Isolating the human impact on clouds

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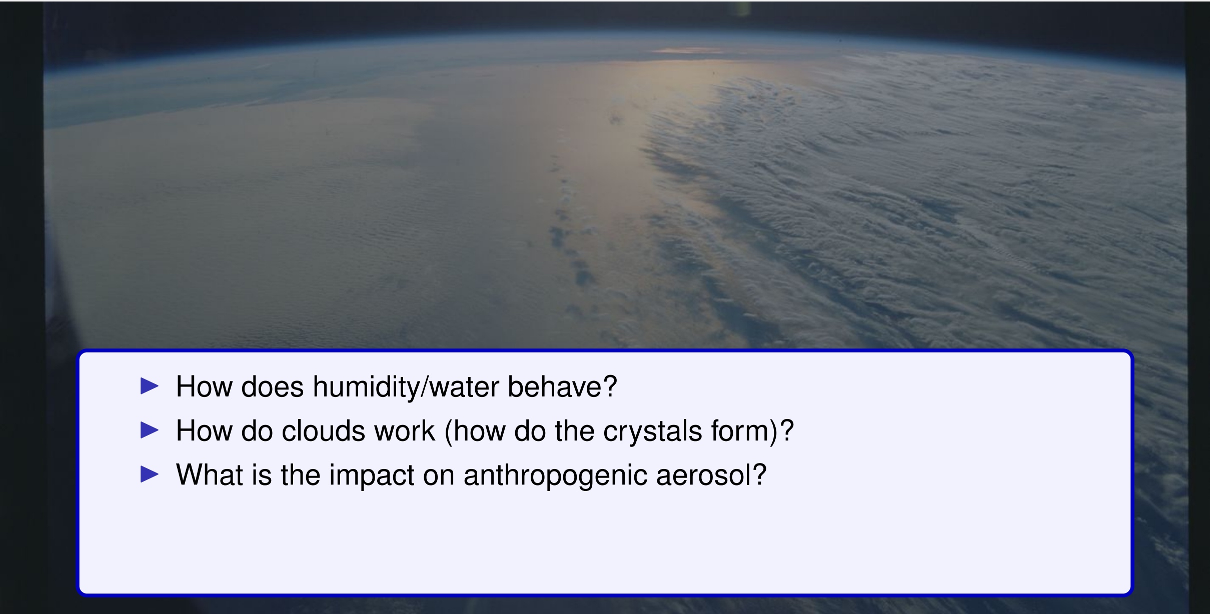
September 17, 2025

Constraining contrail models

- We also need accurate, observationally constrained models of contrails to assess climate impacts
- These need to be tied to specific aircraft (aircraft type matters)
- Microphysical information helps us assess model processes

How does the upper troposphere/lower stratosphere work?



- How does humidity/water behave?
- How do clouds work (how do the crystals form)?
- What is the impact on anthropogenic aerosol?

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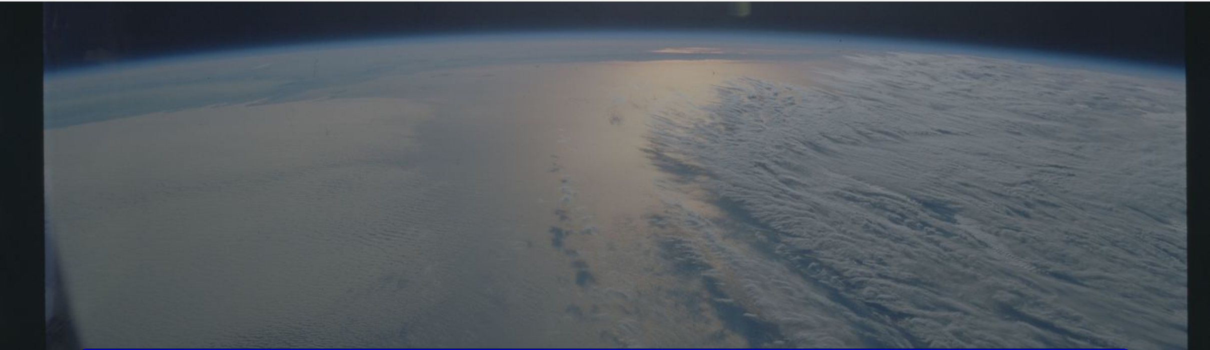

