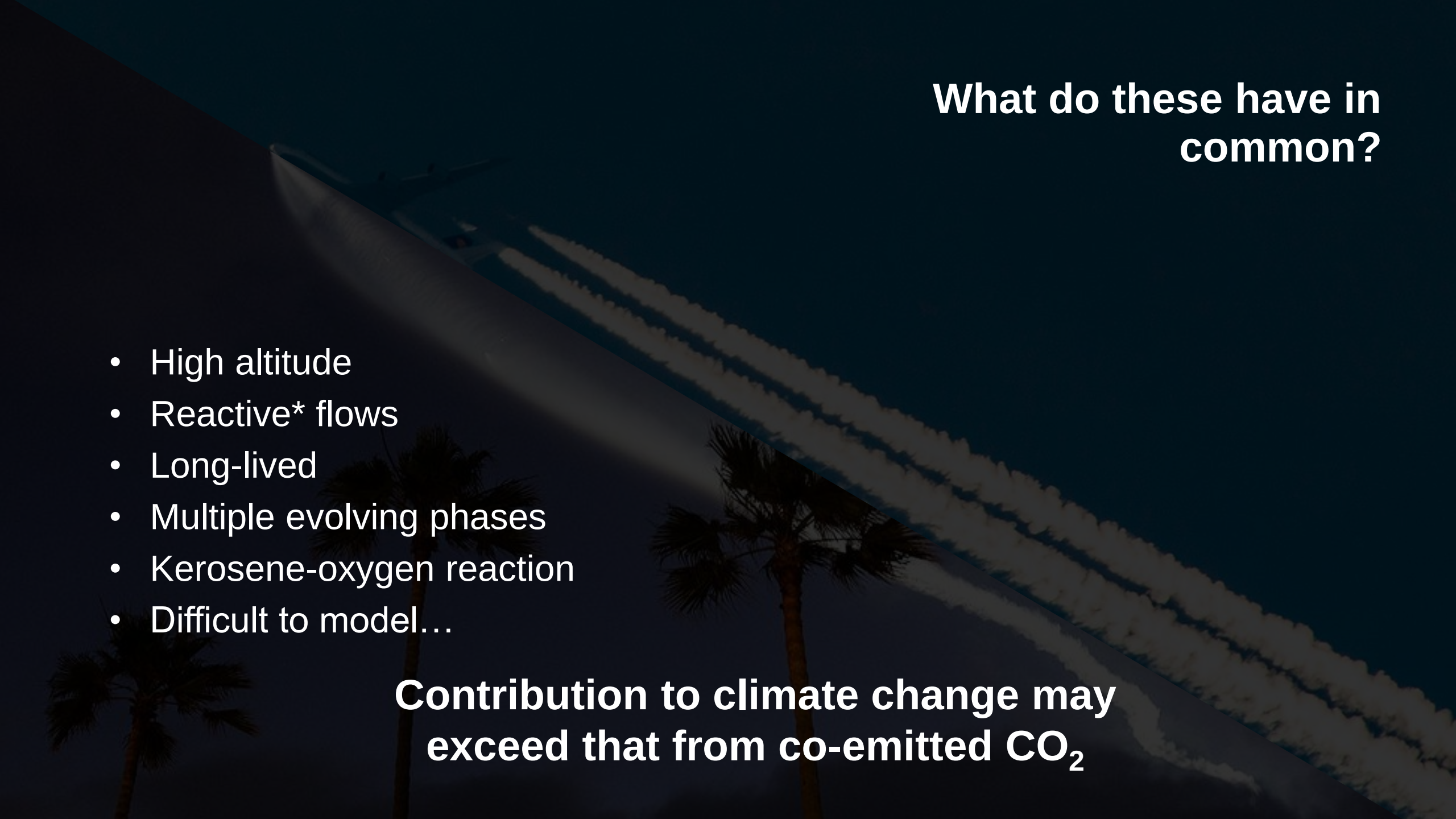
Imperial College London

Brahmal Vasudevan Institute for Sustainable Aviation

Aerospace sustainability and multiphase reactive flows

Sebastian Eastham

What do these have in common?

