Fast Measures to Reduce the Climate Impact from Aviation – Contrail Avoidance and New Fuels

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Fast Measures to Reduce the Climate Impact from Aviation – Contrail Avoidance and New Fuels


DLR ATRA aircraft leaving contrails while using alternative fuels. © *DLR*

Prof. Dr. **Christiane Voigt**
Head of Department Cloud Physics,
German Aerospace Center (DLR)

Date: **Thursday, 28 April 2022, 18:00 CET**
Online: https://purl.org/profscholz/zoom/2022-04-28

Today, contrails contribute the largest share to the climate impact from aviation, even surpassing the warming by its carbon dioxide emissions. While CO2 has atmospheric lifetimes of about a century, contrails live only for few hours and thus provide a fast option to reduce the climate impact from aviation.

The current status of knowledge on aircraft emissions and contrails in light of results from recent aircraft campaigns and research activities will be presented. Operational and technological measures to reduce the climate impact from aviation will be discussed with a focus on contrail avoidance. A contrail avoidance test experiment has been performed during the CIRRUS-HL aircraft campaign in summer 2021. Results from the CIRRUS-HL include the assessment of the quality of weather and contrail forecast. The potential for flight routing for contrail avoidance or reducing contrail warming by a shift to daytime flight routes will be shown. The impact of technological measures, i.e. low aromatic fuels and new engines on emissions and climate will be presented and an outlook on future fuels will be given.

Christiane Voigt *is also Professor for Atmospheric Physics at the University Mainz. Her research focuses on the aviation impact on atmospheric composition and climate. She coordinates aircraft campaigns on emission and contrail measurement in cooperation with international partners and combines the airborne experiments with modelling to investigate the potential of current and future technologies for sustainable aviation.*

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Outline

(1) Climate impact from aviation – focus on contrails

(2) Contrail formation, evolution and properties

(3) Contrail mitigation

→ ATM measures for contrail avoidance

→ Technical progress: sustainable avaition fuels SAF and hydrogen

New consolidated Assessment of the Climate Impact from Aviation

Atmospheric Environment 244 (2021) 117834

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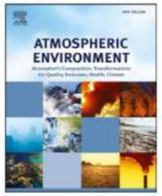

Check for updates

The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018

D.S. Lee[a,*], D.W. Fahey[b], A. Skowron[a], M.R. Allen[c,n], U. Burkhardt[d], Q. Chen[e], S.J. Doherty[f], S. Freeman[a], P.M. Forster[g], J. Fuglestvedt[h], A. Gettelman[i], R.R. De León[a], L.L. Lim[a], M. T. Lund[h], R.J. Millar[c,o], B. Owen[a], J.E. Penner[j], G. Pitari[l], M.J. Prather[k], R. Sausen[d], L. J. Wilcox[m]

→ **Aircraft emissions and contrails** lead to an **energy deposition in the atmosphere** and to **warming**

→ **Aviation** contributes with **~4%** to the **total anthropogenic radiative forcing.**

→ **Large progress** in recent years

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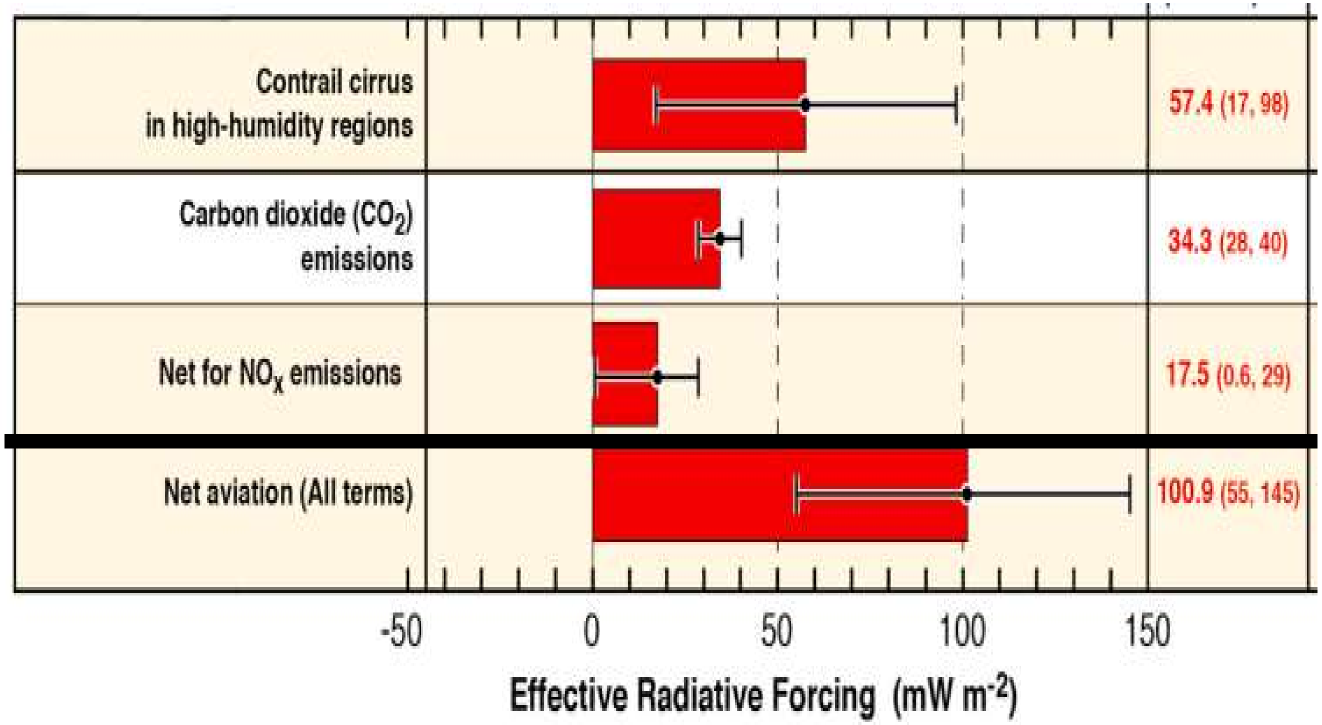
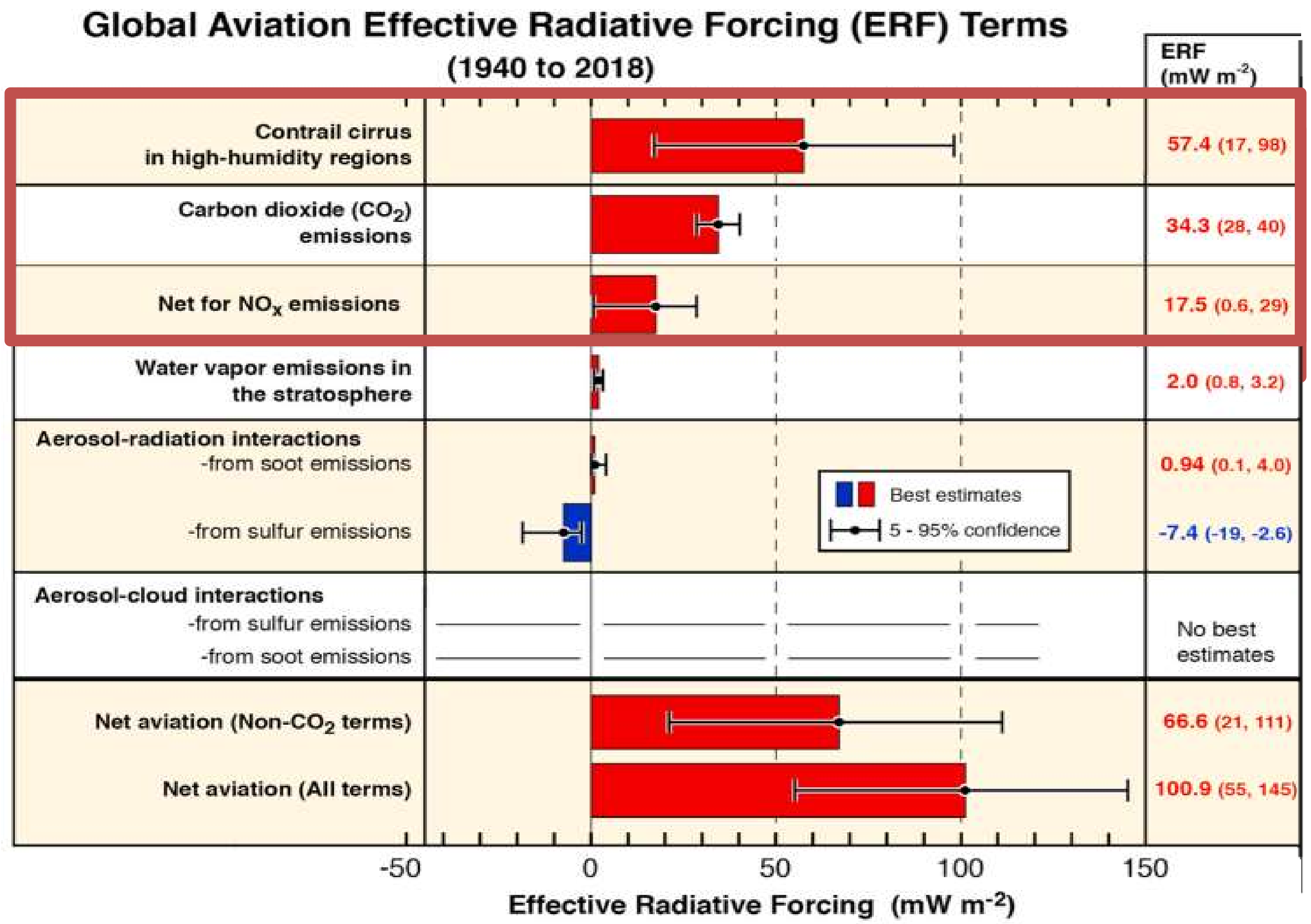
Main Contributors to the Effective Radiative Forcing from Aviation



→ **Contrails have the largest share to the climate impact from aviation**, followed by aviation **CO_2 and NO_x** effects

Lee et al., Atm Env, 2021

Global Aviation Effective Radiative Forcing Terms

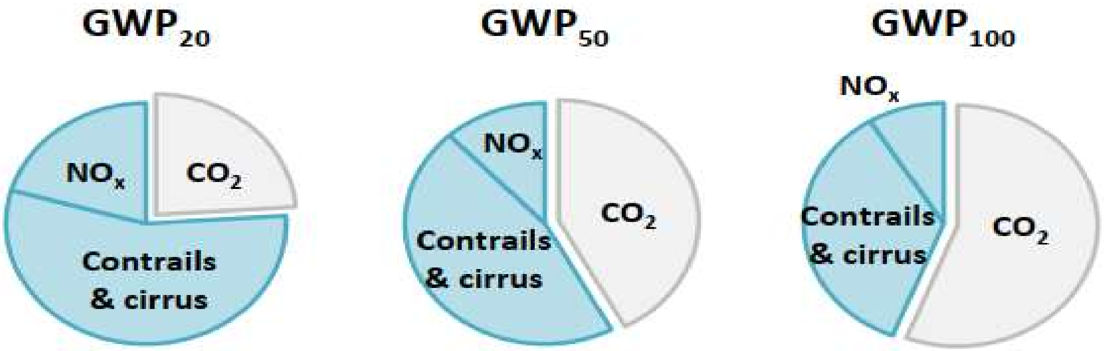


→ **Sustainable aviation** is **more** than **decarbonization.**

→ **A large contribution** comes from **contrails.**

Lee et al., Atm Env, 2021

Comparative impact of CO_2 and non-CO_2 effects for different time scales



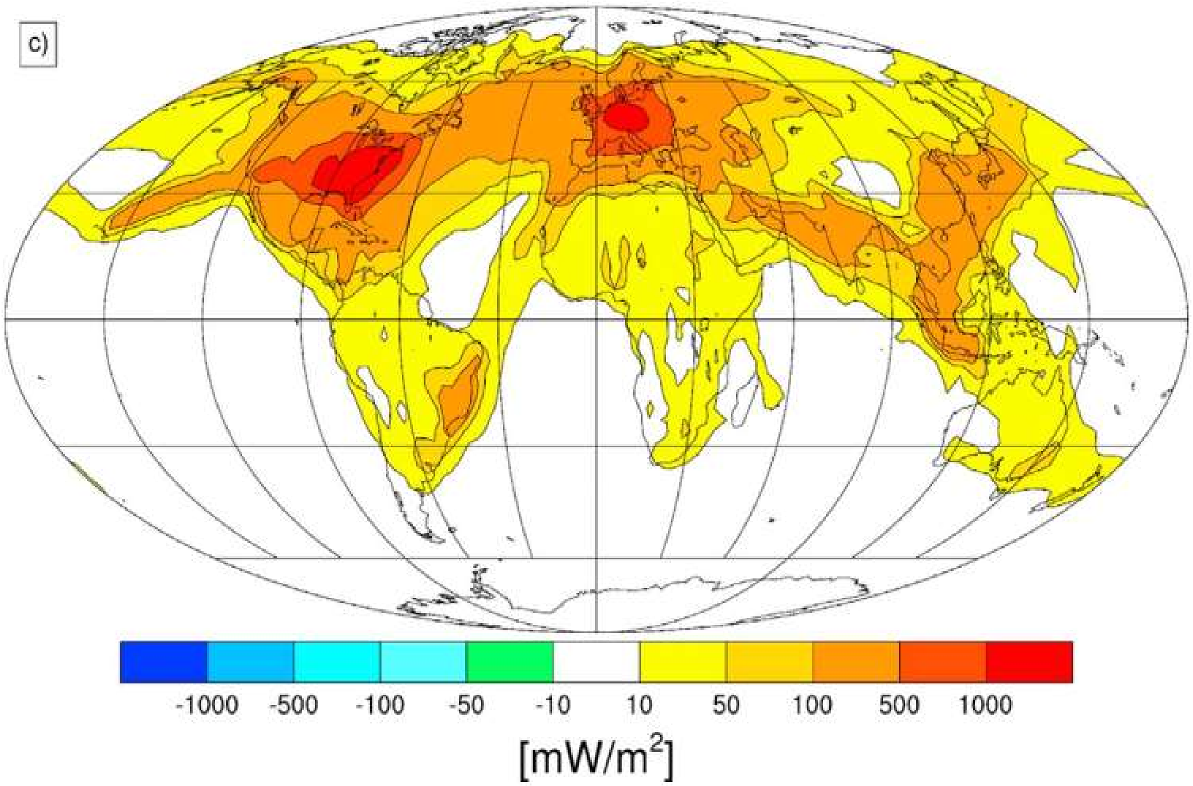
Effect	GWP_{20}	GWP_{50}	GWP_{100}
CO_2 (Gt CO_2)	1034	1034	1034
Contrails and cirrus (Gt CO_2-eq)	*2399*	*1129*	*652*
Net effect of NO_x (Gt CO_2-eq)	*887*	*293*	*163*
Others (Gt CO_2-eq)	*-188*	*-88*	*-51*
Total Gt CO_2-eq	**4128**	**2366**	**1797**
CO_2-eq to CO_2 ratio	**4.0**	**2.3**	**1.7**

