NOVEL PATHWAYS TO SUSTAINABLE AVIATION

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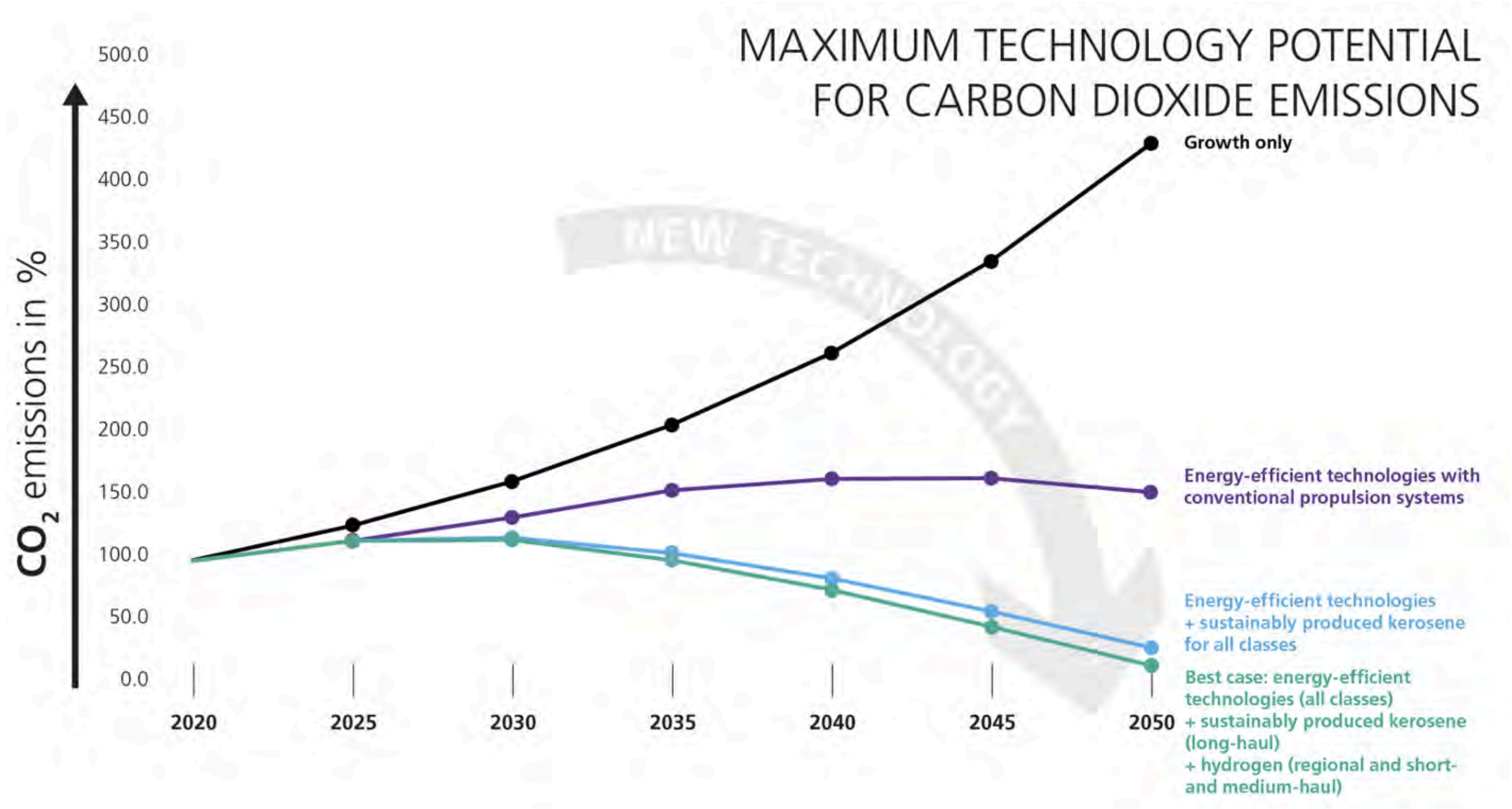
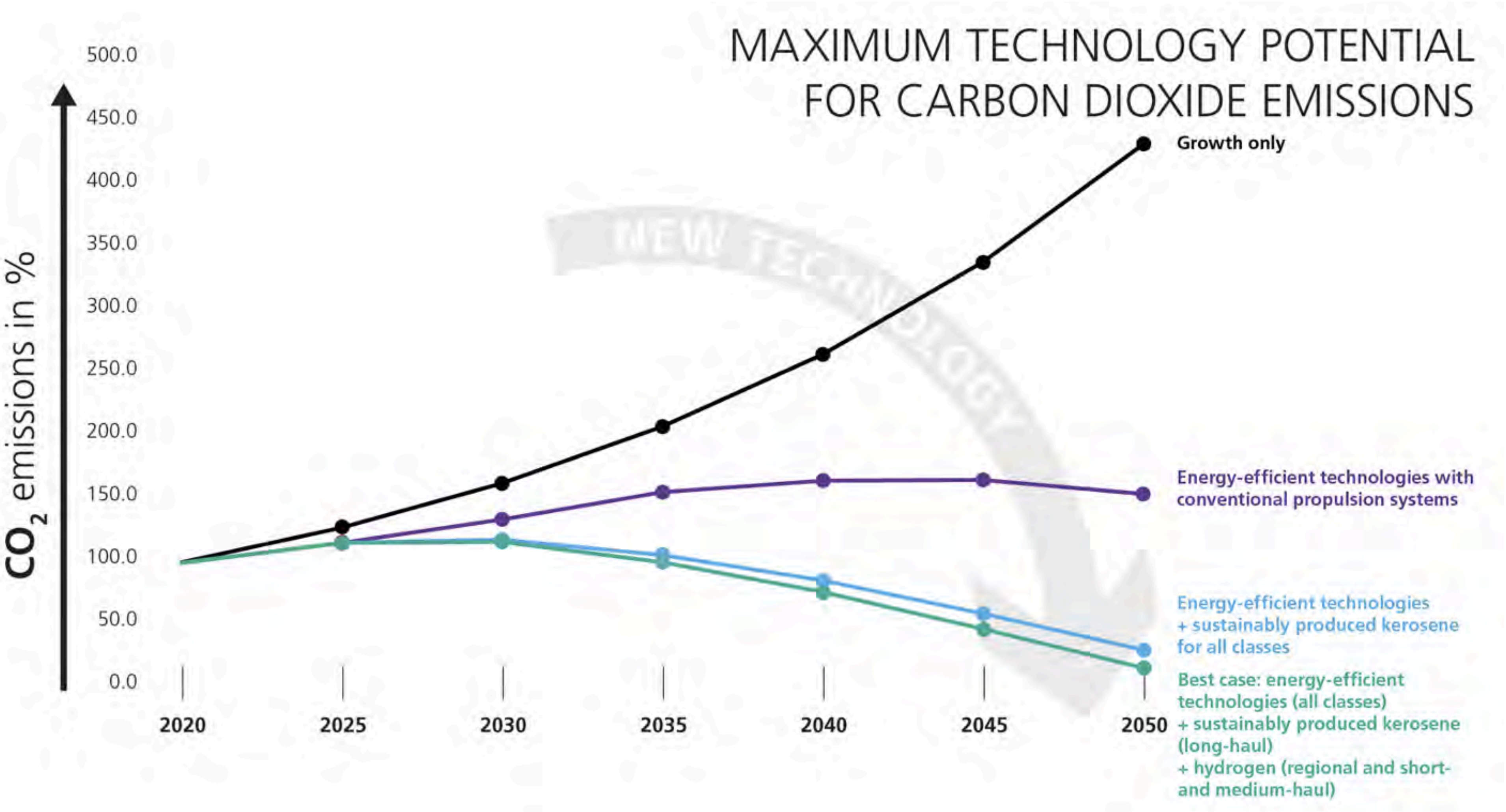
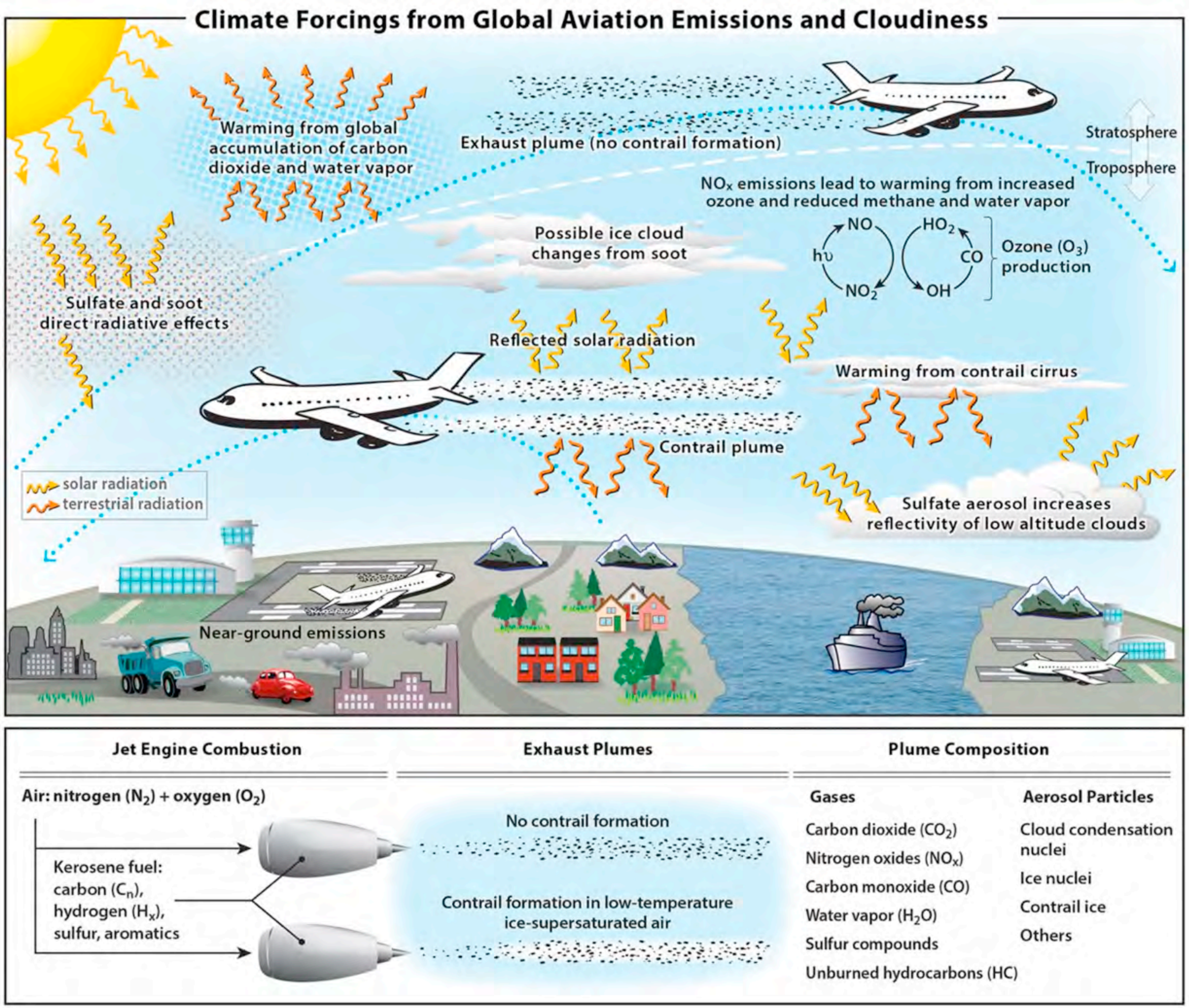
Content

