

The science of aviation's effects on climate (and, debunking some myths)

David Lee

Aviation Reimagined, 5th October 2023

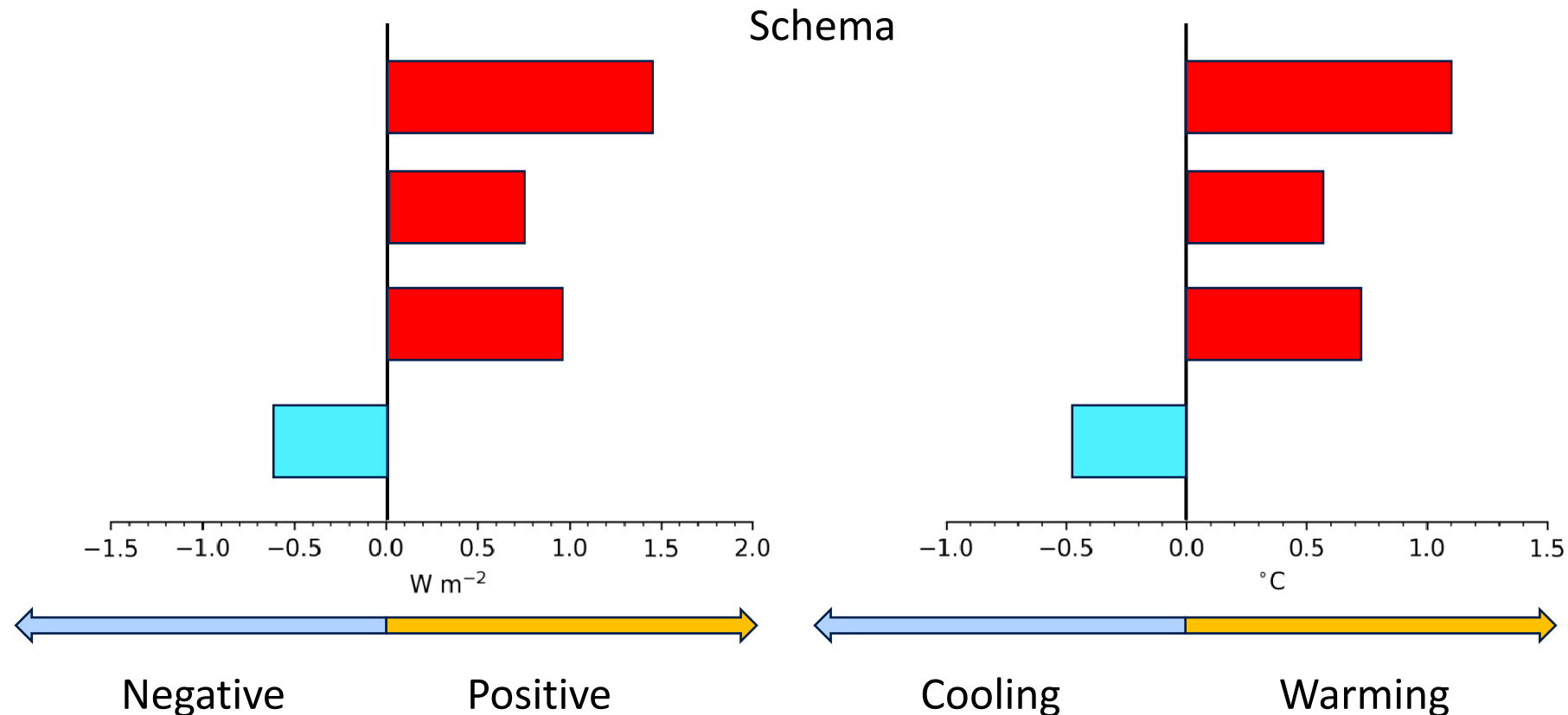
Manchester Metropolitan University



Outline

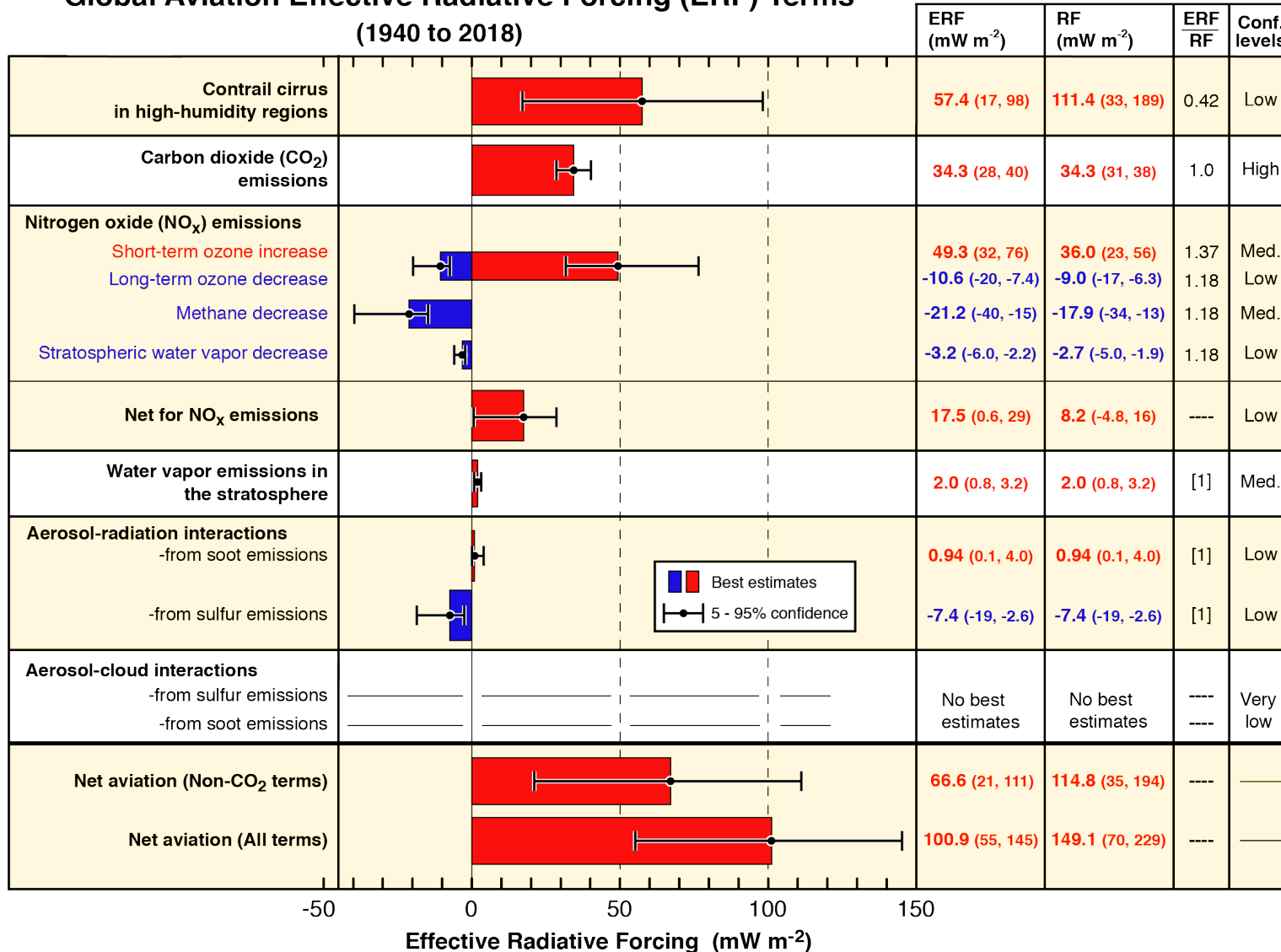
What we are talking about
The largest (present day) non-CO₂ effects
The science requirements for mitigation

What we are talking about: 'radiative forcing' – the metric of climate change in watts per square metre ($W m^{-2}$)