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- How do clouds work (how do the crystals form)?
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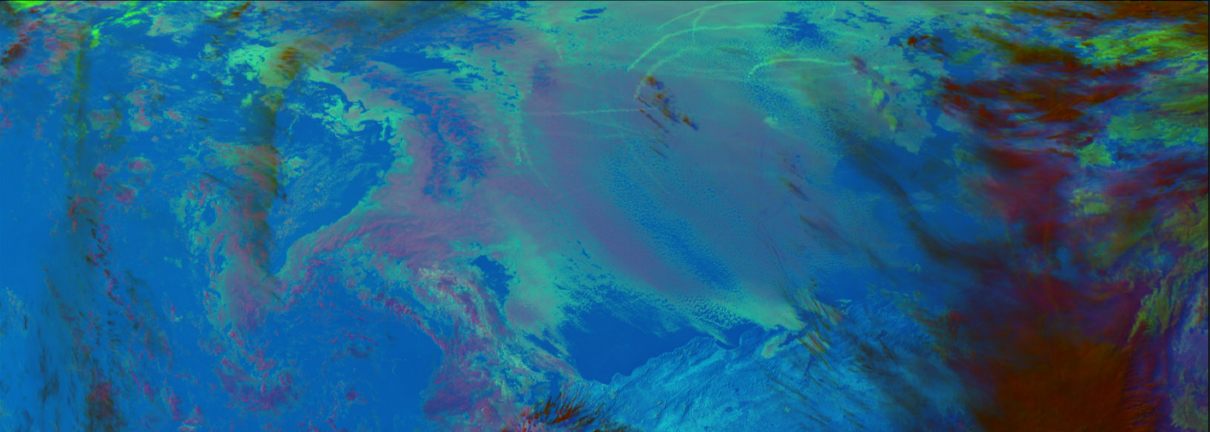
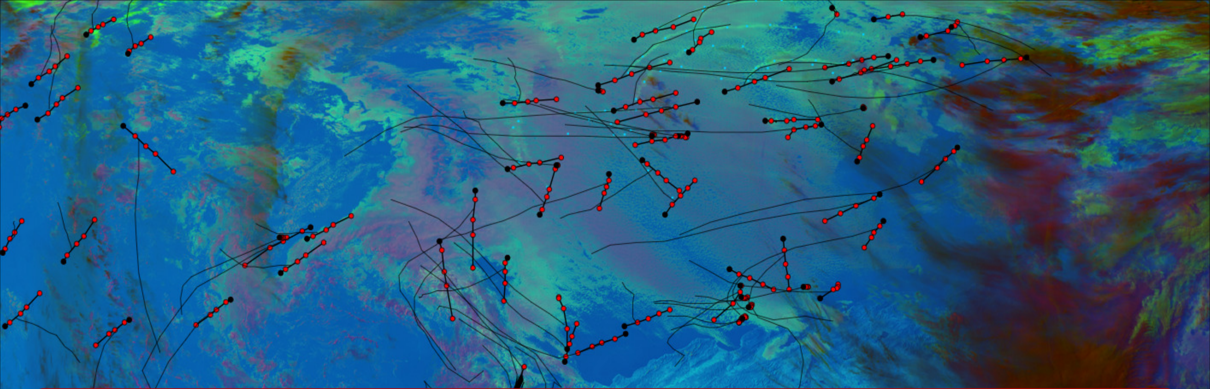
Measurements are sparse, correlations can be misleading about causality

What about an experiment?



Natural Experiments

- What happens if we change the conditions for clouds?
  - But someone else decides where and when



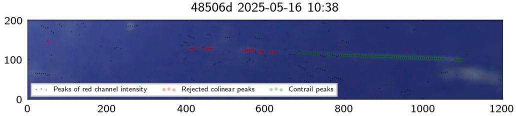
Natural Experiments

- What happens if we change the conditions for clouds?
  - But someone else decides where and when
- This “experiment” must be independent of potential “confounding factors”
  - Ships mostly don’t care about the weather
  - Aircraft are much more sensitive

Short timescales (seconds)

A key aspect of natural experiments is knowing where to look

- Aircraft location data is very helpful
- Can assess contrail formation directly
- Simpler problem than unguided detection



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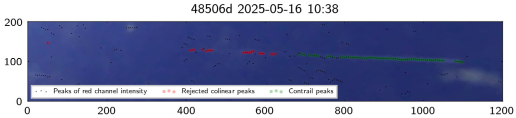
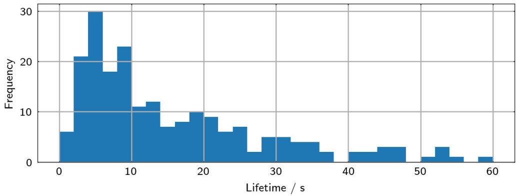
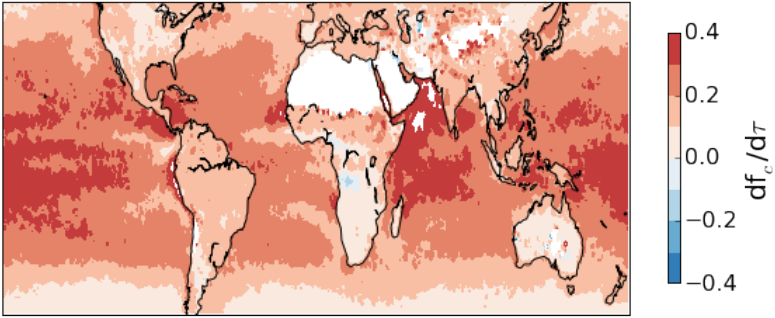
This gives a distribution of transient contrail lifetimes

- With an appropriate mixing model - can be linked to meteorological properties (T, RH)
- Talk to Ollie Driver for more!





Physical pathways - Aerosols and cloud amount



Data from MODIS Aqua (used throughout this work)

What is the aerosol impact on cloud fraction (CF)?

