

ICAO Symposium on Non-CO₂ Aviation Emissions

16 — 18 September 2024
Montréal, Canada



Alex Rap

Associate Professor
University of Leeds

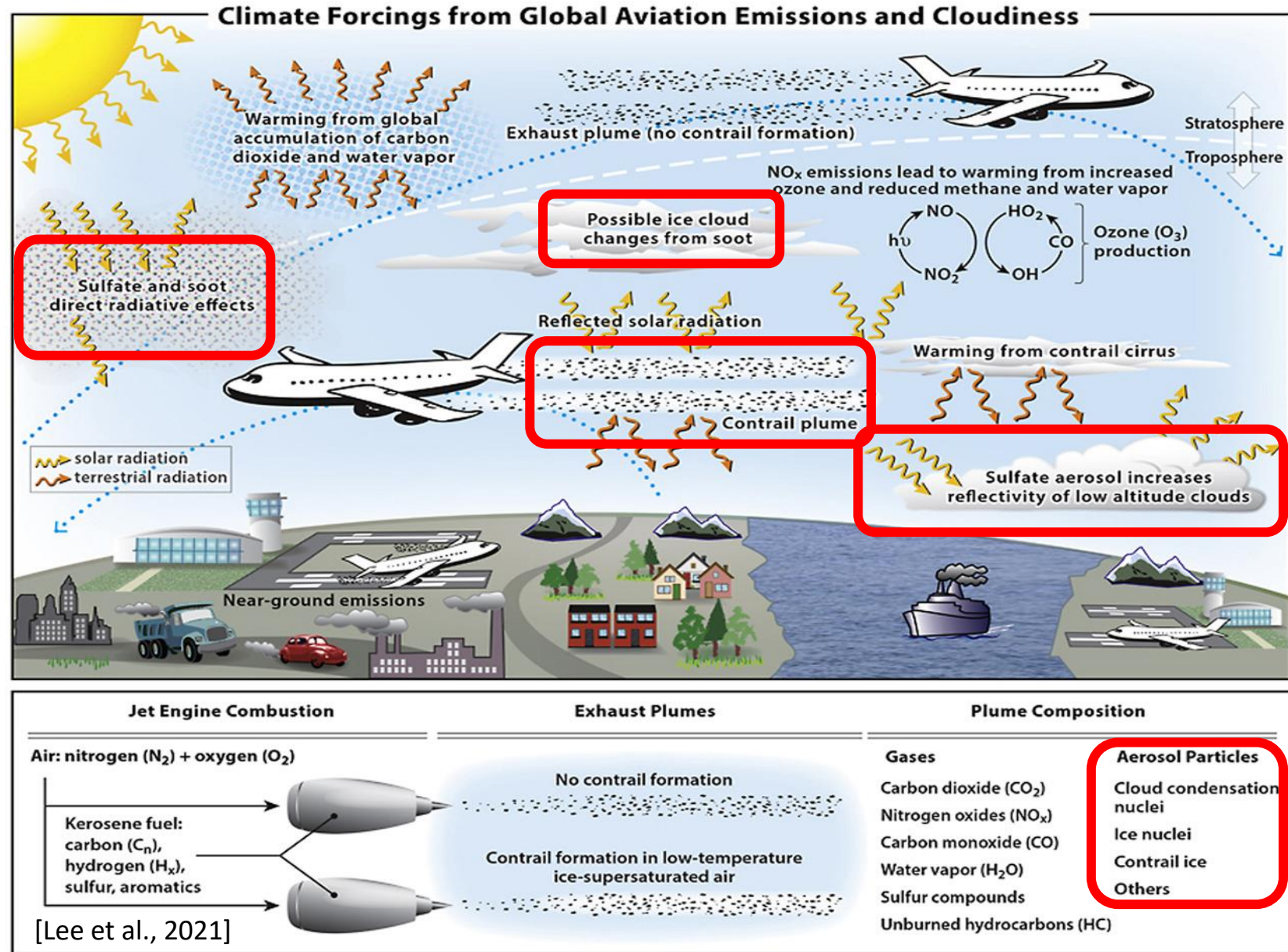
Speaker

Session 1: Scientific Knowledge
Historical overview & State-of-the-art

Aviation aerosols