Table 1: *Comparative impacts of CO_2 and non-CO_2 effects of aviation on GWP_{20}, GWP_{50} and GWP_{100} according to (Lee, et al., 2020), in gigatons (Gt) par year.*

→ **Even at long time scales non-CO_2 effects** are **important.**

From Lee et al., 2021

Golabl distribution of the radiative forcing from contrails

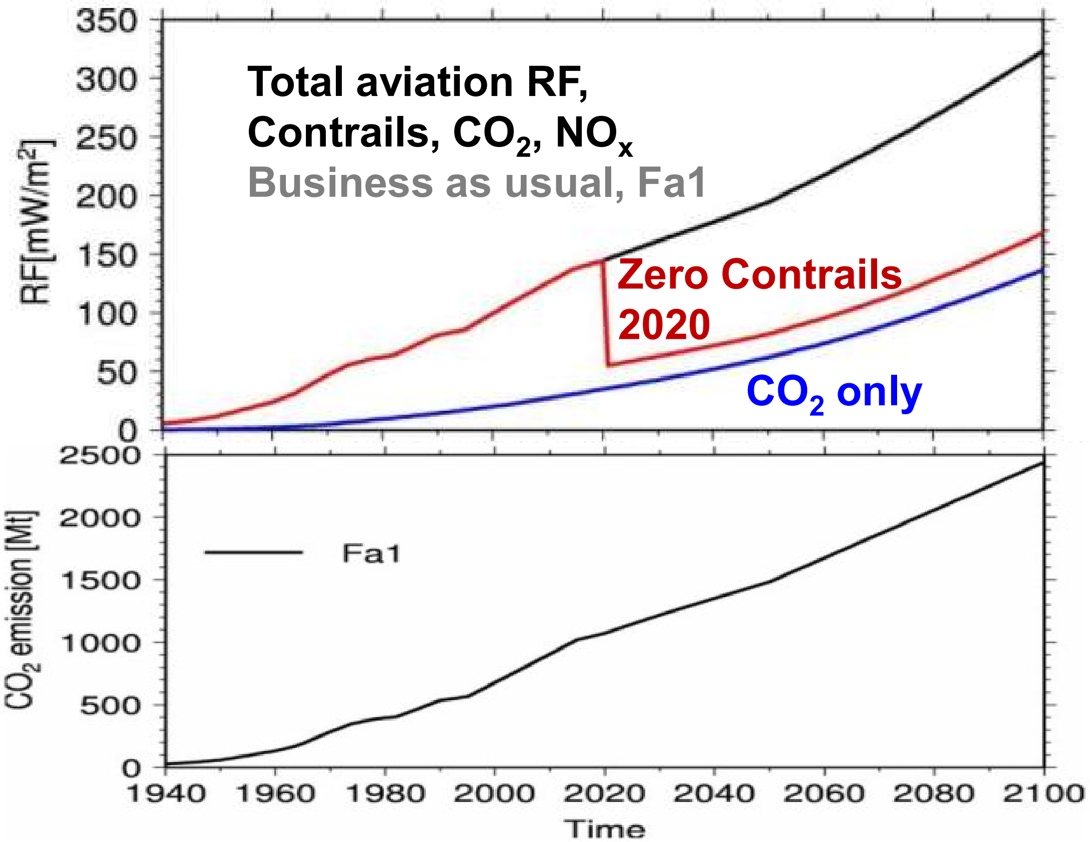


→ **Strong impact** along **air traffic routes** and **above continents.**

→ **Short lifetime** of **contrails**

Burkhardt et al., ACP, 2016

Radiative forcing from Aviation since 1940

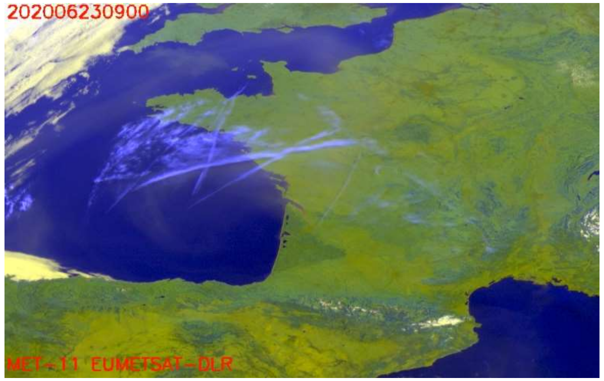


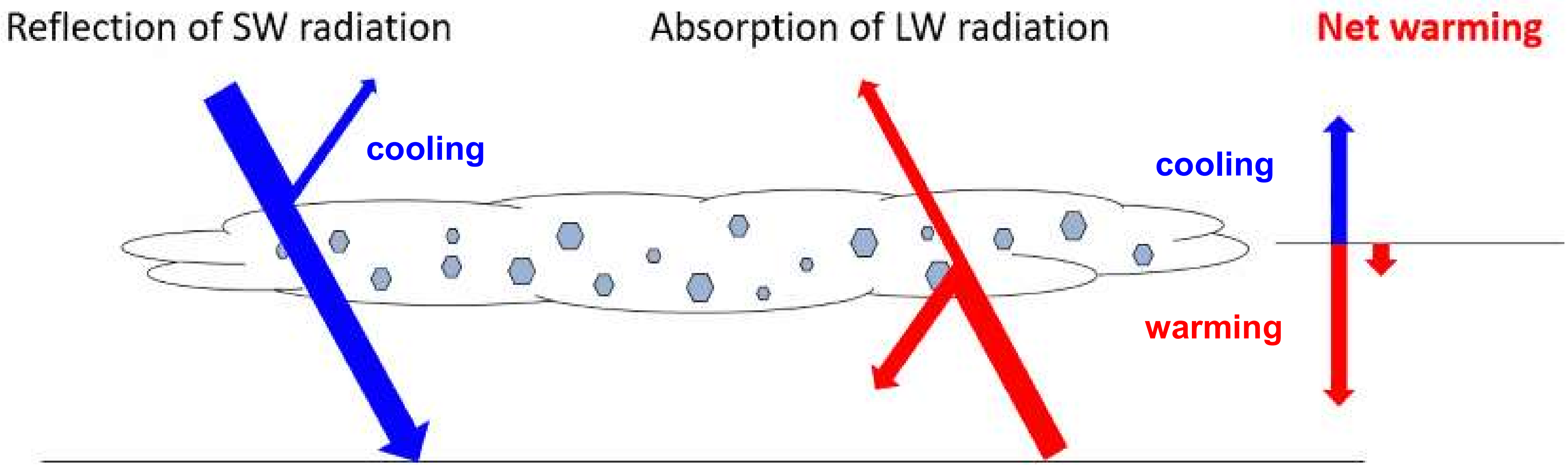
→ Unlike warming by CO_2, **contrails reduction and climate impact responds fast.**

→ **Contrails** are the **wild cards.**

Schumann, 2018

Radiative forcing from contrails





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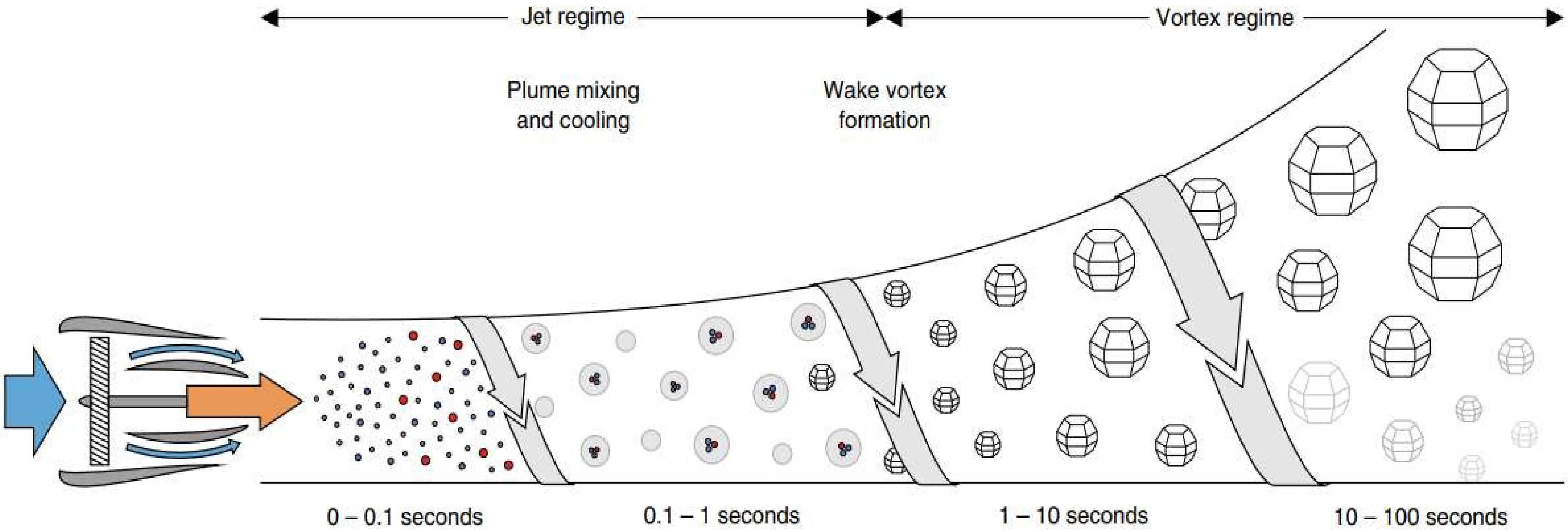
Contrail formation

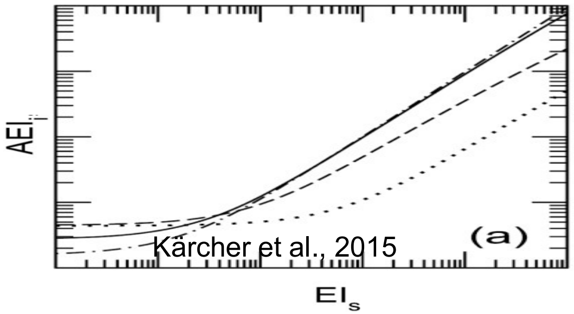


Kärcher, 2018

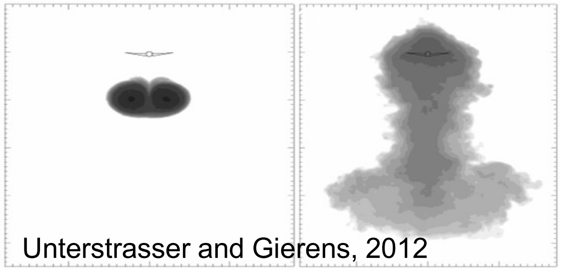
Lifecycle of contrail cirrus

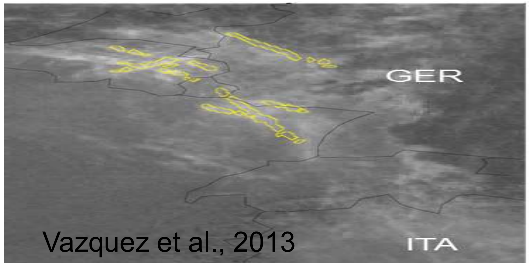
Climate impact

Nucleation	Growth / Dispersion	Sedimentation / Sublimation
sec - m	min – m to km	h – many km



Kärcher et al., 2015

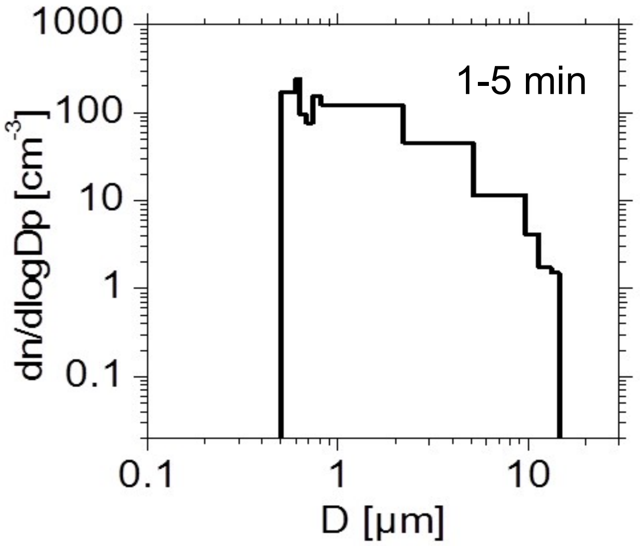

Unterstrasser and Gierens, 2012



Vazquez et al., 2013

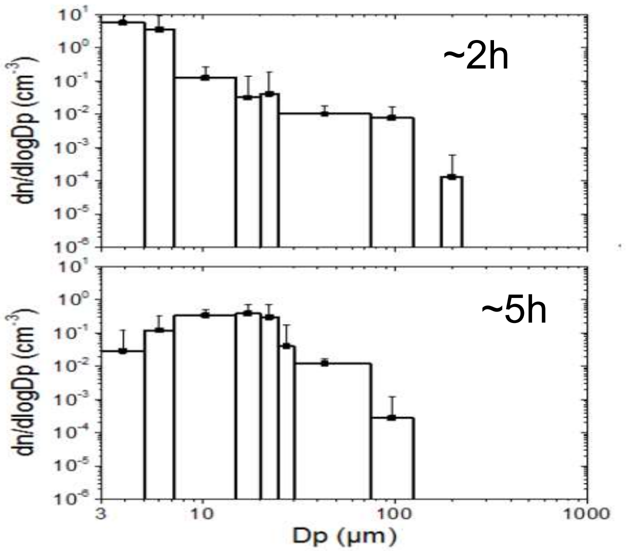
Evolution of the particle size ditribution in contrails

