The climate impact of aviation

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Climate, aviation and airport expansion
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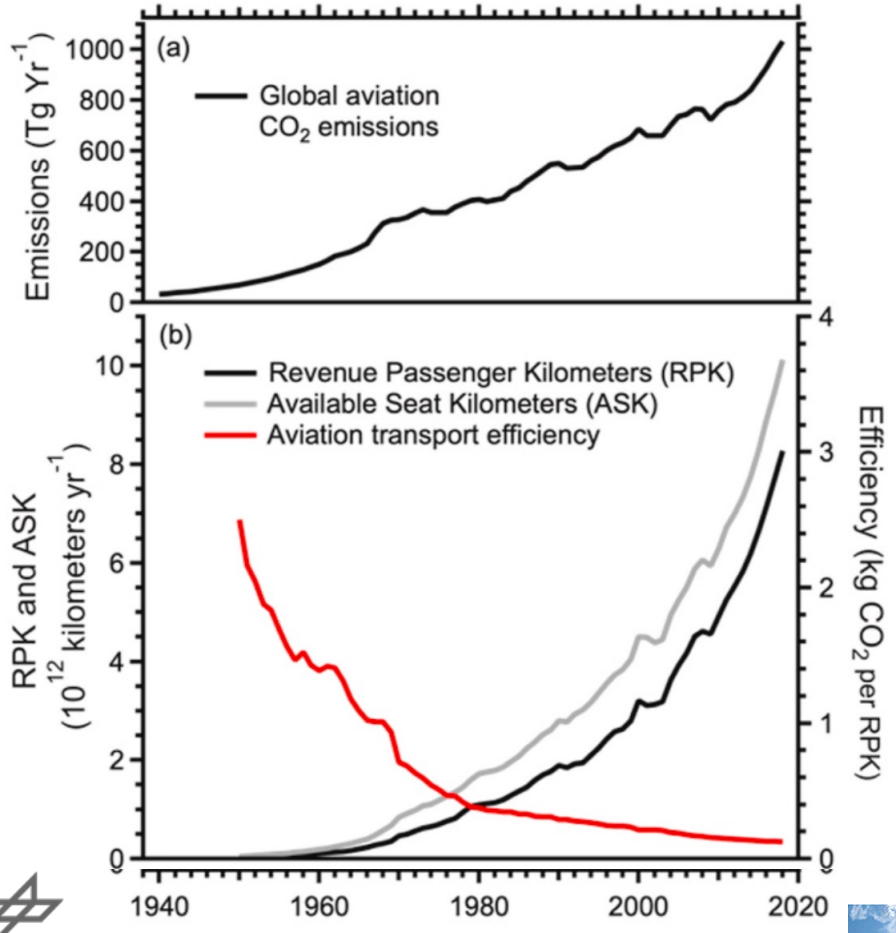
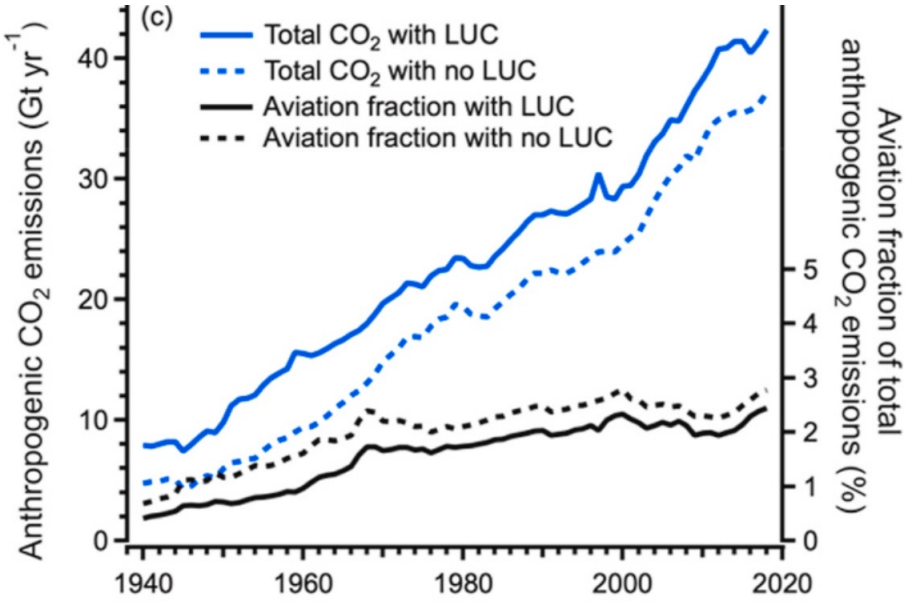
Climate impact of aviation

