

Brief summary of the topics presented at the ICAO Symposium on Non- CO₂ Aviation Emissions



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Ricardo Dupont– ANAC Brasil

meioambiente@anac.gov.br

Agenda

Non-CO2 emissions and climate

Uncertainties

Contrails

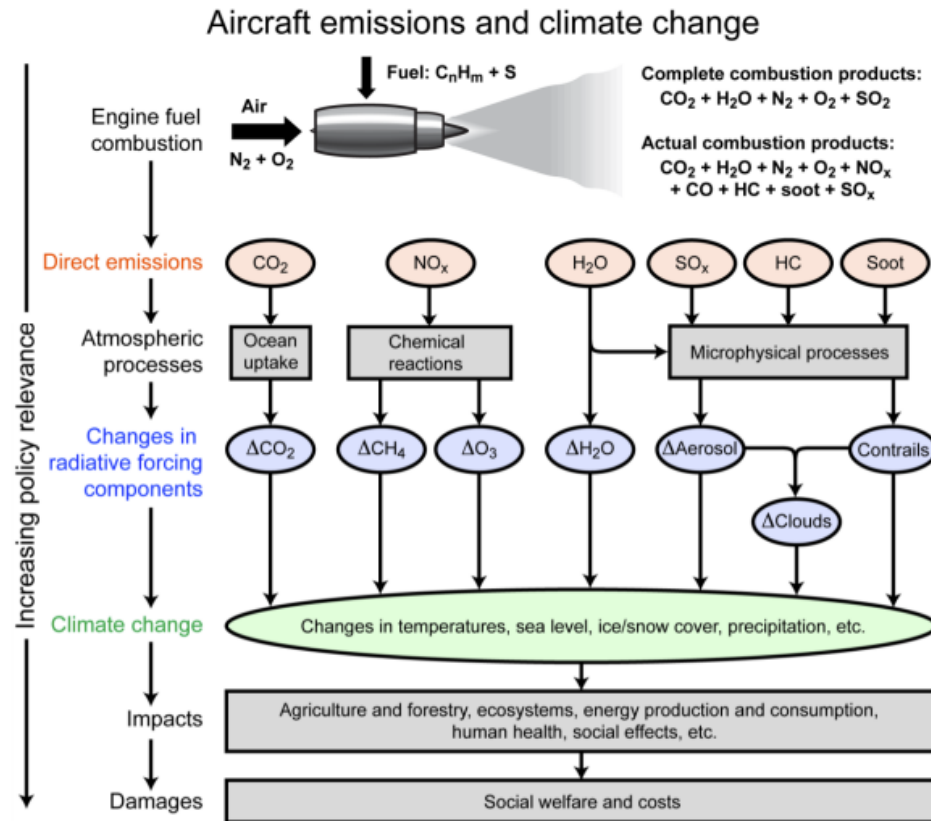
Potential measures to address the matter

Highlights

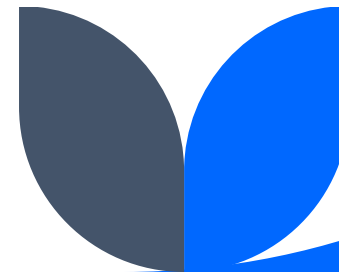


Non-CO₂ emissions and climate

What are 'non-CO₂ emissions'? (as distinct from 'effects')



Lee et al. (2009), based on Prather et al. (1999) and Wuebbles et al. (2007)