Young contrails



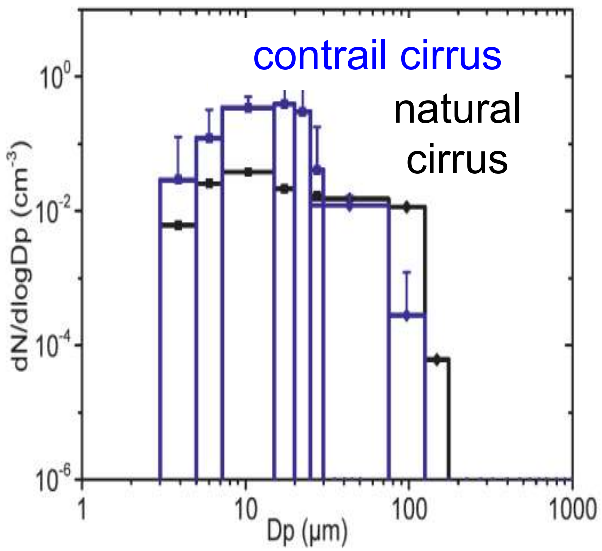
Voigt et al., GRL, 2011

Contrail cirrus



Grewe et al., Aerospace, 2017

Contrail and natural cirrus

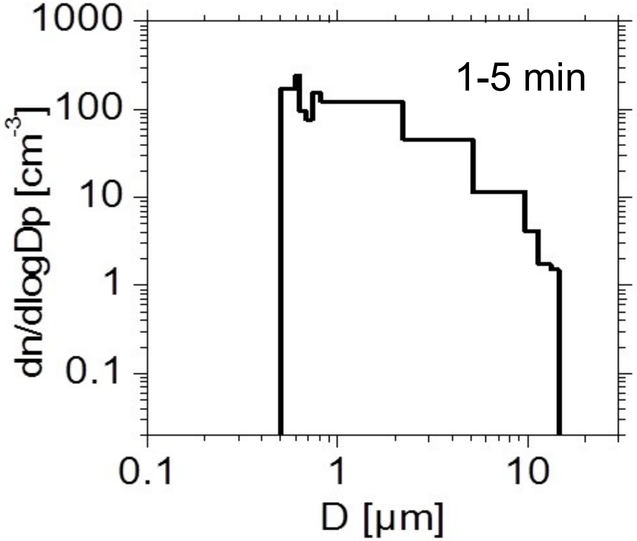


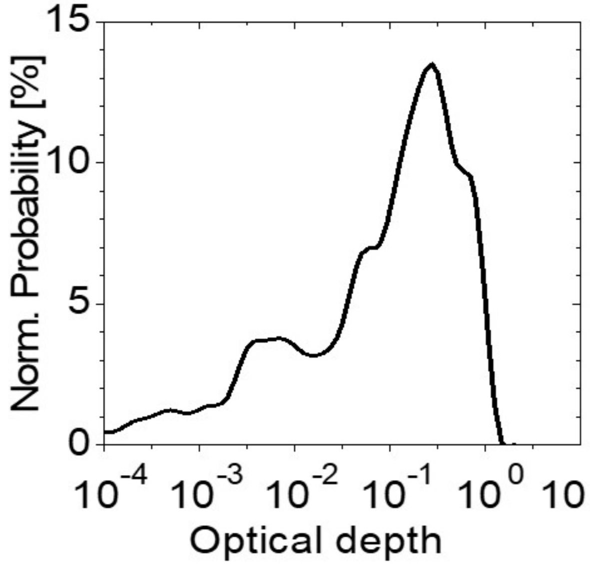
Voigt et al., BAMS, 2017

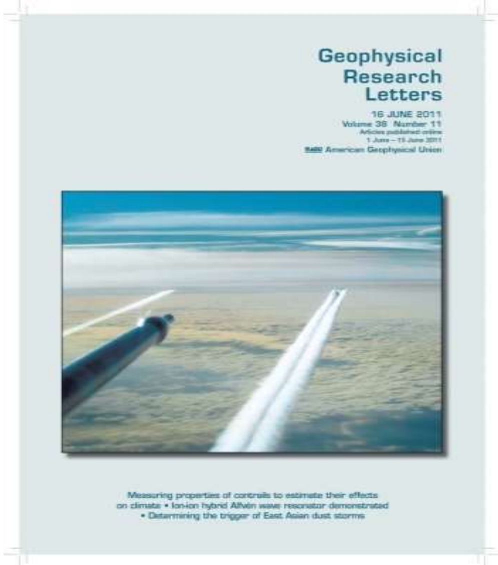
Link between microphysical and optical particle properties

21 Contrails from different aircraft

$$\beta = \int Q_{ext} A_p(D)\, n_p(D) dD = Q_{ext}\, A\, n$$



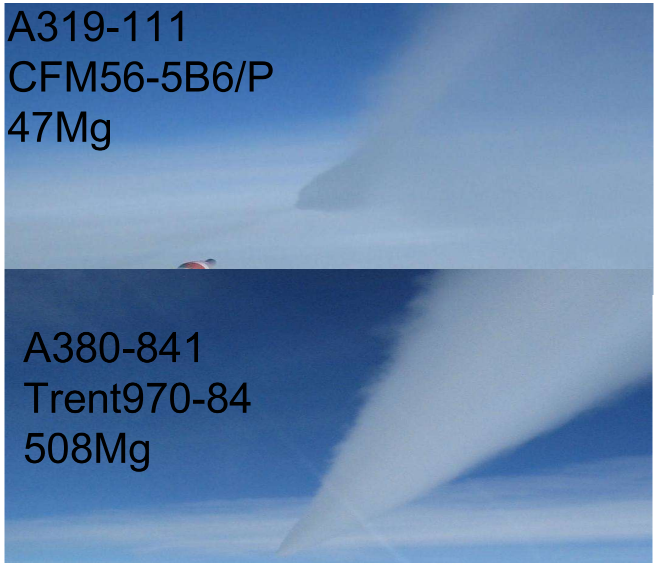




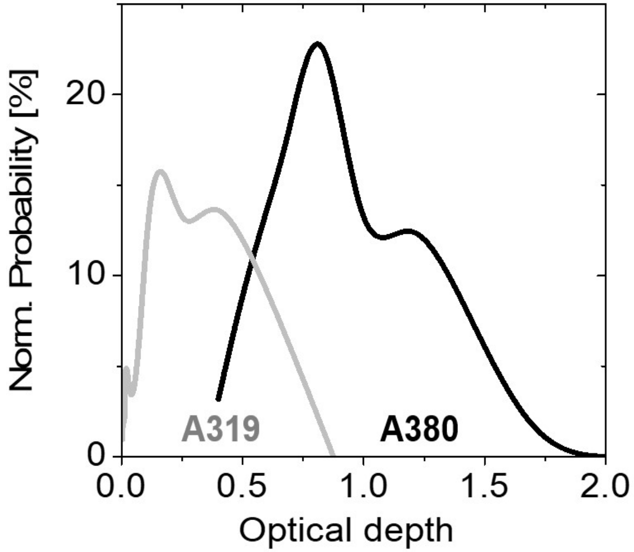
Lufthansa

Impact of aircraft type on contrails

21 Contrails from different aircraft



$$\beta = \int Q_{ext} A_p(D)\, n_p(D) dD = Q_{ext}\, A\, n$$



Heavier aircraft produce

→higher N_{ice} (larger fuel flow)

→extinction β, contrail depth (larger weight)

→ optical depth τ per flight distance under similar meteorological conditions.

➢ Averaged per passenger-km, a larger aircraft has a smaller contrail climate impact

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Jessberger et al., ACP, 2013

Larger aircraft produce thicker contrails
Contrail per seat climate impact of large aircraft is lower wrt small aircraft

Jeßberger et al., 2013; Voigt et al., 2010

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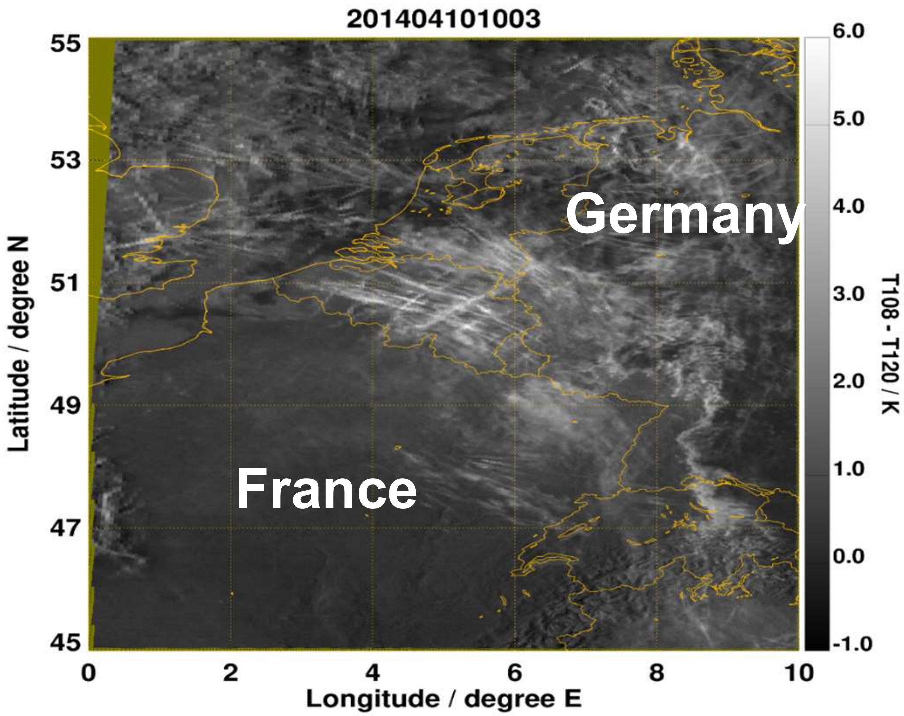
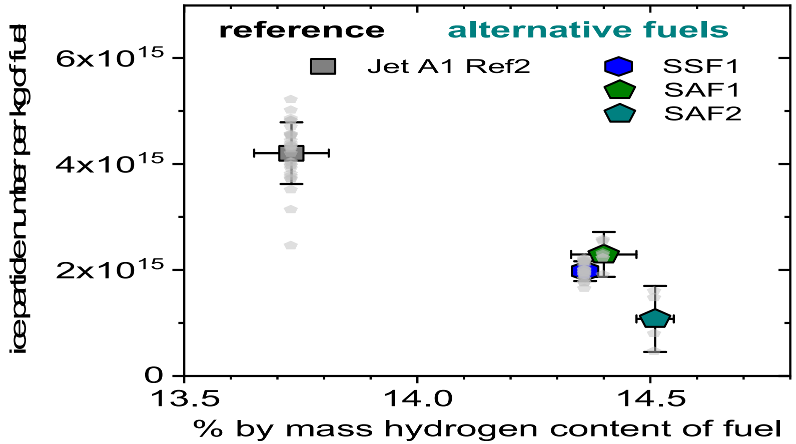
New strategies for sustainable aviation

Flight routing – Contrail avoidance

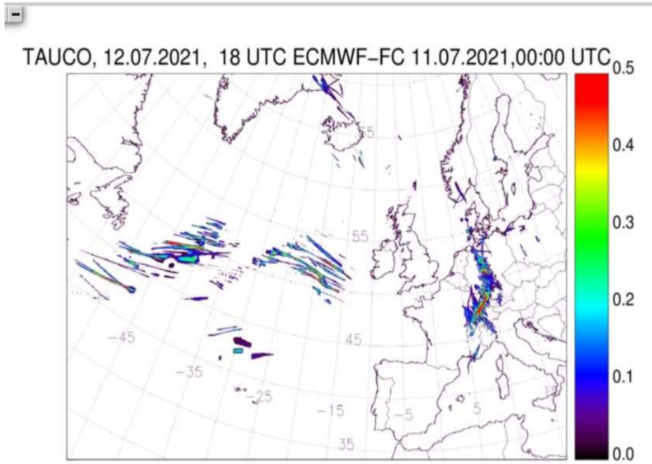


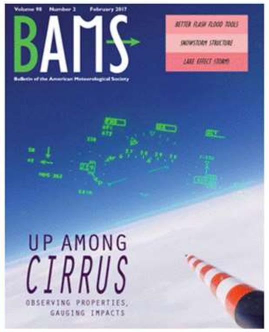
Sustainable Aviation Fuels

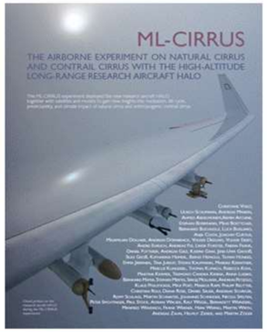


Voigt et al., Nat Comm EE, 2021

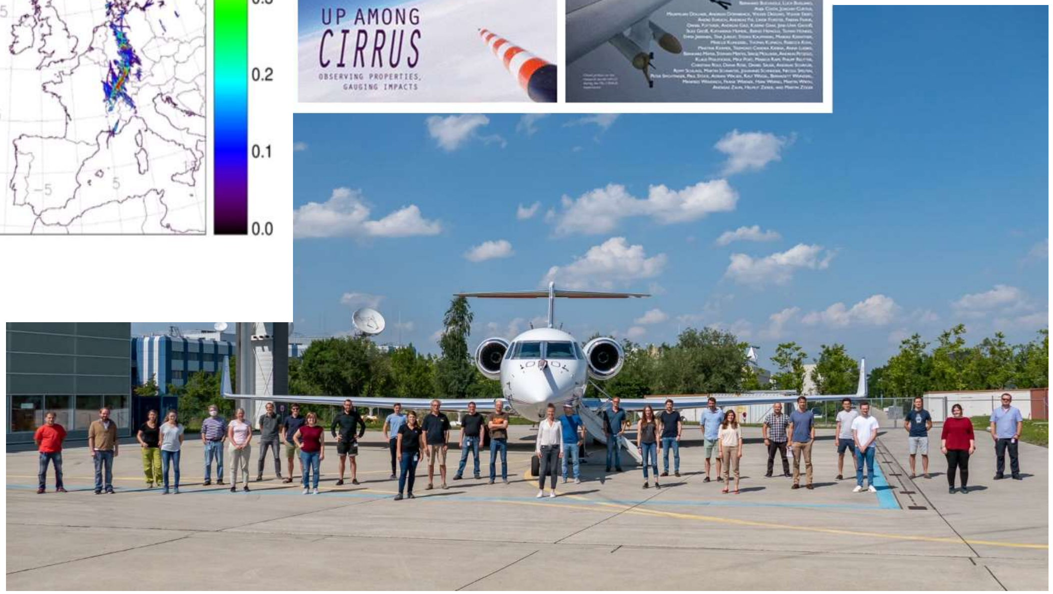
Contrail cirrus measurements during CIRRUS-HL and contrail avoidance