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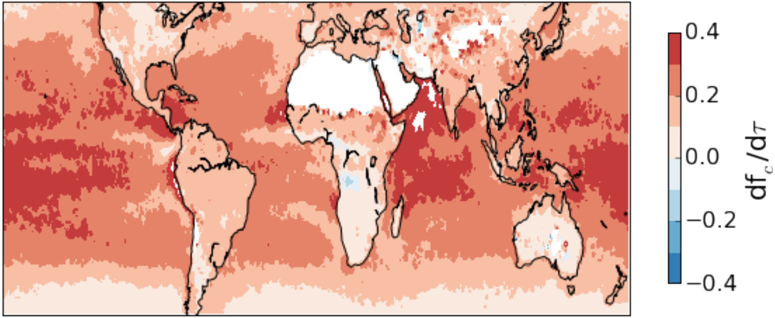

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What is the aerosol impact on cloud fraction (CF)?

- Satellite retrieved aerosol and CF are strongly correlated

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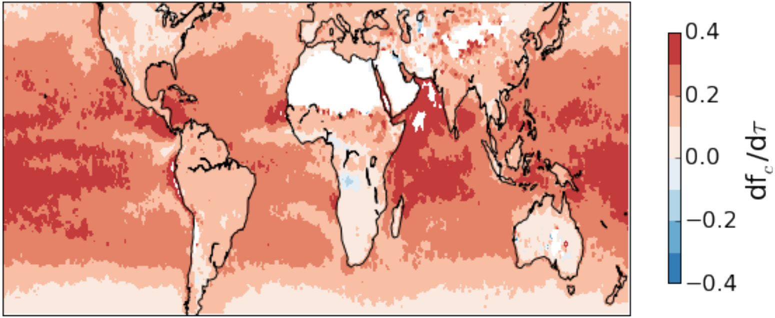

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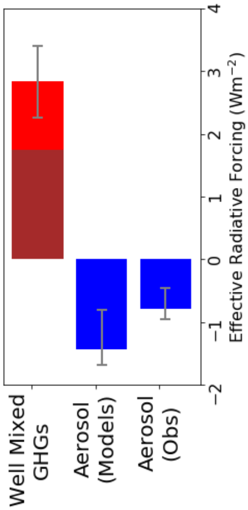

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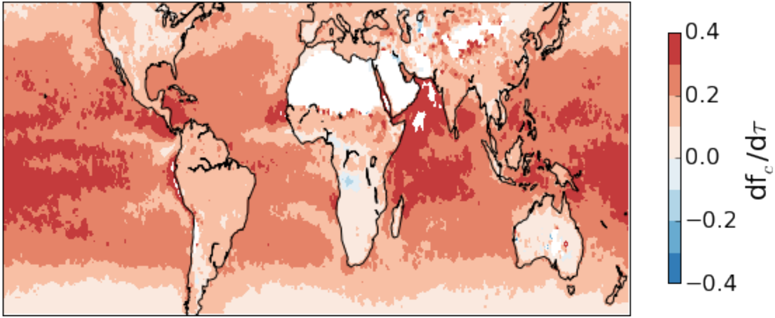

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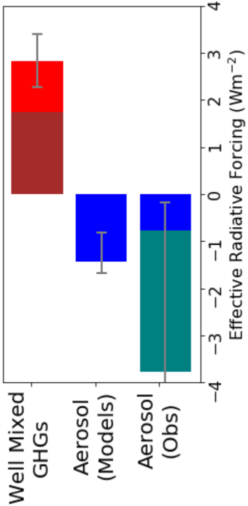

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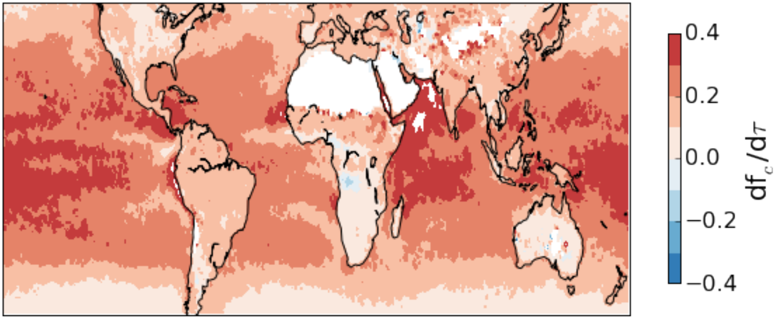

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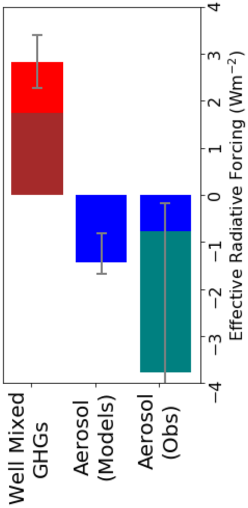
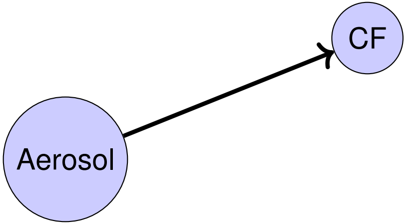


What is the aerosol impact on cloud fraction (CF)?

