

# ICAO Symposium on Non-CO<sub>2</sub> Aviation Emissions

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Speaker

Session 2: Enhancing Scientific Knowledge  
Part I – NO<sub>x</sub> and Particulate Matter

Session 2 : Enhancing Scientific Knowledge  
Part I: Non-CO2 Emissions and Particulate Matter

# Particulate matter emissions and contrails

**Marc Stettler**

Imperial College London

## Key messages

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1

Not all contrails are created equal. Particle emissions modify the properties and lifetimes of contrails, but operations matter too.

2

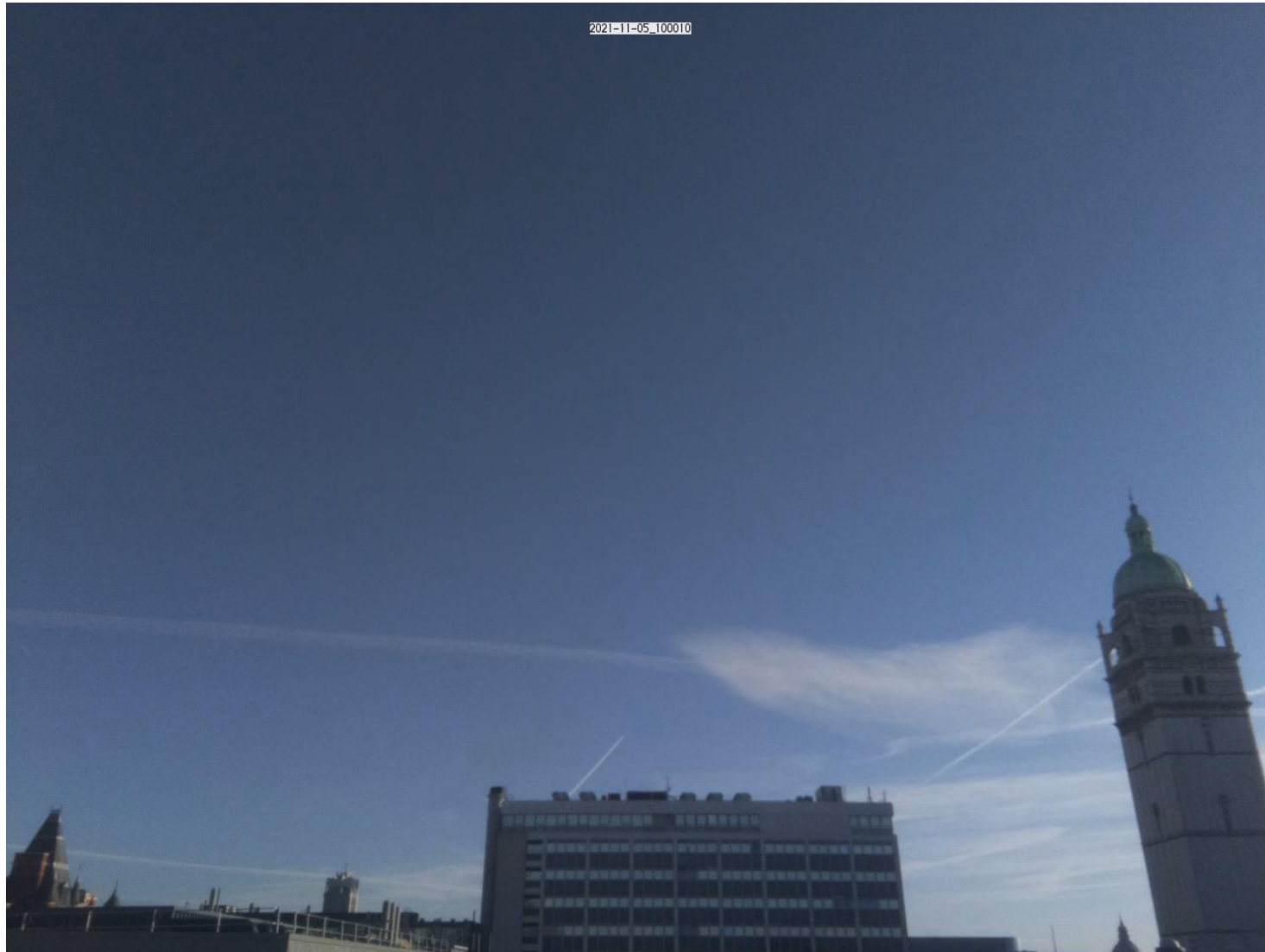
Sustainable aviation fuels will not eliminate contrails.