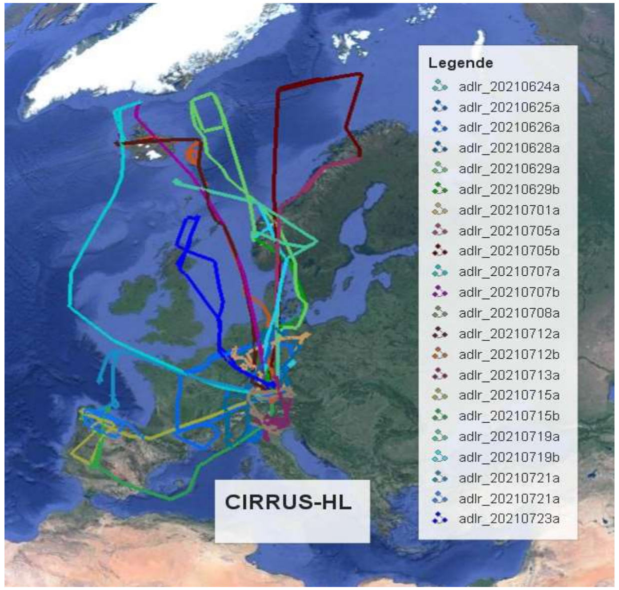






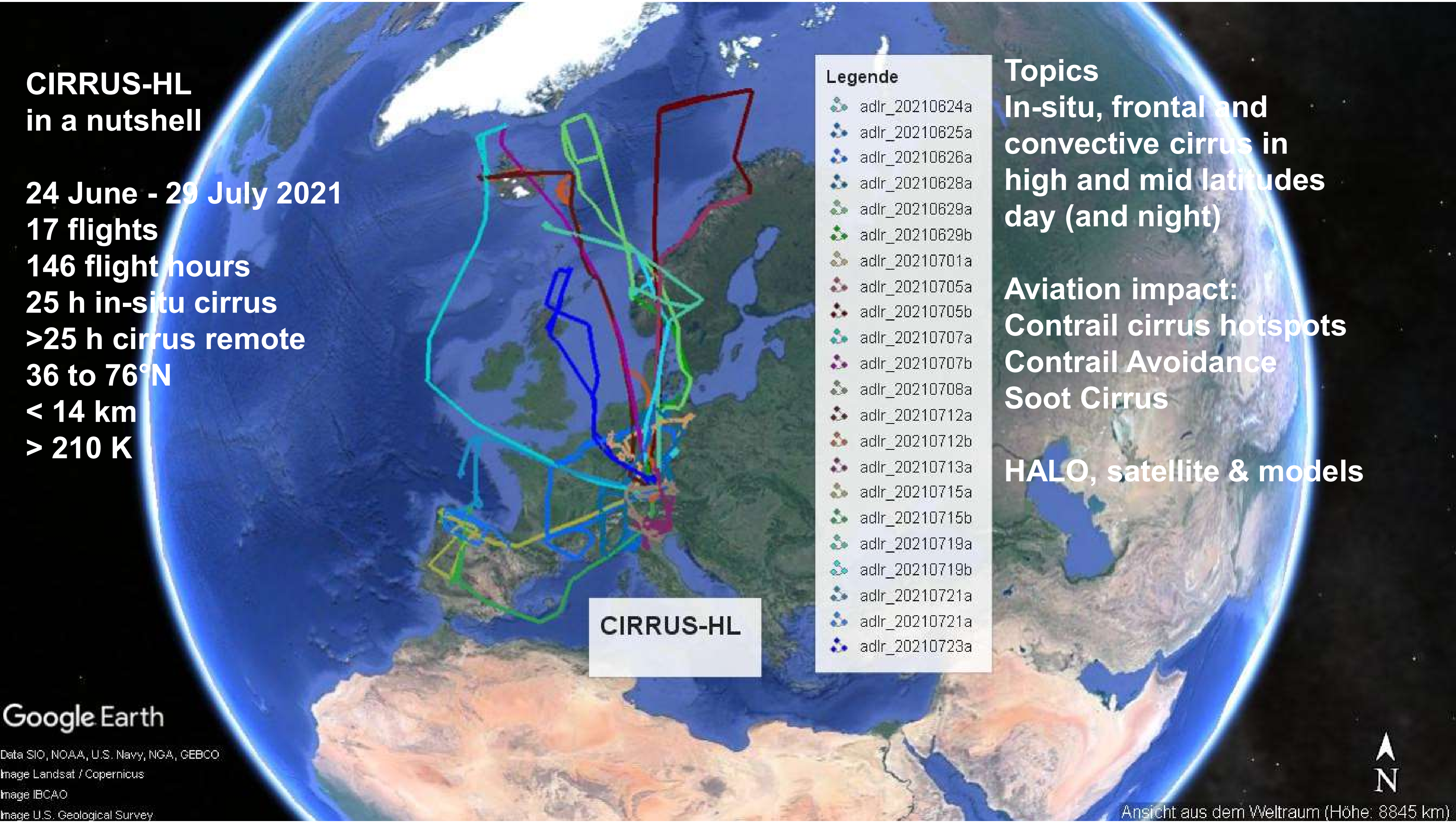
https://cirrus-hl.de





http://www.pa.op.dlr.de/missionsupport/classic/cocip/

Voigt et al., 2017
Voigt et al., SPP HALO, 2021



CIRRUS-HL
in a nutshell
24 June - 29 July 2021
17 flights
146 flight hours
25 h in-situ cirrus
>25 h cirrus remote
36 to 76°N
< 14 km
> 210 K
Legende
adlr_20210624a
adlr_20210625a
adlr_20210626a
adlr_20210628a
adlr_20210629a
adlr_20210629b
adlr_20210701a
adlr_20210705a
adlr_20210705b
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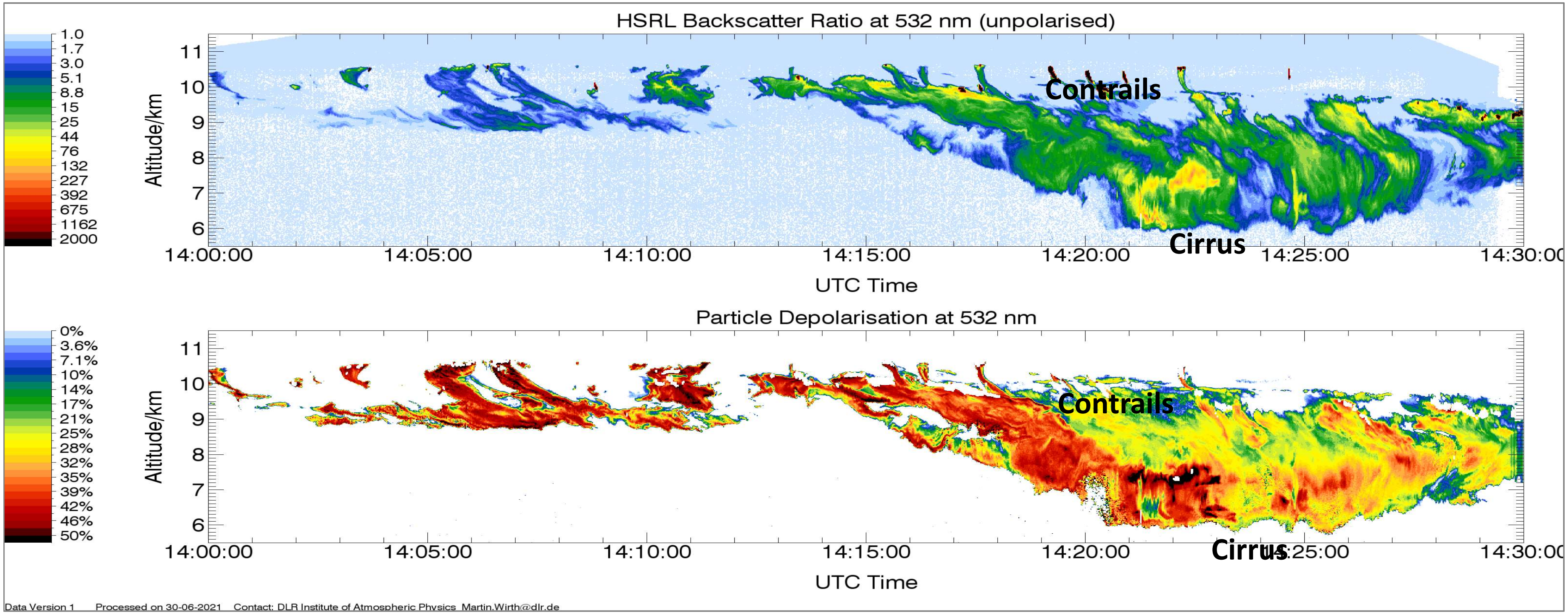
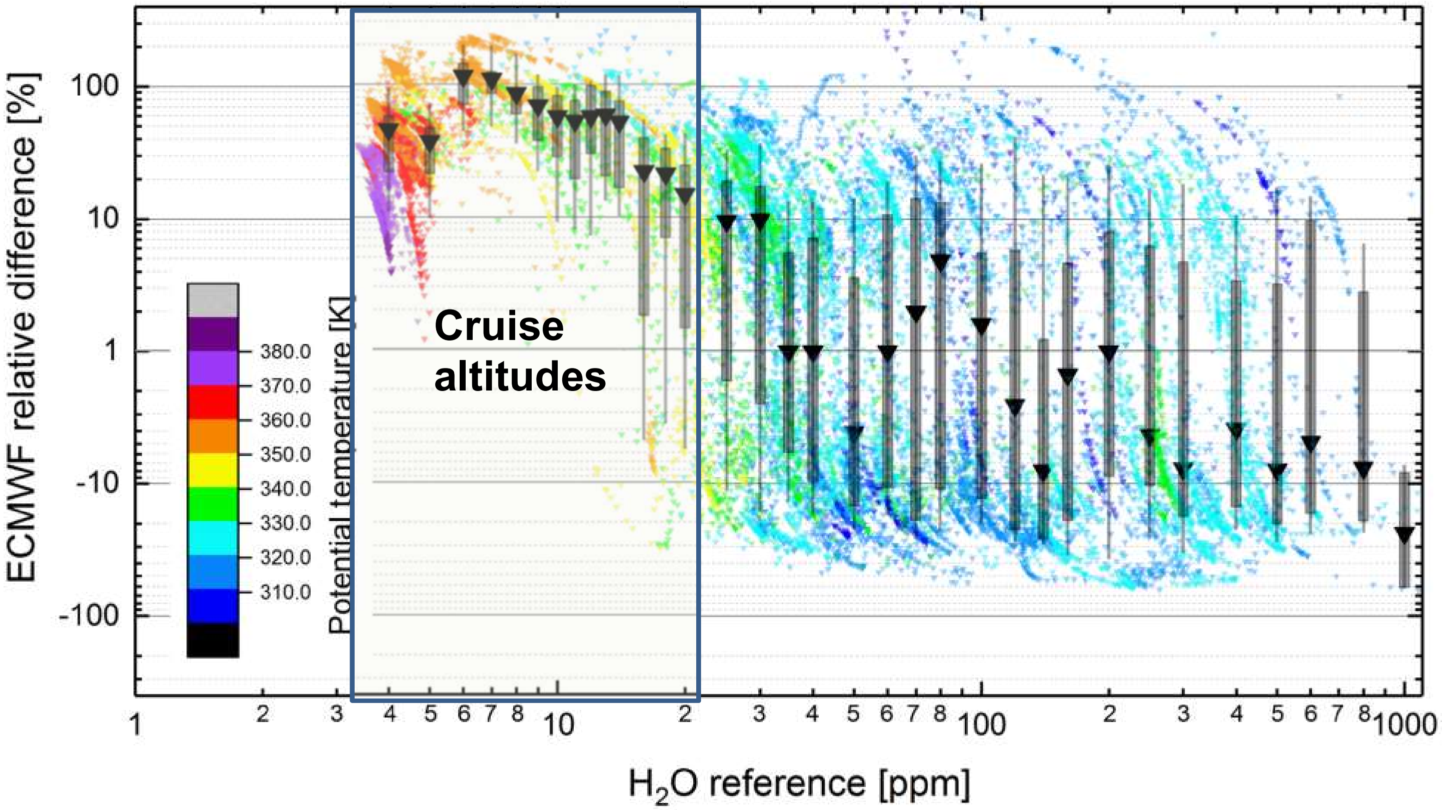
adlr_20210712b
adlr_20210713a
adlr_20210715a
adlr_20210715b
adlr_20210719a
adlr_20210719b
adlr_20210721a
adlr_20210721a
adlr_20210723a
CIRRUS-HL
Topics
In-situ, frontal and convective cirrus in high and mid latitudes
day (and night)
Aviation impact:
Contrail cirrus hotspots
Contrail Avoidance
Soot Cirrus
HALO, satellite & models
Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Image IBCAO
Image U.S. Geological Survey
N
Ansicht aus dem Weltraum (Höhe: 8845 km)