- Satellite retrieved aerosol and CF are strongly correlated
- Implies a forcing of -3 Wm^{-2} (-3.8 Wm^{-2} Total Aerosol)
- Systematic bias due to aerosol humidification

Identifying causality



RH - relative humidity, CF - cloud fraction, N_d - droplet number; Gryspeerdt et al., JGR, 2016

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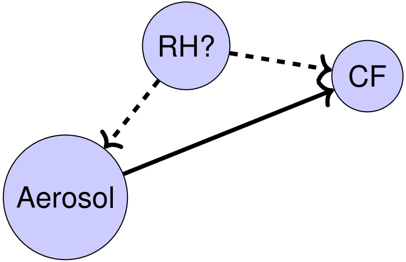

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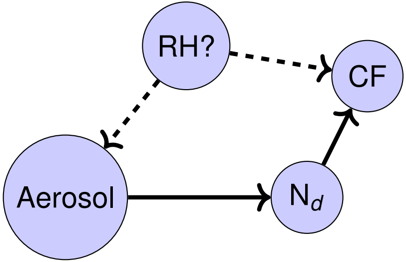

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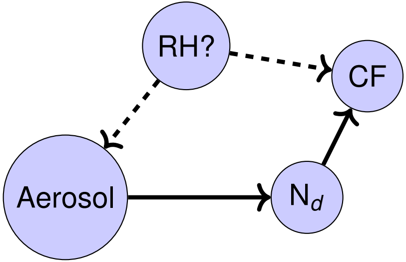

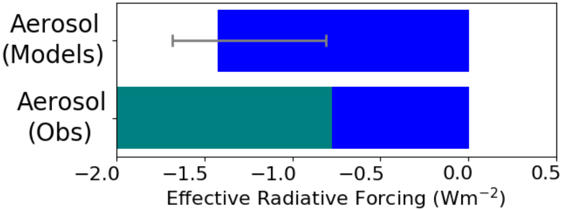

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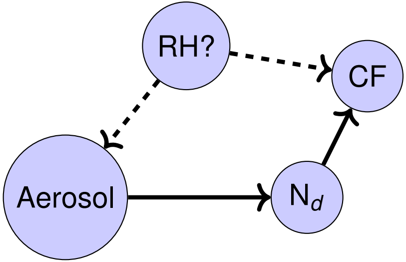

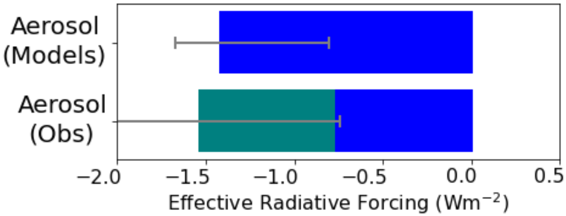

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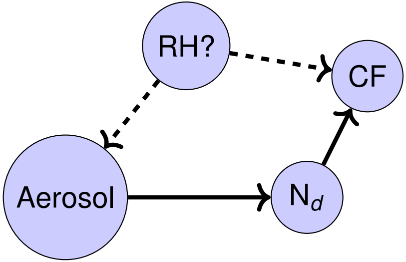
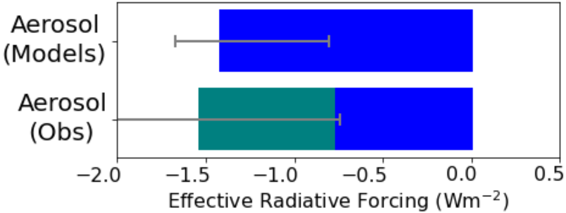




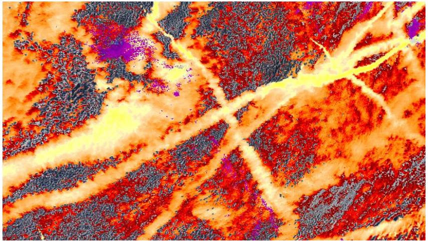
Understanding the physical pathway helps isolate the aerosol effect

RH - relative humidity, CF - cloud fraction, N_d - droplet number; Gryspeerdt et al., JGR, 2016

Microphysics - what happens to the crystals?

VIS-IR imagers give some microphysical information

- Typically 1-2 parameters
- Cloud-top/column integrated



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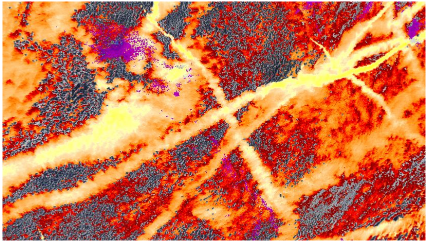