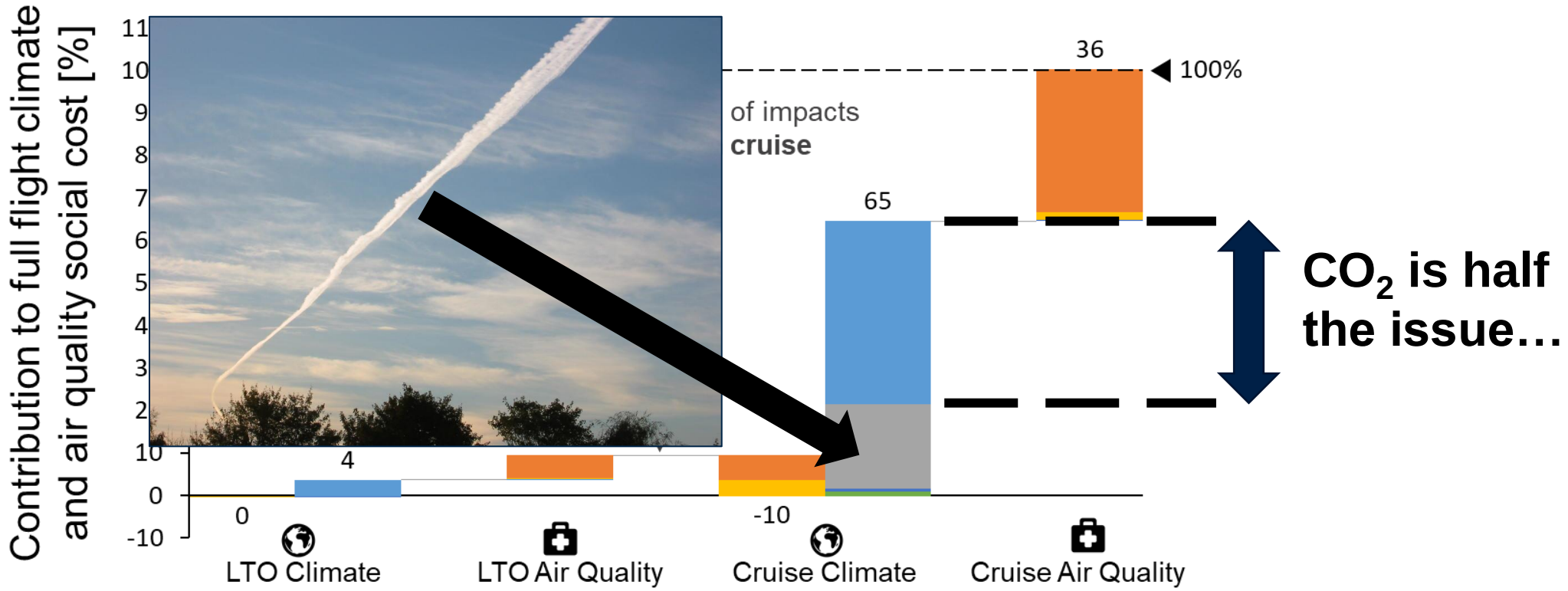


What do these have in common?

- High altitude
- Reactive* flows
- Long-lived
- Multiple evolving phases
- Kerosene-oxygen reaction
- Difficult to model…

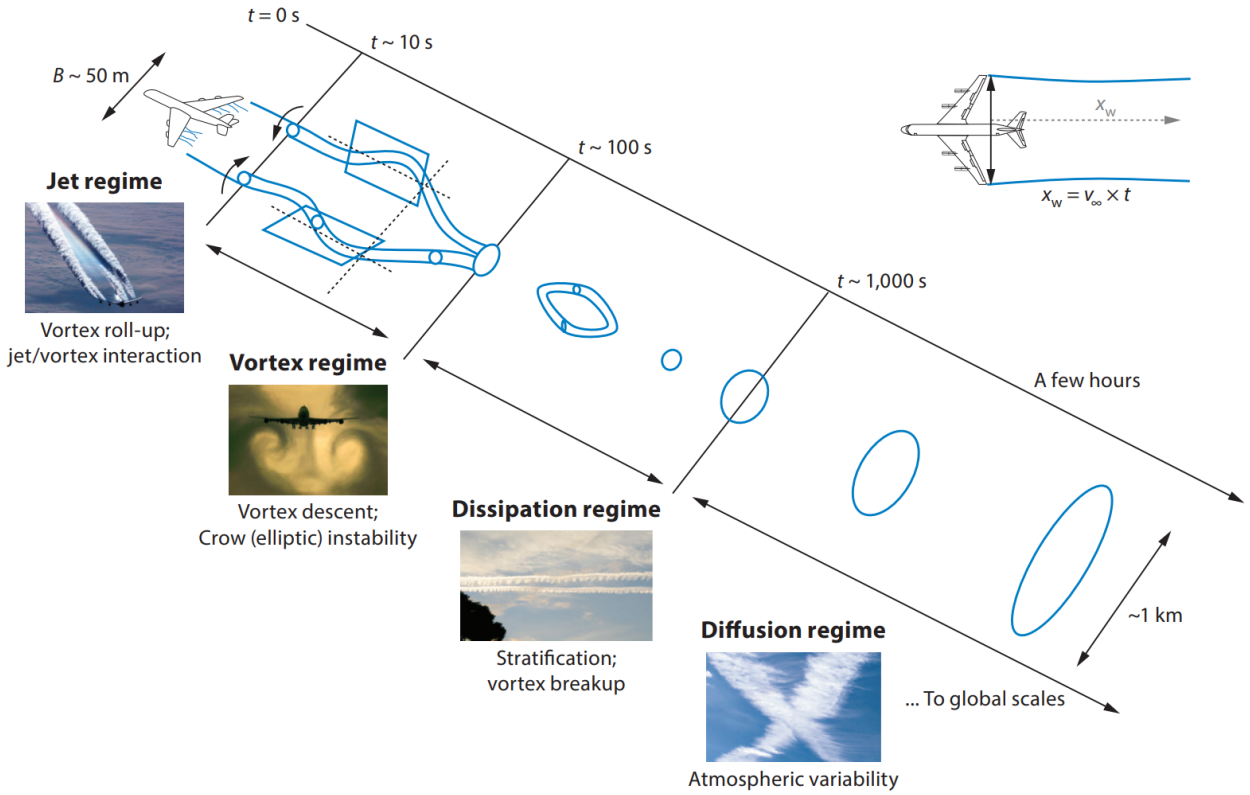
Contribution to climate change may exceed that from co-emitted CO_2

