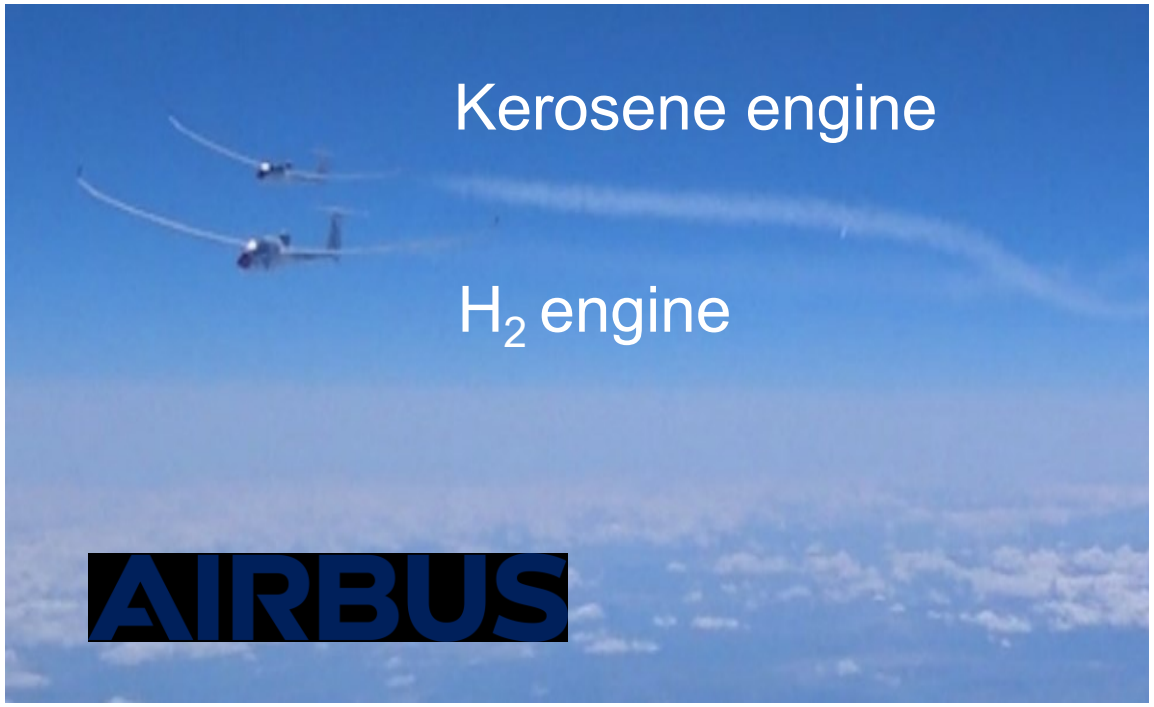
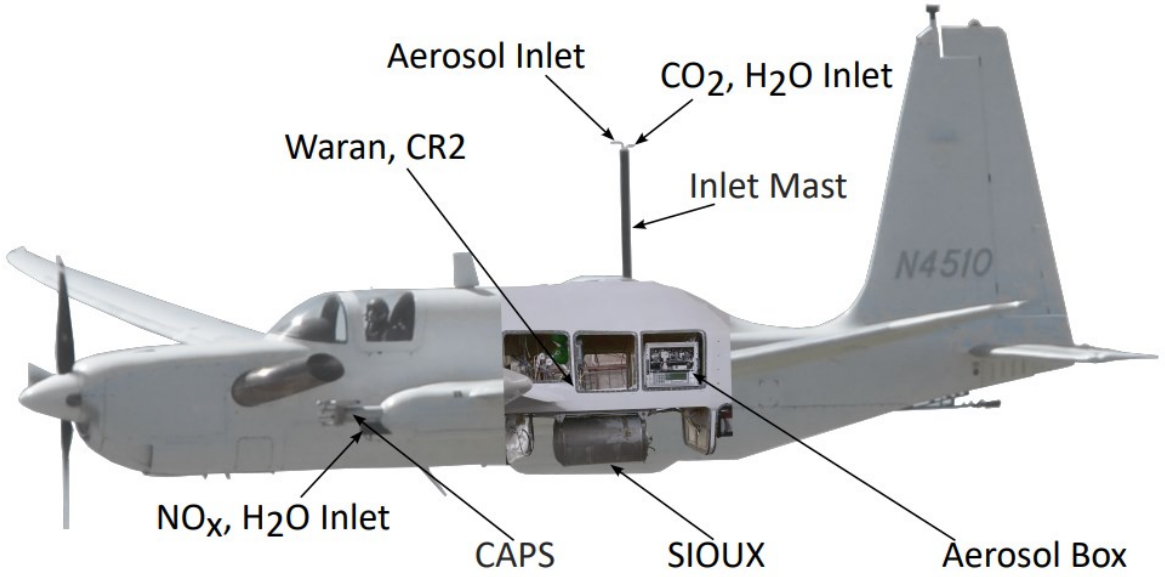
Blue Condor –
First contrail measurement from hydrogen combustion



Source: ISABE-2024-191; Rogero et al. 2024



Neumann et al., to be submitted

- DLR equipped chaser aircraft with ice and aerosol particles and trace gas instruments
- Visual observation: Contrail optical depth is reduced due to fewer ice crystals compared to kerosene contrail

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Thank you

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