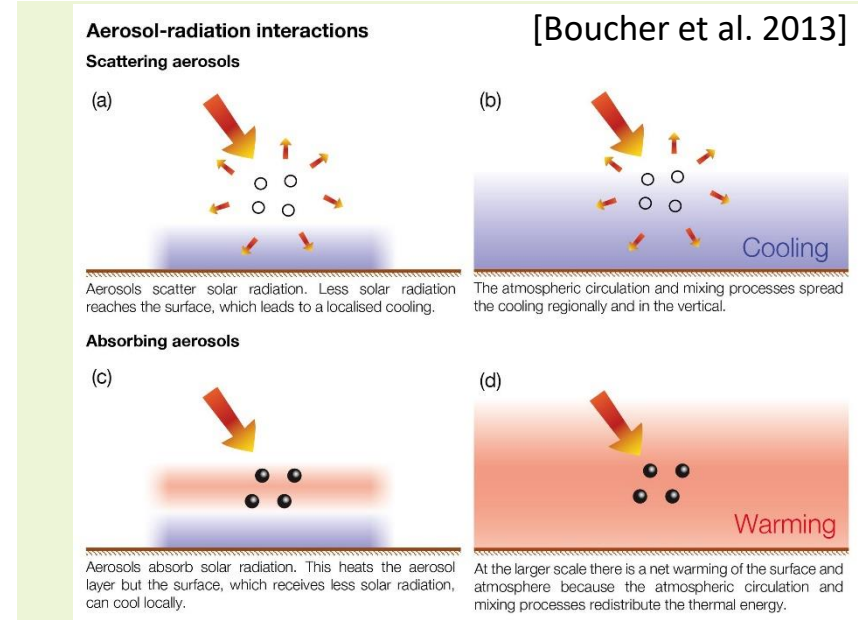
Small exhaust particles (soot, sulfate, nitrate) affecting climate via:

- Aerosol-radiation interactions
- Aerosol-cloud interactions
- Changes to contrail properties

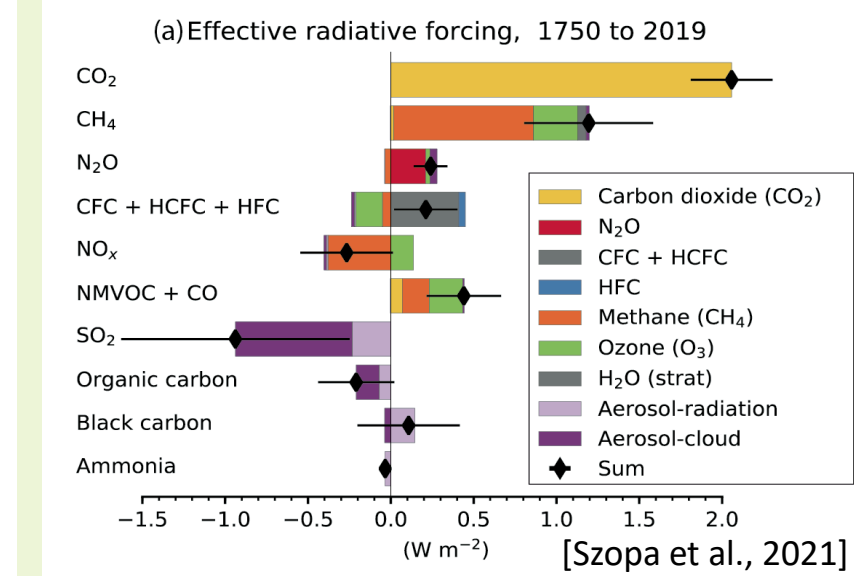
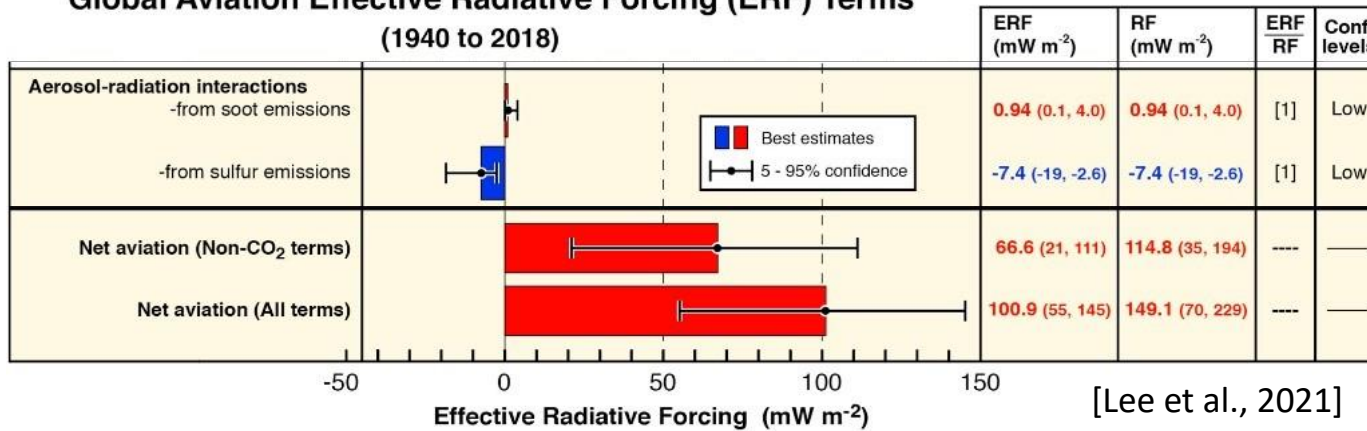