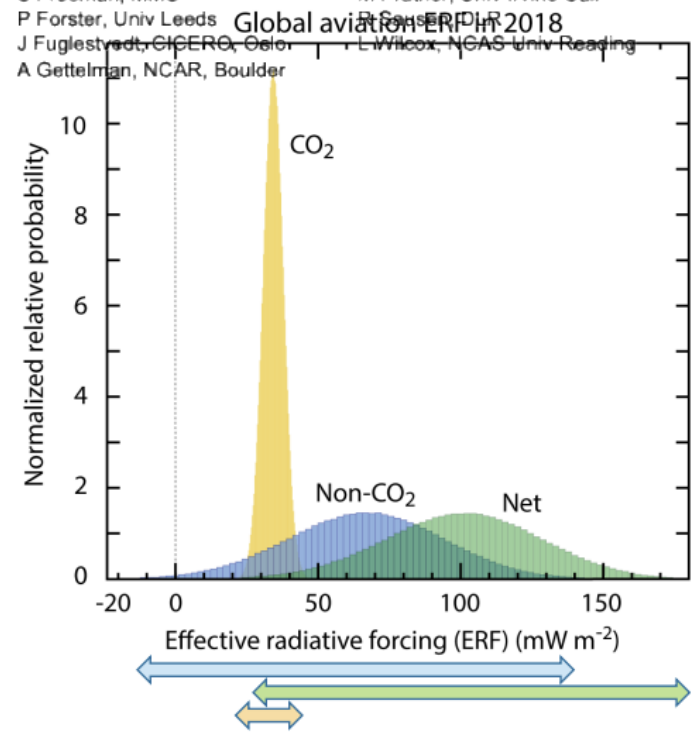
Uncertainties

Global Aviation Effective Radiative Forcing (ERF) Terms (1940 to 2018)

	ERF (mW m ⁻²)	RF (mW m ⁻²)	ERF/RF	Conf. levels
Contrail cirrus in high-humidity regions	57.4 (17, 98)	111.4 (33, 189)	0.42	Low
Carbon dioxide (CO ₂) emissions	34.3 (28, 40)	34.3 (31, 38)	1.0	High
Nitrogen oxide (NO _x) emissions	49.3 (32, 76)	36.0 (23, 56)	1.37	Med.
Short-term ozone increase	-10.6 (-20, -7.4)	-9.0 (-17, -6.3)	1.18	Low
Long-term ozone decrease	-21.2 (-40, -15)	-17.9 (-34, -13)	1.18	Med.
Methane decrease	-3.2 (-6.0, -2.2)	-2.7 (-5.0, -1.9)	1.18	Low
Stratospheric water vapor decrease				
Net for NO _x emissions	17.5 (0.6, 29)	8.2 (-4.8, 16)	---	Low
Water vapor emissions in the stratosphere	2.0 (0.8, 3.2)	2.0 (0.8, 3.2)	[1]	Med.
Aerosol-radiation interactions -from soot emissions	0.94 (0.1, 4.0)	0.94 (0.1, 4.0)	[1]	Low
-from sulfur emissions	-7.4 (-19, -2.6)	-7.4 (-19, -2.6)	[1]	Low
Aerosol-cloud interactions -from sulfur emissions	No best estimates	No best estimates	---	Very low
-from soot emissions	No best estimates	No best estimates	---	Very low
Net aviation (Non-CO ₂ terms)	66.6 (21, 111)	114.8 (35, 194)	---	---
Net aviation (All terms)	100.9 (55, 145)	149.1 (70, 229)	---	---



- D S Lee, MMU
- D Fahey, NOAA
- A Skowron, MMU
- M Allen, Univ Oxford
- U Burkhardt, DLR
- Q Chen, Peking Univ
- S Doherty, CIRES, Univ Col
- S Freeman, MMU
- P Forster, Univ Leeds
- J Fuglestad, CICERO, Oslo
- A Gettelman, NCAR, Boulder
- R De Leon, MMU
- L Lim, MMU
- M. Lund, CICERO, Oslo
- R Millar Univ Oxford/CCC
- B Owen MMU
- J Penner, Univ Michigan
- G Pitari, Univ l'Aquila
- M Prather, Univ Irvine Cali
- R Sausen, DLR
- L Wilcox, NCAS Univ Reading