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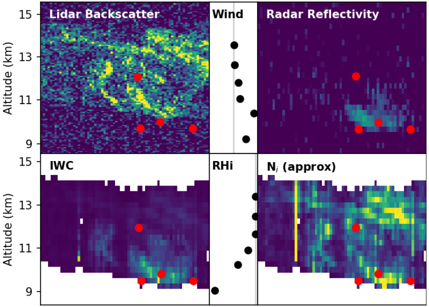
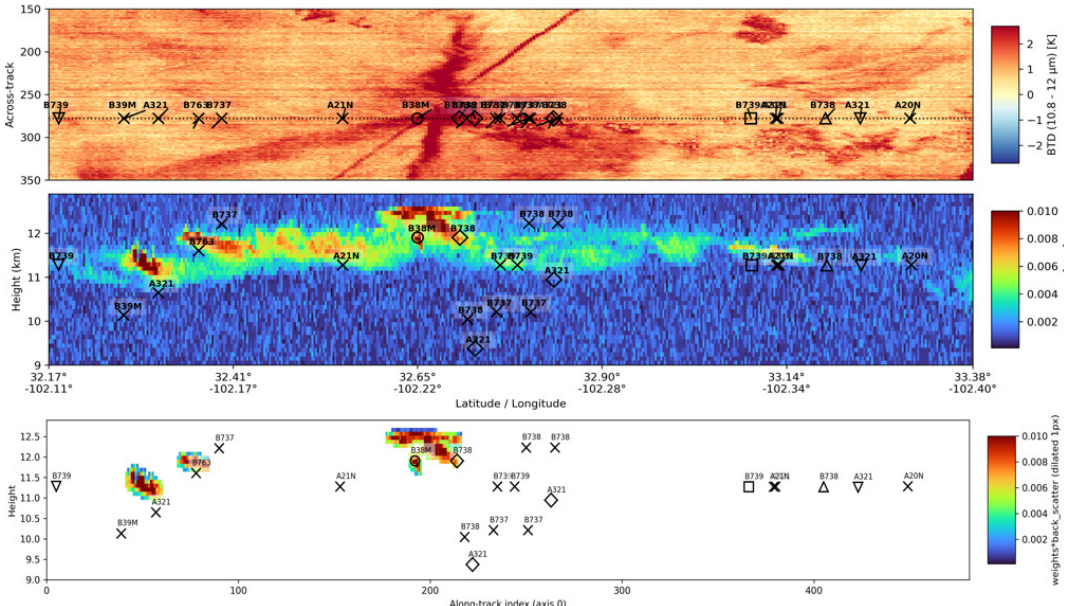


Radars and lidars give a more detailed picture

- Number concentration is key, but difficult to retrieve
- Some existing algorithms, but clear-air contrails are “extreme”

EarthCARE

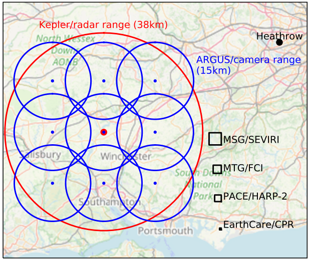


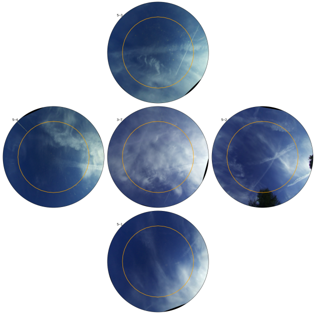
Across-track
BTD (10.8 - 12 µm) [K]
Height (km)
Latitude / Longitude
32.17° -102.11°
32.41° -102.17°
32.65° -102.22°
32.90° -102.28°
33.14° -102.34°
33.38° -102.40°
Height
Along-track index (axis 0)
weights*back_scatter (dilated 1px)
B739
B39M
A321
B763
B737
A21N
B38M
B738
A20N

Time-resolved observations

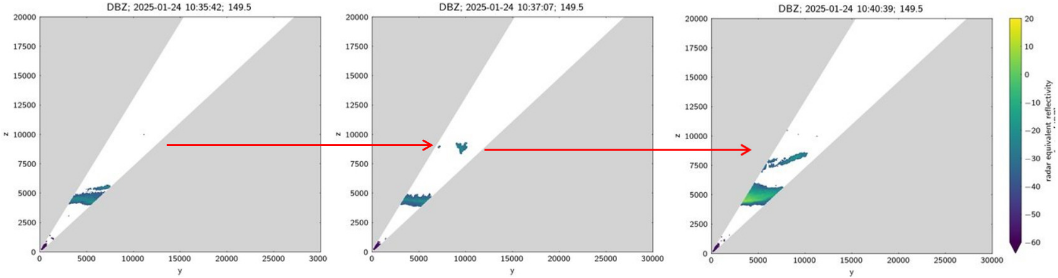
COBALT (Contrail observations and lifecycle tracking) project

- Build up a picture of contrail lifecycles
  - Matched to aircraft
  - With microphysics information (where possible)
- Use a network of ground cameras
  - Facing upwards to reduce width ambiguity
  - Overlapping to simplify aircraft attribution
- Linked to a range of satellite observations
- And a scanning cloud radar





Kepler (radar) observations



Aim:

- Camera network matched to a 35GHz cloud radar (Kepler)
- Track advected aircraft locations to watch contrail evolution