The latest aviation climate science assessment

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

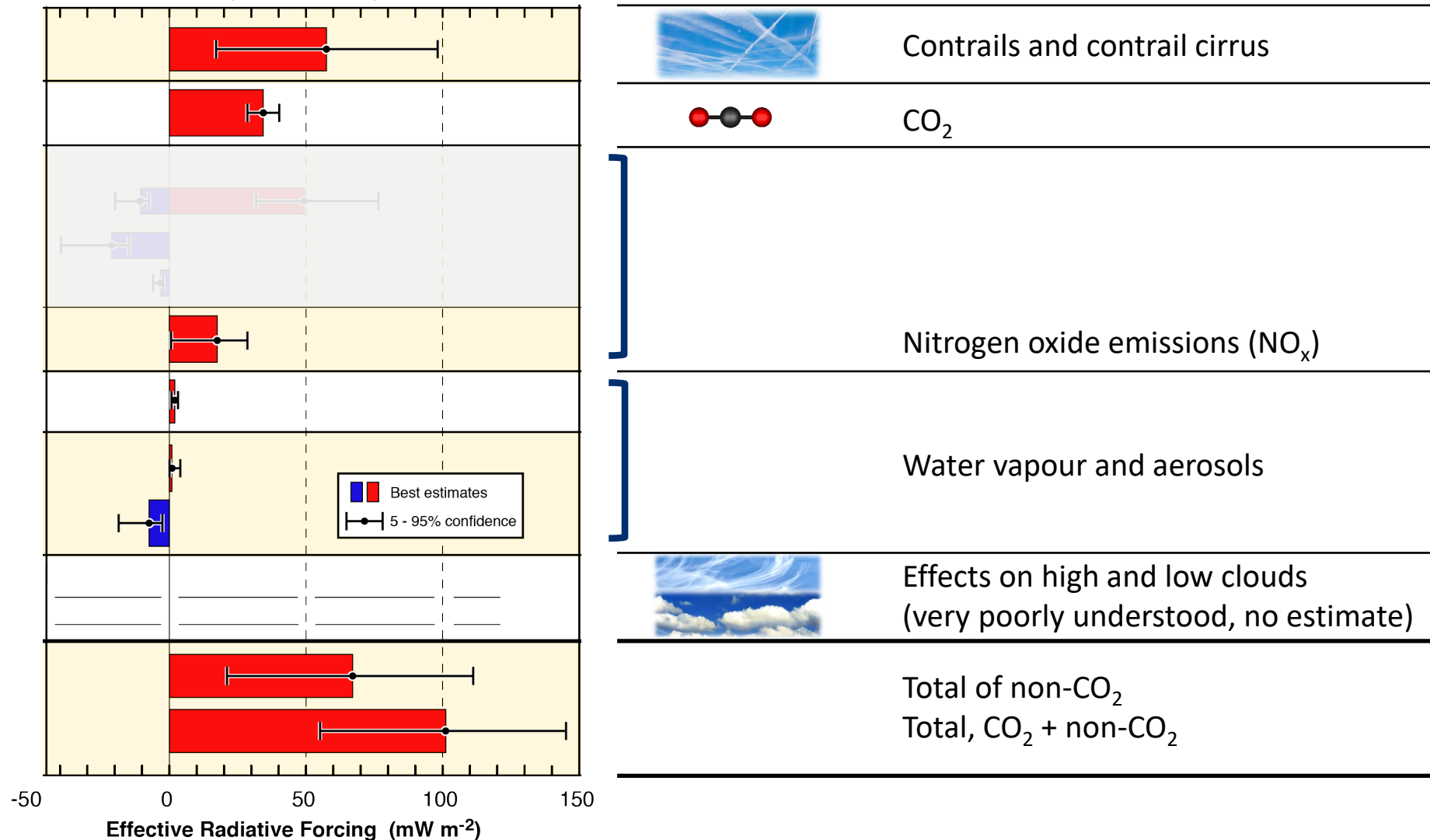


Lee et al. (2021) Atmos. Environment

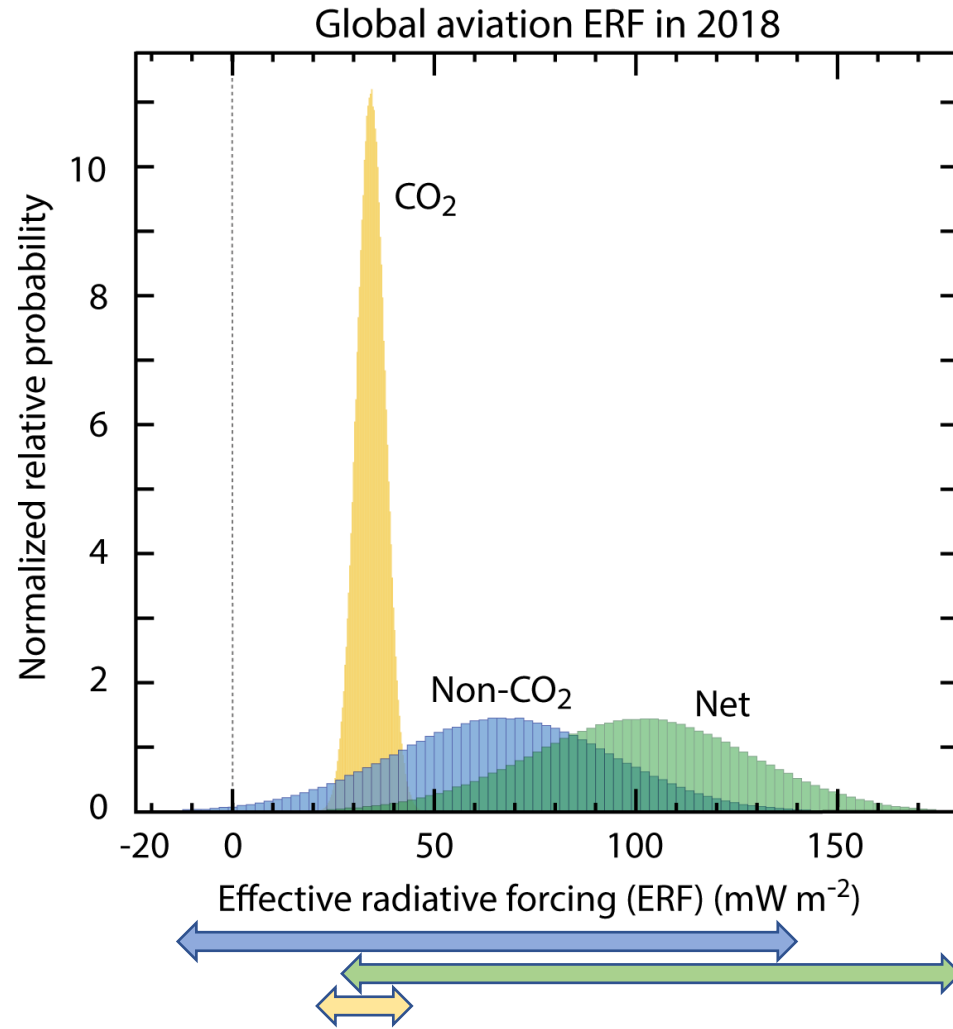
- D. Fahey, NOAA, USA
- A Skowron, MMU, UK
- M Allen, Univ Oxford, UK
- U Burkhardt, DLR, Germany
- Q Chen, Peking Univ, China
- S Doherty, CIRES, Univ Colorado, USA
- S Freeman, MMU, UK
- P Forster, Univ Leeds, UK
- J Fuglestad, CICERO, Oslo, Norway
- A Gettelman, NCAR, Boulder, USA
- R De Leon, MMU,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