- CO_2 emissions of aircraft
- Non-CO_2 effects of aviation
- Mitigating the aircraft-induced climate impact

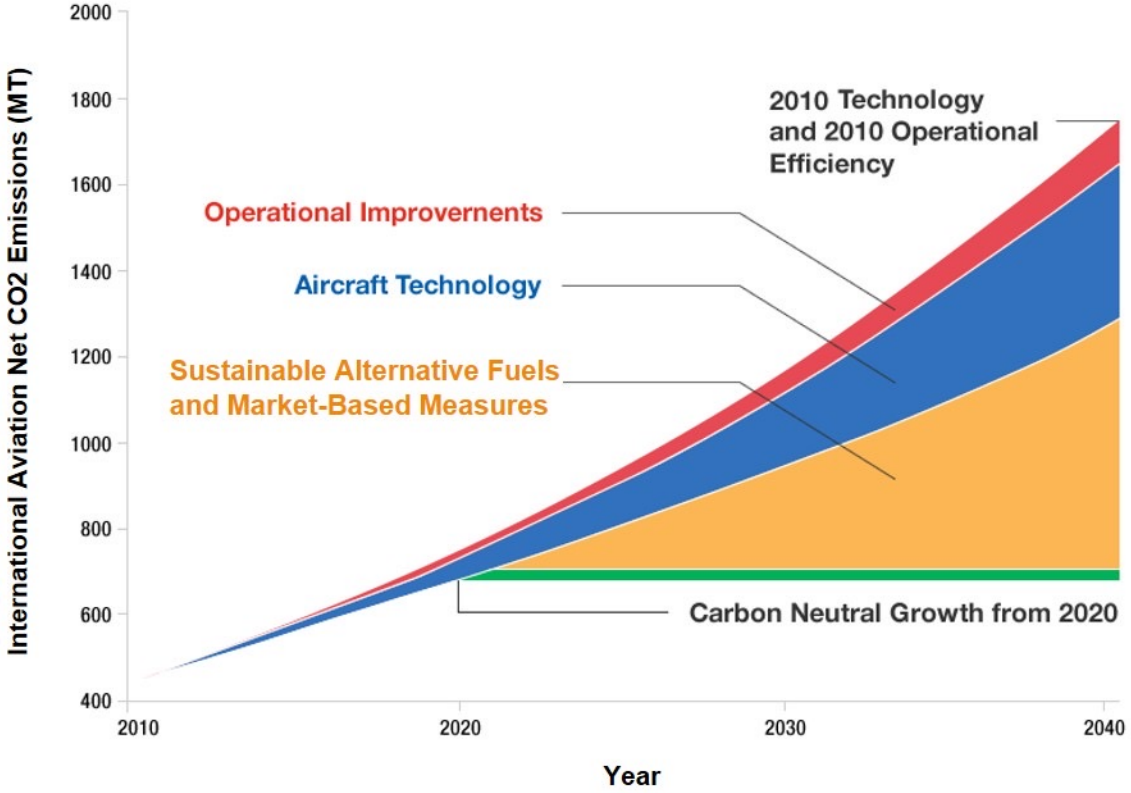
Aircraft CO_2 emissions





Lee et al., 2021

ICAO's concept towards carbon neutral growth (CNG)