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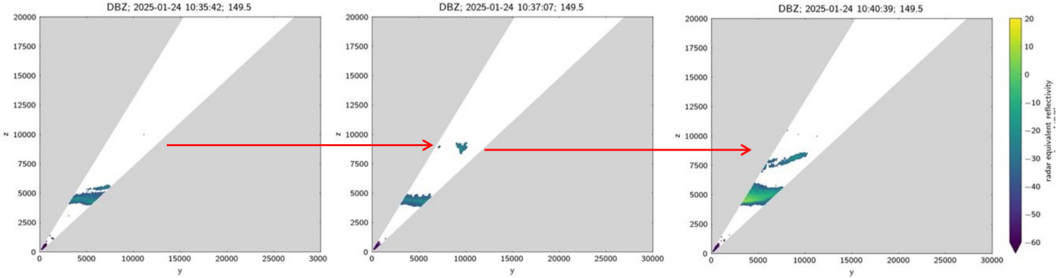

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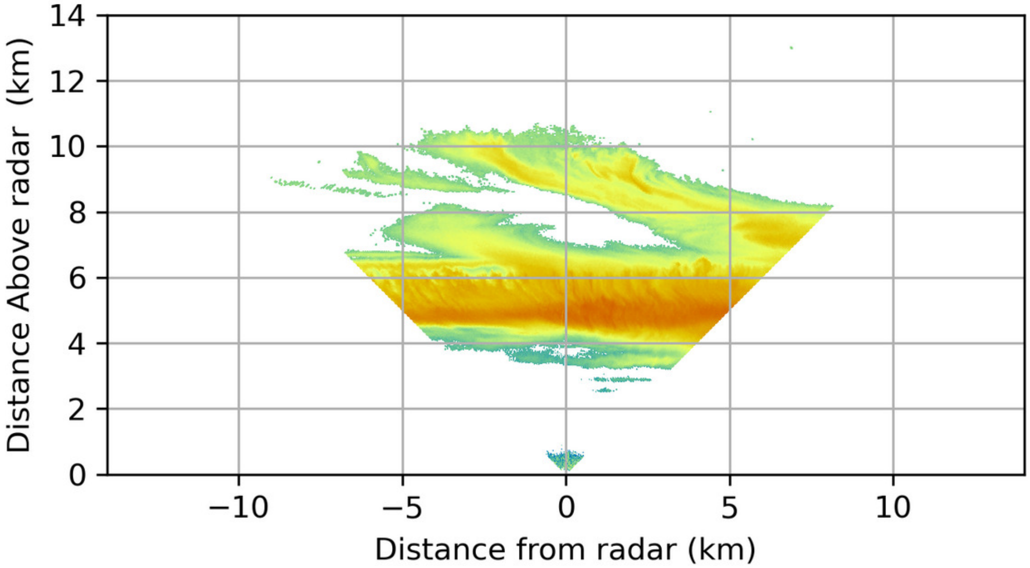
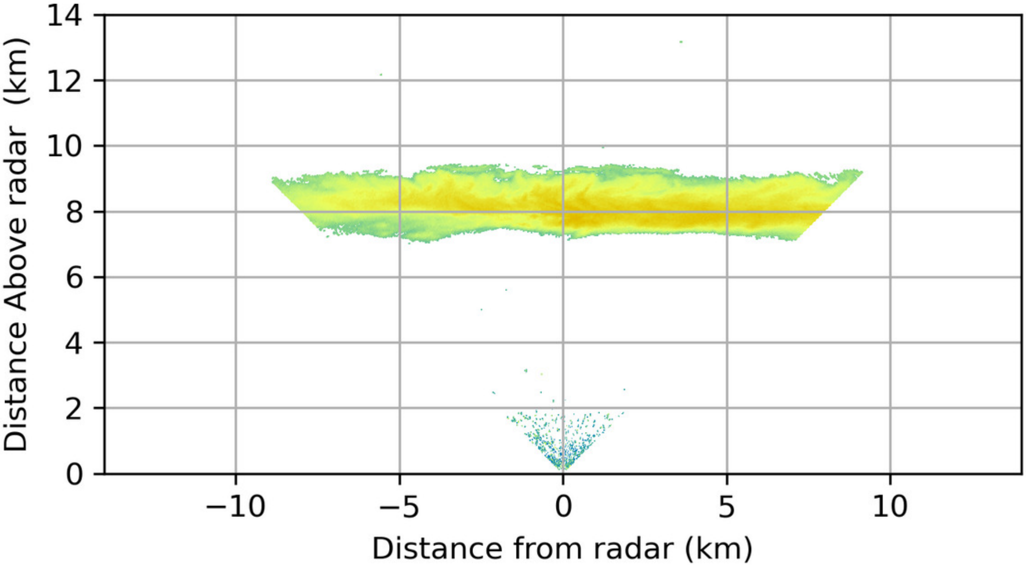
Reality:

- (Very) difficult to predict contrail formation from individual aircraft
- Smaller crystals (such as in contrails) create a long feedback time
- Targeting scans lowers chance of accidental observations