3

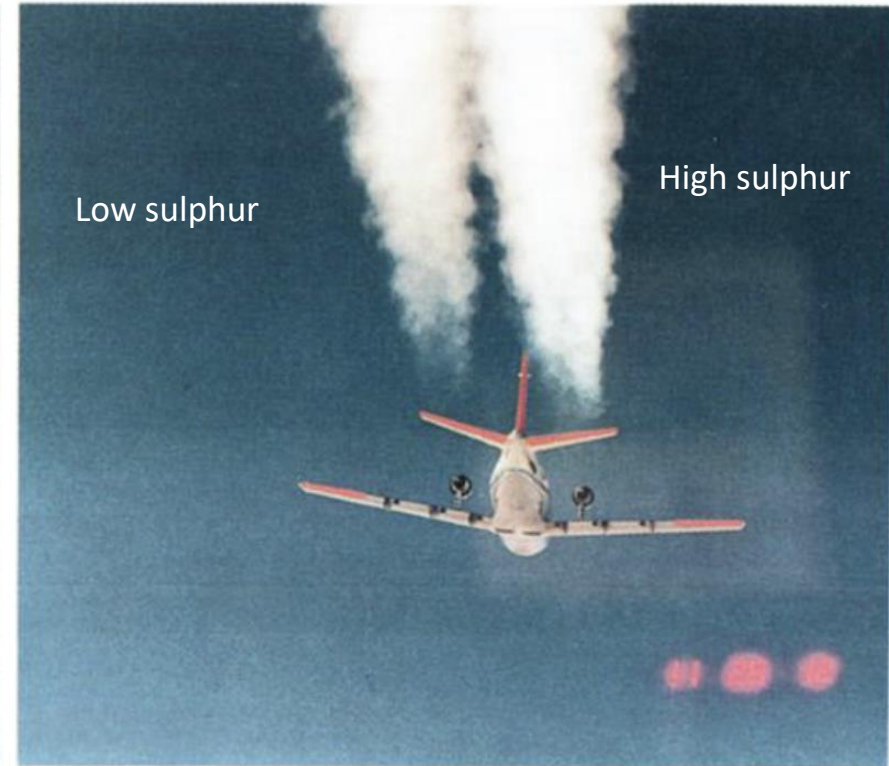
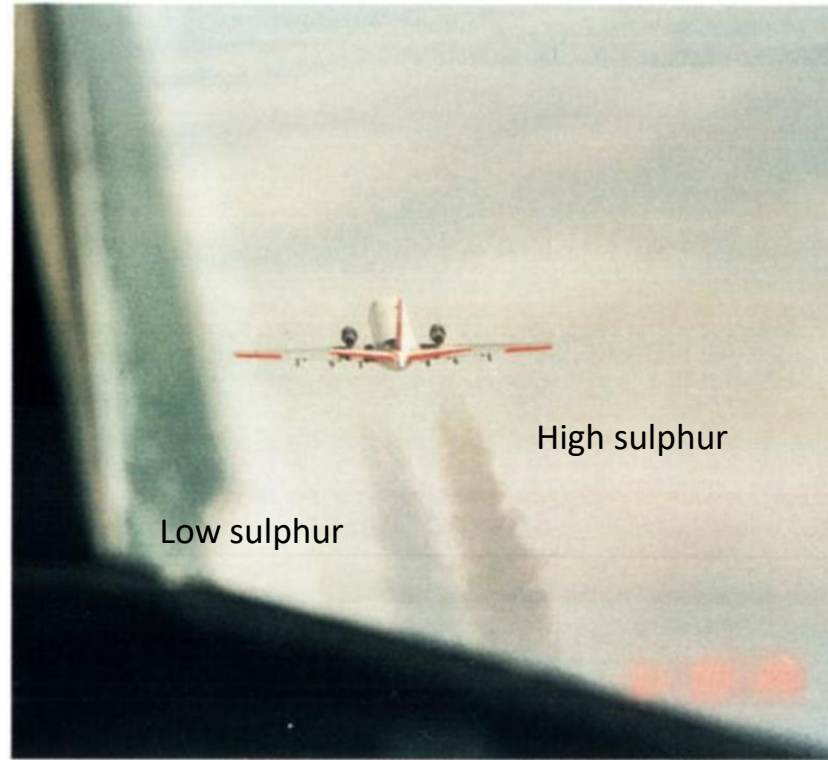
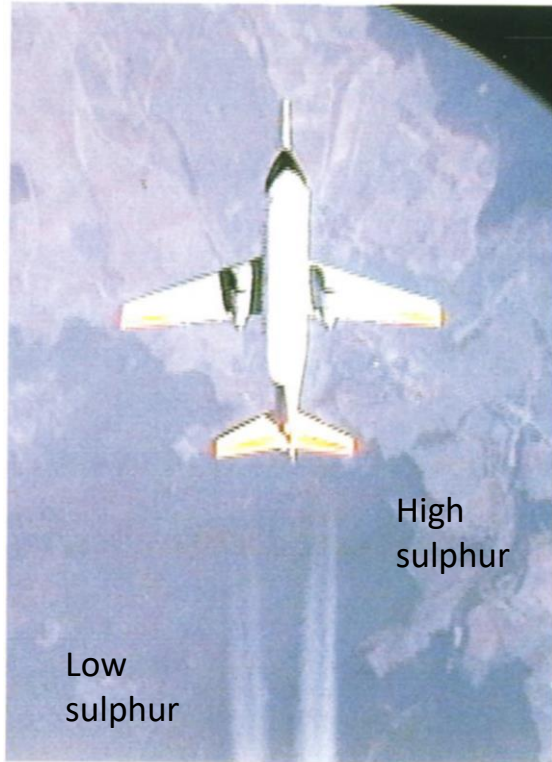
As nvPM emissions reduce, we need to minimise vPM emissions

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# Not all contrails are created equal