LIDAR backscatter and particle depolarization of contrail cirrus



WALES HSRL LIDAR: Wirth, Groß, Dekoutsidis, DLR

Need to enhance the quality of weather forecast in the UTLS



→ Good agreement in free troposphere

→ Discrepancies in UTLS region

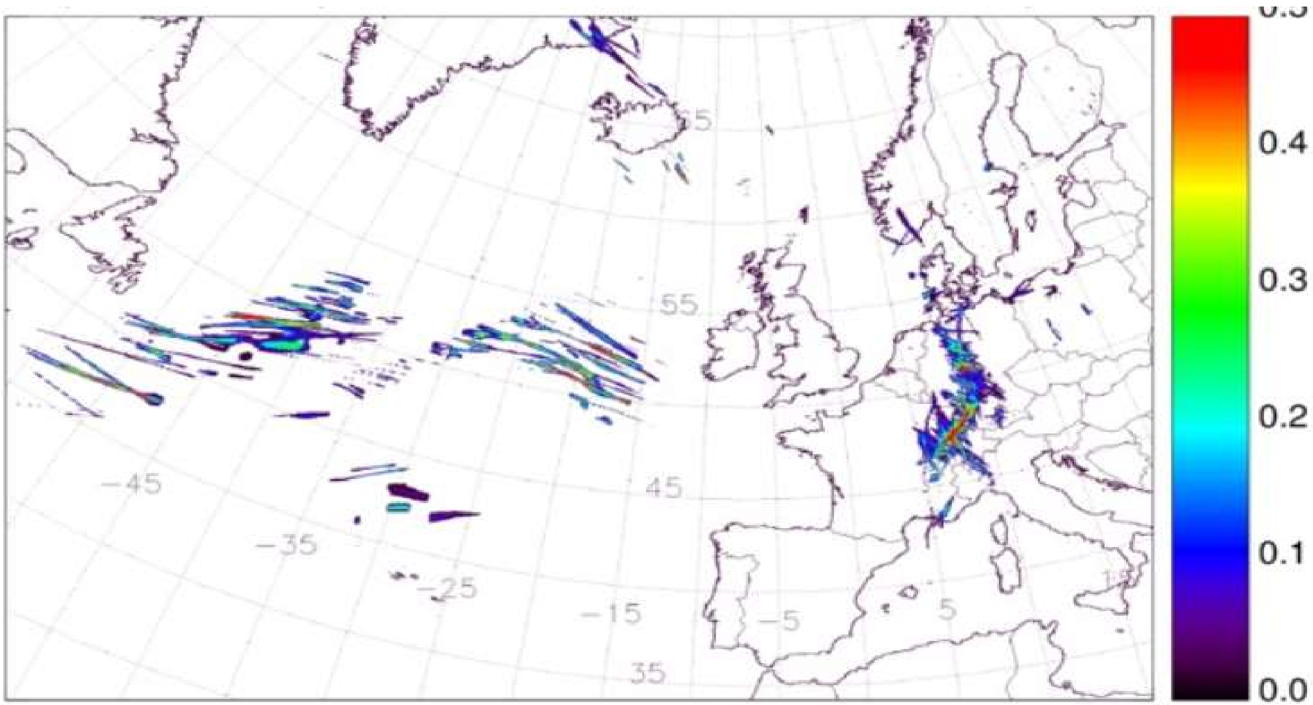
→ UTLS H2O and T base to derive RHI and cloud properties

→ Need to evaluate weather models in UTLS with in-situ data

Kaufmann et al., ACP, 2018

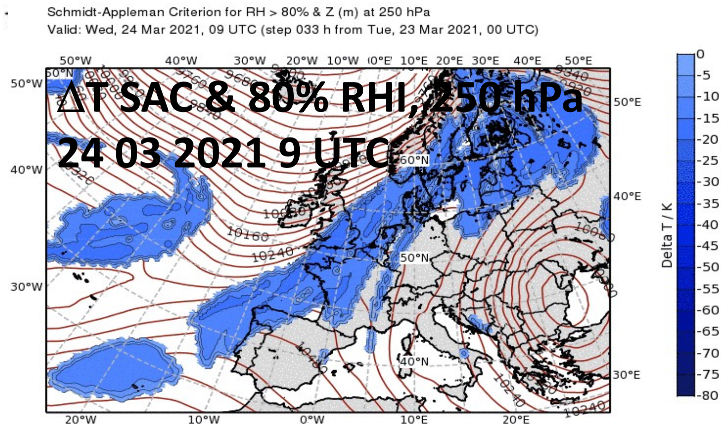
Contrail cirrus prediction with COCIP

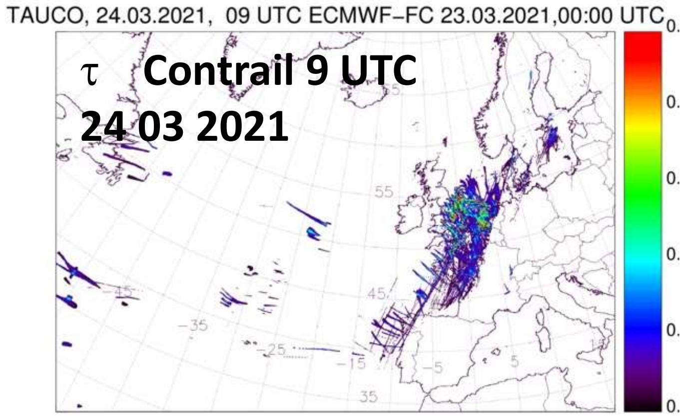
Contrail cirrus prediction for 12/07/2021, 18:00

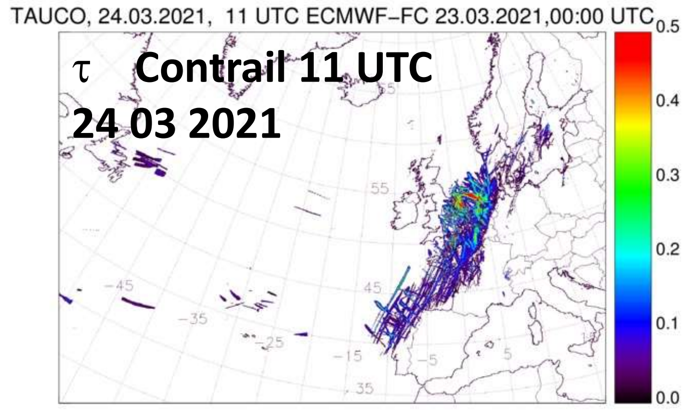


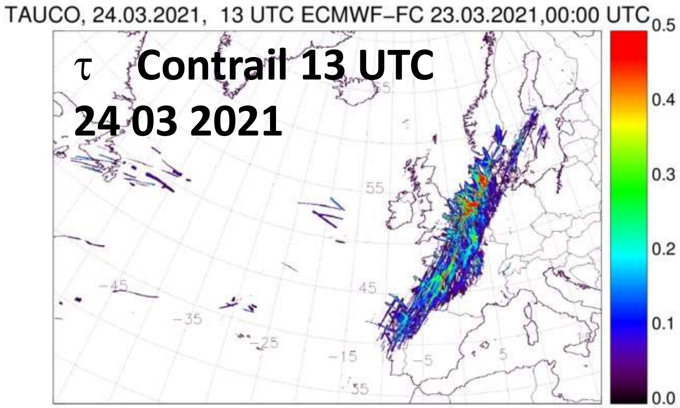
Schumann et al., ACP, 2021a

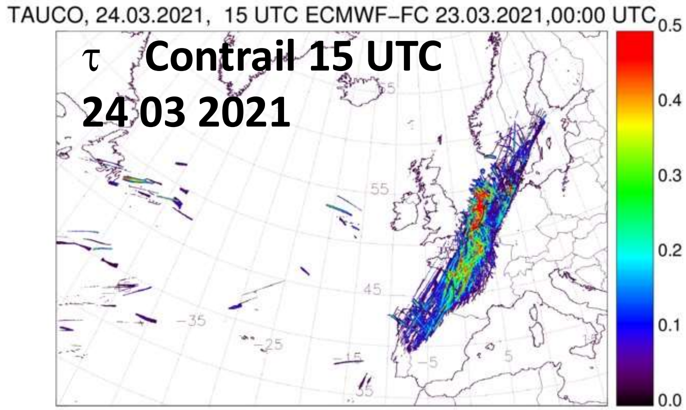
Fast evolution of contrail regions











Schumann, 2012; Voigt et al., 2017

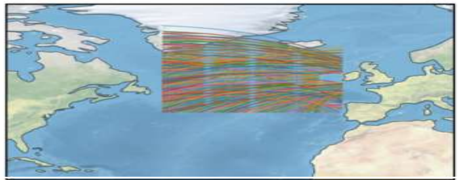
COCIP contrail model

Input

Aircraft data BADA, NATS, PS

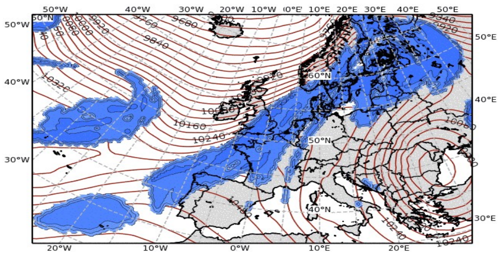
Performance	← PS
TAS, PM, TOM, Envelope checks-> PM/TOM adjustment	← BADA3
FF, EI_{soot}	← Soot

Aircraft routes (Eurocontr, SPIRE,…)



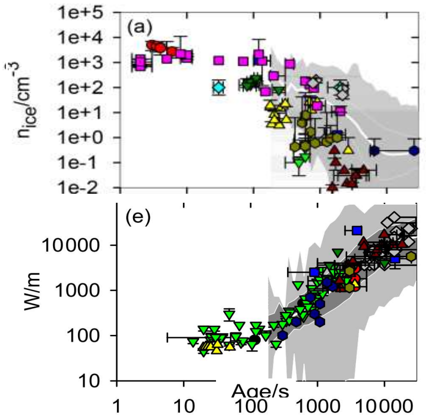
Contrail formation and life cycle

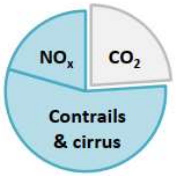
Weather data (ECMWF ERA, IFS, …)