Why contrails matter to aviation



Grobler et al., 2019

Contrails as a multiphase reactive* flow



Complex – four distinct phases, evolving over several hours

Cross section size:

- Formation: ~10^0 m^2
- Evaporation: ~10^8 m^2

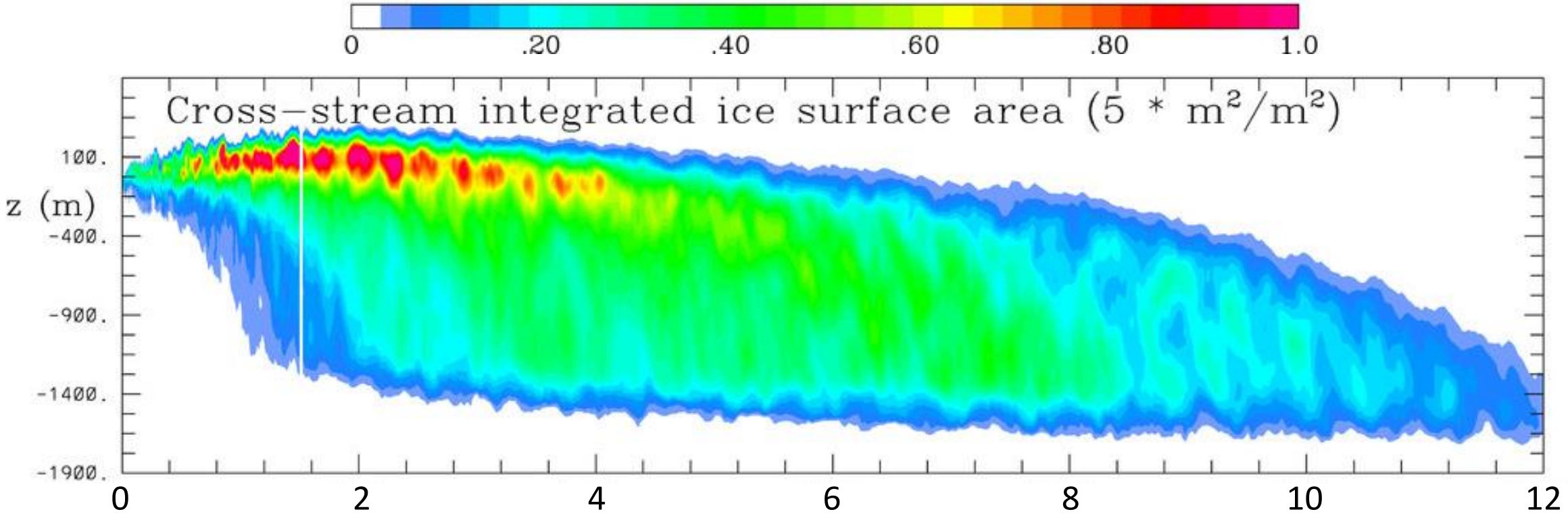
Lifetime: 0 – 12 hours?