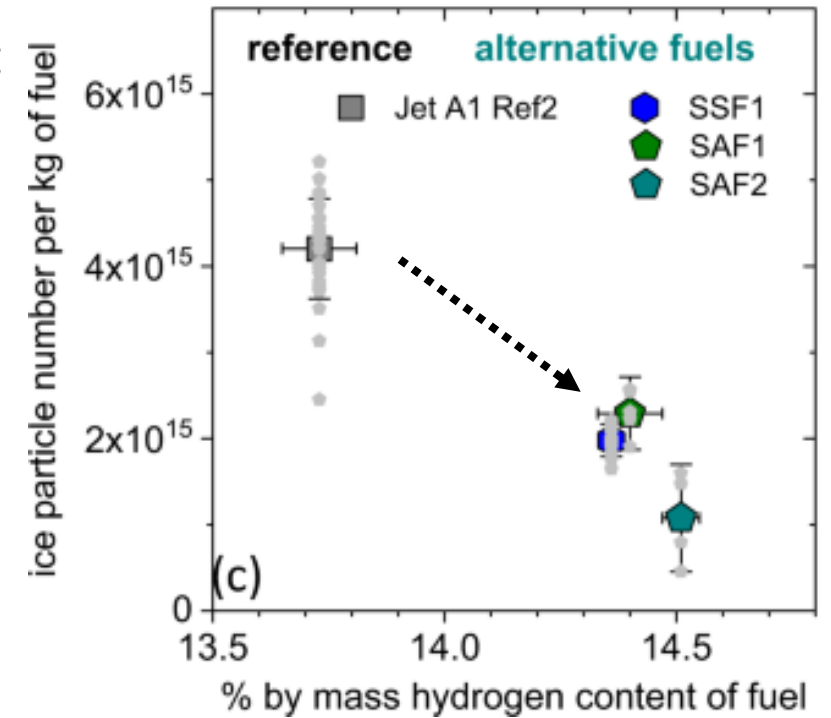
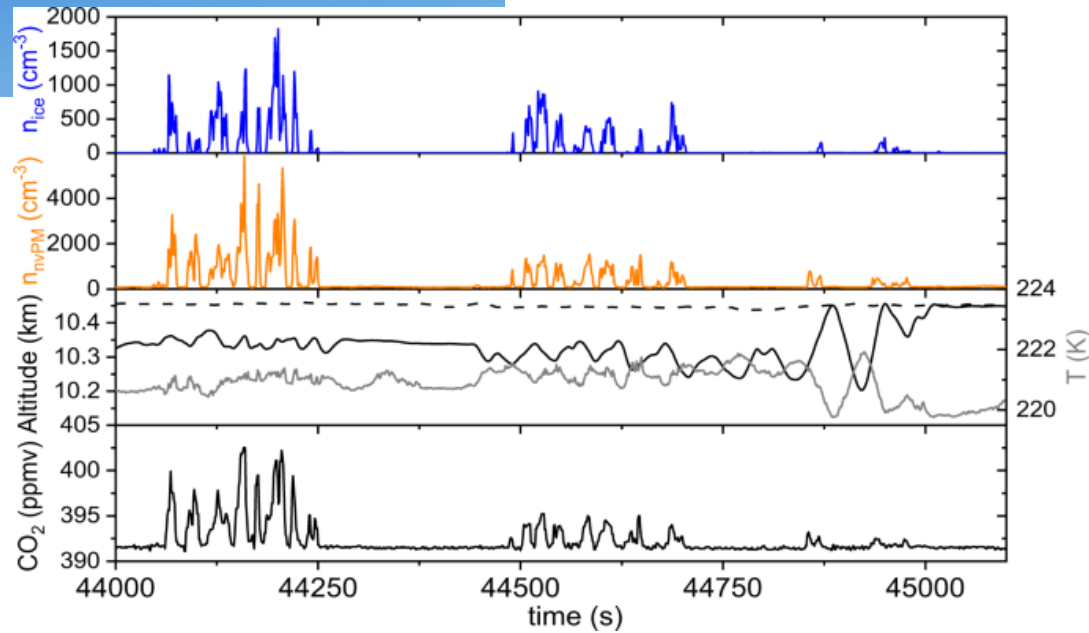