A simplified view of the science assessment

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



Non-CO₂ uncertainties are large: CO₂ uncertainties are small



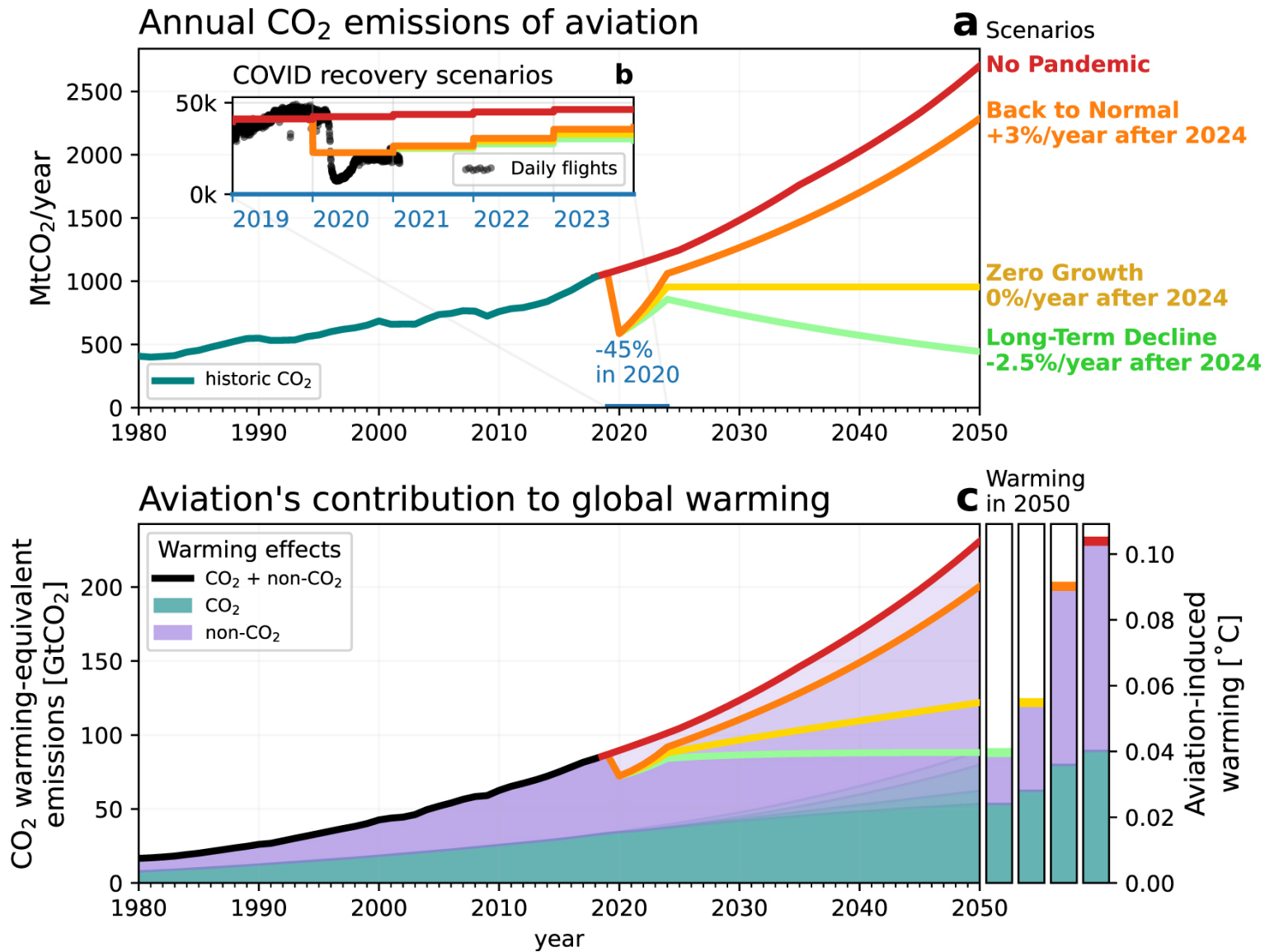
Clearing up misunderstandings

- Non-CO₂ is “more important” than CO₂
- Non-CO₂ effects will grow with increased traffic, and in the future
- We can easily avoid contrails
- SAF will reduce contrails
- The above are just a ‘taster’ of the misunderstandings and myths...!