Aerosol-radiation interactions

- Soot ERF-ARI: 0.94 (0.1,4.0) mWm⁻² for 0.0093 Tg soot emitted.
- Sulfate ERF-ARI: -7.4 (-19, -2.6) mWm⁻² for 0.37 Tg SO₂ emitted.



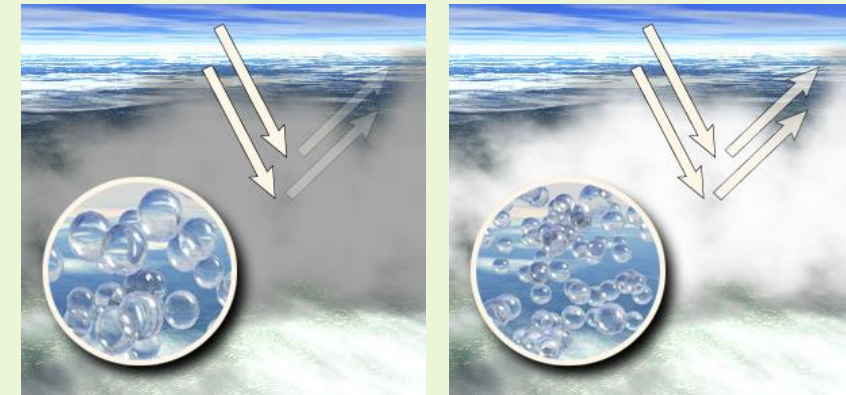
Global Aviation Effective Radiative Forcing (ERF) Terms (1940 to 2018)



Aerosol-cloud interactions

Currently no best estimate.

- Sulfate ERF-ACI via effects on liquid clouds:
 - Likely to have a negative forcing (i.e. cooling).
 - Existing estimates: -37 to -76 mW m⁻² (Gettelman and Chen, 2013; Kapadia et al., 2016).
- Soot ERF-ACI via effects on ice clouds:
 - Forcing highly uncertain: existing estimates -479 to 288 mW m⁻². (uncertainty in homogeneous and heterogeneous ice nucleation processes, soot ice nucleation ability).

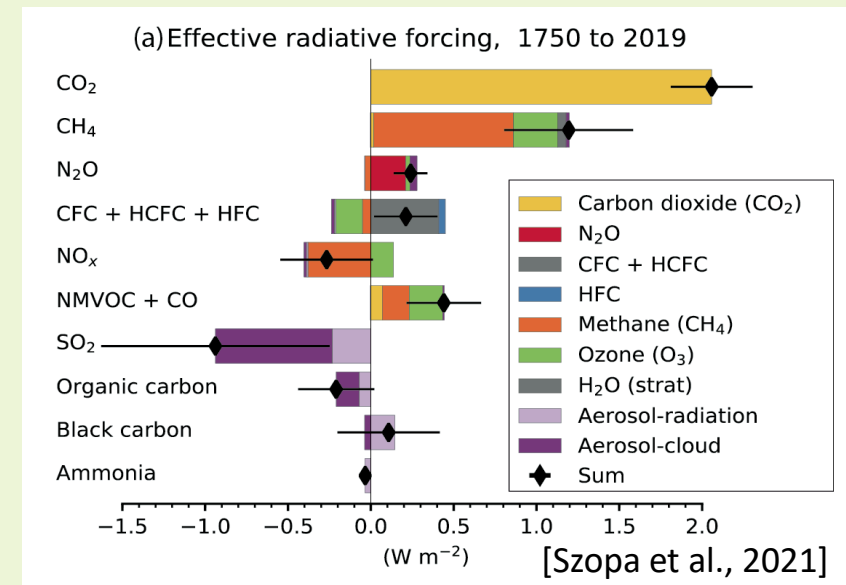


[http://earthobservatory.nasa.gov]