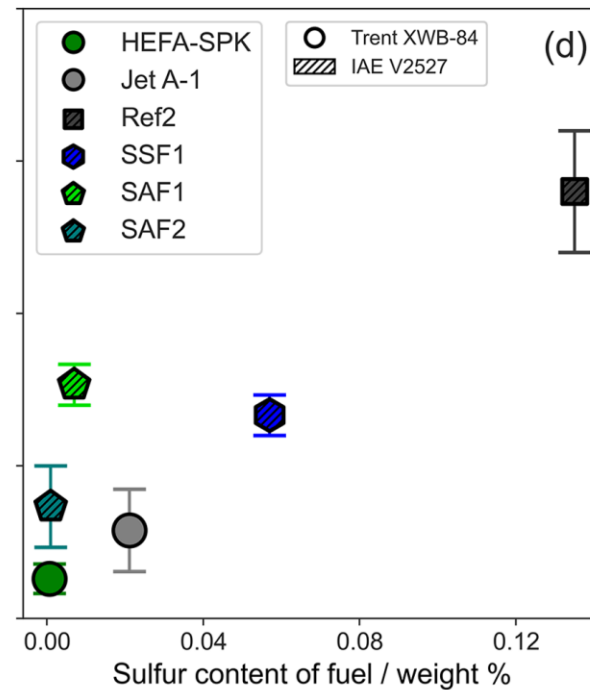
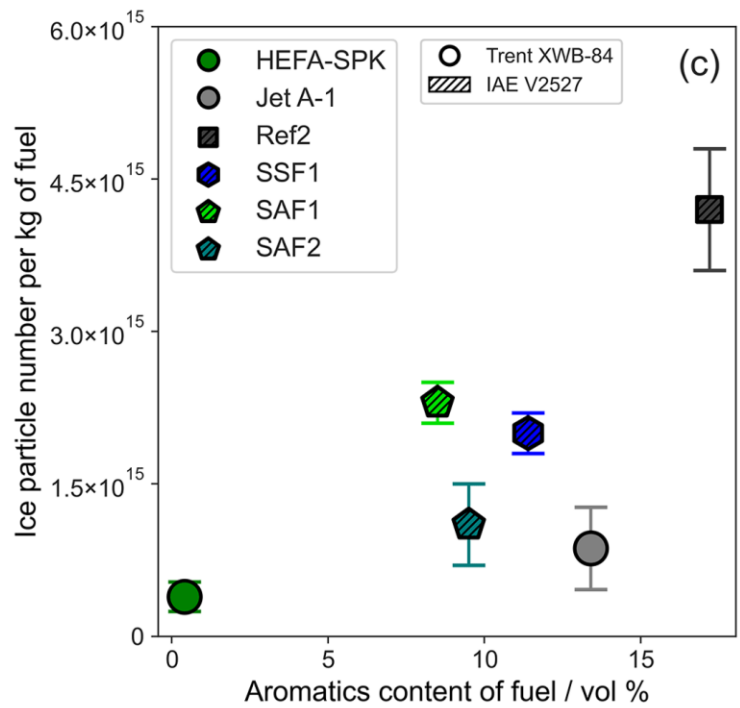
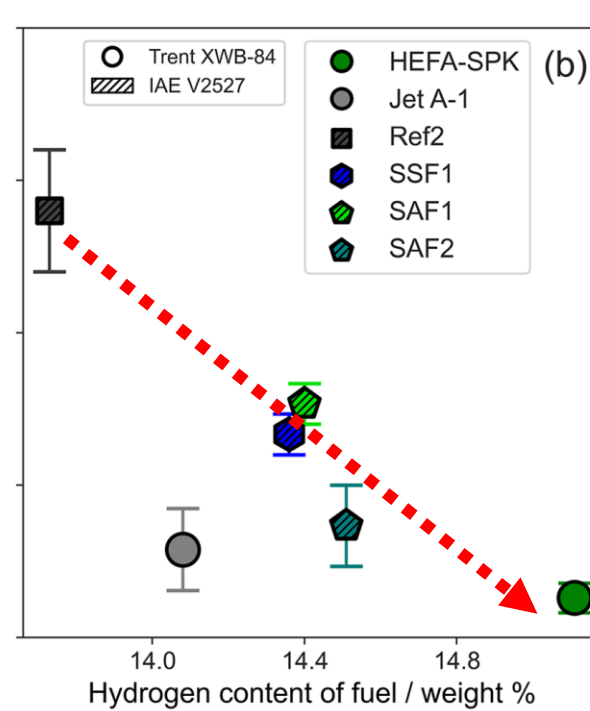
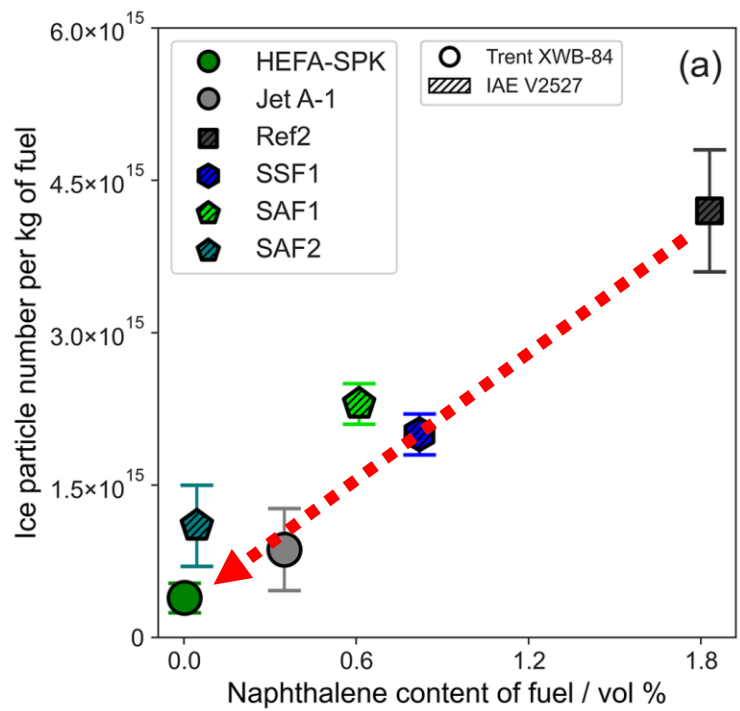
# Visible differences in contrails due to fuel sulphur content





## Effects of fuels on young contrails





## Ice particle number correlated with

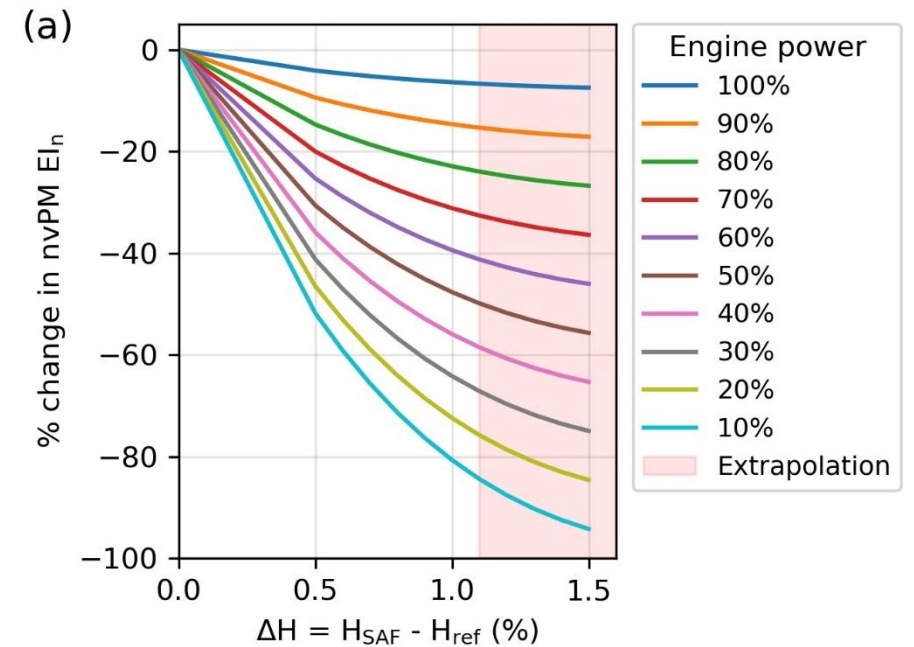
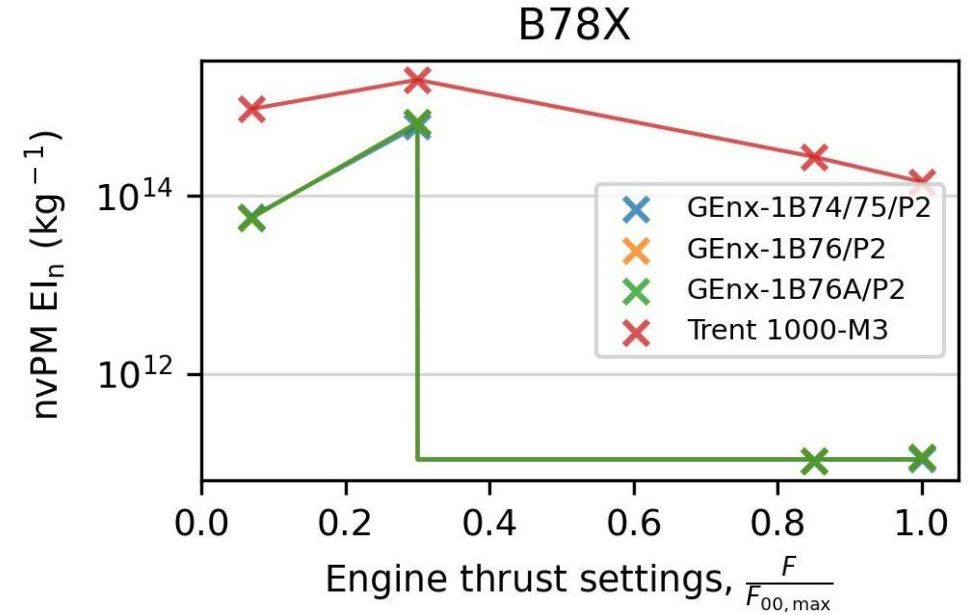
- Naphthalene content
- Fuel hydrogen content