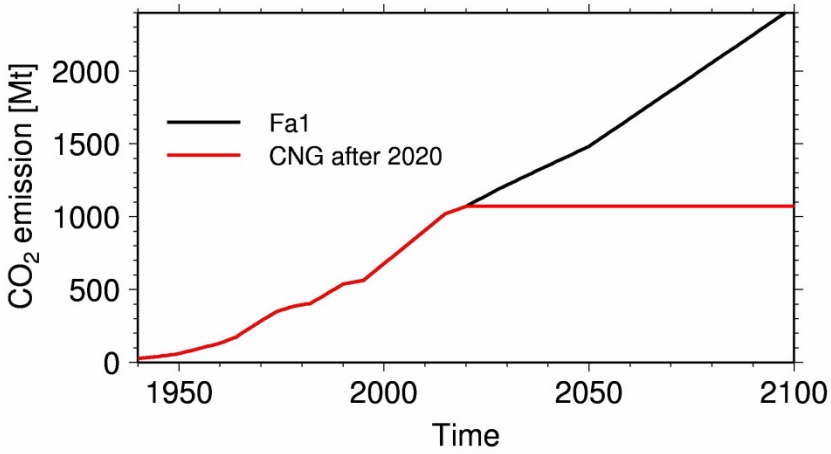


Created by the Carbon Markets Express website based on ICAO document.

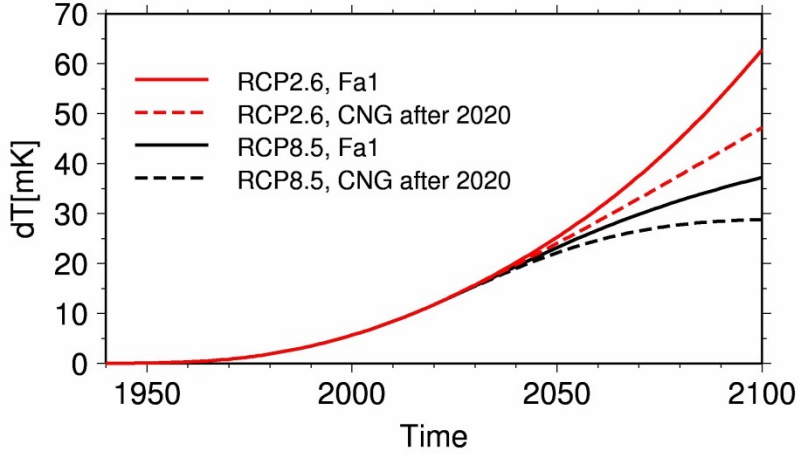
based on *www.carbon-markets.go.jp*

What does carbon neutral growth mean wrt. temperature change?

emissions



temperature change



The aviation-induced temperature change non-linearly depends on the background CO_2 concentration.

Also with CGN the aviation-induced temperature change will grow, in particular, for scenario RCP2.6 (approximately fitting to the 2 °C target of the Paris agreement).