Clearing up misunderstandings

“Non-CO₂ is “more important” than CO₂”

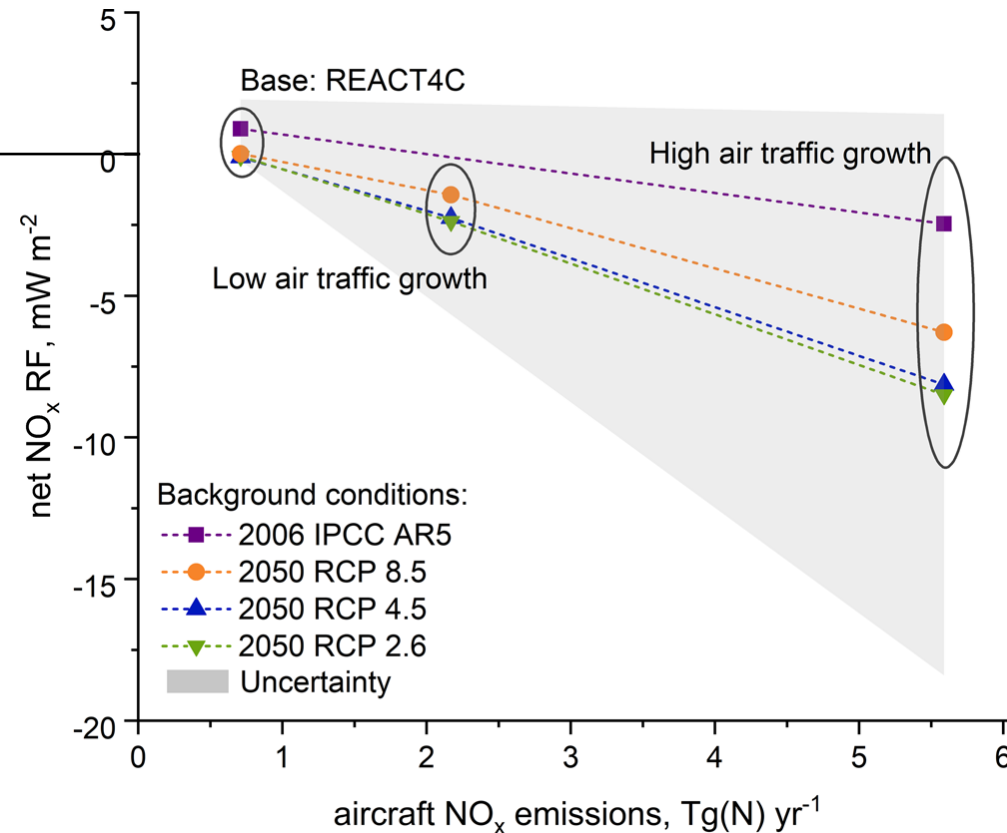
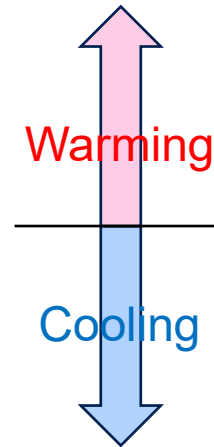
Non-CO₂ effects currently represent 66% of the ERF (within uncertainties, true but this may not always be the case)