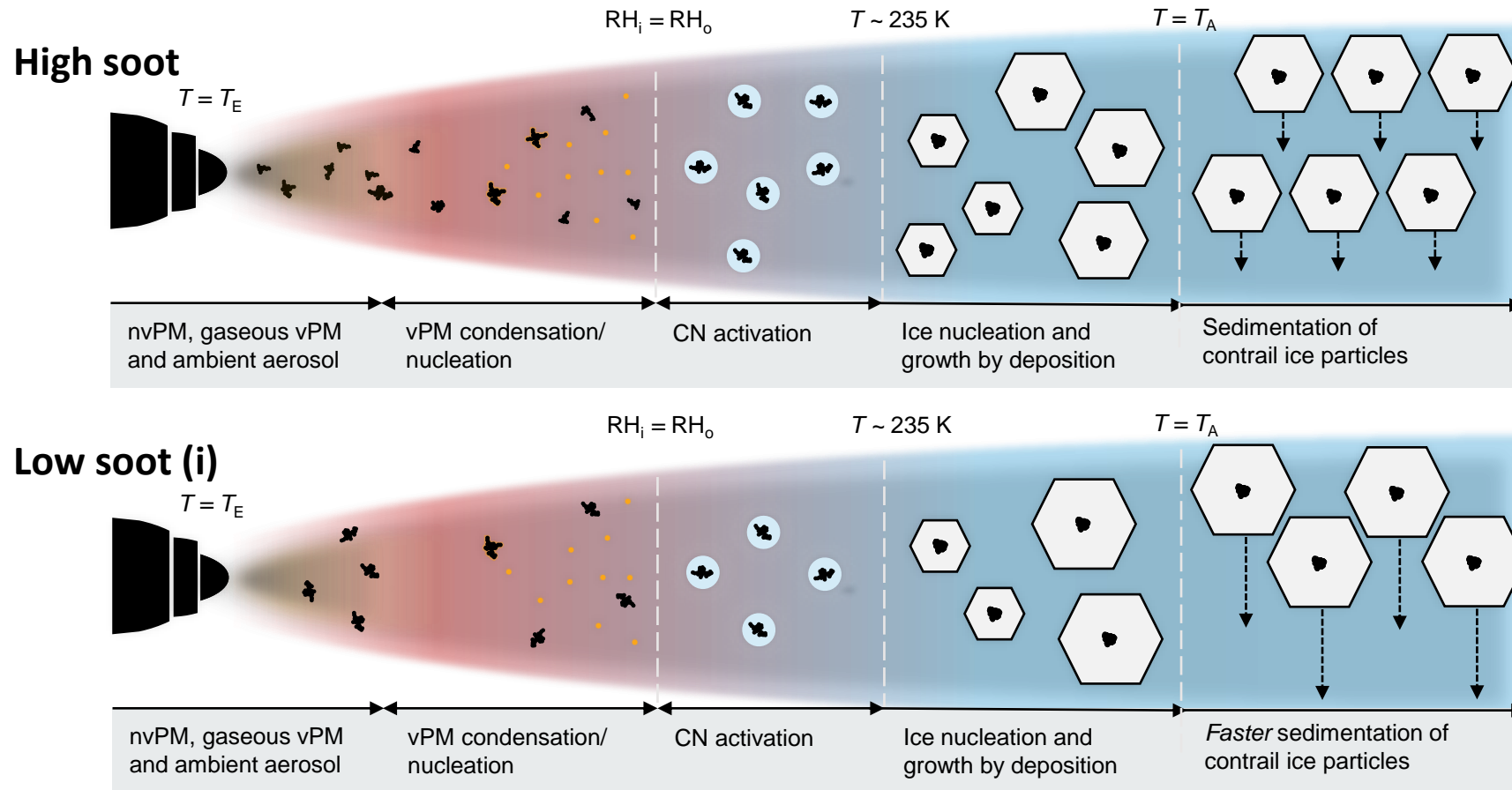
# Factors affecting particle emissions

- Engine technology
  - e.g lean-burn combustion
- Alternative fuels
  - Sustainable aviation fuels
  - Low aromatic / naphthalene / sulphur fuels
  - Hydrogen
- Lubrication oil venting