- Short re-cap
- Aviation related Climate Impact: focus on contrails
- Technical progress: SAF / H_2
- Conclusion


MAXIMUM TECHNOLOGY POTENTIAL
FOR CARBON DIOXIDE EMISSIONS
CO_2 emissions in %
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
2020
2025
2030
2035
2040
2045
2050
NEW TECHNOLOGY
Growth only
Energy-efficient technologies with conventional propulsion systems
Energy-efficient technologies + sustainably produced kerosene for all classes
Best case: energy-efficient technologies (all classes) + sustainably produced kerosene (long-haul) + hydrogen (regional and short- and medium-haul)

For the climate-neutral air transport system of the future, DLR is committed to support the decoupling of air traffic growth and it’s climate impact.
DLR is thus assessing combinations of all potential technologies towards this objective




Climate Forcings from Global Aviation Emissions and Cloudiness
Warming from global accumulation of carbon dioxide and water vapor
Exhaust plume (no contrail formation)
Stratosphere
Troposphere
NOx emissions lead to warming from increased ozone and reduced methane and water vapor
Possible ice cloud changes from soot
NO
HO2
hυ
CO
NO2
OH
Ozone (O3) production
Sulfate and soot direct radiative effects
Reflected solar radiation
Warming from contrail cirrus
Contrail plume
solar radiation
terrestrial radiation
Sulfate aerosol increases reflectivity of low altitude clouds
Near-ground emissions
Jet Engine Combustion
Exhaust Plumes
Plume Composition
Air: nitrogen (N2) + oxygen (O2)
Kerosene fuel: carbon (Cn), hydrogen (Hx), sulfur, aromatics
No contrail formation
Contrail formation in low-temperature ice-supersaturated air
Gases
Carbon dioxide (CO2)
Nitrogen oxides (NOx)
Carbon monoxide (CO)
Water vapor (H2O)
Sulfur compounds
Unburned hydrocarbons (HC)
Aerosol Particles
Cloud condensation nuclei
Ice nuclei
Contrail ice
Others

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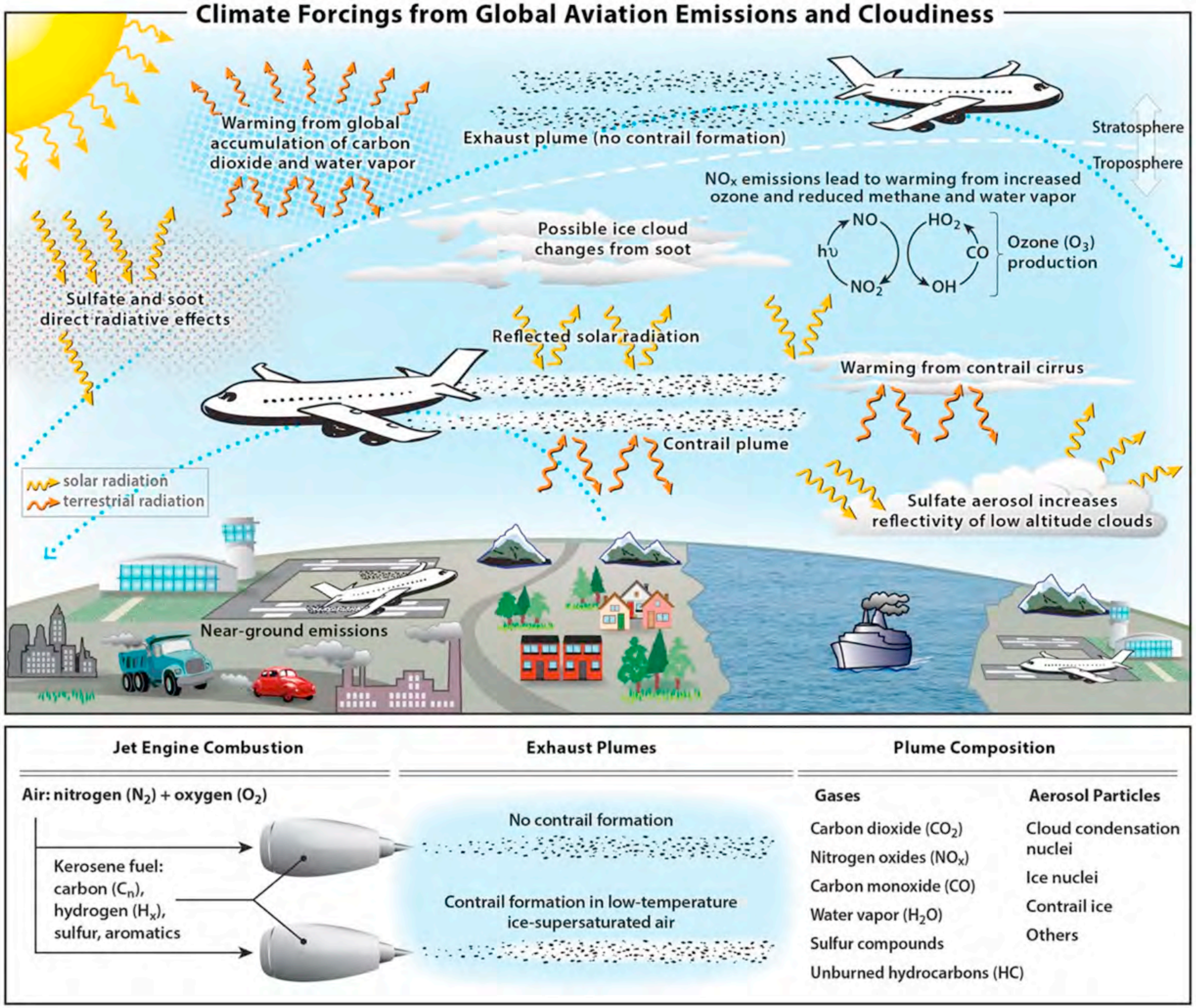