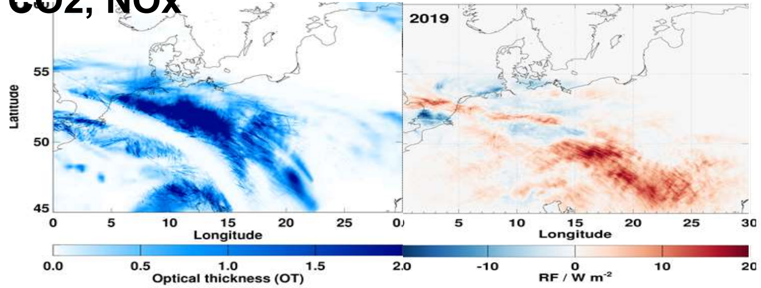
Model Output Contrail properties

n, iwc, tau, lifecycle, cover, LW/SW

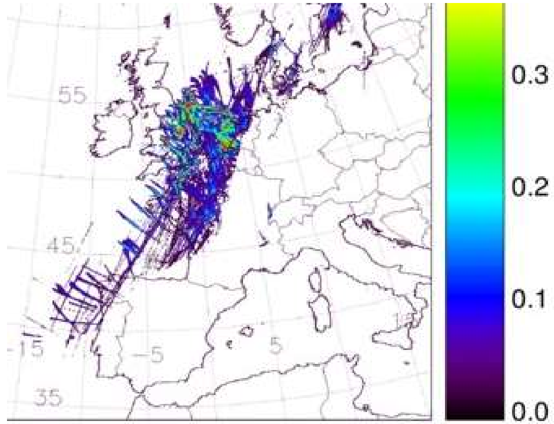


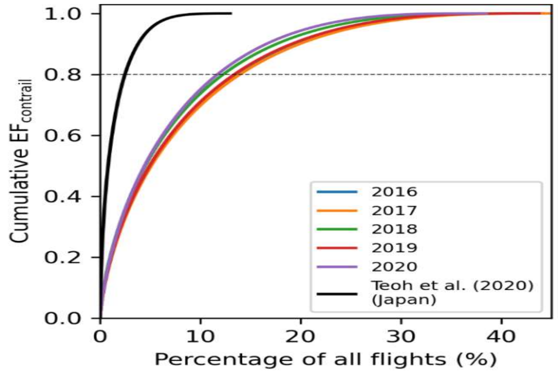


Climate impact Tau, RF, EF, GWP20, CO2, NOx

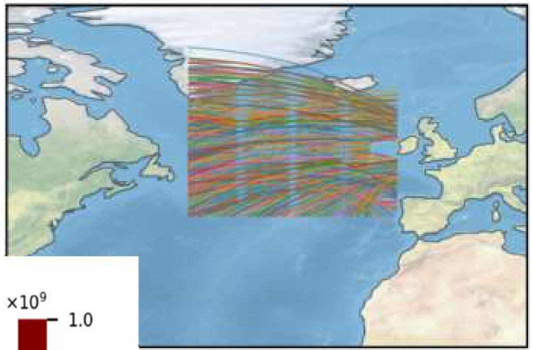


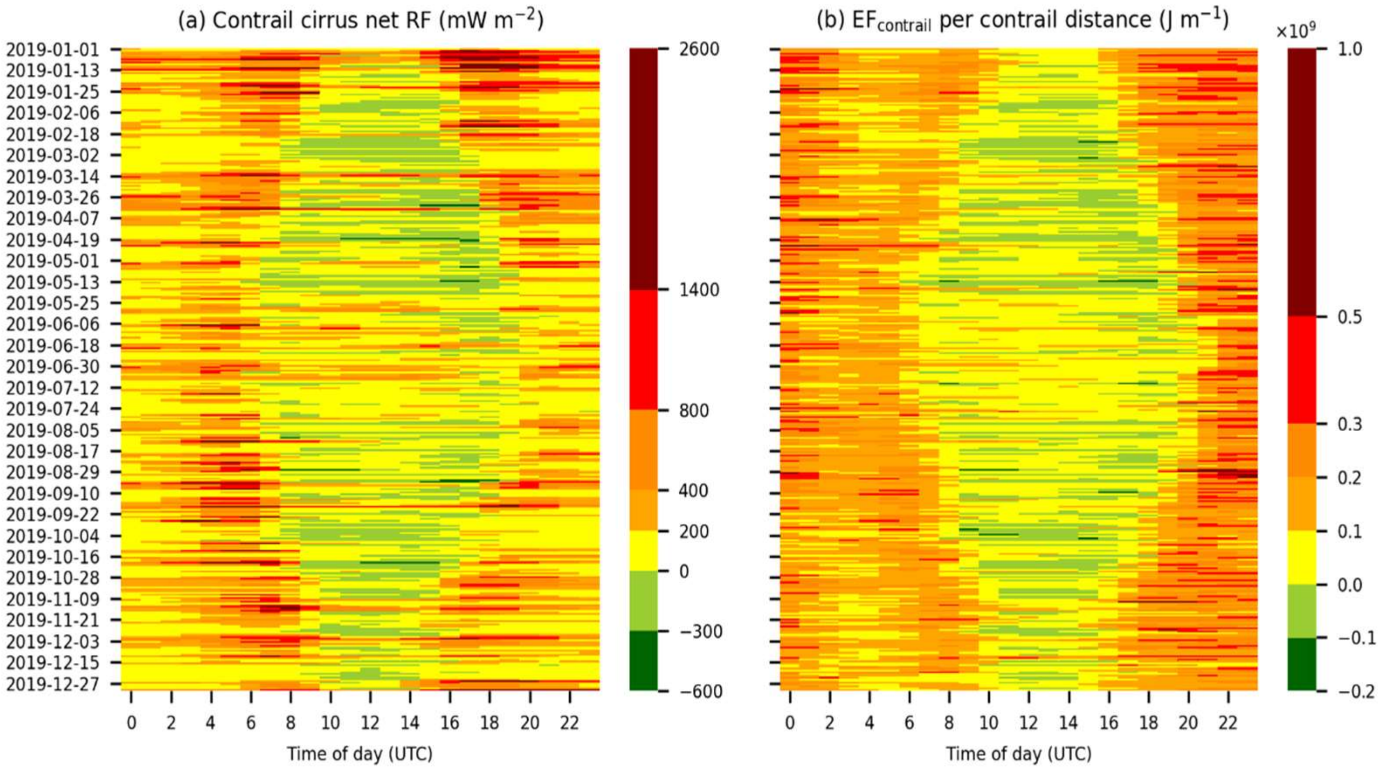
Contrail prediction, mitigation, avoidance





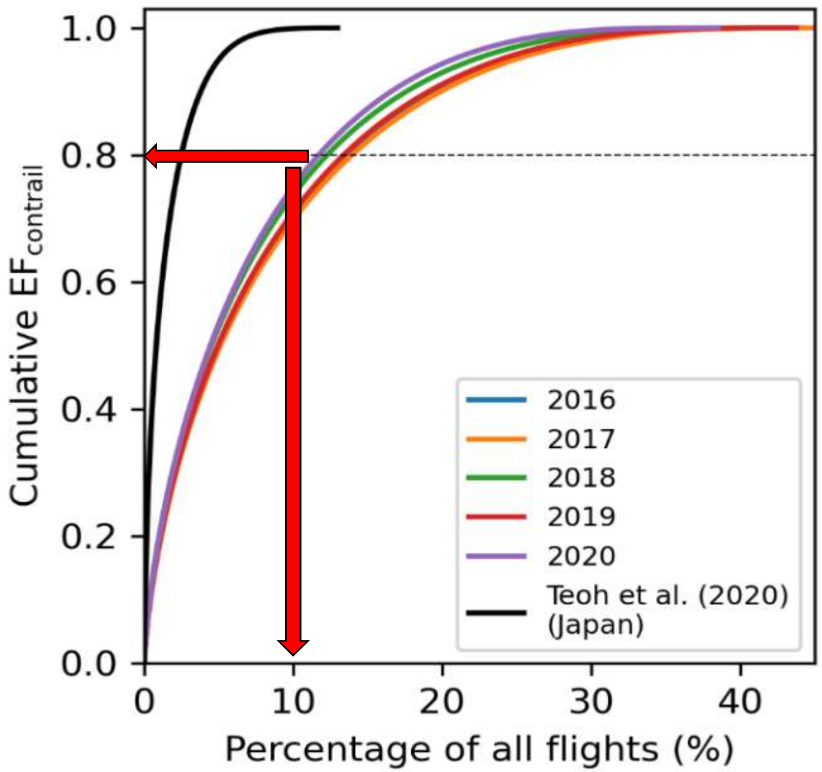
Seasonal and hourly contrail radiative forcing

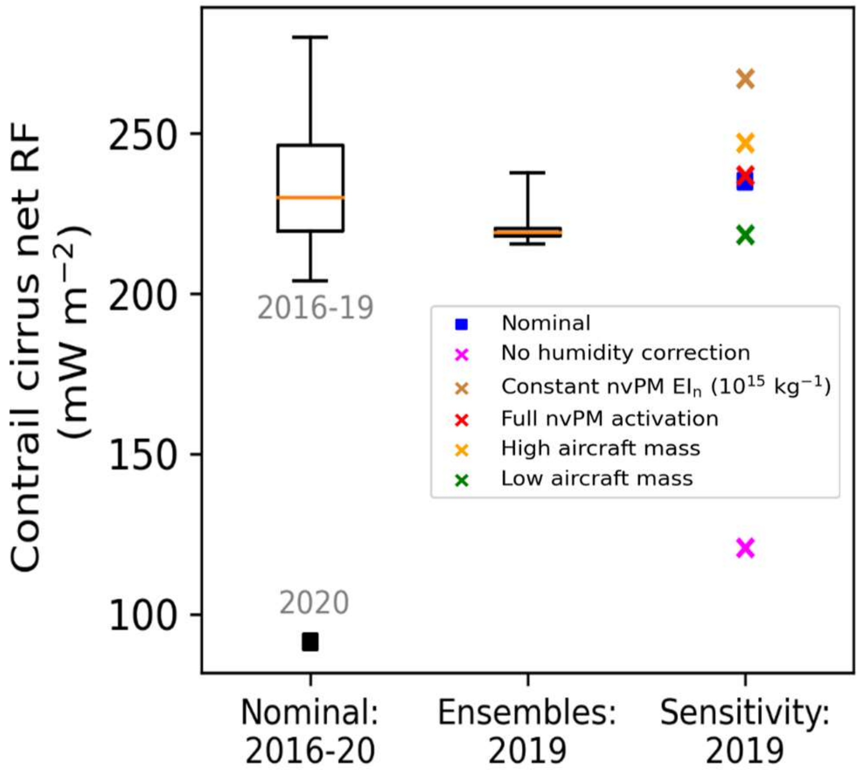




Teoh, Voigt et al., ACPD, 2022

<12% of the flights cause 80% of the contrail forcing
COCIP model for avoidance and to derive contrail mitigation scenarios





Teoh, Voigt et al., ACPD, 2022

Outline

(1) Climate impact from aviation – focus on contrails

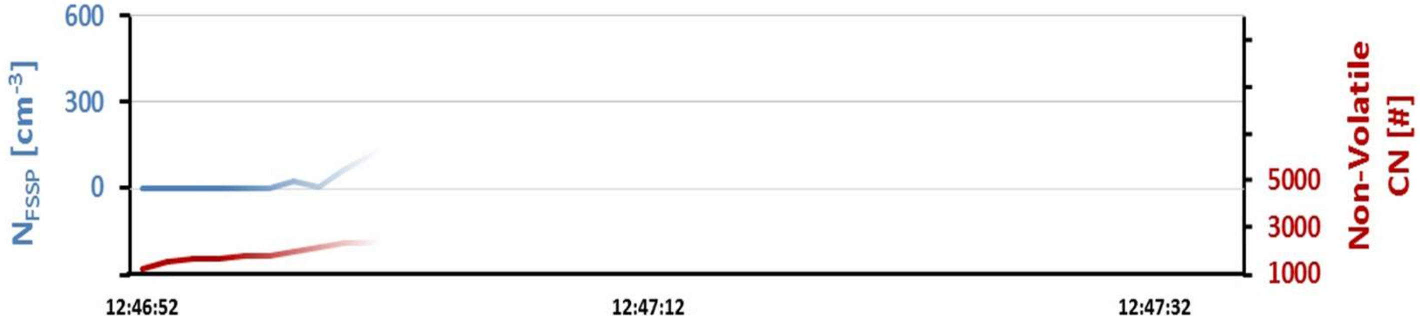
(2) Contrail formation, evolution and properties

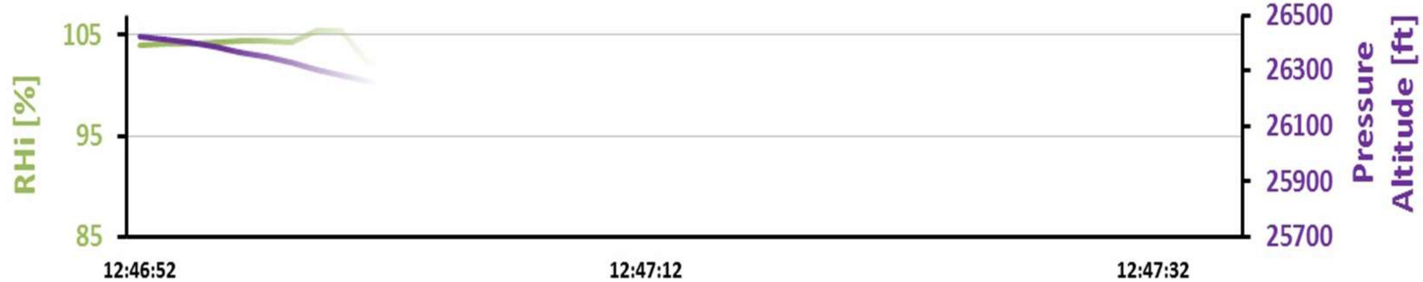
(3) Contrail mitigation

→ ATM measures for contrail avoidance

→ **Technical progress: sustainable avaition fuels SAF and hydrogen**

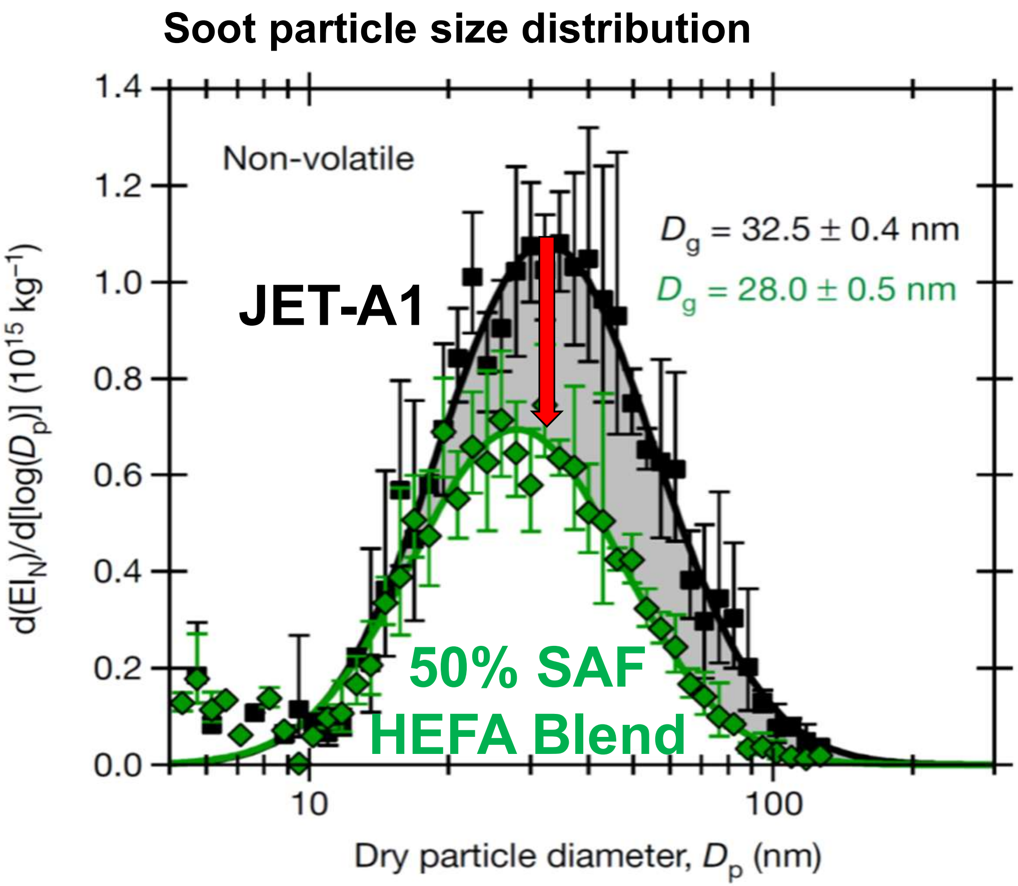
Messung von Kondensstreifen mit Biotreibstoffen