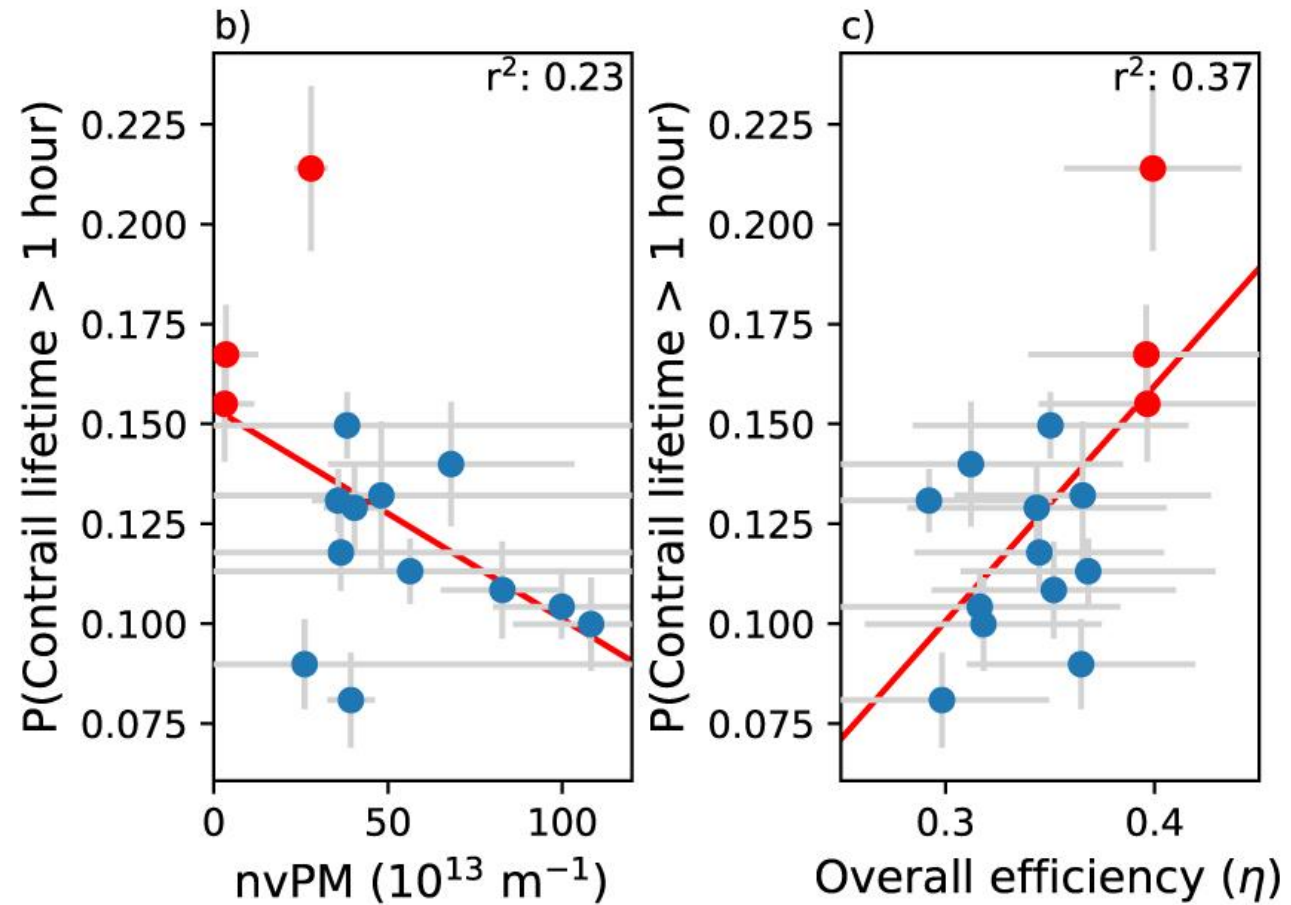
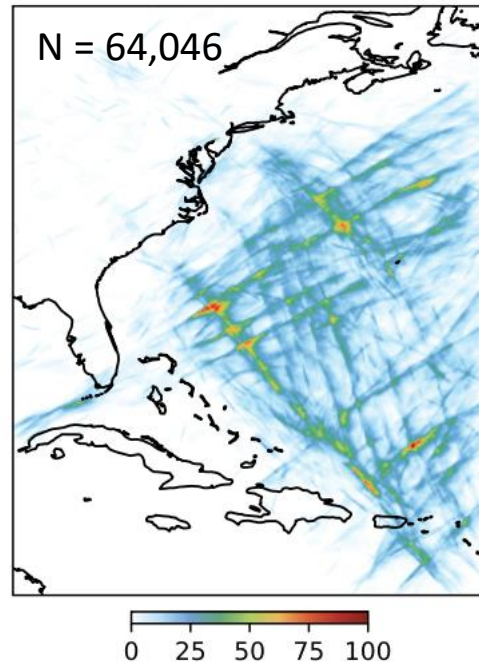
Boies et al (2015)  
 Teoh et al. (2020)  
 Teoh et al. (2022)  
 Teoh et al. (2023)  
 Ponsonby et al. (2024)





## Observable differences in contrails different aircraft and engines

c) Tracked counts



# Sustainable aviation fuels

## Caiazzo et al. (2017) [USA]

Increase in contrail occurrence and the lower albedo of contrails forming in the biofuel case outweigh the cooling effect of optical depth reduction,... leads to a **higher average net radiative forcing** of between 0% and +18%

## Teoh et al. (2022) [N. Atlantic]

Fleetwide adoption of 100% SAF increases contrail occurrence (+5%), but lower non-volatile particle emissions (-52%) **reduces the annual mean contrail net radiative forcing** (-44%)... targeting 1% SAF at a 50% blend ratio to ~2% of flights responsible for the most highly warming contrails reduces  $EF_{contrail}$  by ~10%

## Märkl et al. (2024) [Global]

Global mean radiative forcing estimate for the 100 % SAF run is  $53 \text{ mW m}^{-2}$  for the year 2018... **a decrease in the contrail cirrus radiative forcing of 26%.**