→ **There is more…..** but **with larger uncertainties.**

→ **Aviation contributes 3.5%** to the **total anthropogenic warming (ERF).**

→ **Largest contribution** from **contrail cirrus.**

→ **Positive (warming) effect** despite **uncertainties….**

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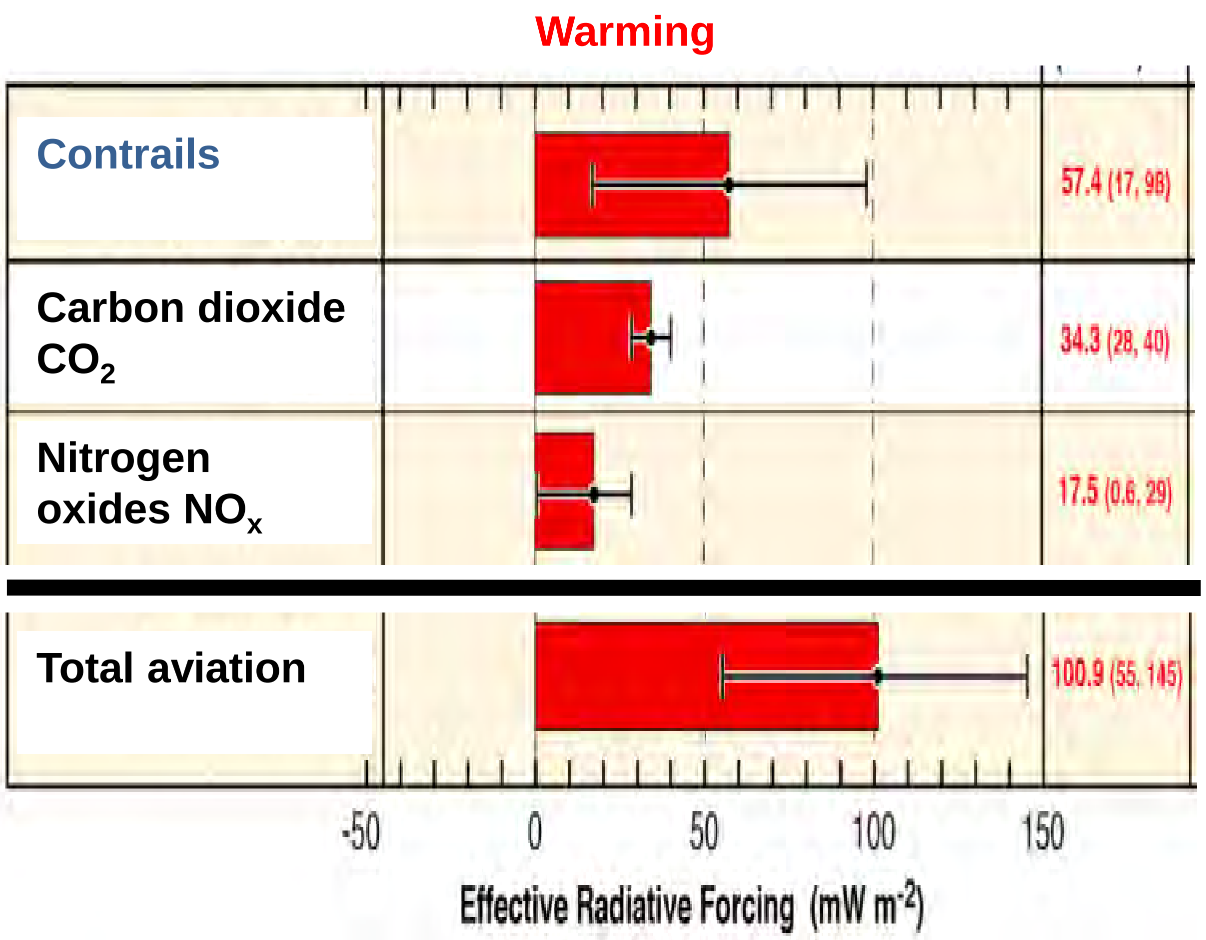
Main Contributors to the Climate Impact from Aviation



→ **1/3** of the **climate impact from aviation** (1940 to 2018) comes from **CO_2.**

→ **2/3** from **non-CO_2 effects**

→ **Contrails** have the **largest contribution** to **ERF.**

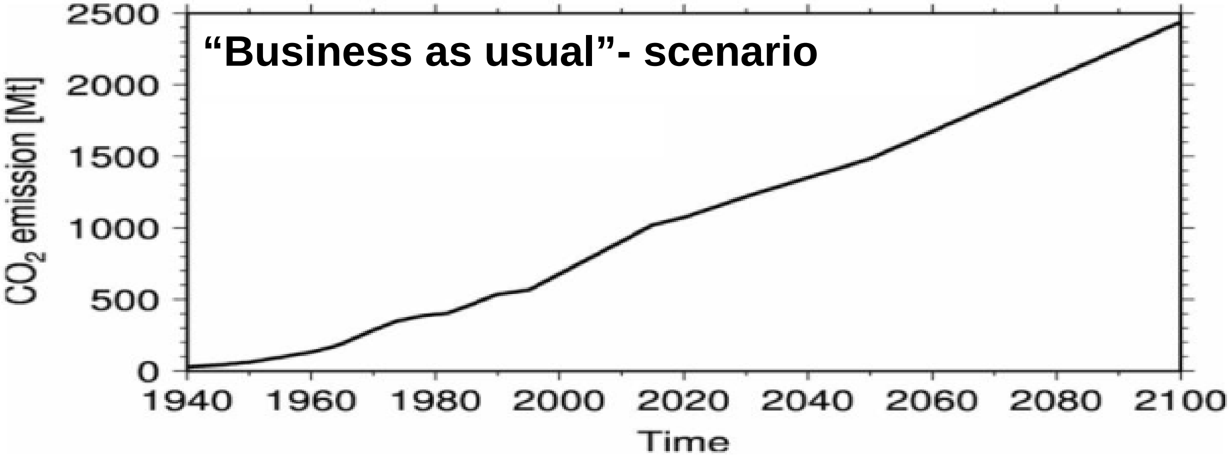
→ **Sustainable aviation** is more than decarbonization.

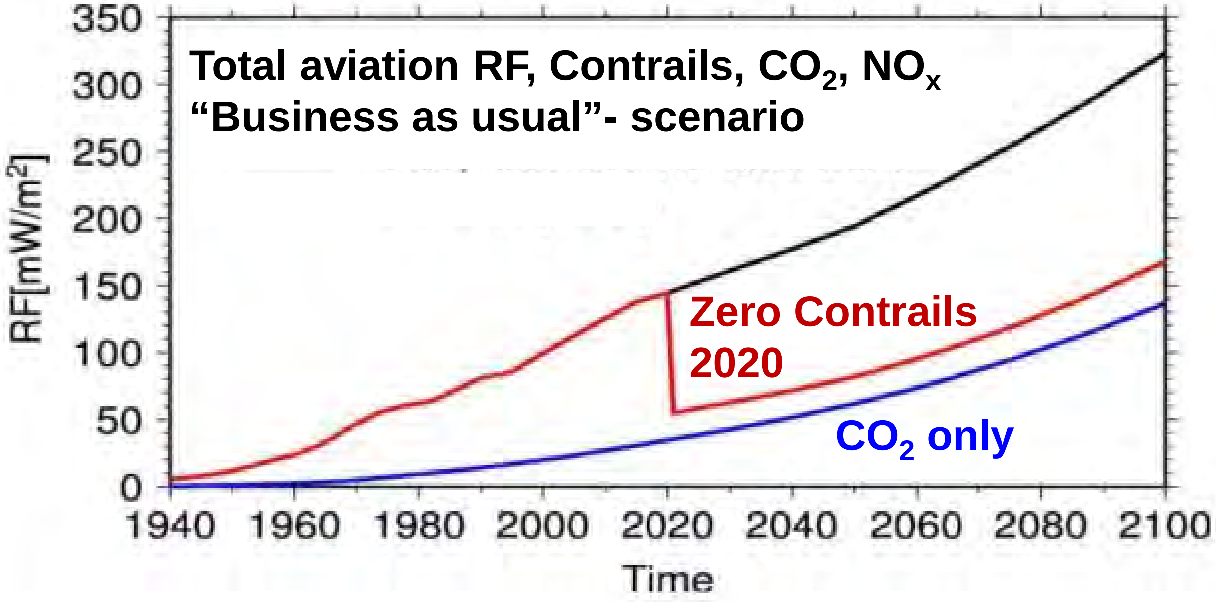
→ There is the **need** to **reduce** **non-CO_2 effects.**

→ Need to **set incentives** to profit from the **climate benefit** from **non-CO_2 effects** (**contrails**).