An open question

Contrail impacts are proportional to their lifetime, so…

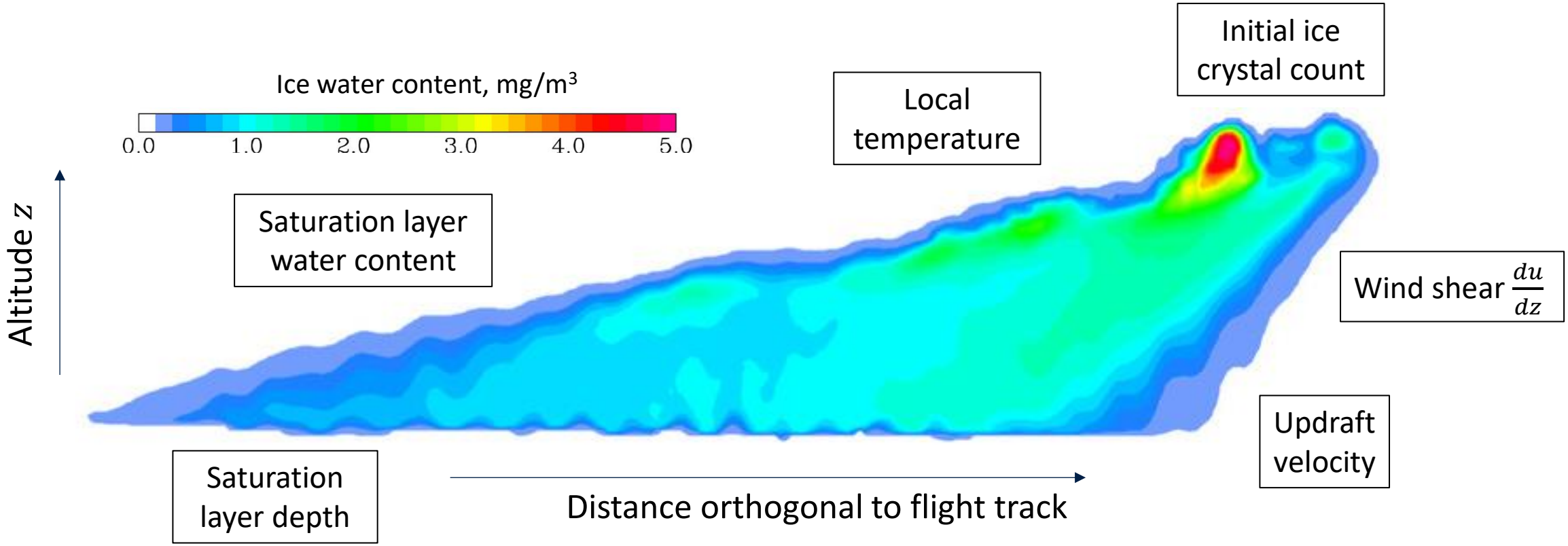
Why do contrails die?

One fate for contrails: “settling out”



Lewellen et al., 2014 (Part I)