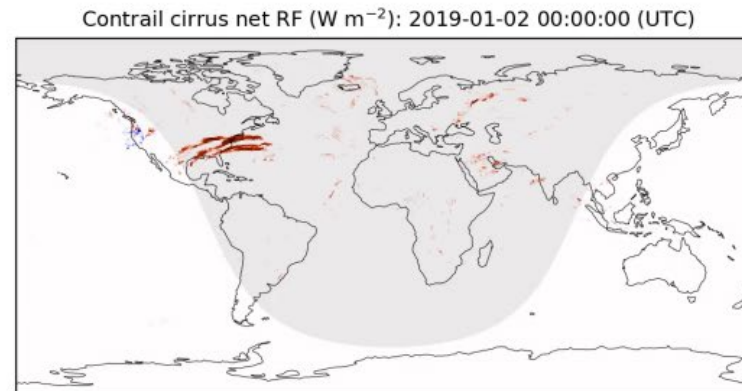
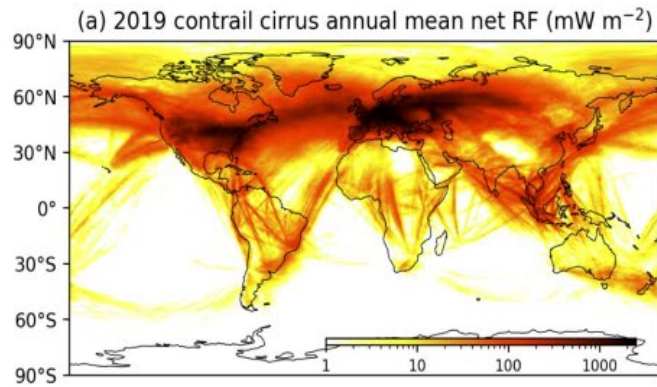
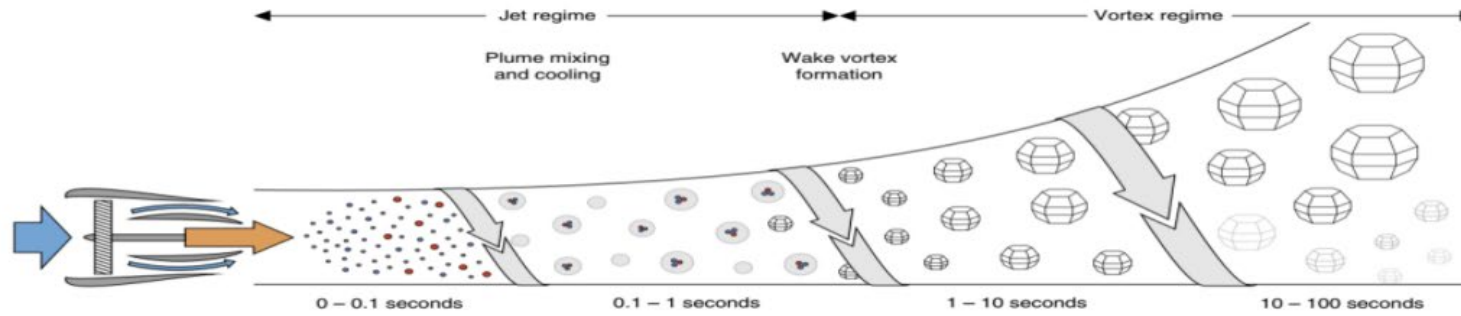


Lee et al. (2021) Atmospheric Environment



Contrails

Contrail formation and climate effect



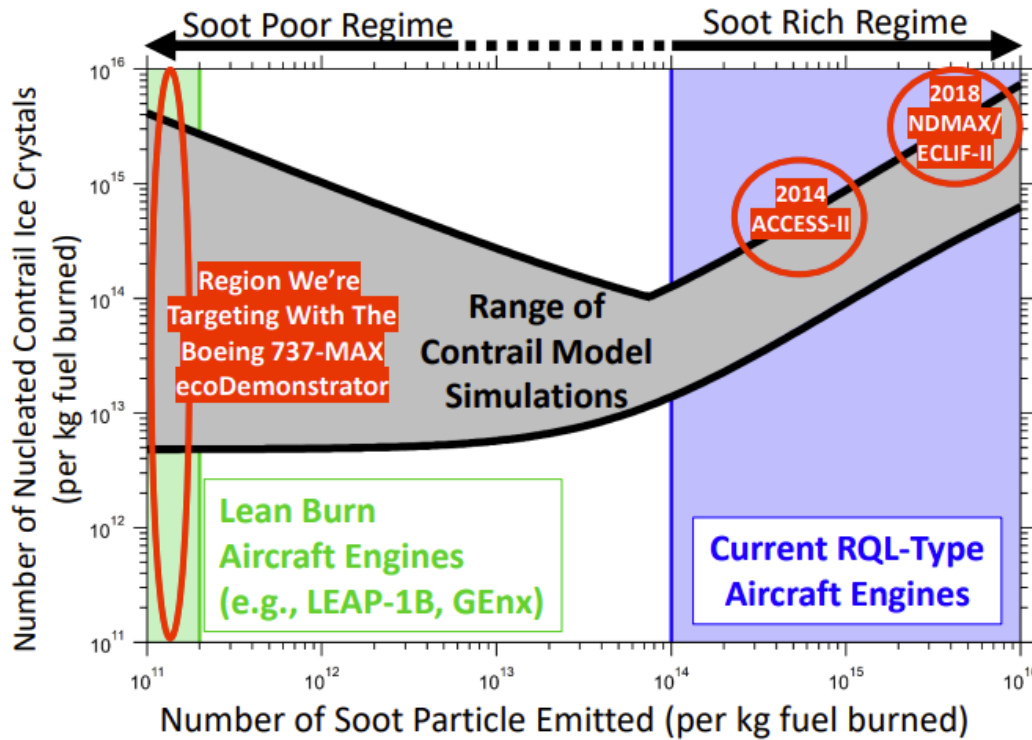
Kärcher et al., Nat Comm, 2018; Teoh et al., ACP, 2024