Wind-aligned scans



Spot the aircraft



Distrails

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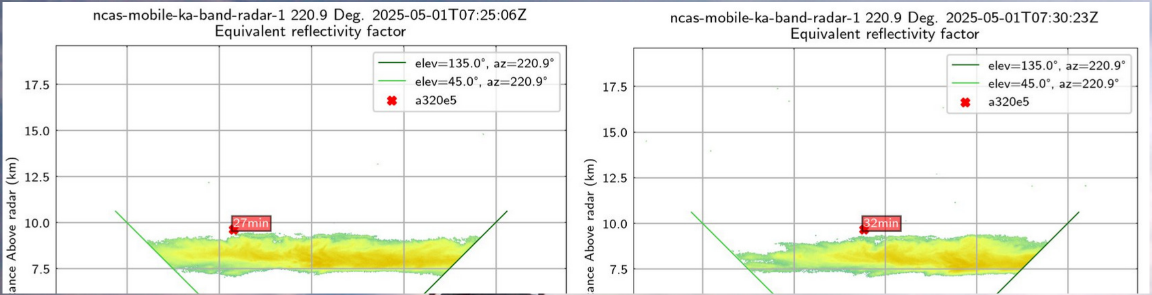
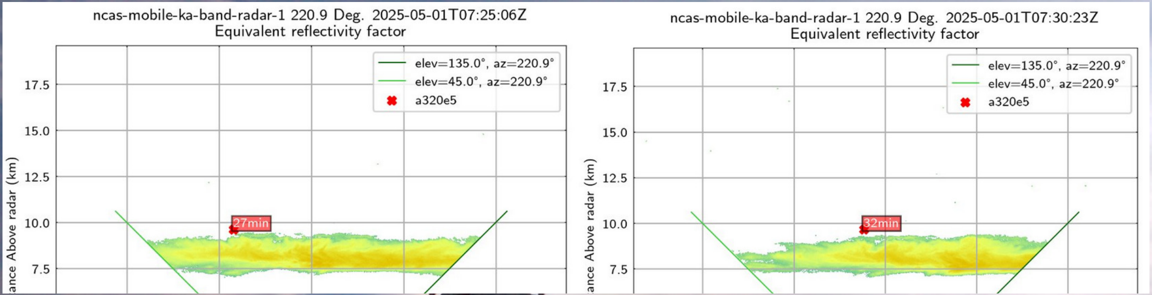


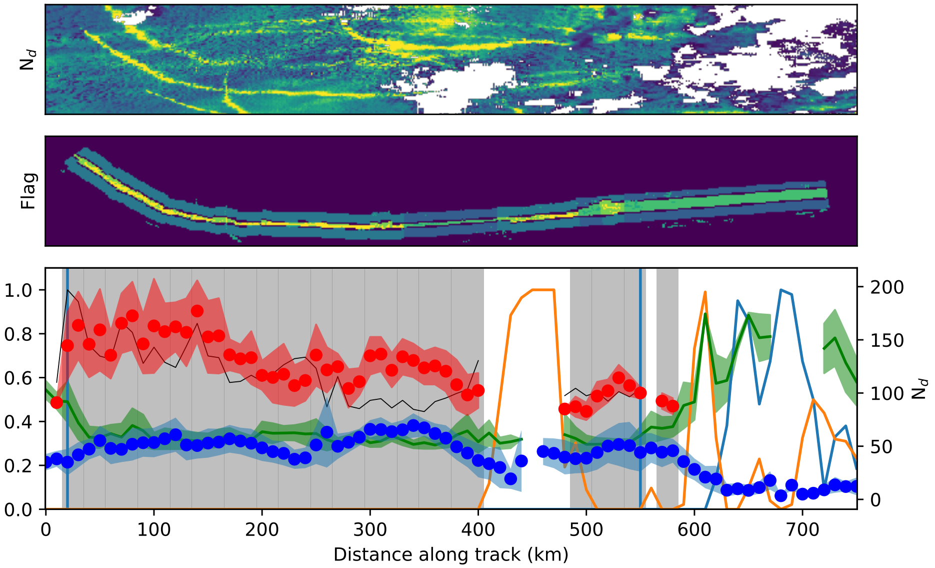
- Temporal evolution gives more confidence in the observations

Distrails

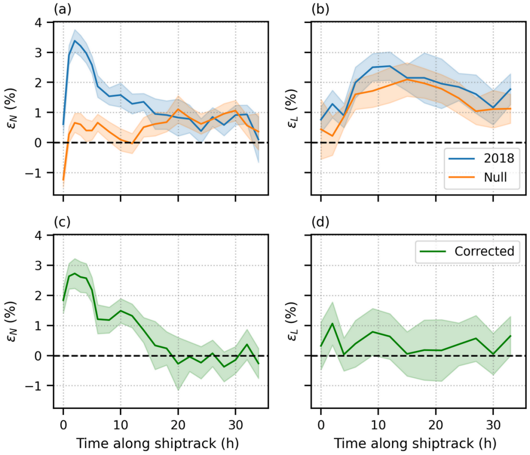


- Temporal evolution gives more confidence in the observations
- Considerable uncertainty with wind advection
- Significant depth for the distrail (1km) from a small aircraft (GLEX)
- Cameras also observe an embedded contrail

Measuring “advected” properties



Shiptrack evolution



Shiptracks see a big increase in droplet number (blue)