Factors affecting contrail properties

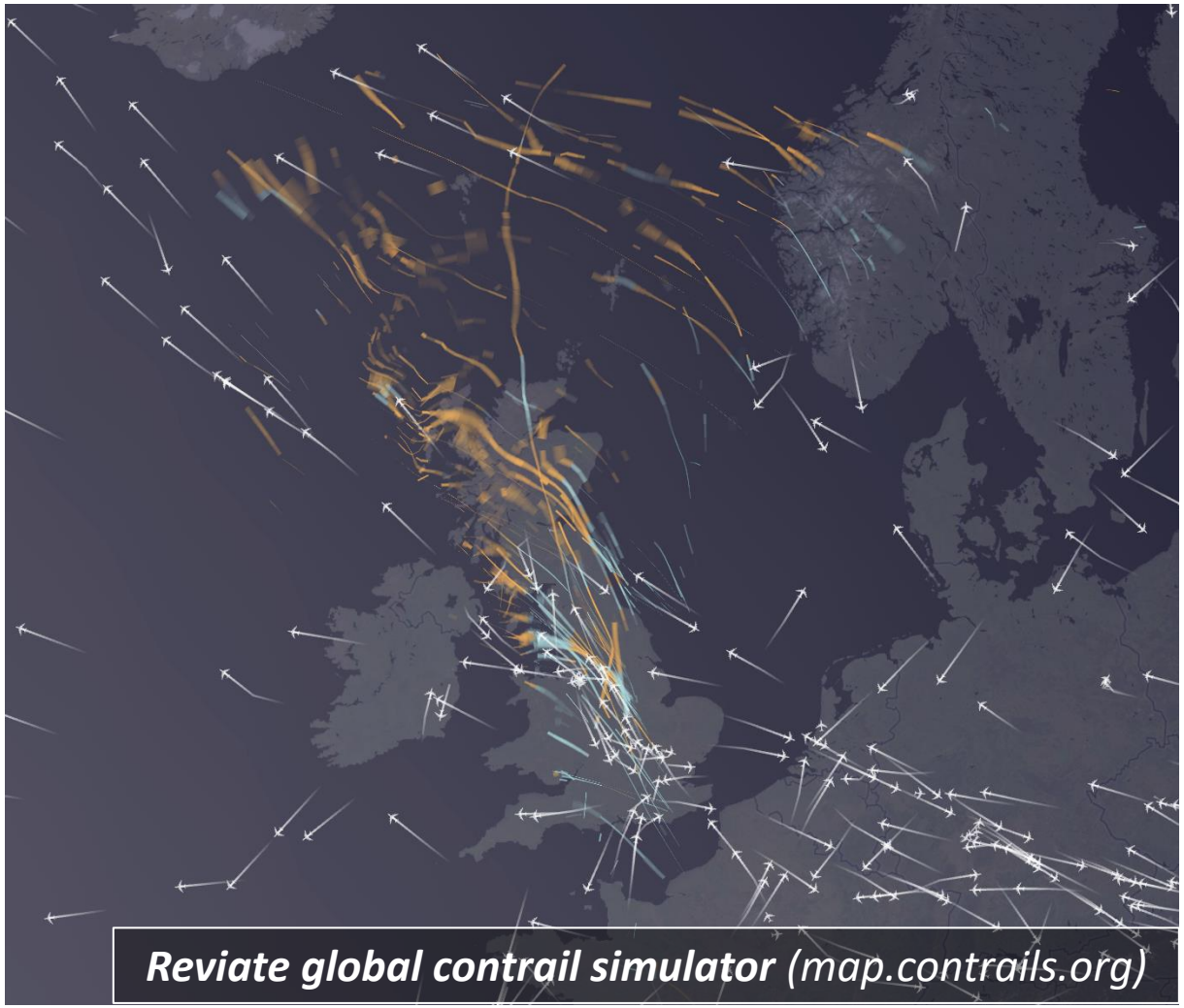


Lewellen et al., 2014 (Part II)

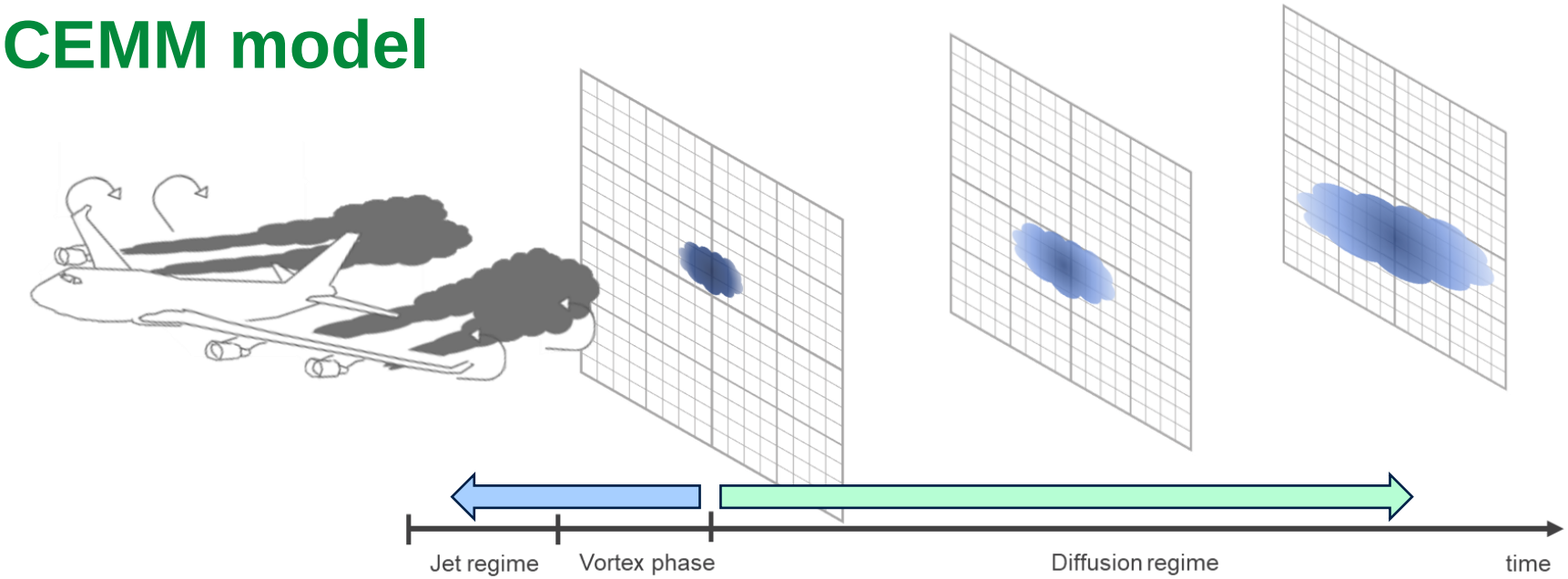
Another fate: synoptic-scale motions

- Gravitational settling of particles accelerated by shear thinning? Or…

- Synoptic scale motions causing the air mass to warm and all local contrails to evaporate?