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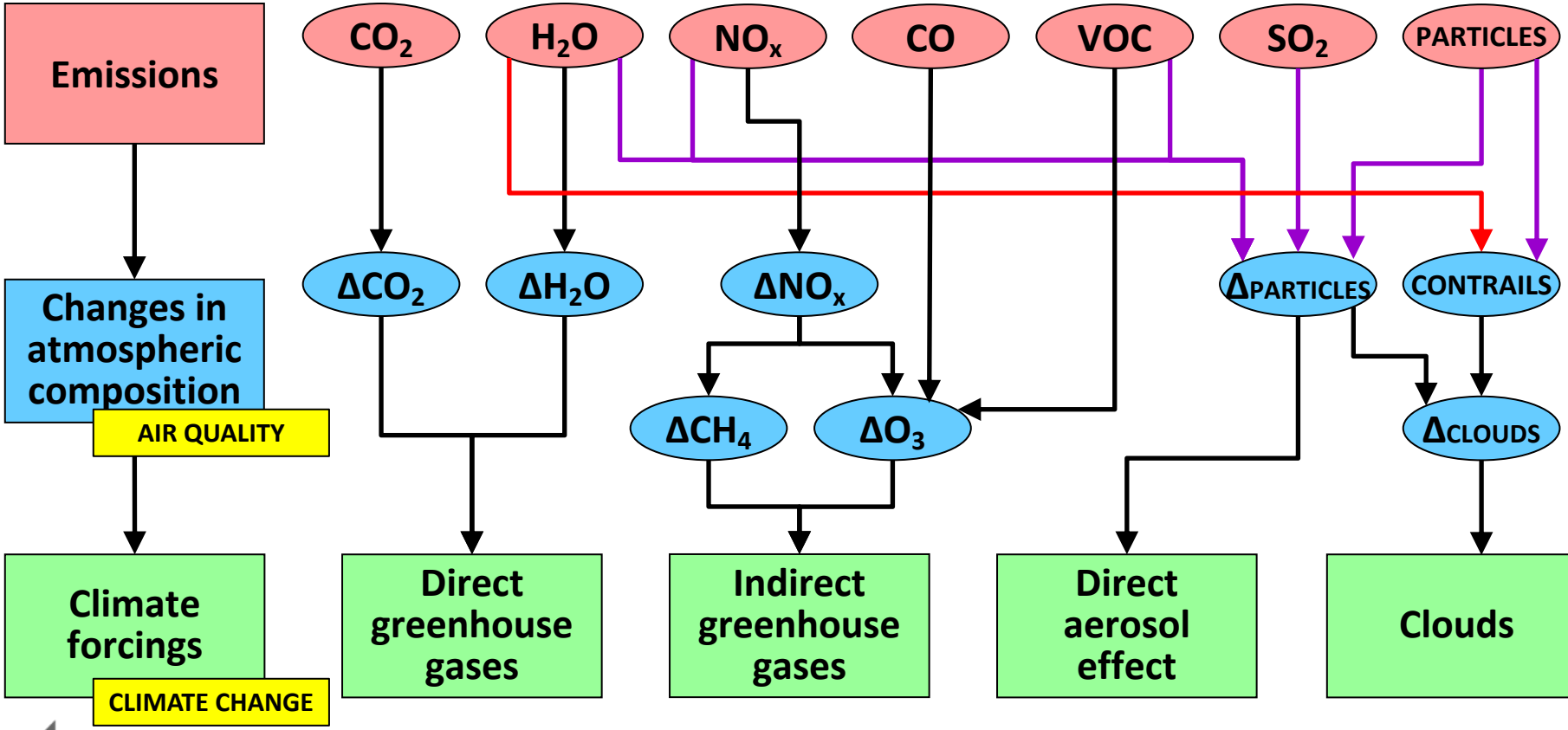
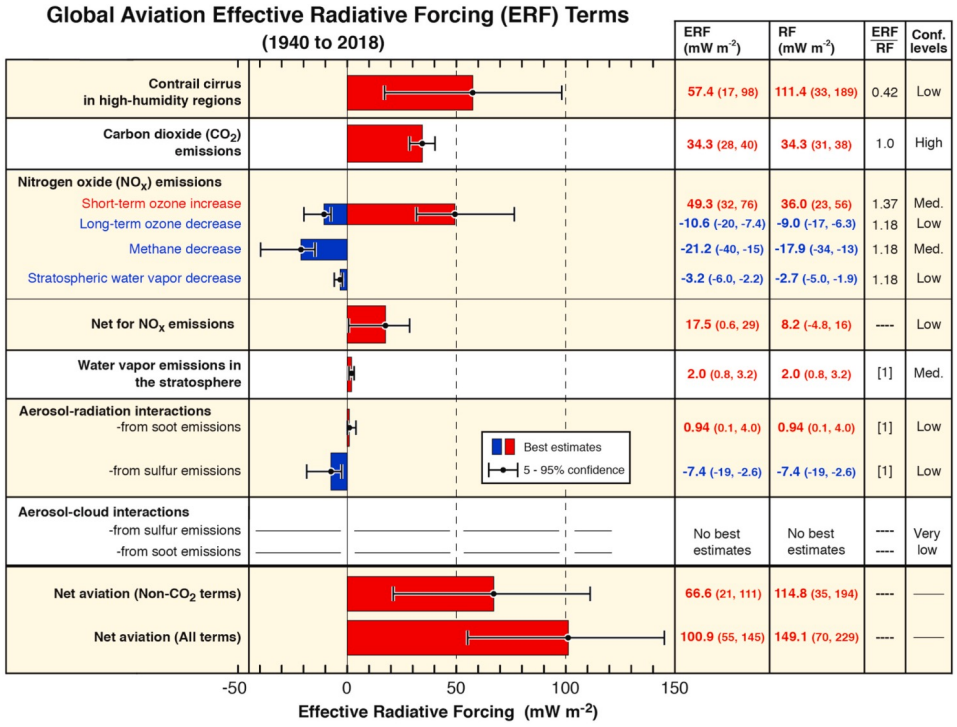
Atmospheric effects of emissions from the aviation sector