- This decreases over time

There is also a large increase in cloud water content

- This increases over time

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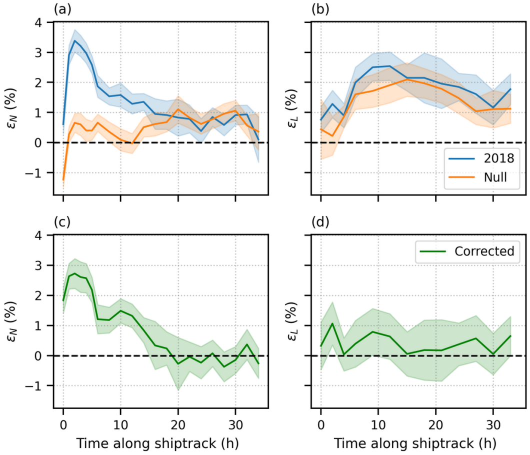

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- No droplet number response

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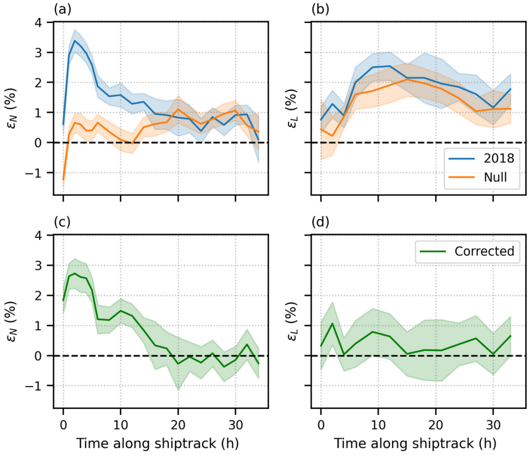

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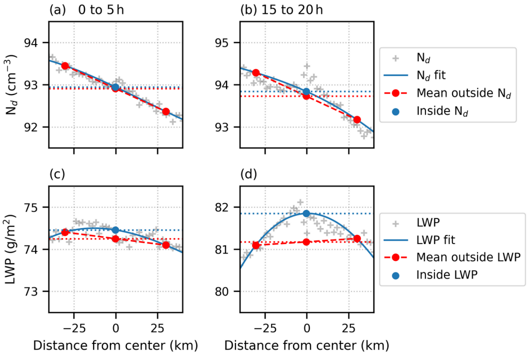
- **A increase in cloud water - with no ship!**

The “invisible shiptracks bias”



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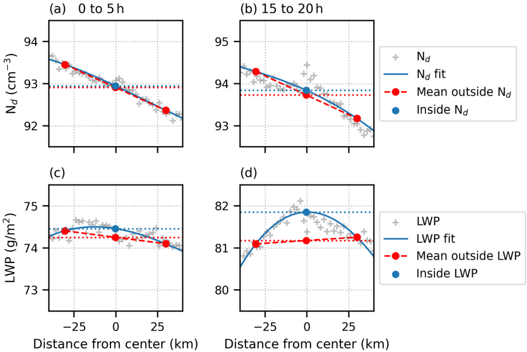

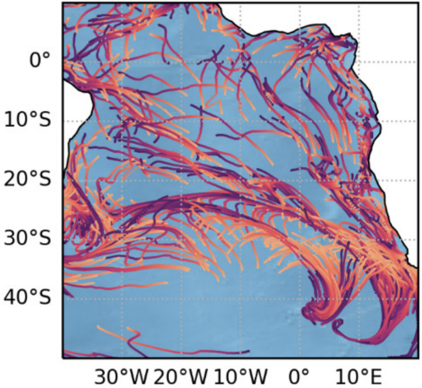

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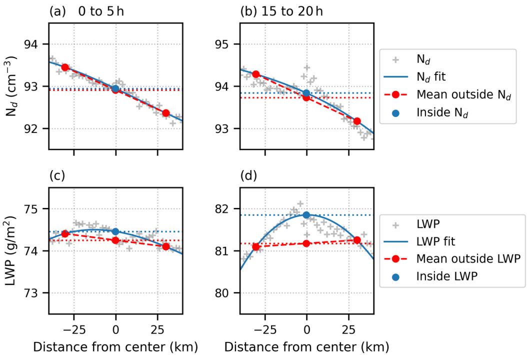

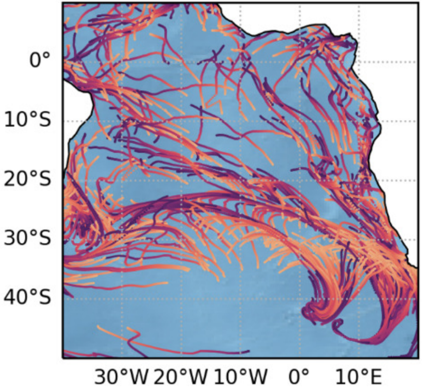

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Natural experiments are useful to isolate aerosol/aircraft effects

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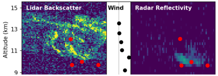

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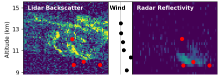
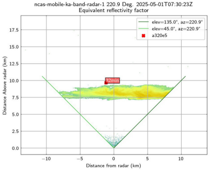
- Can build confidence in observed features (such as distrails)





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Careful with your choice of counterfactual

- The “invisible shiptracks bias” can be large
- The “natural experiment” idea requires independence from weather
- Aircraft routes are very weather dependent