The APCEMM model



Early plume model:

1. **Schmidt-Appleman** equivalent formation criteria (well-mixed (0D) with ambient entrainment)
2. Parameterized **vortex losses**
3. **Monodisperse aerosol** with evolving size

Mature plume:

1. **2D gridded** model
2. Turbulent **diffusion**, **shear**, and **particle settling**
3. Resolves **ice crystal size distribution** (38 size bins)

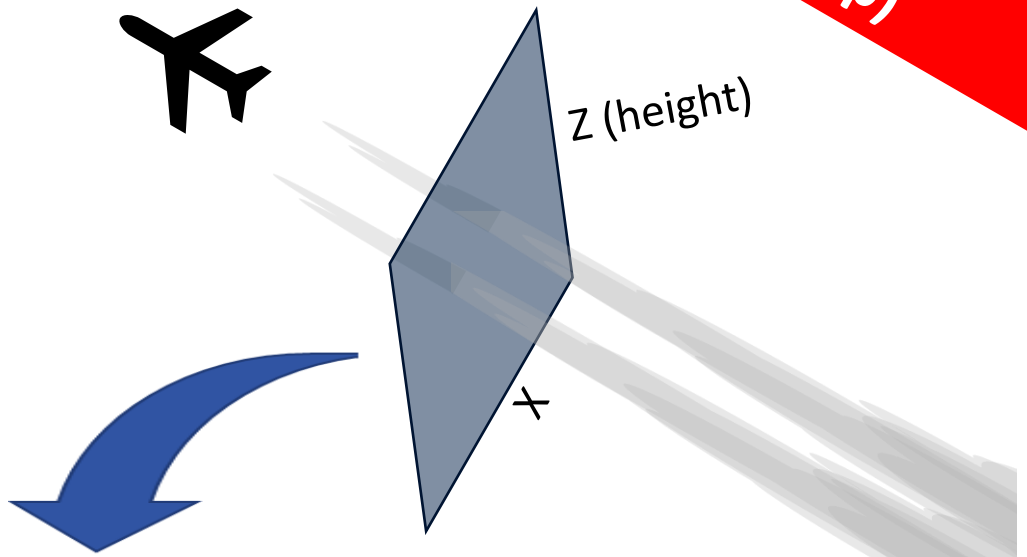
Fritz et al (2020). The role of plume-scale processes in long-term impacts of aircraft emissions. *Atmospheric Chemistry and Physics*, *20*(9), 5697–5727

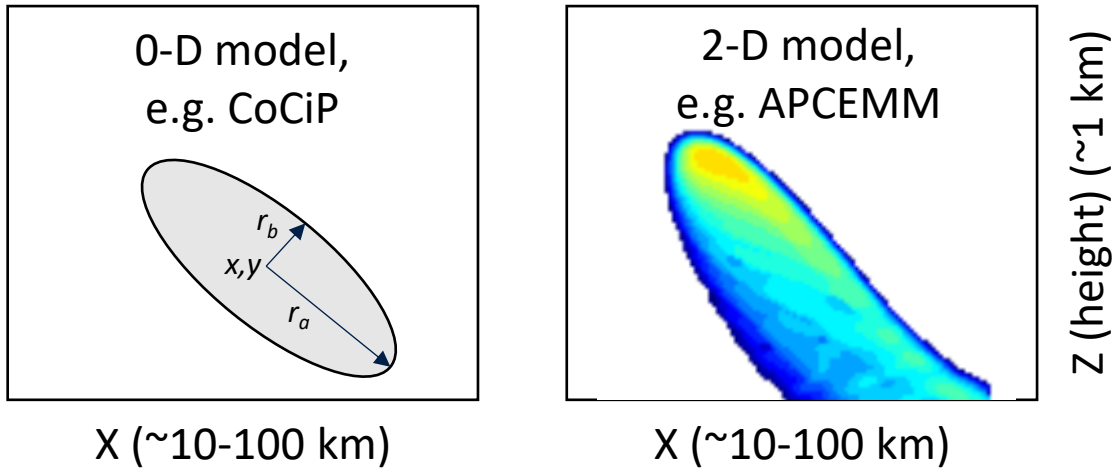
Grobler et al. (in prep)

Representing the mixing problem

Two representations:

- Contrail is a single well-mixed volume (0D): rapid mixing with environment
- Water must mix in to the contrail over time (2D)



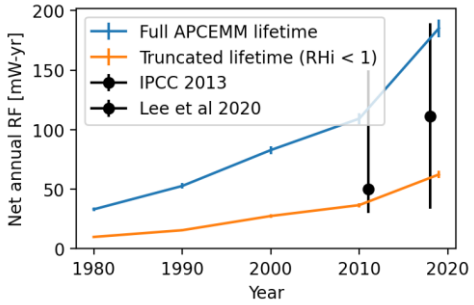


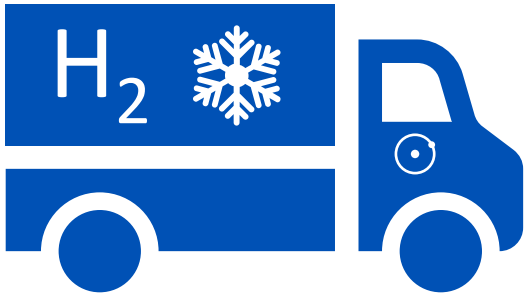
Grobler et al. (in prep)