Contrails

vPM role in contrail formation?

Great Potential of SAF and Advanced Combustor Technology



Need to understand engine particle emissions in the “soot-poor” regime in order to connect to contrail formation and climate impacts

Emissions reductions also beneficial for air quality

Figure adapted from Kärcher, *Nature Communications*, 2018.

Red circles show the approximate Number Eis observed during the 2014 ACCESS-II and 2018 ND-MAX/ECLIF-II flight test series.

Moore et al., *Nature*, 2017; Voigt et al., *Nature Comms. Earth & Environ.*, 2021

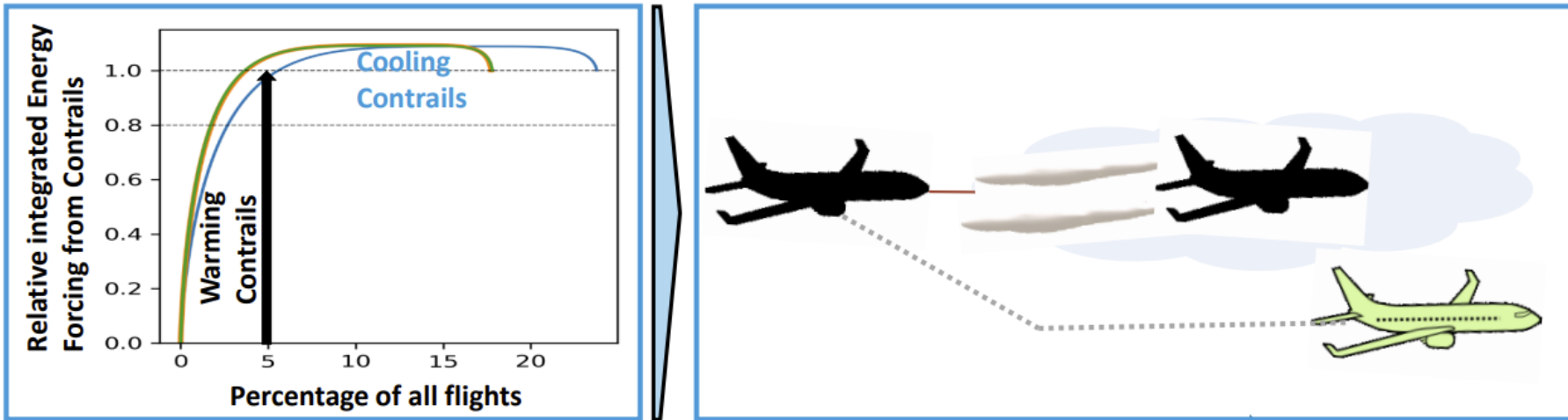
Rich Moore (NASA) TAC-5 talk 2022



Potential measures to address contrails

Potential for contrail reduction

(1) Short to mid term: Climate optimized flight routes to avoid contrails



More demonstration trials, weather and contrail model developments needed, satellite evaluation, CO2 offset needs to be calculated requires support from ATM, Airlines, stakeholders