Source: Klöwer et al. (2021), *Environmental Research Letters*

Clearing up misunderstandings

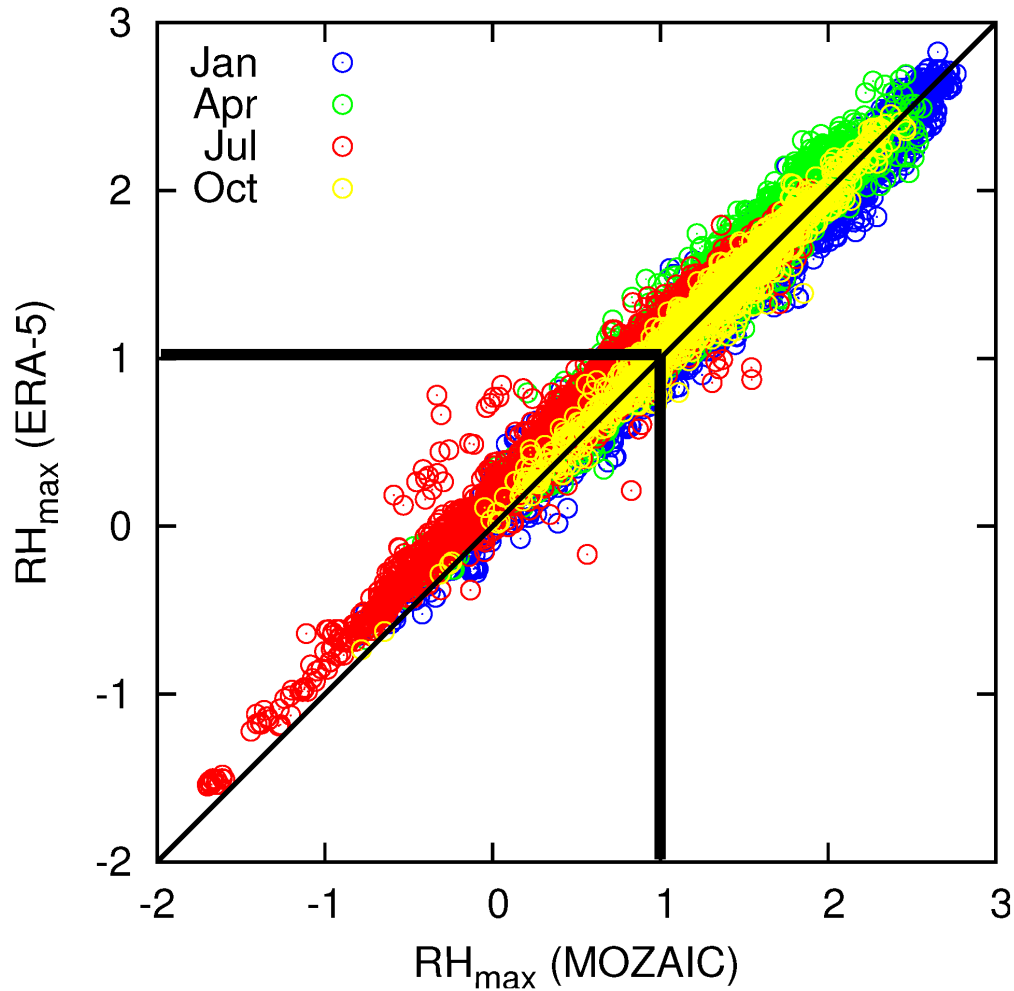
- “Non-CO₂ effects will grow with increased traffic, and in the future”
- Let’s look at the case of NO_x emissions
 - There is no unique aviation net NO_x ERF per unit aviation emission
 - The background emissions matter
 - The future net NO_x ERF could be negative if surface emissions decline (according to SSP2.6) (Skowron et al., 2021; Terrenoire et al., 2022)
 - The additional negative term of nitrate aerosol may, or may not be important (Terrenoire et al., 2022; Barrett et al?)