Effective radiative forcing (ERF)



Lee et al., 2021

$\Delta T = \lambda \, ERF$

- The non-CO_2 effects contribute at least 2/3 to the total aviation ERF.
- Non-CO_2 effects also occur if alternative fuels are used, in particular H_2.
- The magnitute of the non-CO_2 effects depends on location and time of the emissions.

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How can we mitigate the climate impact of aviation?

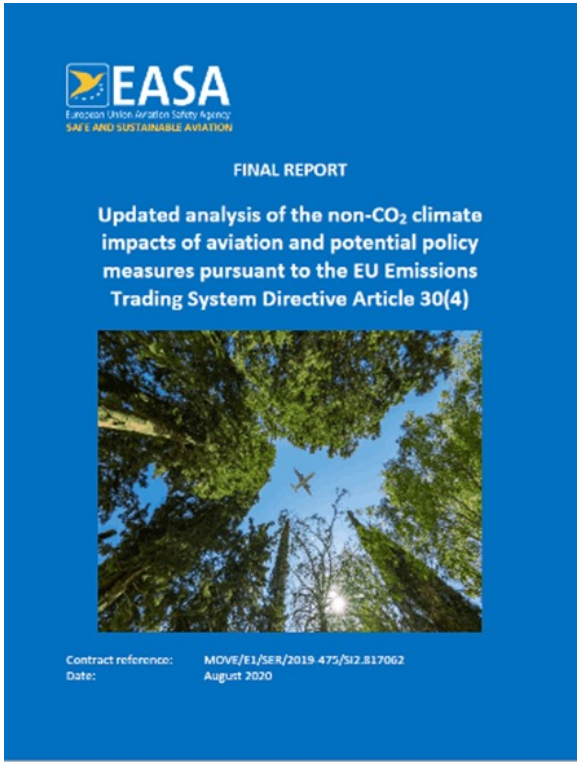
Focus more on emissions:

- ✈ Reduction of the specific emissions (e.g., alternative fuels, hydrogen/electric powered aircraft)
- ✈ Reduction of the absolute emissions

Focus more on impact of emissions:

- ✈ Climate optimized aircraft (e.g., for flights at lower cruise altitude and lower Mach number)
- ✈ Eco-efficient flight trajectories (requires adapted ATM)

Non-CO_2 effects of aviation: Concepts in Europe



Arrowsmith et al., 2020

Type of Measure		Main non-CO_2 effect(s) addressed by the measure
Financial	1. NO_X charge	NO_X
	2. Inclusion of aircraft NO_X emissions in EU ETS	NO_X
Fuel	3. Reduction in maximum limit of aromatics within fuel specifications	Soot particulates and contrail-cirrus
	4. Mandatory use of Sustainable Aviation Fuels (SAF)	Soot particulates and contrail-cirrus
ATM	5. Avoidance of ice-supersaturated areas	Contrail-cirrus
	6. A climate charge	All (NO_X, water vapour, soot, sulphates, contrails)