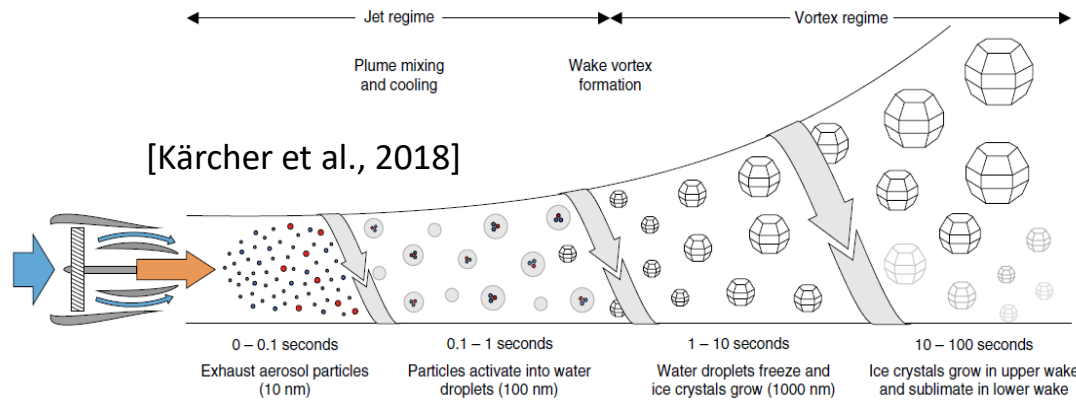
Global Aviation Effective Radiative Forcing (ERF) Terms (1940 to 2018)

	ERF (mW m ⁻²)	RF (mW m ⁻²)	ERF/RF	Conf. levels
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-CO₂ terms)	66.6 (21, 111)	114.8 (35, 194)	----	----
Net aviation (All terms)	100.9 (55, 145)	149.1 (70, 229)	----	----

Effective Radiative Forcing (mW m⁻²) [Lee et al., 2021]

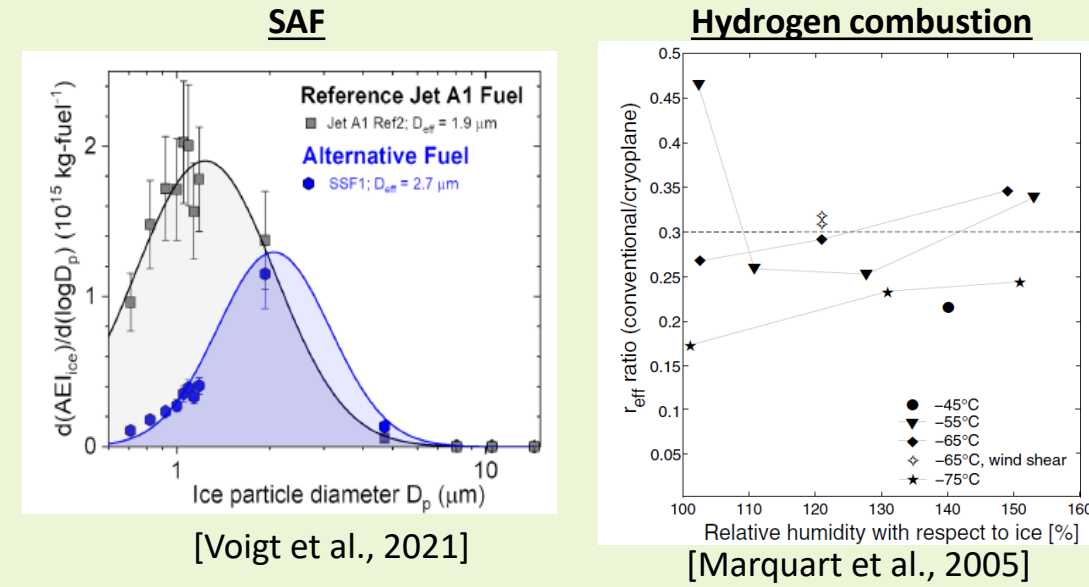


Aerosols and contrail properties



- Compared to kerosene, SAF and Hydrogen combustion engines will produce fewer particles in the exhaust.
- Background aerosol will largely define contrail ice crystal sizes for hydrogen combustion.
- **Fewer, but larger contrail ice crystals** → **smaller ERF**