Lee et al., Atm Env, 2021

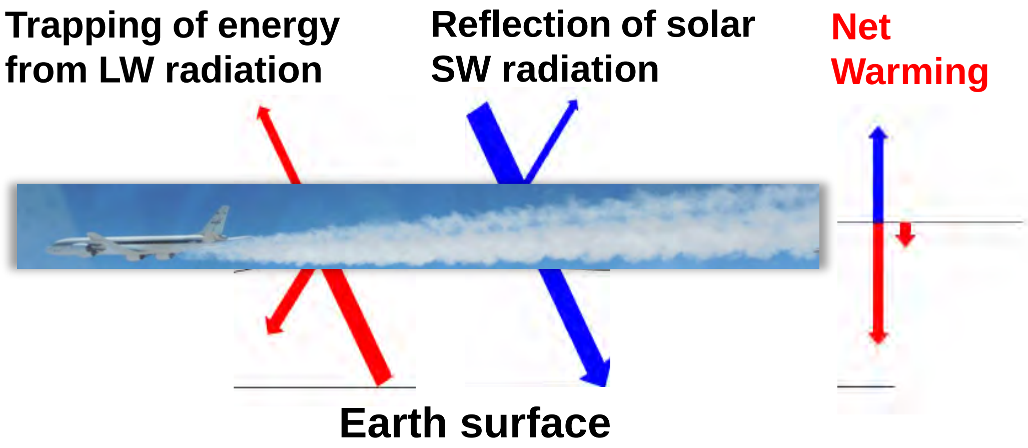
Radiative forcing from aviation since 1940





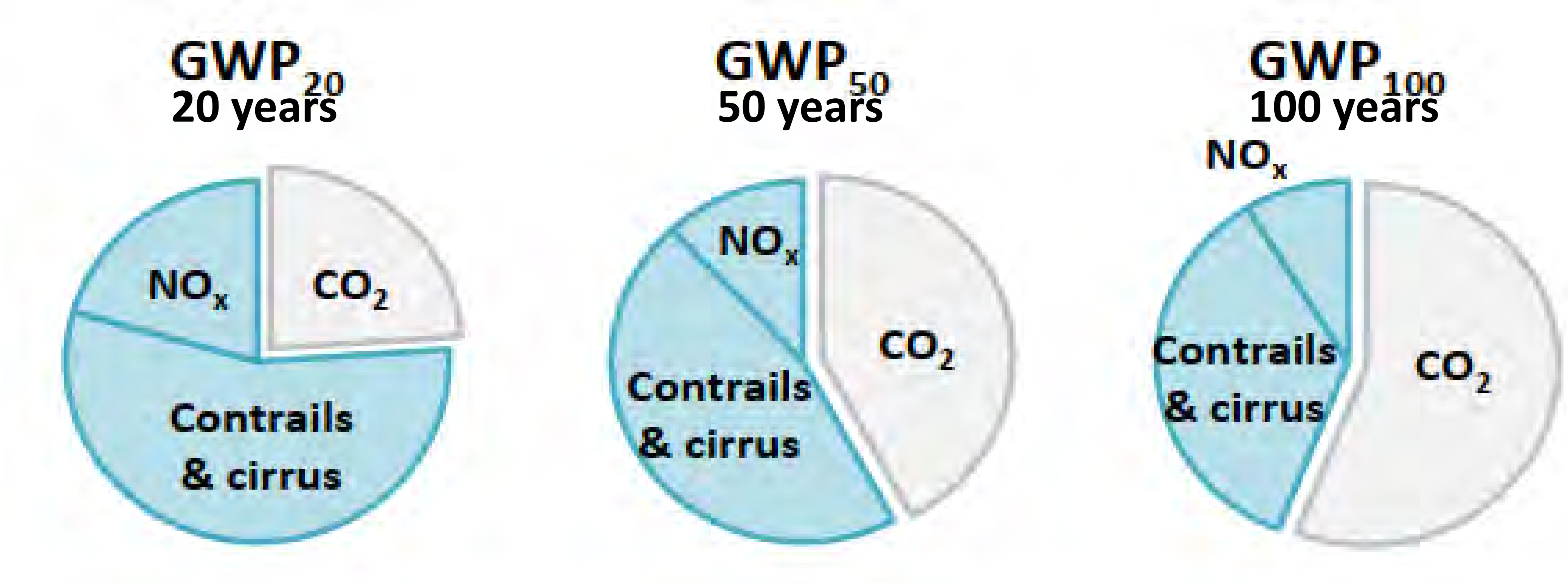
→ **Contrails deposit energy** in the atmosphere only during their **lifetime** of **few hours.**

→ The **mitigation** of **non-CO_2 effects** provides a **fast solution** to the aviation climate challenge.



Schumann, 2018

Global Warming Potential of aviation CO_2 & non-CO_2 on different time scales

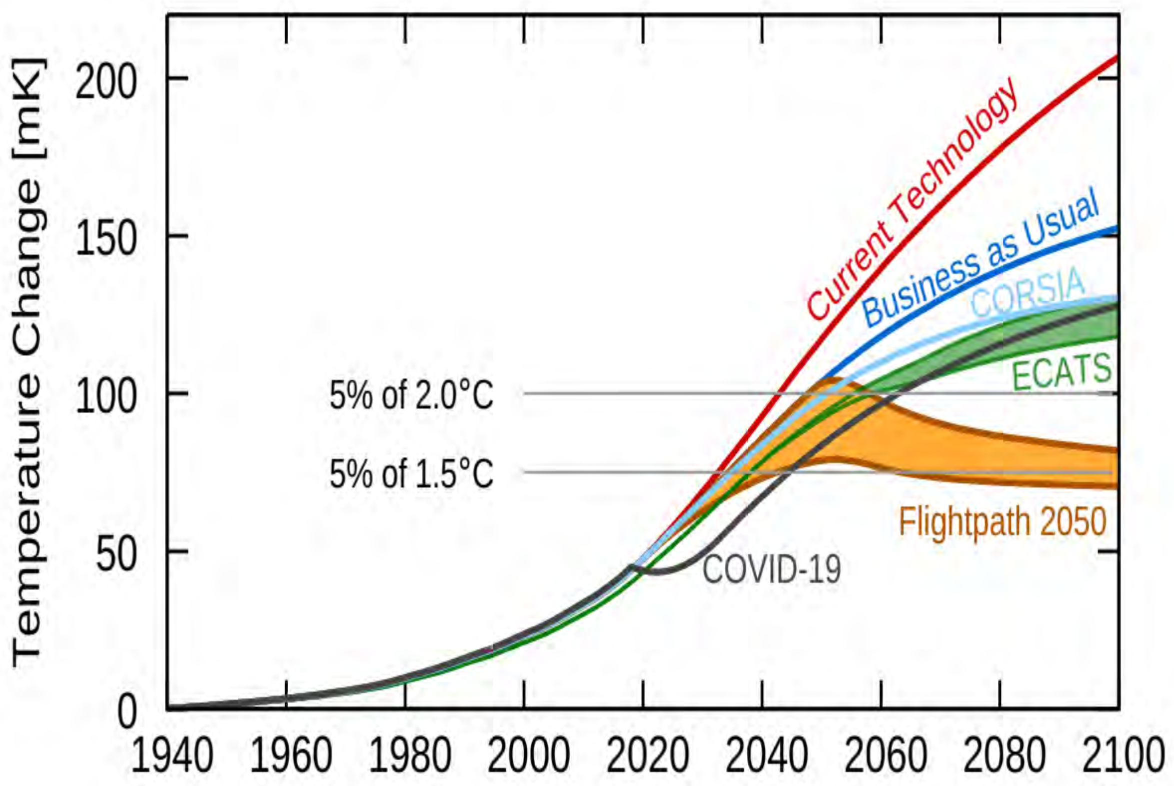


→ **Non-CO_2 effects** are **important, even on long time scales.**

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**

From Lee et al., Atm Env, 2021

Are the goals usefull to stabilize the aviation contribution to global warming?



→ The goals of **Flightpath 2050** (-75% CO_2; -90% NO_x) aim to stabilize the aviation contribution to global warming.