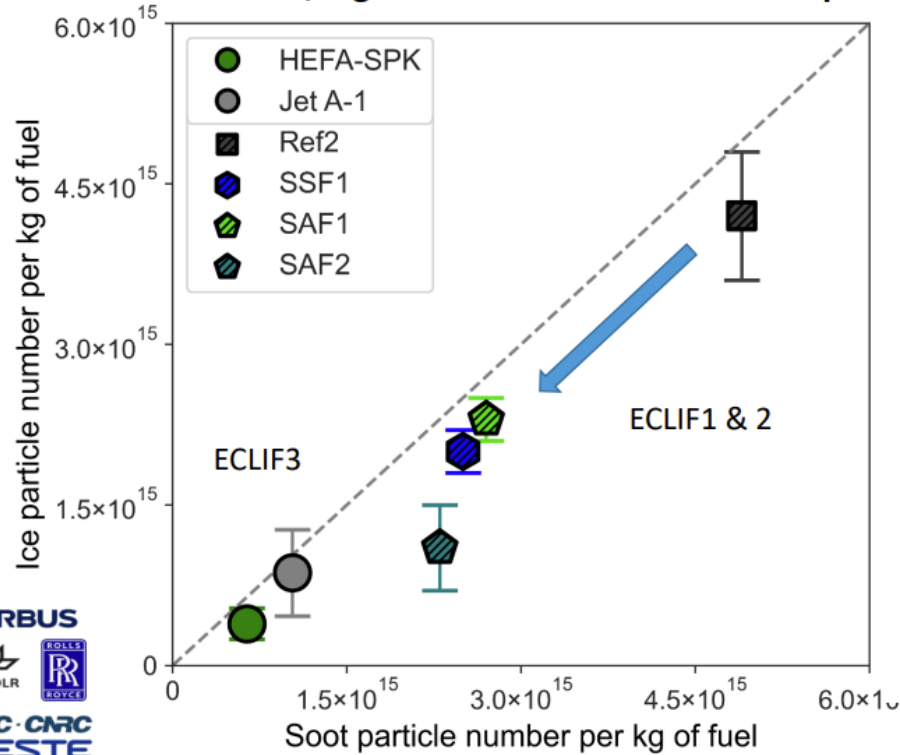
Teoh et al., ACP, 2022; 2023; 2024; Martin-Frias et al., 2024; Bourassa et al., 2024; Niklass et al., 2023; Grewe et al., 2019



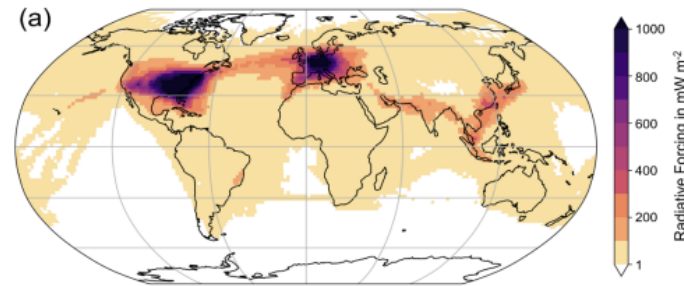
Potential measures to address contrails

(2) SAF and engine technologies reduce CO₂ footprint and contrails

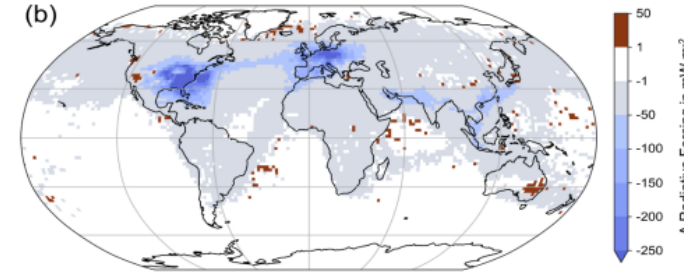
Low aromatic, high H fuels reduce soot and ice particles and the radiative forcing from contrails



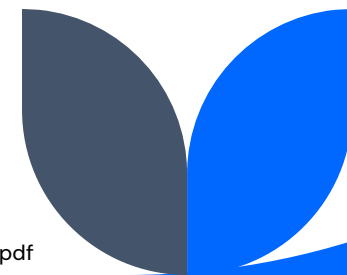
Global annual mean RF contrails in 2018 (72mW/m²)



Reduction in contrail RF by 100%SAF

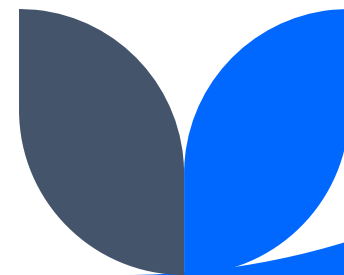


Moore et al., Nat., 2017; Voigt et al., Comm EE, 2021; Märkl et al., ACP, 2024, Dischl et al., Harlass et al., acc. ACP, 2024



Highlights

- Need for further research on cause and effect (e.g., vPM)
- Need to reduce uncertainties
- Potential opportunity on operational measures, with associated consequences
- Regulations already put in place





Gracias
Thank you
Obrigado

meioambiente@anac.gov.br