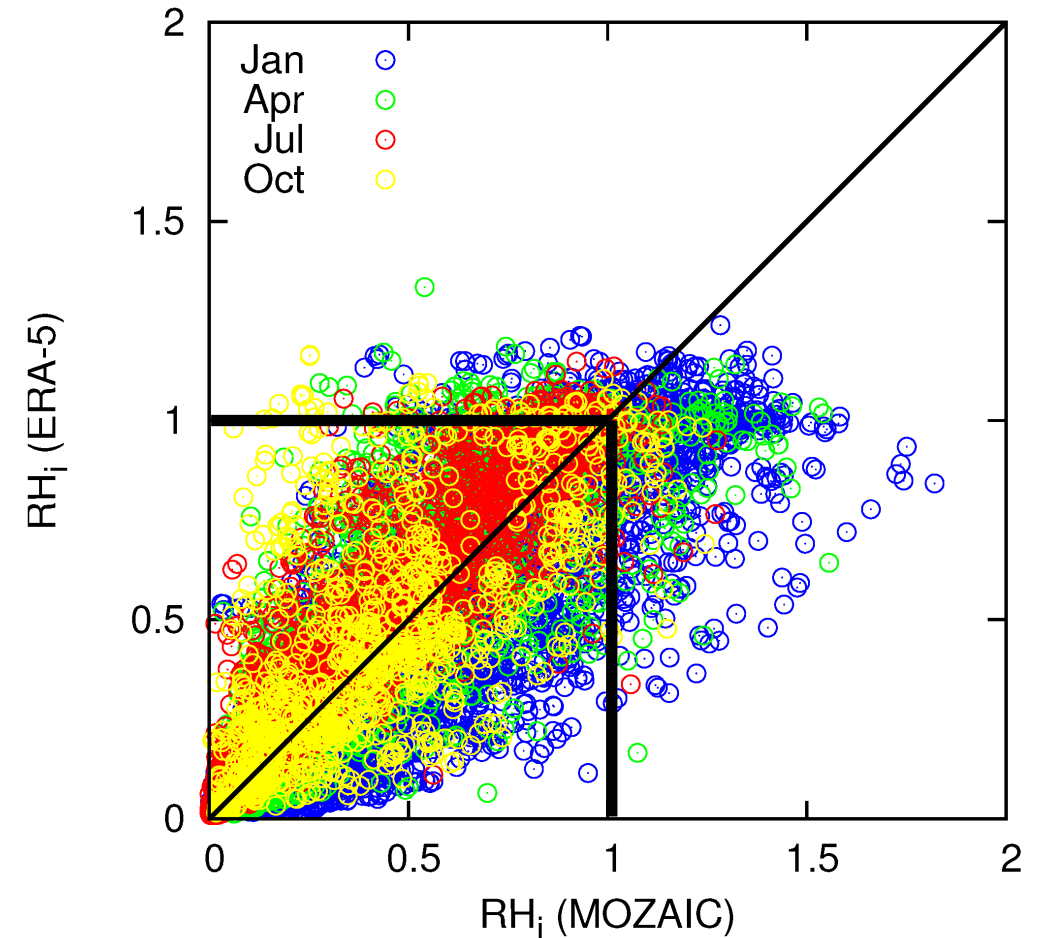
Clearing up misunderstandings

- “We can easily avoid contrails”
- Four critical questions:
 - Do we know the size of the global forcing
 - Can we predict where they will occur”?
 - Can we predict the forcing on a flight by flight basis?
 - How do we ‘trade’ and reduced contrail forcing for possible extra CO₂?

Unpacking the “can we predict ISSR?” question

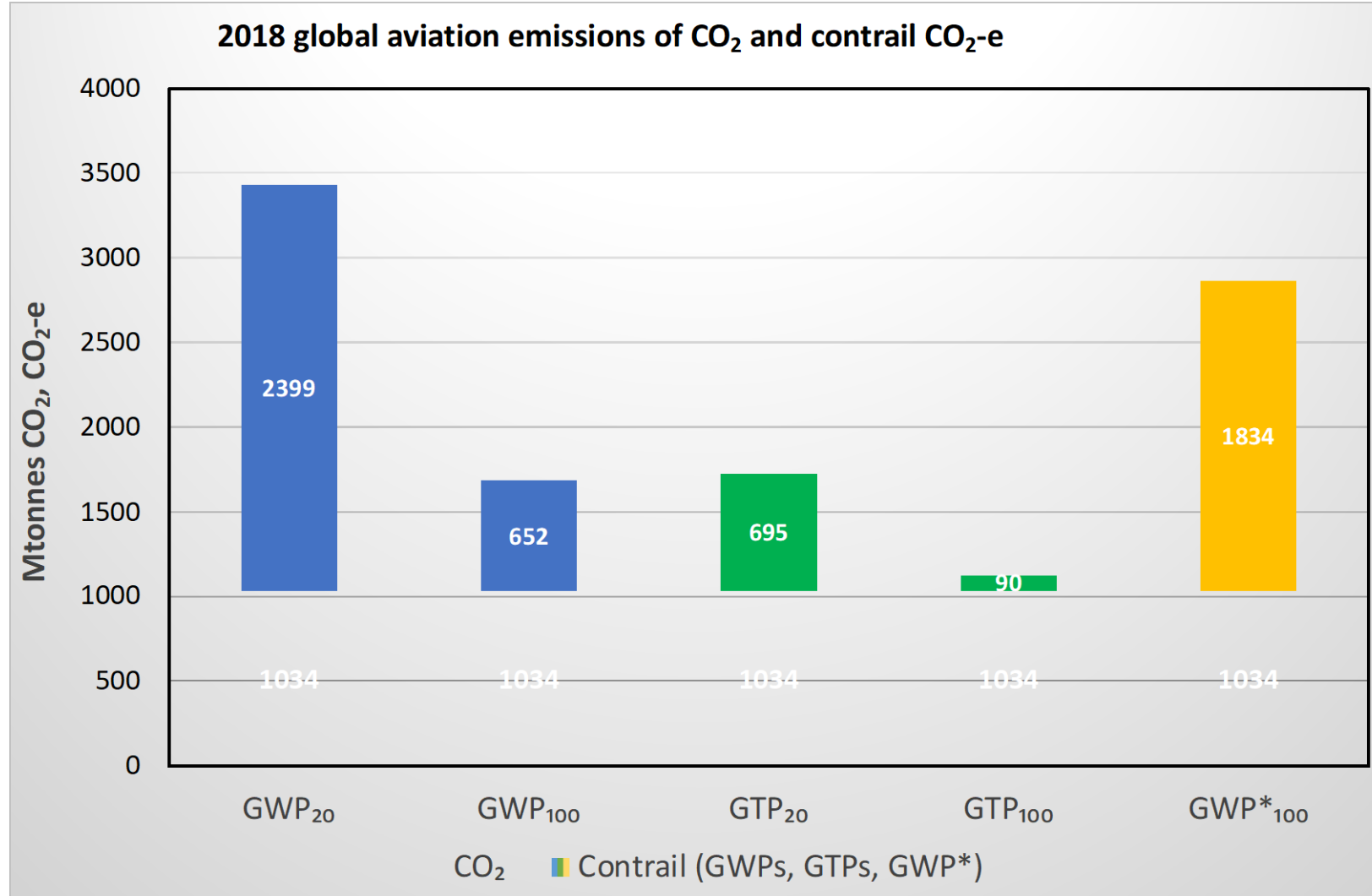


Comparison of contrail formation conditions expressed as relative humidity in the exhaust plume in the moment when the temperature reaches T_{max} , for MOZAIC (x-axis) and the corresponding ERA-5 data (y-axis).