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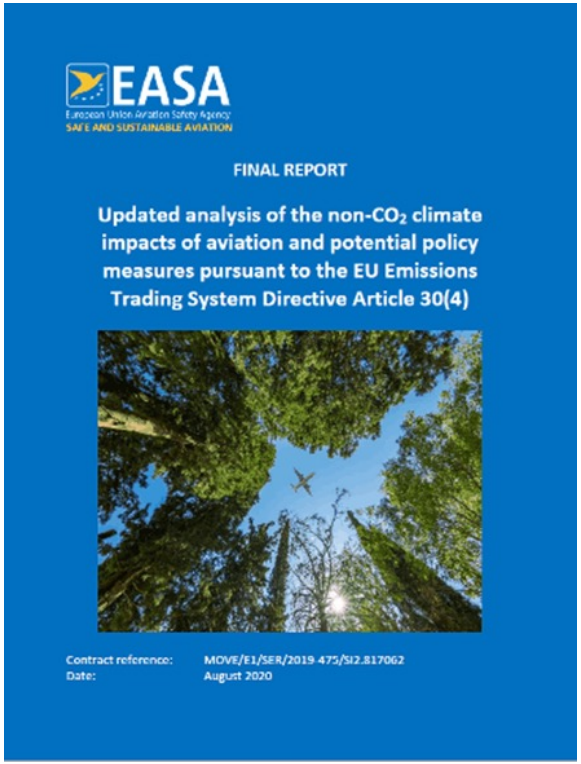

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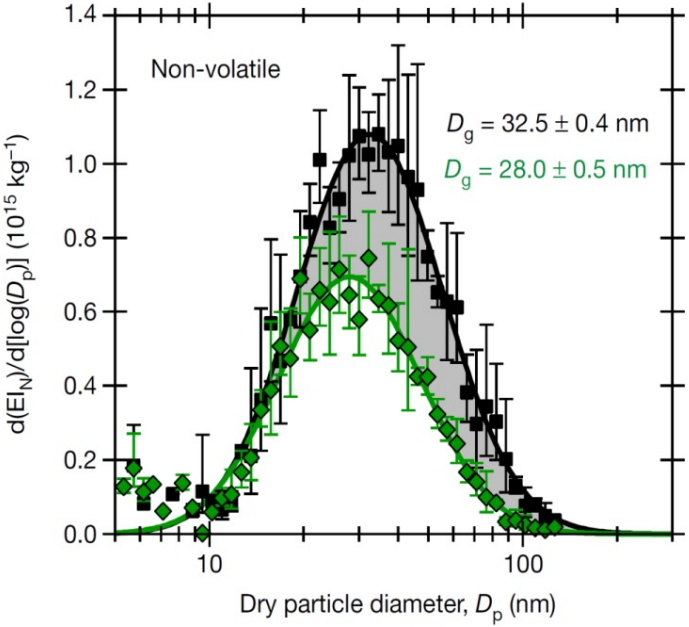
Alternative fuels with less aromatics

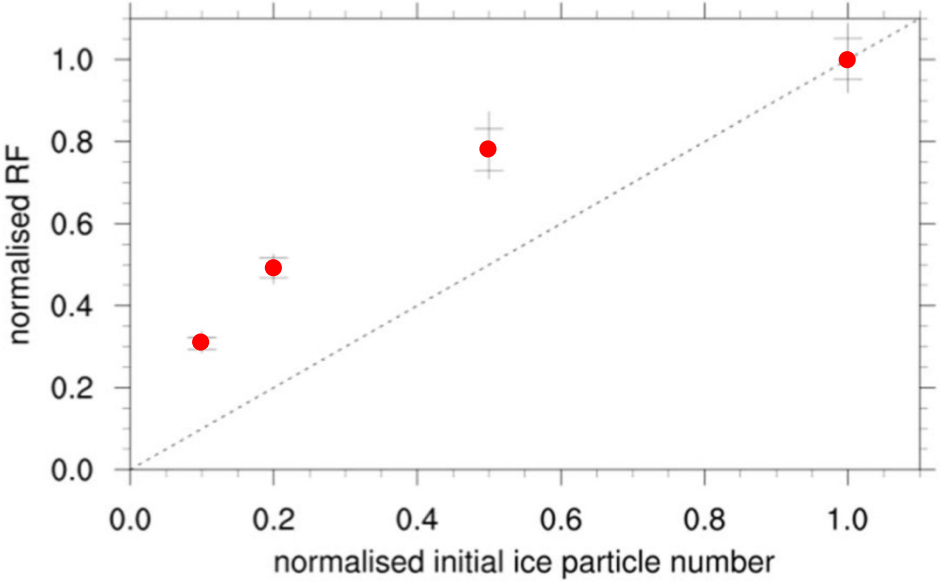
particle emissions



Soot particles emissions are reduced by 40-60% for HEFA blend, mainly due to reduction of aromatic content.