ECLIF 1&2 - Ground and in-flight measurements of emissions and contrails from SAF

Low aromatic sustainable aviation fuels reduce soot emissions

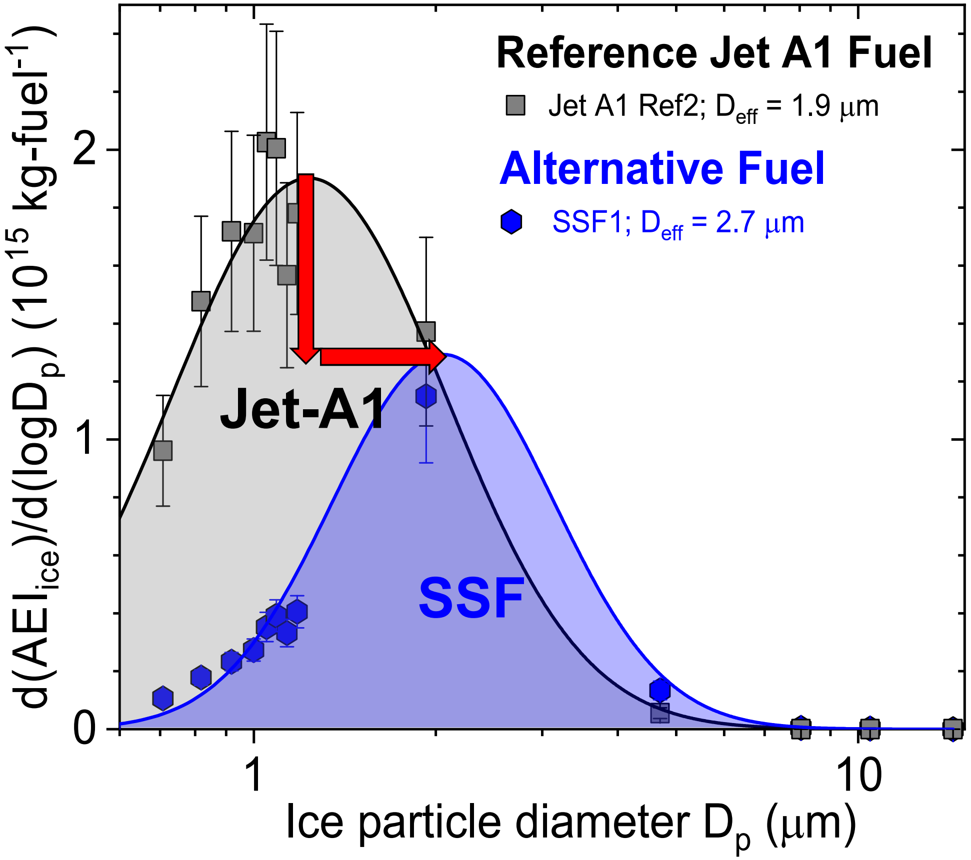


Camelina

Moore et al., Nature, 2017

Cleaner burning jet fuels reduce contrail cloudiness

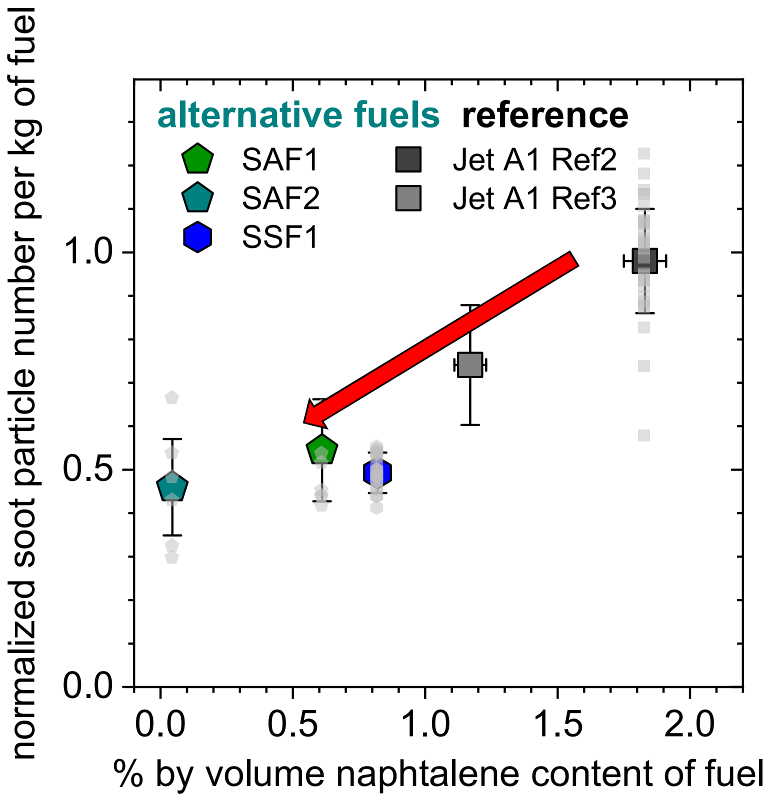
Contrail ice crystal size distribution

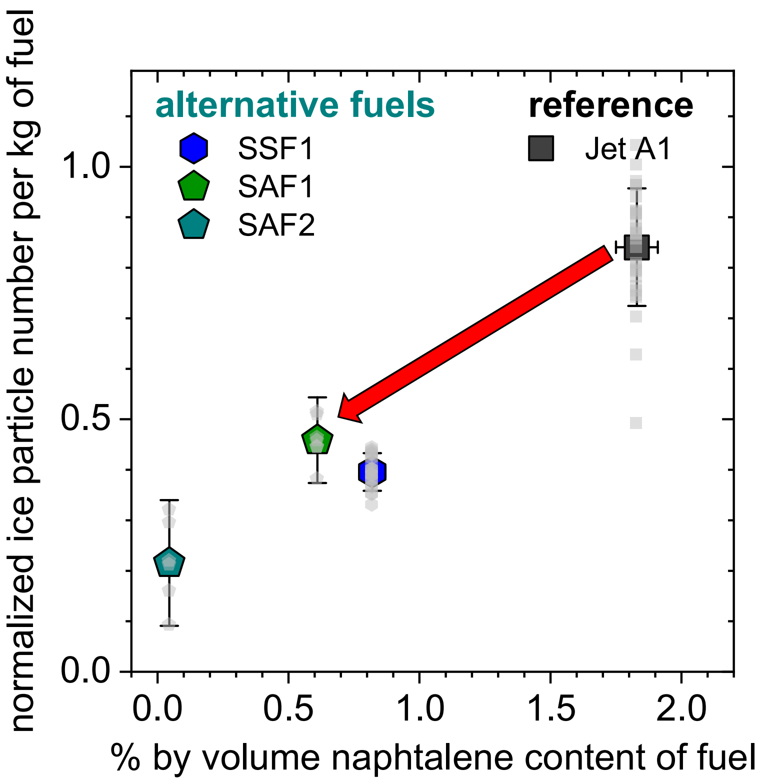


Voigt et al., Comm EE, 2021

nature

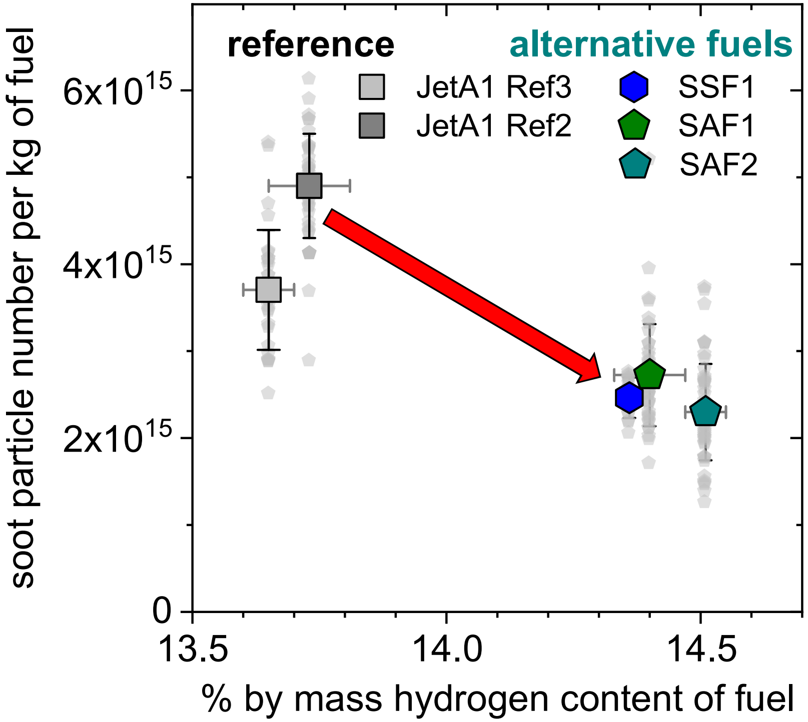
Cleaner burning jet fuels reduce contrail cloudiness – Dependence of EI on Aromatic / Naphtalene content of fuels

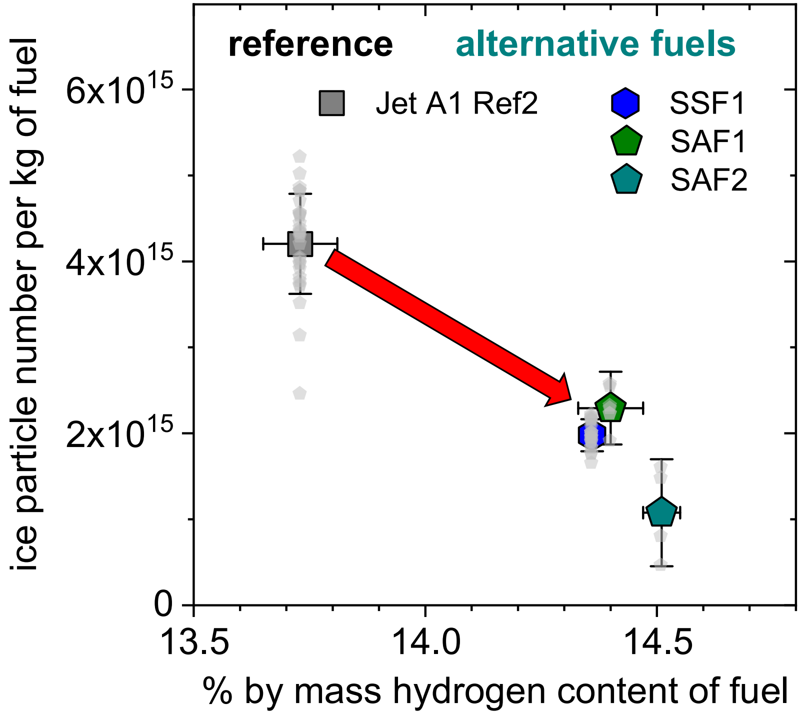




Voigt et al., Comm EE, 2021

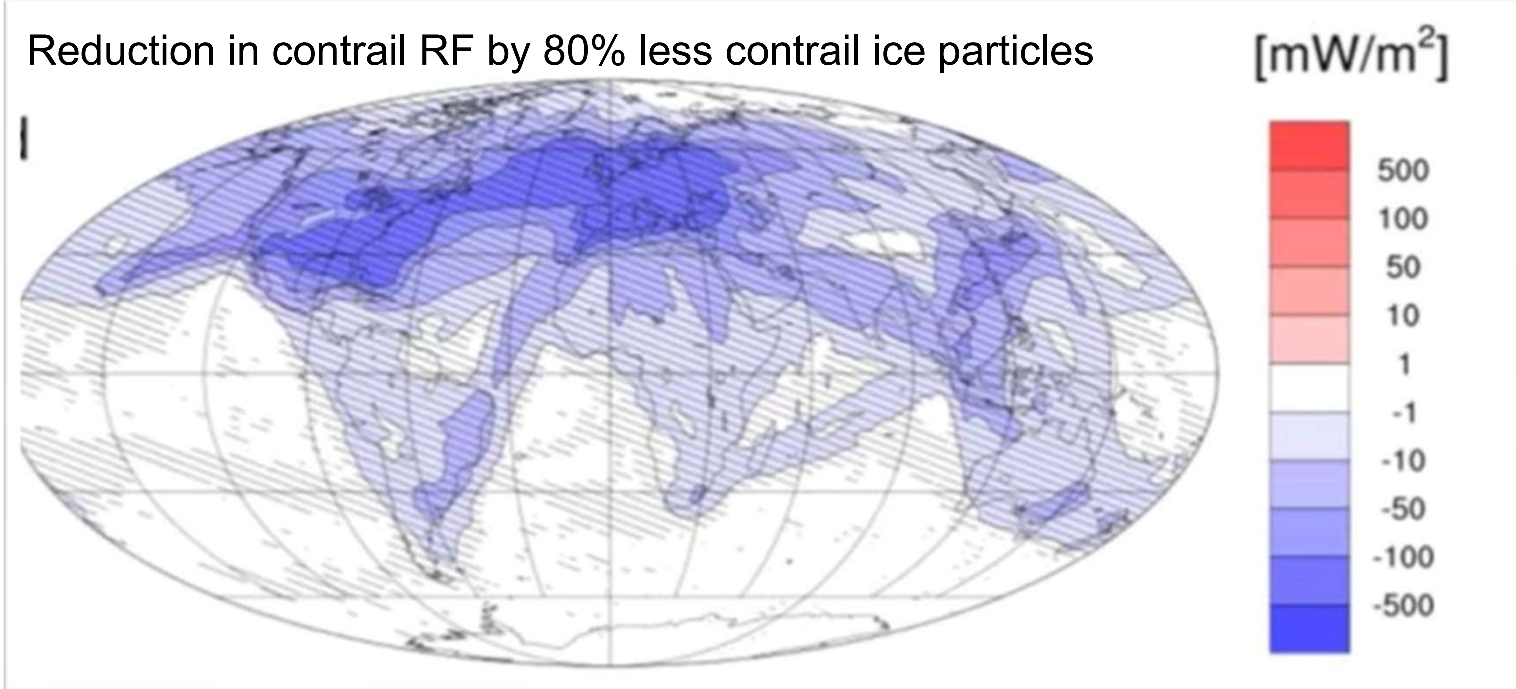
Cleaner burning jet fuels reduce contrail cloudiness
Dependence of EI on H-content of fuel