Comparison of relative humidity with respect to ice for MOZAIC (x-axis) and the corresponding ERA-5 data (y-axis). Colours are as in Figure 1. Contrails are persistent when $RH_i \geq 1$.

Unpacking the “how to convert contrails to CO₂-e?” question

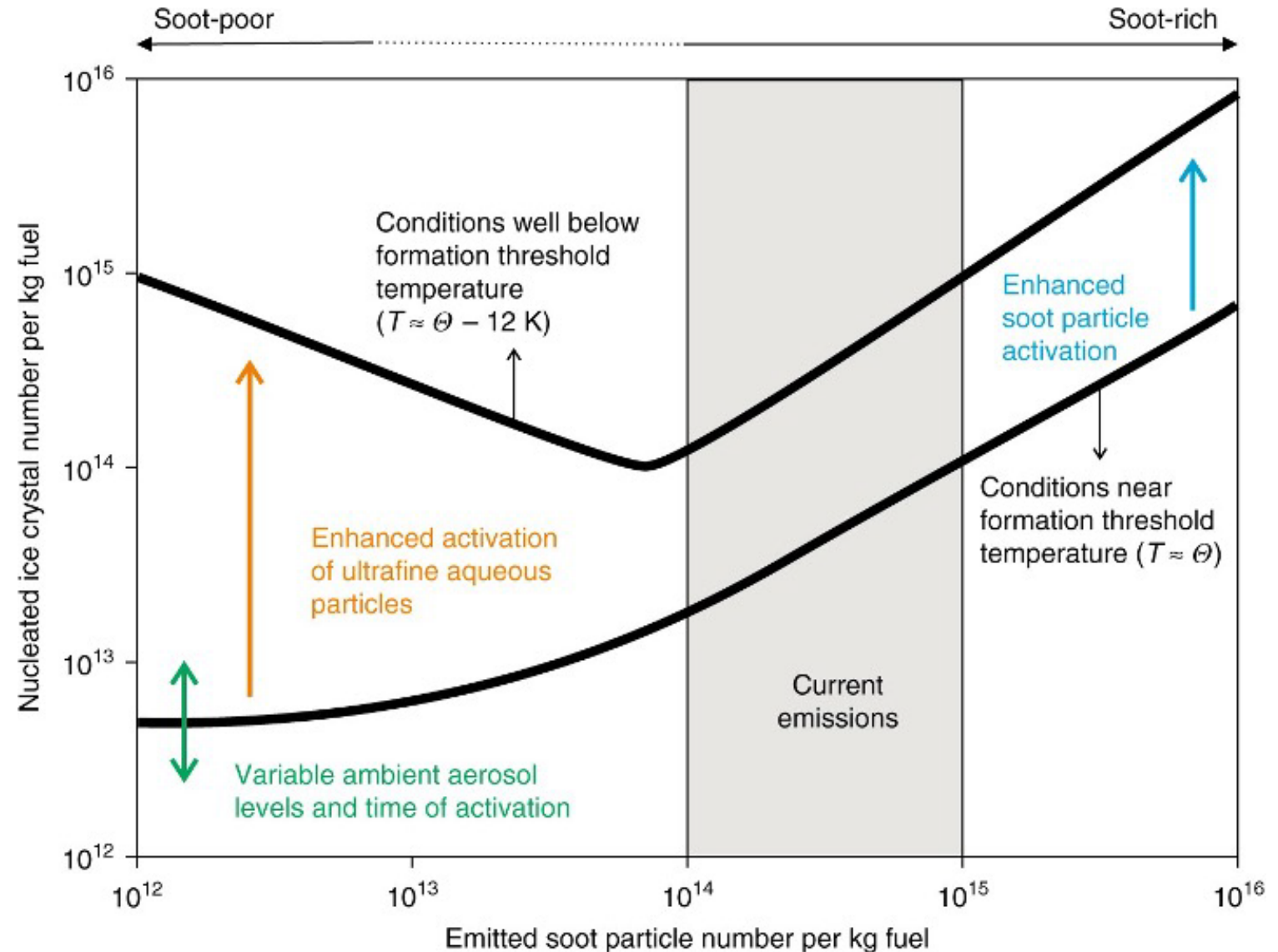


CO₂ emission equivalents illustration

- Two types; GTP, GWP (GWP* is derivative)
- Two (arbitrary) time horizons of 20, 100 years
- All the answers are correct (for fossil fuel)
- Uncertainties have not been included but would reflect those in the ERF chart
- Which would you choose?

Mitigation of contrails with SAF, is this a clear win-win?

**Do we know
what will
happen if SAF
is used?
(maybe not...)**



The profound and pernicious nature of CO₂

- Every additional tonne of fossil CO₂ emitted adds half a trillionth degree of warming (even in a declining emission scenario)
- If emissions of non-CO₂ were to be constant, they would add no further warming
- Mitigation is by no means a straightforward or easy issue
- (other than “fly less”)

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