Moore et al., 2017

RF as function of soot particles



The radiative forcing non-linearly decreases with the number of initial ice particles, which is approx. proportional to the number of emitted soot particles.

Burkhardt et al., 2017

Do non-CO_2 effects of aviation disappear in a carbon neutral world?

	effects from NO_x (O_3, CH_4)	aerosol effects	formation of contrails	contrails and contrail cirrus radiatitve forcing	indirect cloud effects
market-based measures (CORSIA, ICAO)	=	=	=	=	=
biofuels, PTL	=	↘	=	↘	↘
e2flight: H_2 drives gas turbine or diesel engine	↘	↘	↗	?	↘
e2flight: H_2 for fuel cells	0	0	↗	?	0
e2flight: batteries (too heavy)	0	0	0	0	0

↗	stronger impact than conventional
=	same impact as conventional
↘	smaller impact than conventional
0	no impact
?	impact not known

only emissions from operation considered

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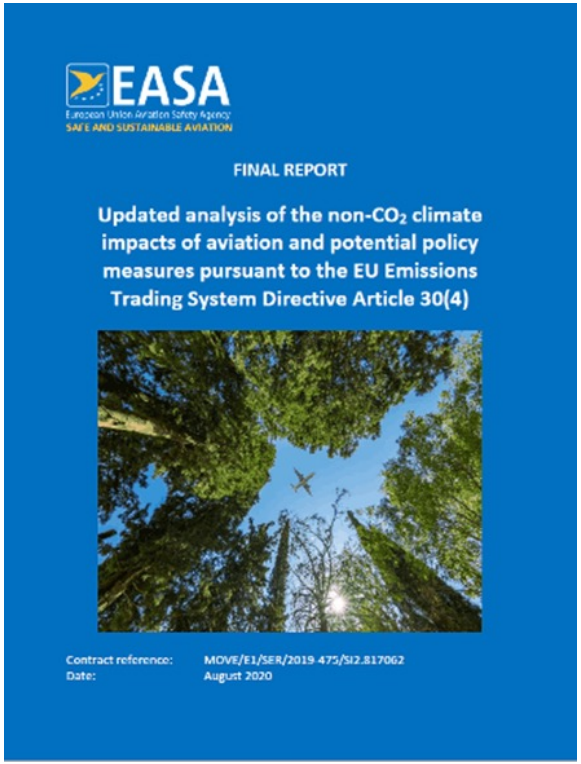

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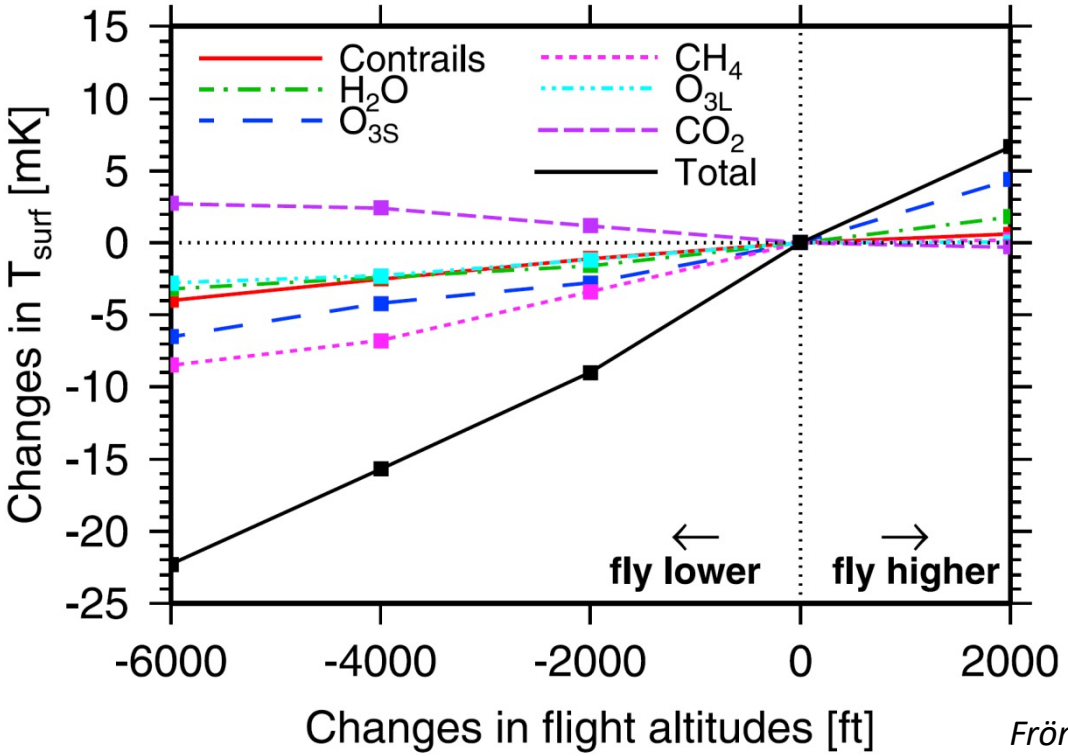
Aviation-induced temperature change from global changes of cruise altitude