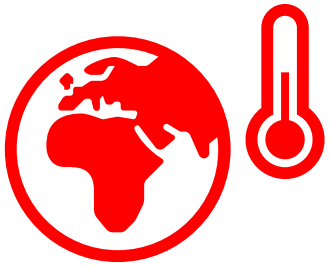
The effect on global contrail climate impact

Impacts vary significantly depending on mixing assumptions –
results currently confidential

Upcoming challenges

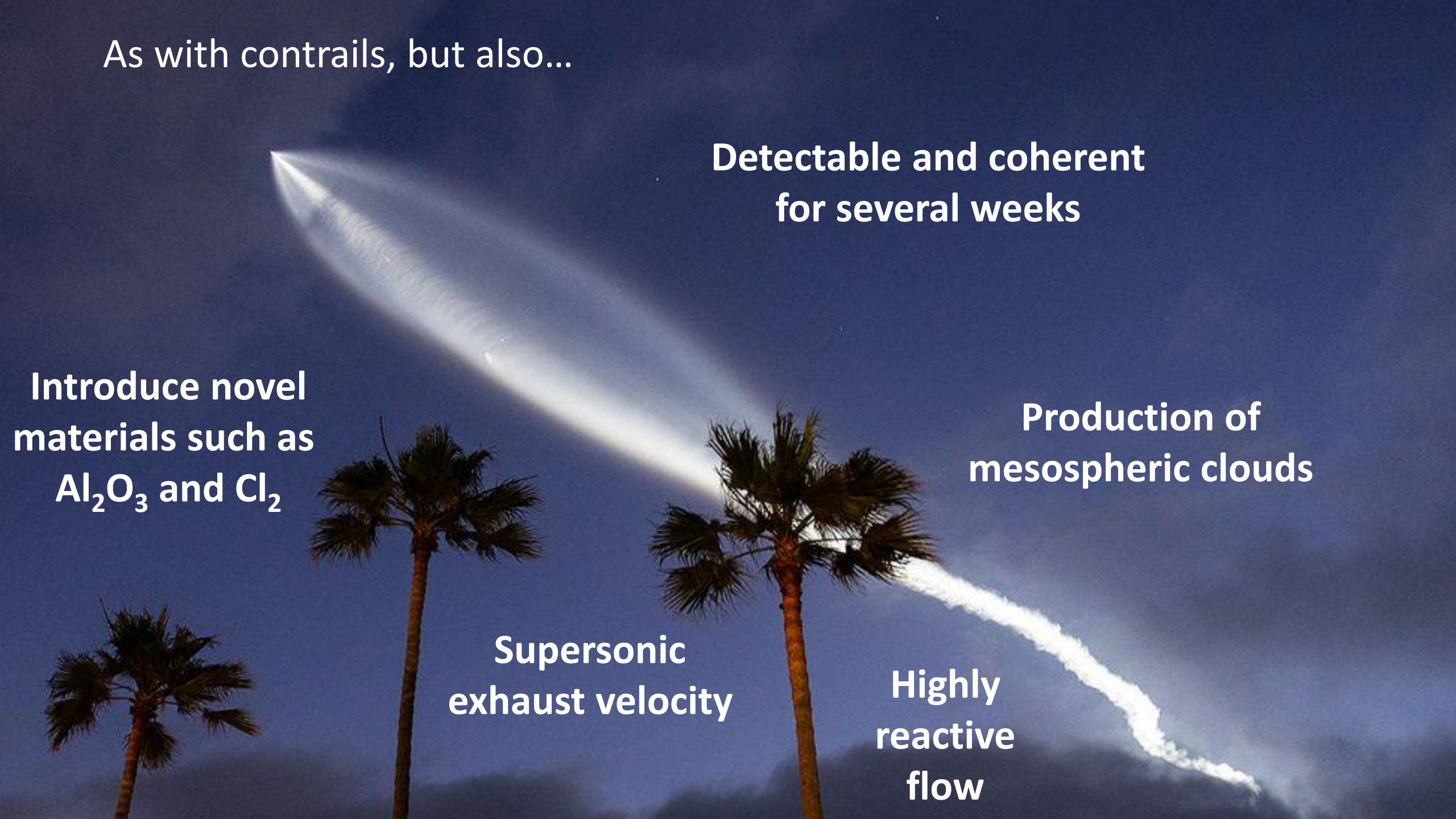






- What really dictates the lifetime of contrails?
- How will contrail impacts change with new fuels?
- What will a changing climate mean for contrail climate impacts?