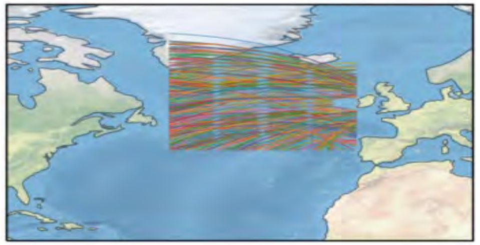
→ Nevertheless the **Goals of Flightpath** 2050 are hardly achievable, therefore stabilization is **unrealistic**

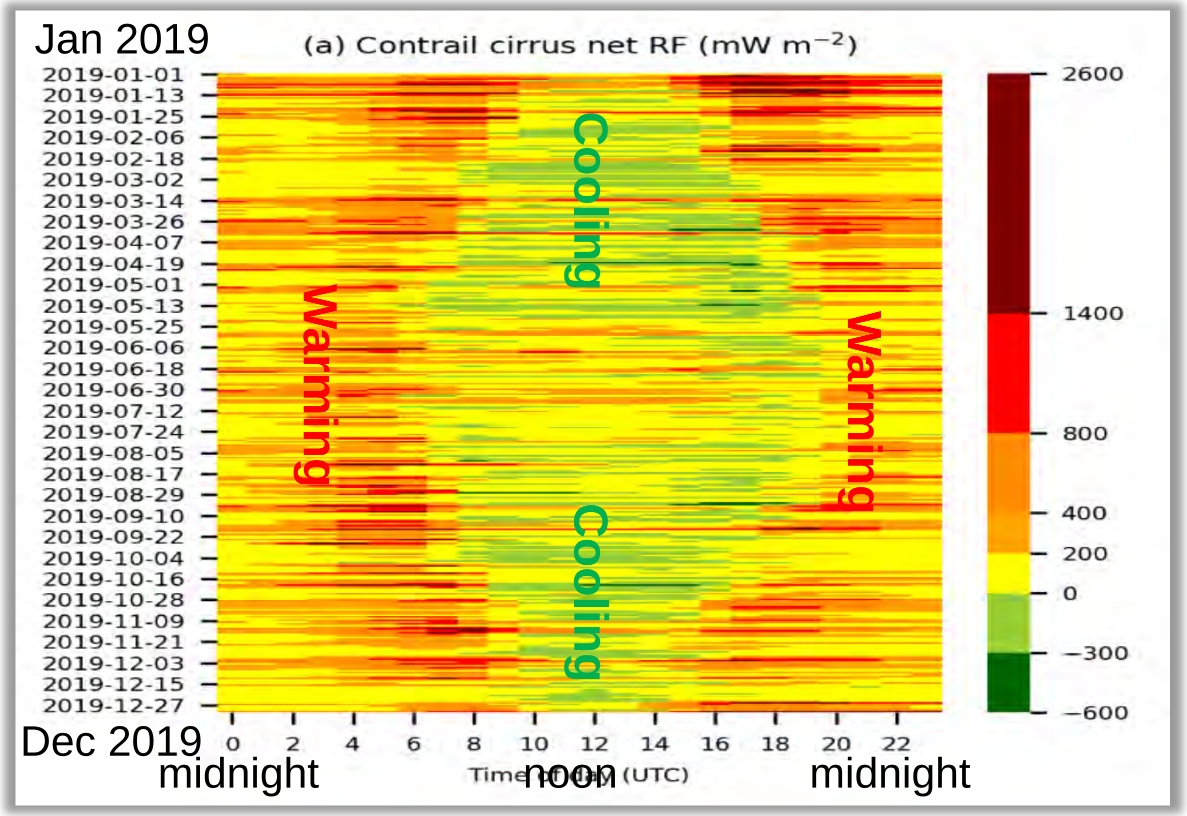
→ COVID19 lesson: sustained change in travel behavior can contibute to a reduced temperature increase

→ **Other means required**

Grewe et al., Nat. Comm., 2021

Contrails cool at noon and warm during the night





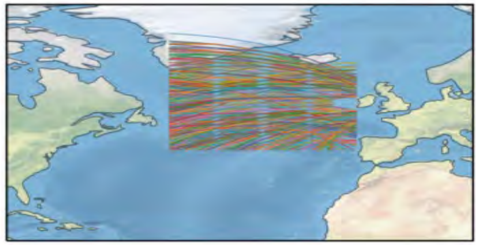
→**Daily and hourly net radiative forcing from contrail cirrus** in the northern Atlantic flight corridor in 2019.

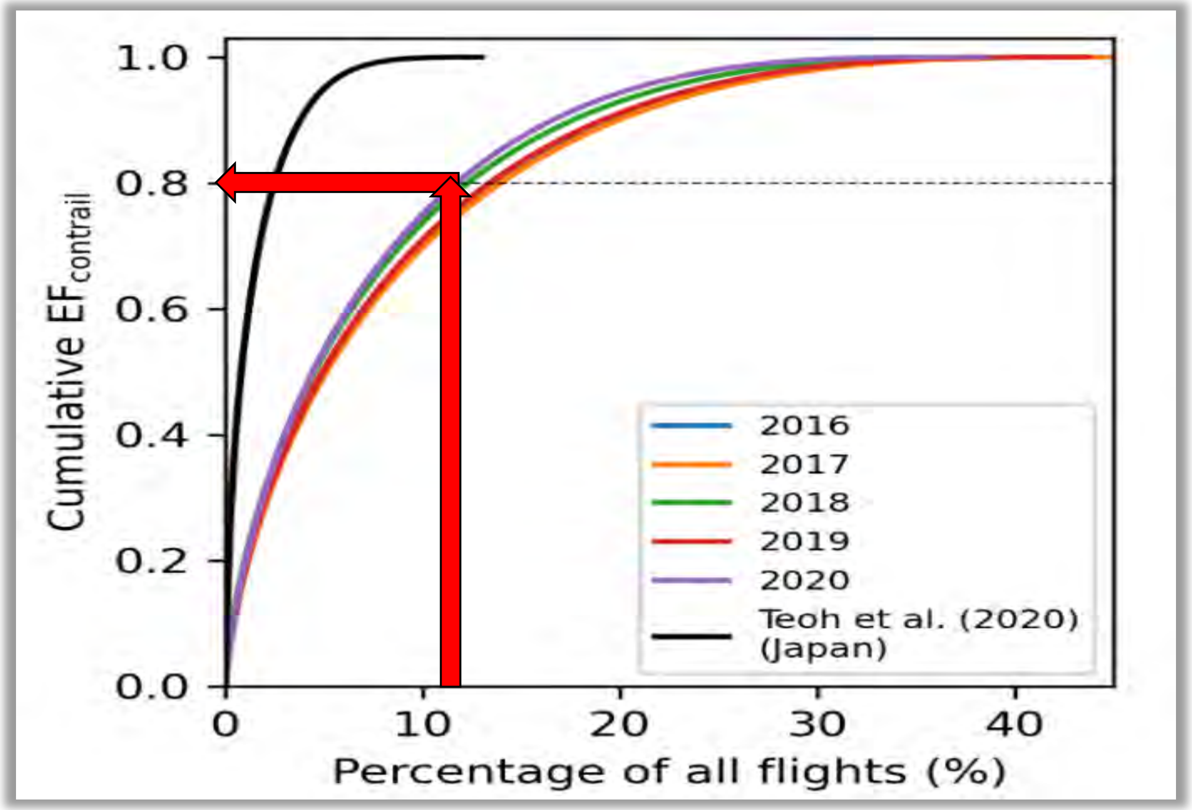
→ **Contails cool** at **noon**, no need to mitigate.

→ **Need** for **contrail mitigation** in selected **morning, evening** and **night time flights.**

Teoh et al., ACPD, 2022

Reduction of the aviation climate impact by contrails





→ Most of the flight do not produce contrails.

→ **12% of flights** in the northern Atlantic region produce **80%** of the **contrail energy forcing**.

→ Only **few flights** have to be **rerouted** for **significant climate gain!**

→ **Targeted use** of **future fuels** in case of low availability to **increase the climate benefit**.

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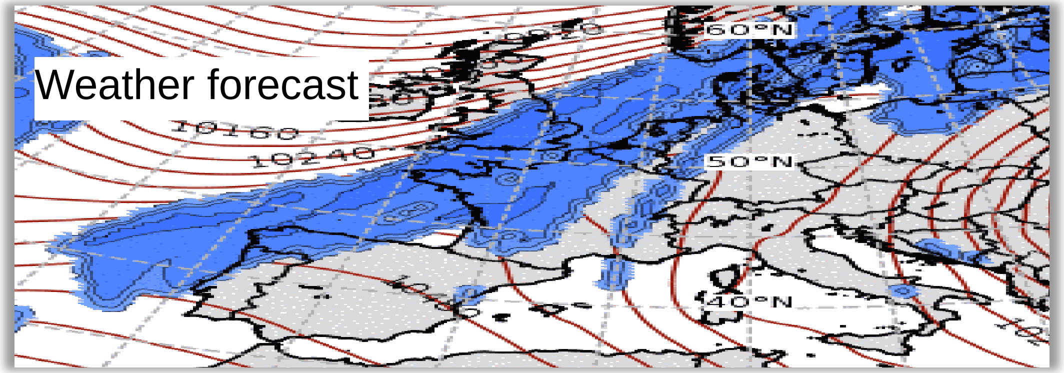
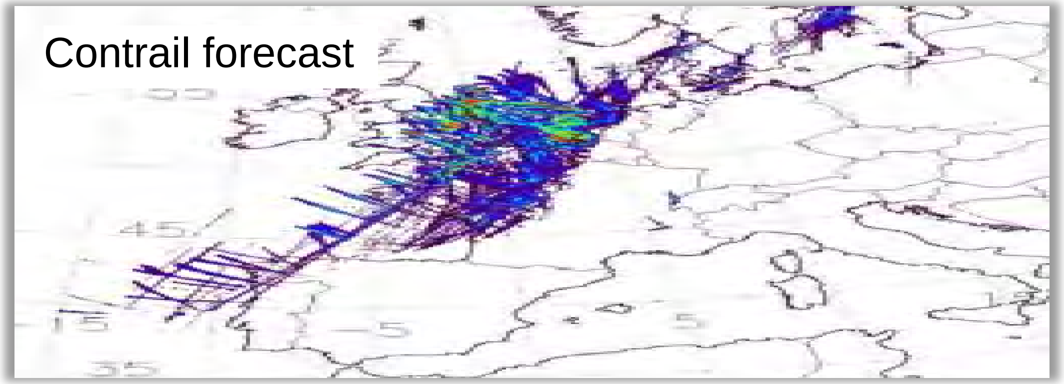
Teoh, Schumann, Voigt et al., ACP, 2022