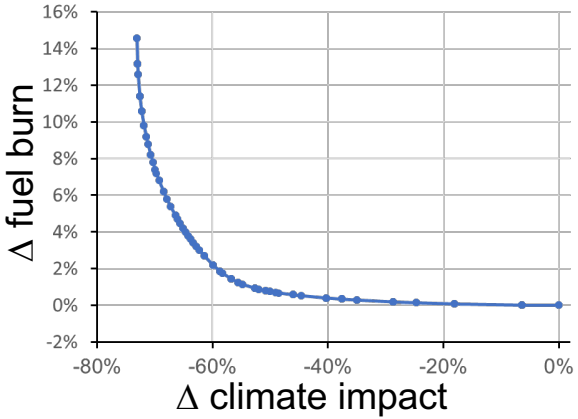


Frömming et al., 2012

Eco-efficient flight trajectories

The magnitude of the non-CO_2 effects significantly differs from flight to flight and, hence, cannot simply be accounted by a constant factor. Hence, a simple multiplicator is a wrong method.

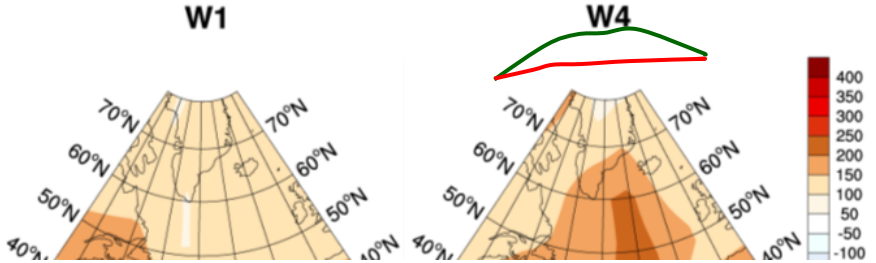
Preferably fly at locations and altitudes, where the climate impact is particularly low.



based on Matthes et al., 2020

Climate change functions
(climate cost functions) [10^{-14} K / kg(N)]

weather 1 **weather 4**



Routes illustrative

Frömming et al., 2021

The total climate impact (CO_2 and non-CO_2 effects) is strongly reduced as only small additional fuel burn.

Final remarks

- Aviation significantly contributes to global warming, and the aviation share has been growing.
- The non-CO_2 effects (from NOx, contrail cirrus, particles) are particularly large for the aviation sector. Comparing non-CO_2 effects and CO_2 for strategic decisions requires suitable metrics. The knowledge about the aviation non-CO_2 effects has been increased substantially.
- Some of the non-CO_2 effects are warming, others are cooling. The uncertainty remains high, in particular for the indirect aerosol effects.
- The life time of the non-CO_2 effects is shorter that of CO_2, but the forcing is larger.
- The climate impact of aviation can be mitigated by
  - reduction of specific emissions,
  - alternative fuels,
  - eco-efficient flight trajectories (e.g., climate-optimal trajectories, climate restricted areas, climate charged areas)
  - ...

The end