As with contrails, but also…



Detectable and coherent for several weeks

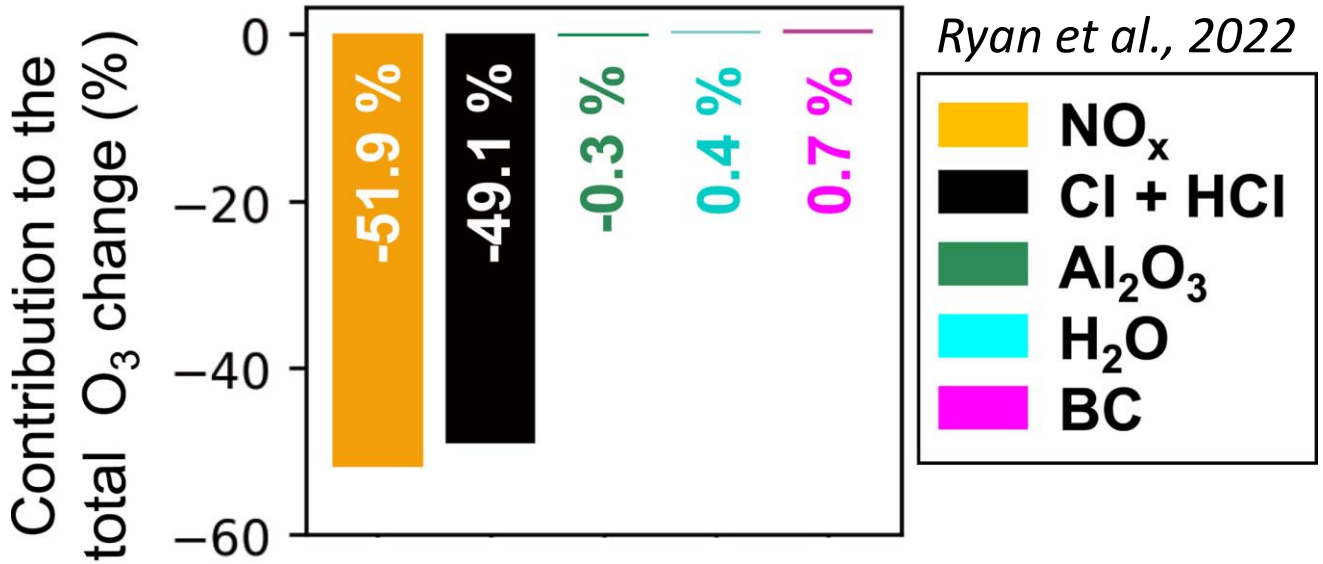
Introduce novel materials such as Al_2O_3 and Cl_2

Production of mesospheric clouds

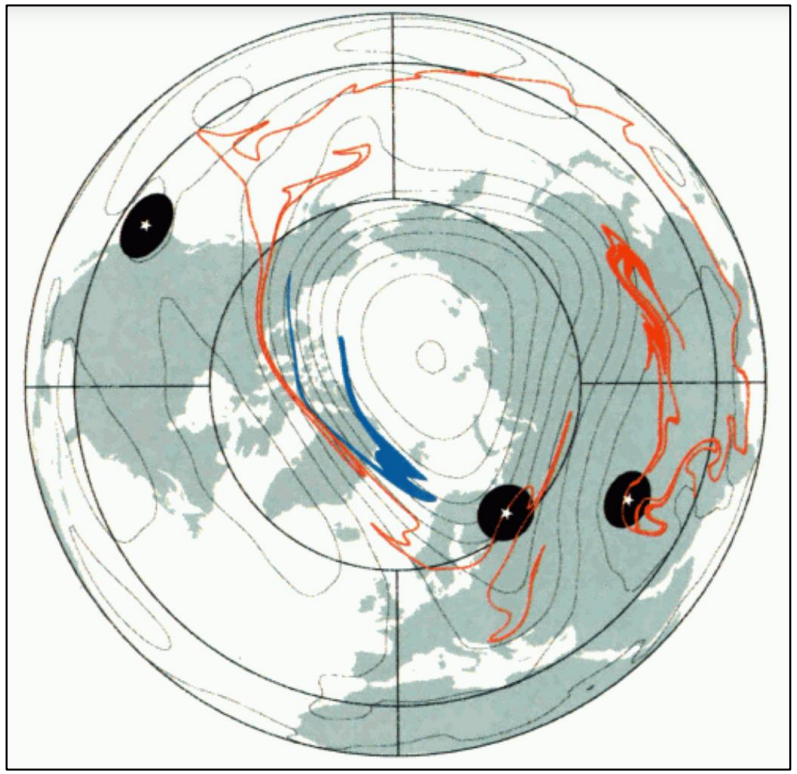
Supersonic exhaust velocity

Highly reactive flow

The trouble with (t)rockets



Ryan et al., 2022



Newman et al., 2001

Closing thoughts

- Multiple challenges in aerospace sustainability which are **long-lived reactive multiphase flows**

- New modelling techniques needed which can bridge scales:
  - Millimetres to 100s of kilometres
  - Milliseconds to weeks

- Impacts **as-yet unknown** – and could shape future of the industry

Imperial College London

Brahmal Vasudevan Institute for Sustainable Aviation