Ecoefficient flight routing and contrail avoidance





→ **Contrails form** and **move** with **specific weather systems.**

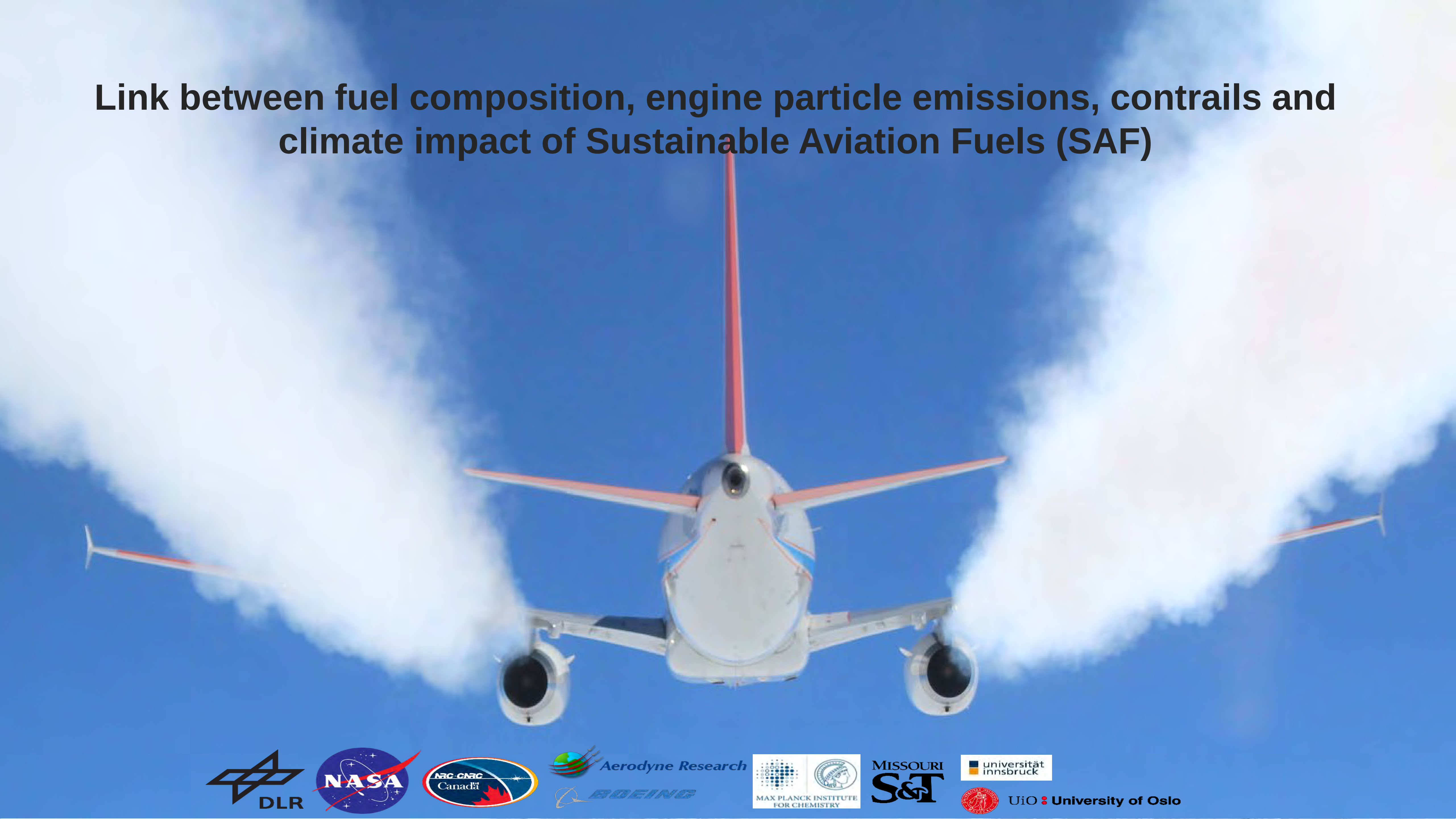
→ **Dedicated weather/contrail forecasts needed.**

→ **First contrail avoidance trials** by DLR, Eurocontrol, MUAC **show** that **contrail avoidance is possible.**

Further mitigation options: Future Fuels

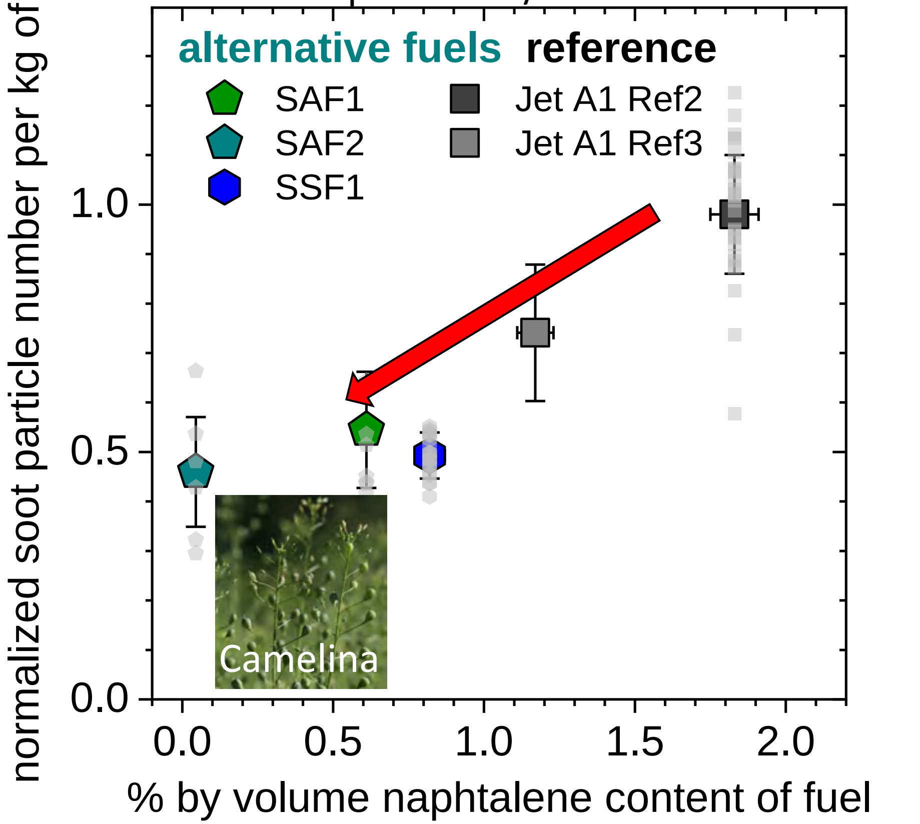
Schumann, 2022

Link between fuel composition, engine particle emissions, contrails and climate impact of Sustainable Aviation Fuels (SAF)