# Engine technology

## Burkhardt et al. (2018) [Global]

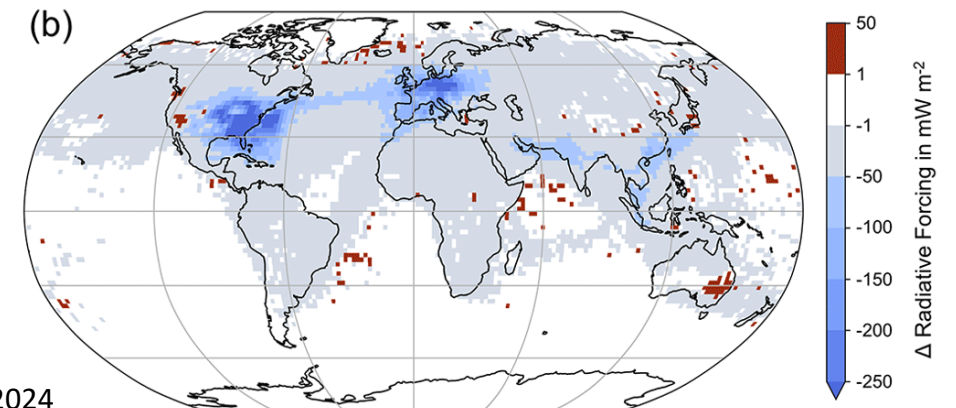
Contrail cirrus lifetimes and coverage are strongly reduced leading to significant reductions in contrail cirrus radiative forcing... A reduction in the initial ice crystal number of 80% leads to a **decrease in contrail cirrus radiative forcing by 50%**

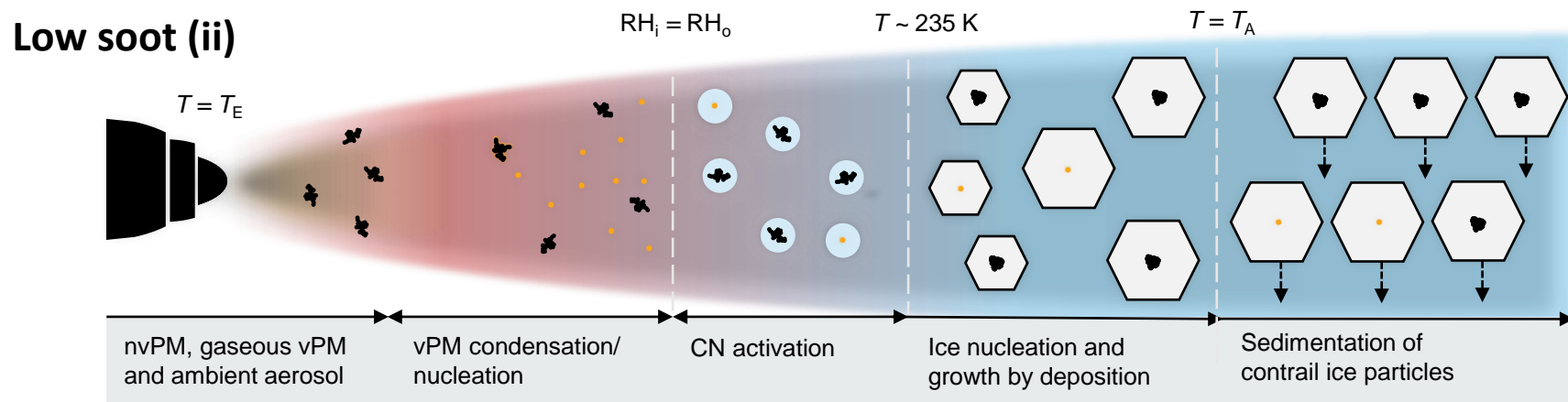
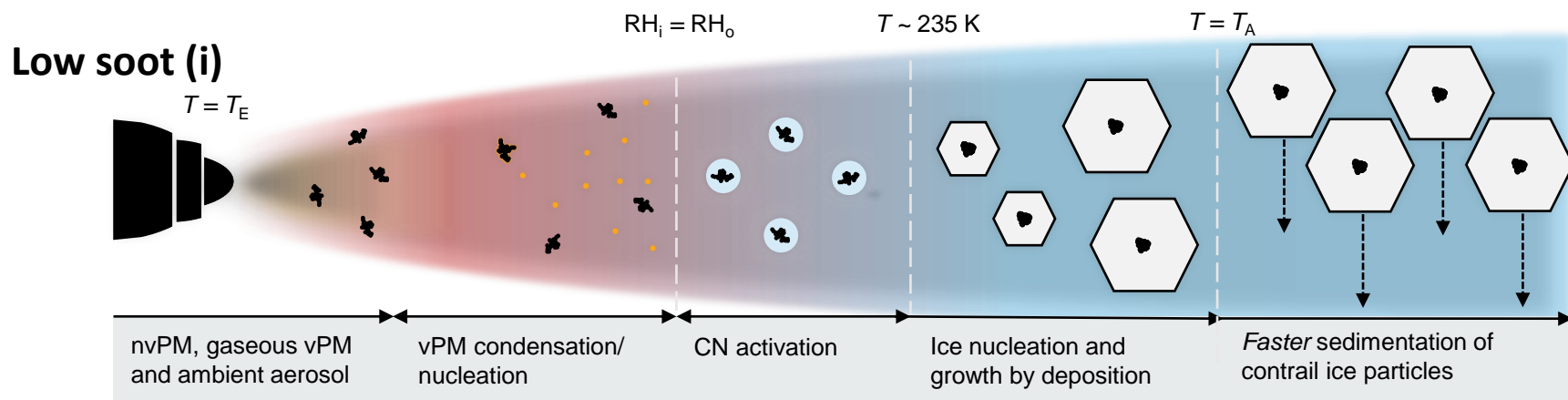
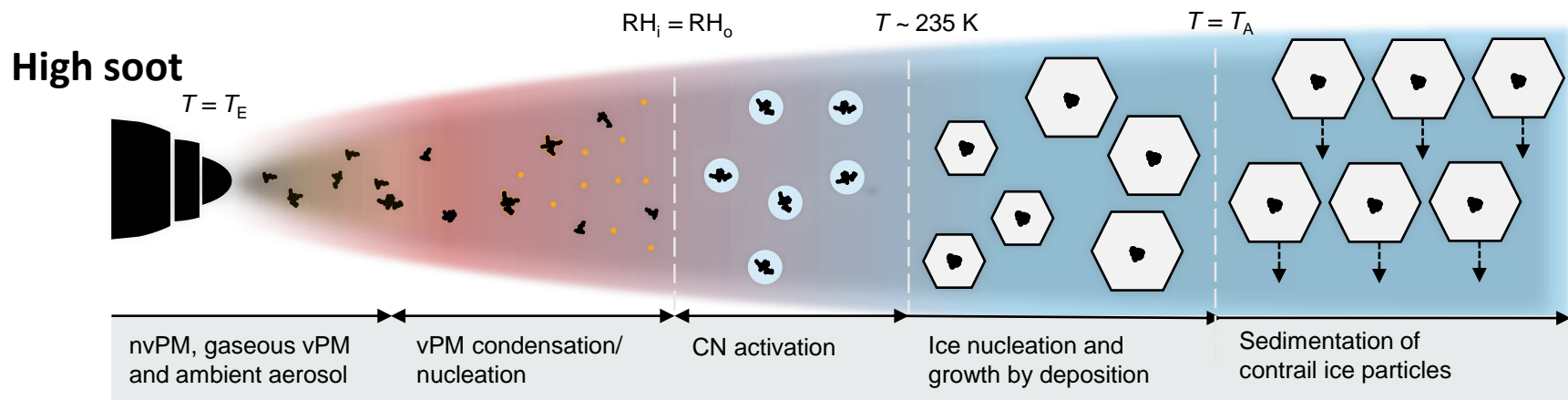
## Teoh et al. (2020) [Japan]