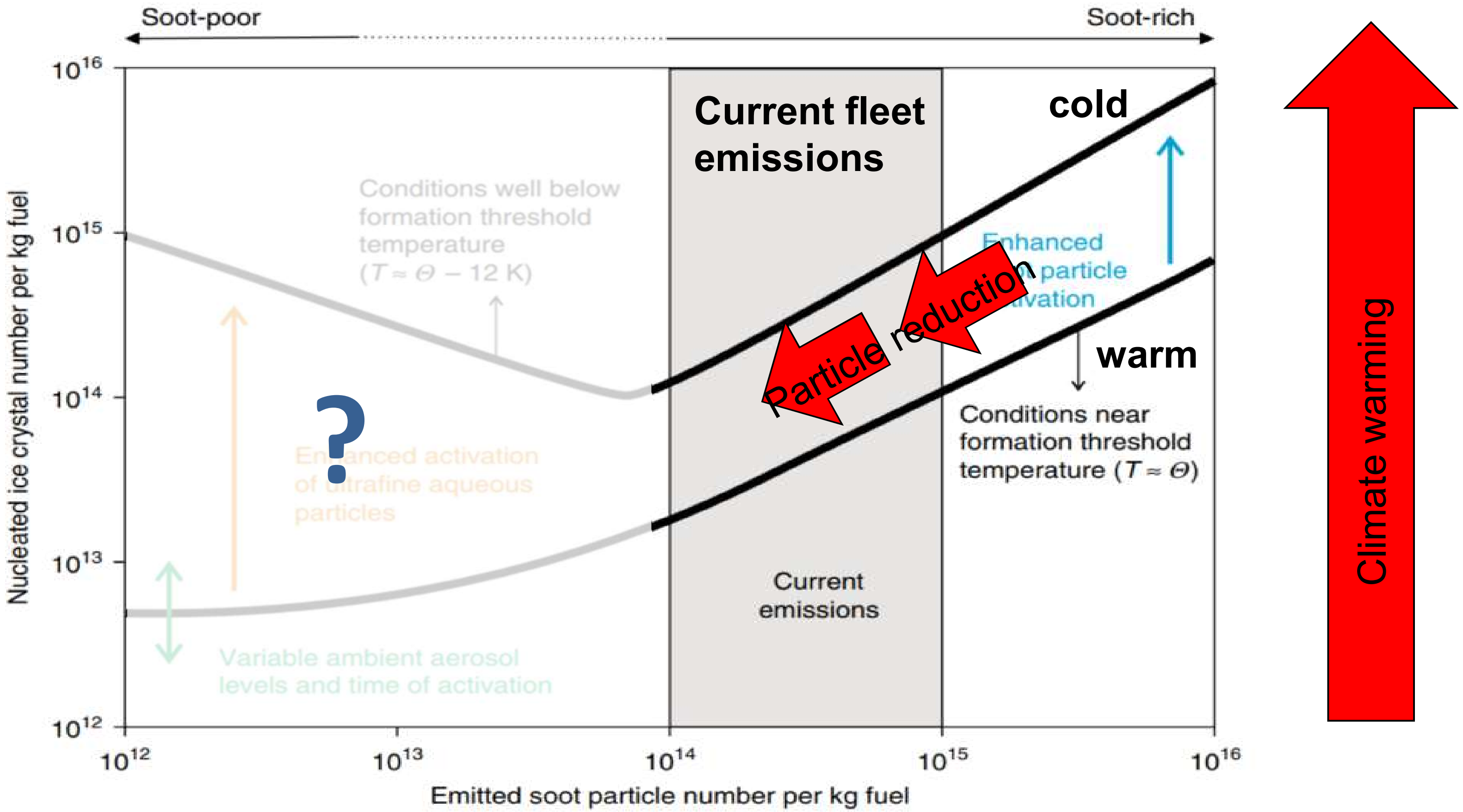
Voigt et al., Comm EE, 2021

Lower climate impact by reduced ice numbers in contrails



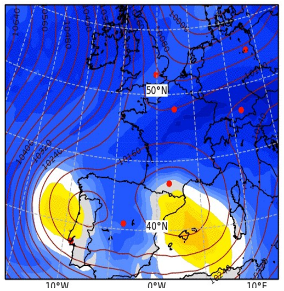
ECLIF provides the link between fuel composition, emissions, contrails and climate impact

Reducing particle emissions, contrails and aviation‘s climate impact



Kärcher, 2018

Next steps ECLIF3
A350 with Trent-XWB engines and 100%SAF



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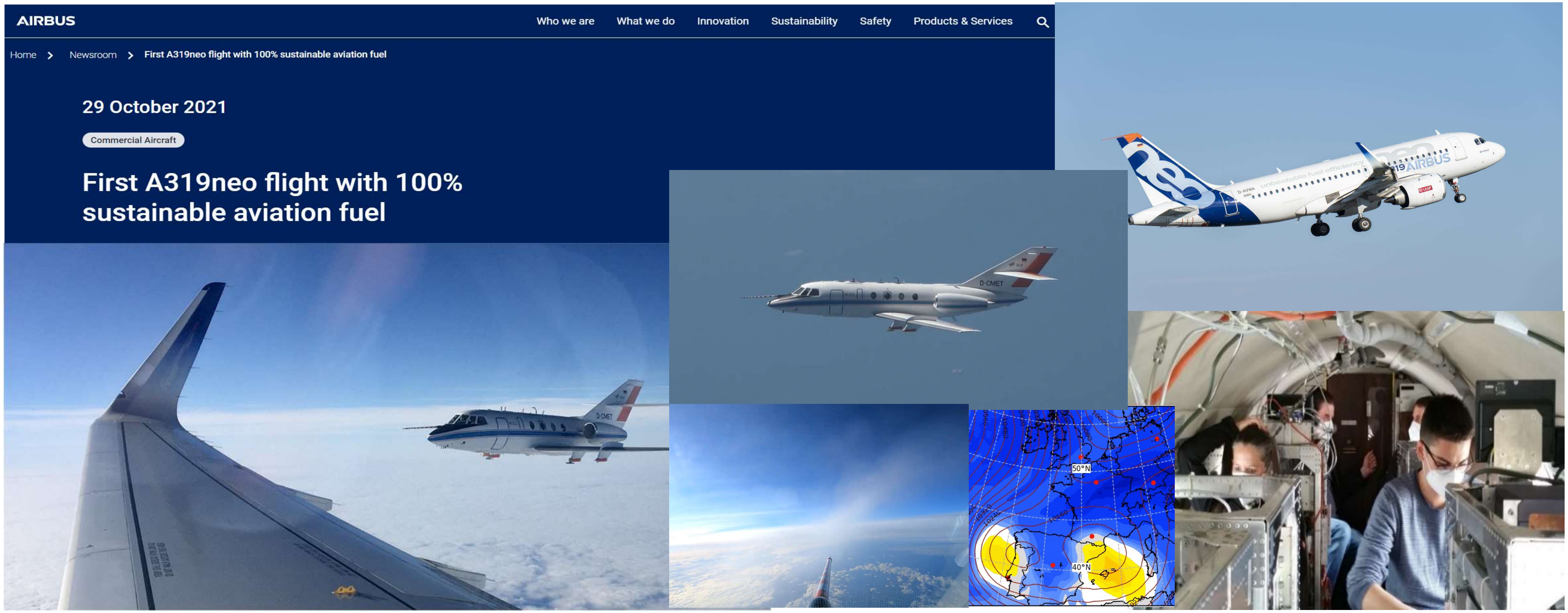
https://www.dlr.de/content/en/articles/news/2021/01/20210318_first-in-flight-100-percent-sustainable-fuel-emissions-study.html

Volcan - A319neo with Leap 1A engines and 100% SAF



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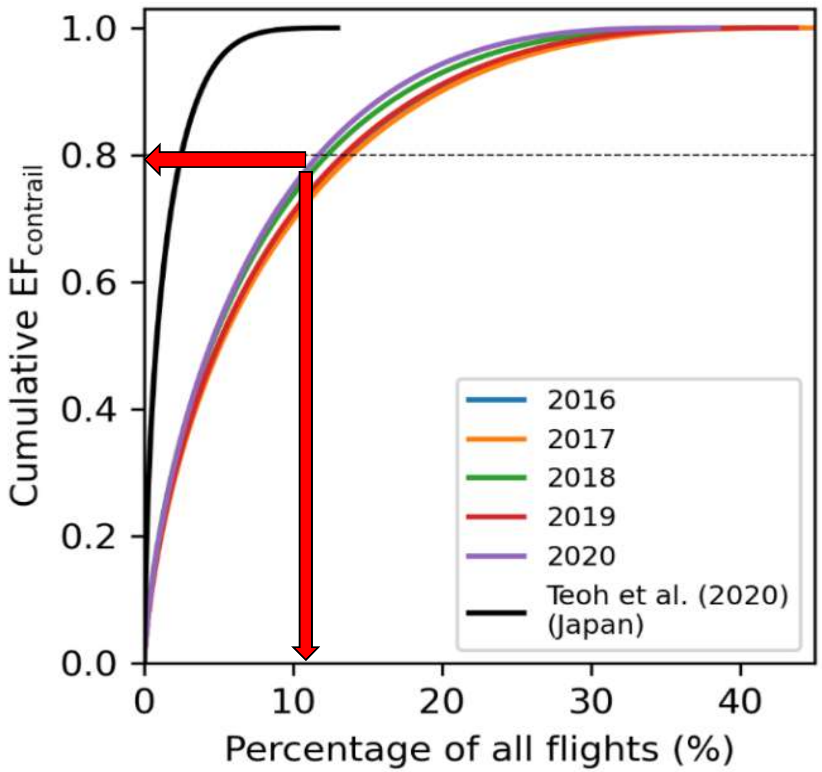
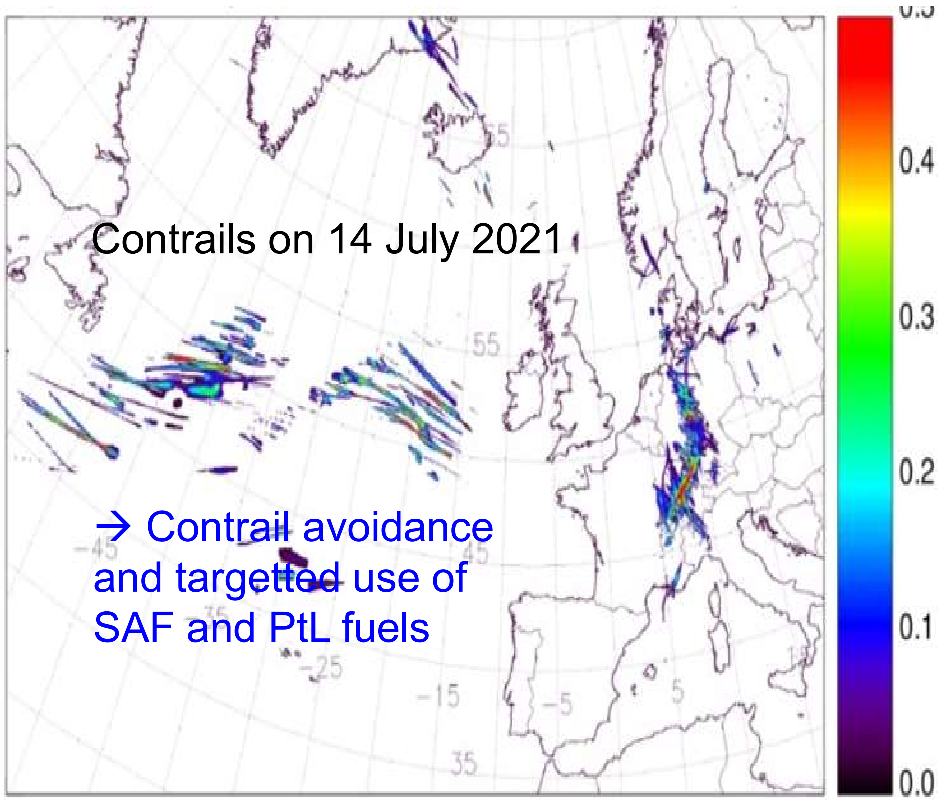
https://www.airbus.com/en/newsroom/press-releases/2021-10-first-a319neo-flight-with-100-sustainable-aviation-fuel

Combine ATM and SAF – Targetted use of SAF and PtL fuels





Take home messages

→ Future **sustainable aviation** needs to **reduce CO_2, particles** and the **contrail climate impact.**

→ **Non-CO_2 effects (contrails)** provide the **largest share** to the **climate impact from aviation.**

→ Unlike CO_2, **contrail mitigation** acts on **time scales** of **hours – fast reduction possible.**

→ **SAF / PtL** have **a lower CO_2 footprint in the LCA and lead to particle & contrails reduction.**

→ **Hydrogen fuels** have **no CO_2 emissions, particles & contrail effect to be investigated.**

→ **Measurements are required to investigate low particle emission scenarios.**

→ There is **no single solution for green aviation.**

→ **Different technologies** are required for major progress: enhanced **efficiency, clean propulsion by modern fuels and engines, and ATM.**

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