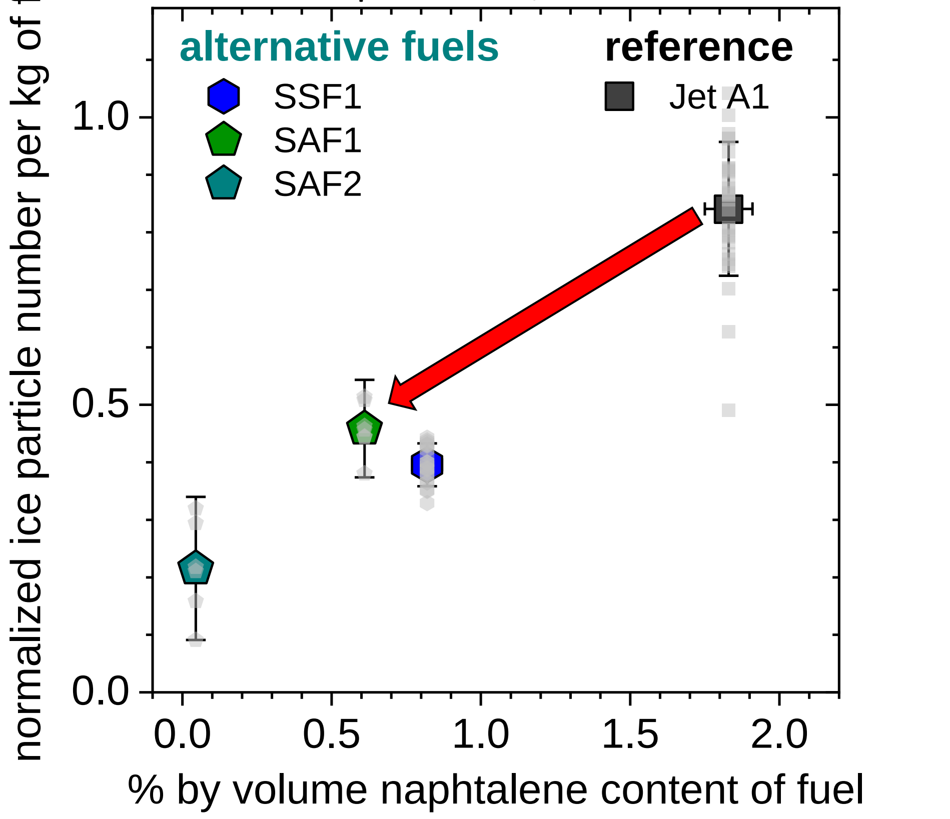


Cleaner burning jet fuels reduce soot particles and contrail cloudiness

Reduction in soot emissions for SAF with reduced naphthalene/aromatic fuel content

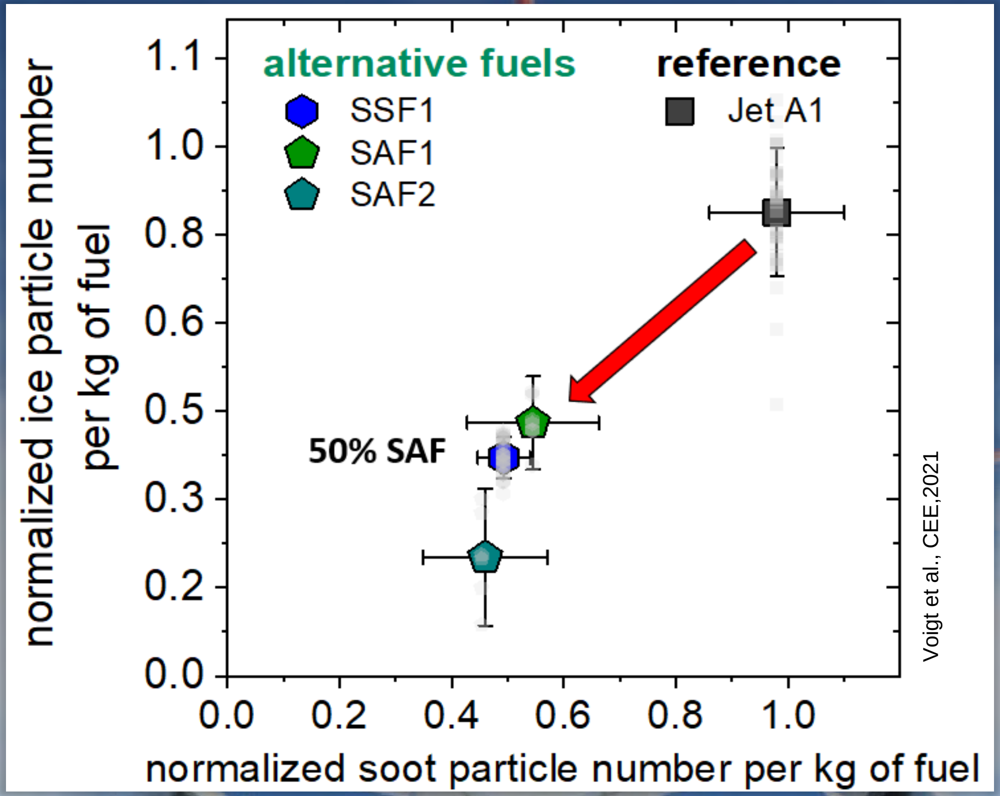


Reduction in contrail ice particles for SAF with reduced naphthalene/aromatic fuel content



Voigt et al., Comm EE, 2021

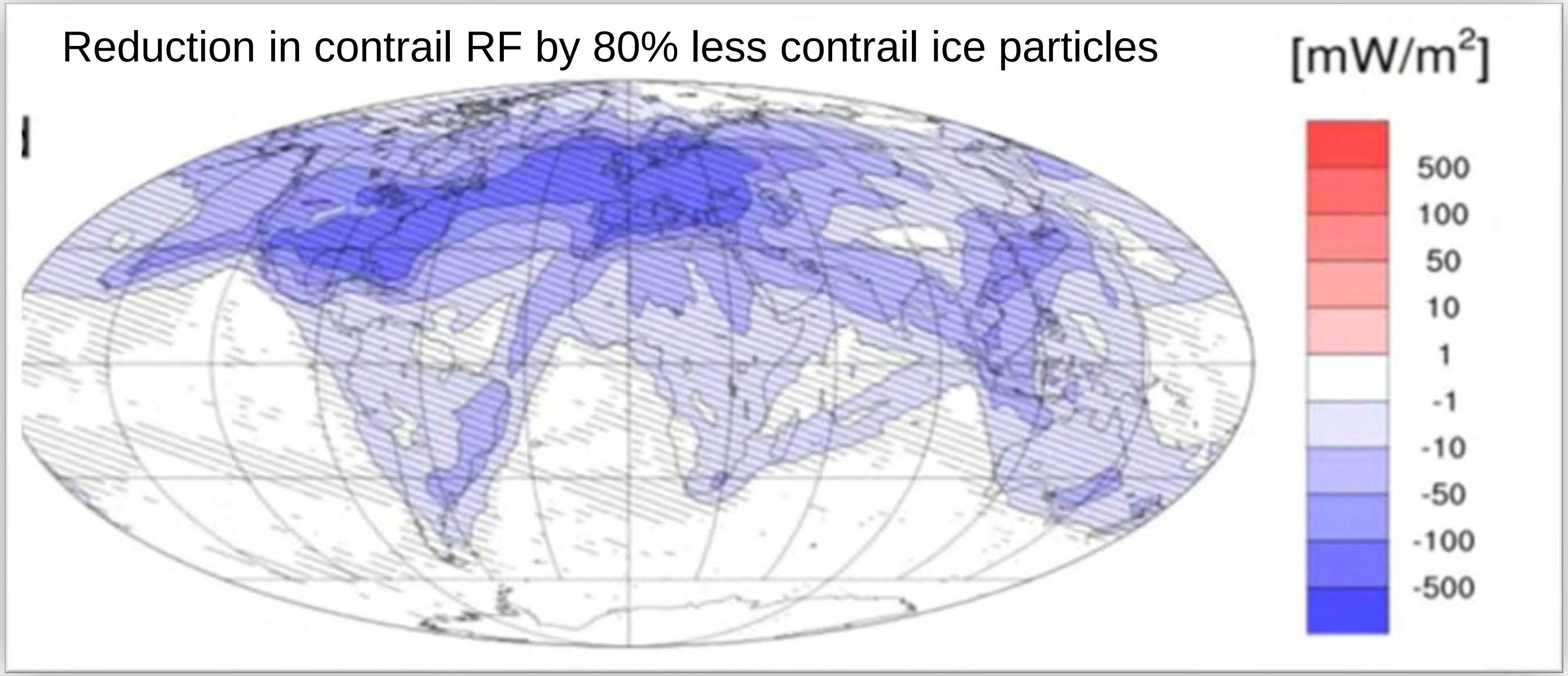
Link between fuel composition, engine particle emissions, contrails and climate impact of Sustainable Aviation Fuels (SAF)



→ **SAF** & **Synthetic Fuels** have a **low content** of **aromatic soot particle precursors.**