Contrail ice crystal size – Kerosene vs alternative fuels



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
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-CO₂ terms)	66.6 (21, 111)	114.8 (35, 194)	----	----
Net aviation (All terms)	100.9 (55, 145)	149.1 (70, 229)	----	----

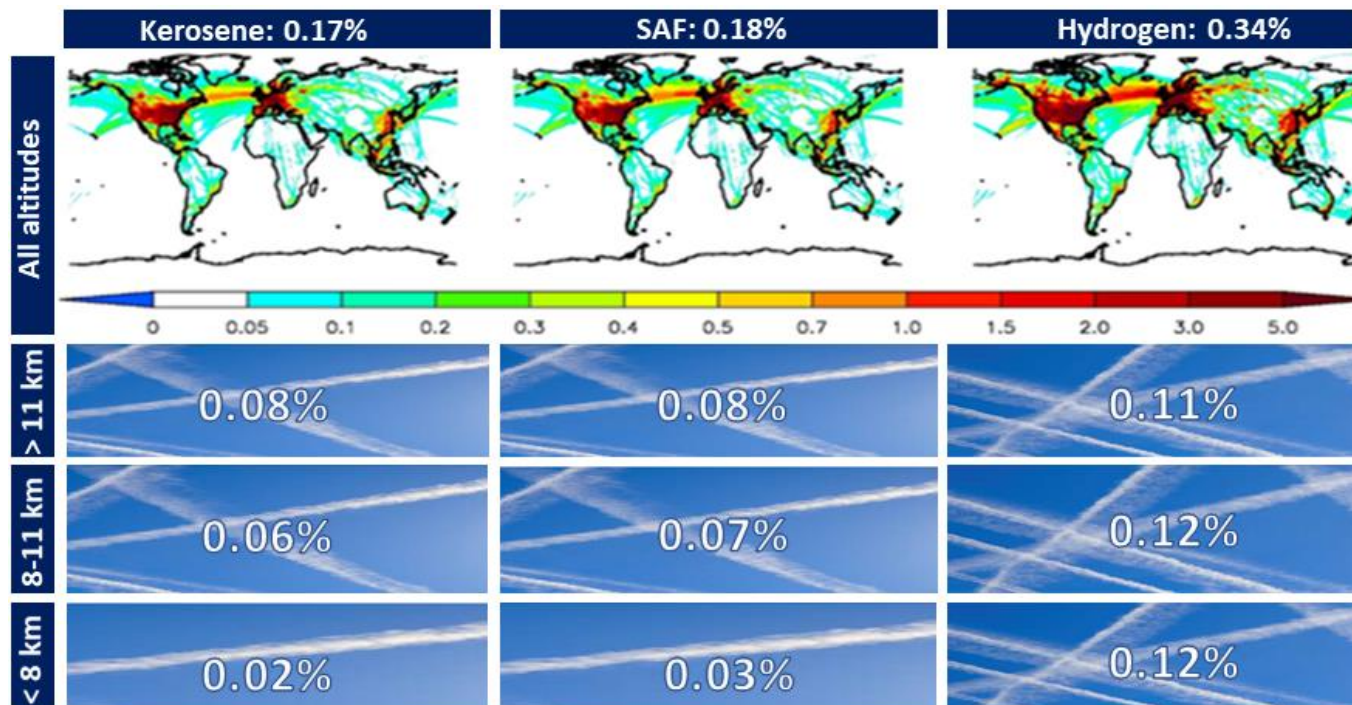
Effective Radiative Forcing (mW m⁻²)

[Lee et al., 2021]

Alternative fuels aerosol emissions and contrail properties

Modelling work as part of the UK's Aerospace Technology Institute (ATI) Fly Zero project (Rap et al., 2021)

- Large uncertainties associated with several assumptions



- Larger water vapour emissions of SAF and hydrogen combustion engines will lead to increases in contrail cover, primarily at lower altitudes.
- Despite the increased contrail cover, simulations indicate a likely reduction in contrail cirrus ERF:
 - Assuming the ice particle size is 1.4× (SAF) and 3× (hydrogen) larger than for kerosene, the simulated contrail cirrus ERF:
 - Kerosene: 78 mW m⁻²
 - SAF: 63 mW m⁻²
 - Hydrogen: 57 mW m⁻²

[Rap et al., 2021]

Thank You