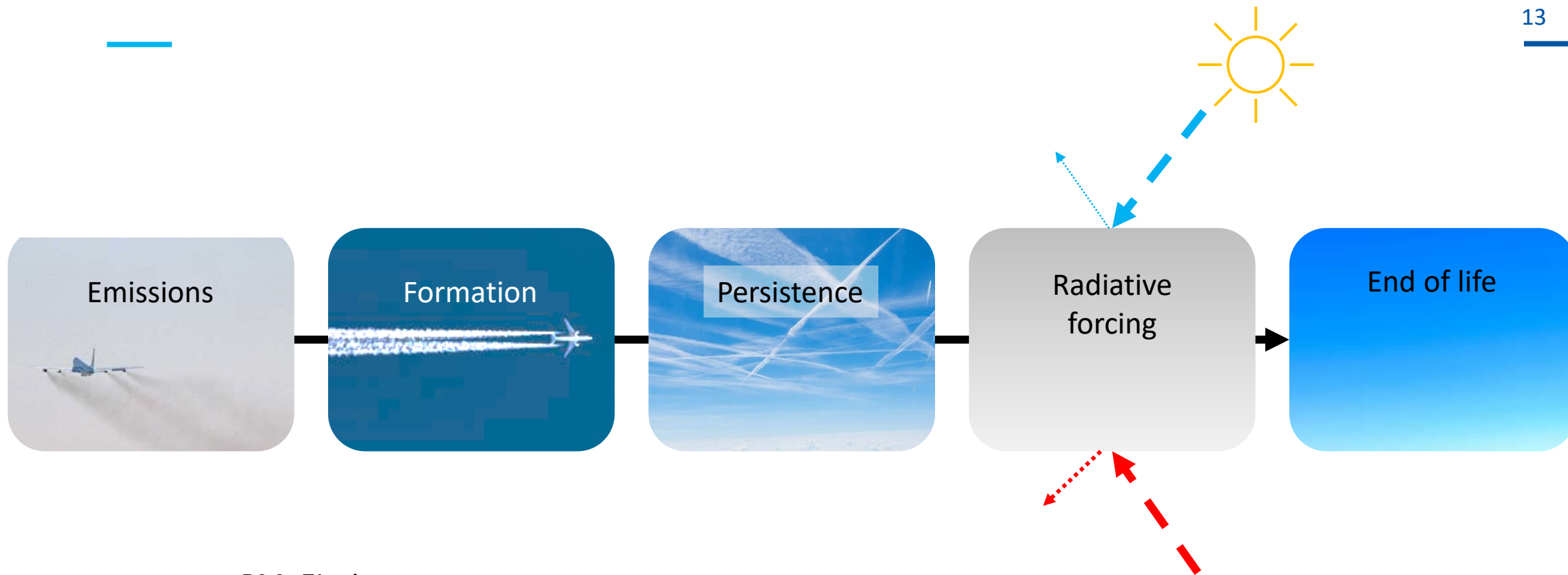
Widespread use of new engine combustor technology, which reduces particle emissions, could achieve a **70% reduction in the contrail EF**

## Teoh et al. (2024) [Global]

Reducing soot particle emissions by a factor of 10 **reduces global contrail RF by ~80%**







nvPM: EI, size  
vPM: EI, size, composition  
Water -> SAC  
Efficiency

Ice particle size -> sedimentation  
Ice particle concentration -> optical thickness

## Key messages

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# 1

Not all contrails are created equal. Particle emissions modify the properties and lifetimes of contrails, but operations matter too.

⇒ Reducing particle emissions reduces contrail lifetime and radiative forcing

# 2

Sustainable aviation fuels will not eliminate contrails.

⇒ We will need other means to reduce contrails, e.g. routing / scheduling. We need more observations for high SAF blend flights.

# 3

As nvPM emissions reduce, we need to minimise vPM emissions

⇒ vPM are not currently regulated. We need data on number, size and composition of nvPM.

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# Thank You