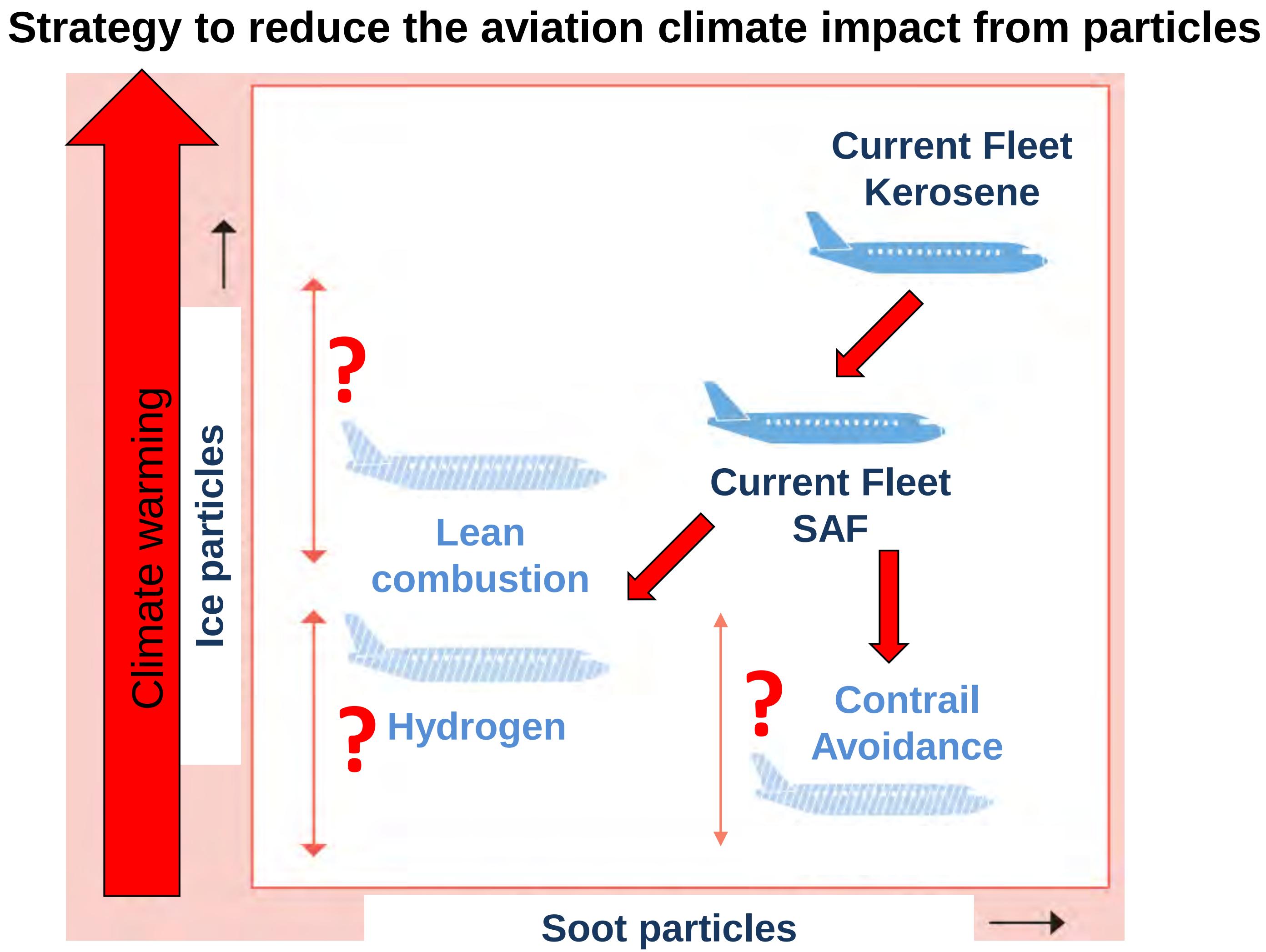
→ This leads to a **reduction** in **particle emissions** and **contrails** and to a **fast climate gain.**

Reduced ice crystal number lead to reduced contrail climate impact



→ Strategy to reduce aviations particle impact by **Future Fuels**

Cleaner Skies by Future Fuels



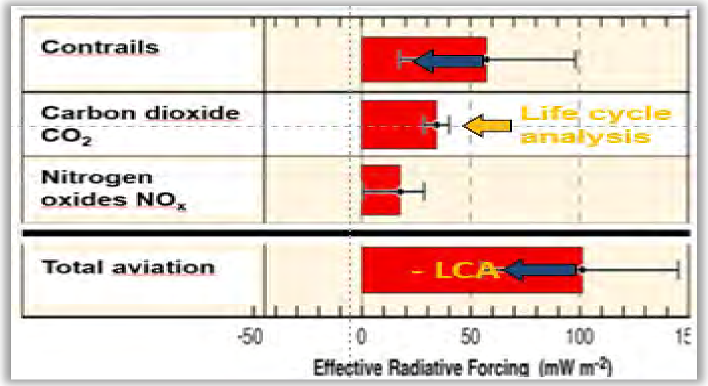
Voigt et al., 2022

DLR-Strategy to Assess Emissions and Climate Impact of Future Fuels

50 / 100% SAF(HEFA), Syn Fuels ECLIF1,2,3, VOLCAN

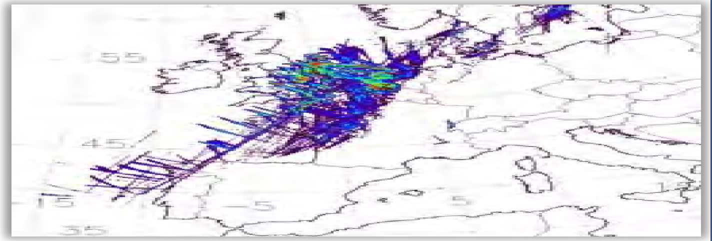
DLR/NASA/NRC/FAA/MPG/DFG
AIRBUS/Rolls-Royce/NRC/Neste
Safran/Dassault/ONERA 2021

First 100% SAF release of passenger aircraft and in-flight measurements
DC8, A320, A350, A319neo, Falcon

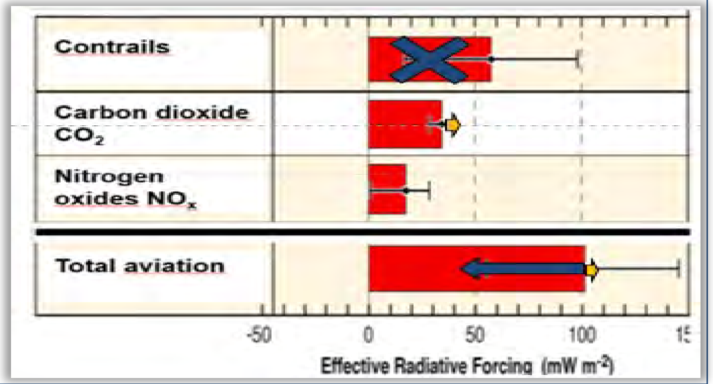


CIRRUS-HL Contrail avoidance trail

DLR/MUAC/EUROCONTROL
DFG, HGF, MPG, ETH, 2021

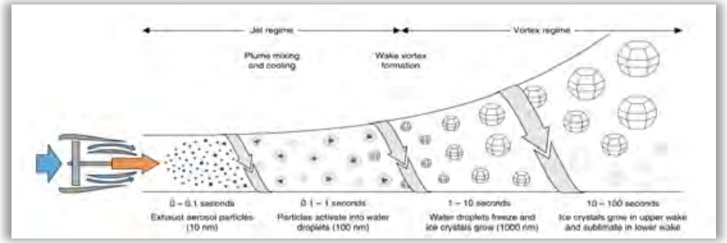


Contrail, day, nighttime contrails and DLR-MUAC contrail avoidance trial

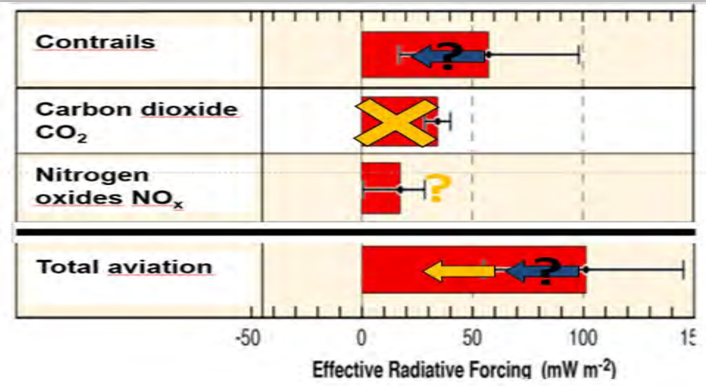


Hydrogen Combustion and Fuel Cells

Collaboration with industry & academia



Research to assess climate impact from H2 Combustion & Fuel Cells



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Conclusion

→ The **growth** of aviation needs to be **decoupled** from its **climate impact**

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

→ **Fast reduction** of **non-CO_2 effects like contrails (fewer particles) is possible** (contrail avoidance trial)

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

→ **Hydrogen fuels** have **no CO_2 emissions, nevertheless: contrail effect to be investigated**

→ There is **no single solution for aviation,** we **have to act now on "all frontiers"**

→ **Different technologies** are required to be **progressed: more efficient engines and airframes, future fuels, ATM, …**

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