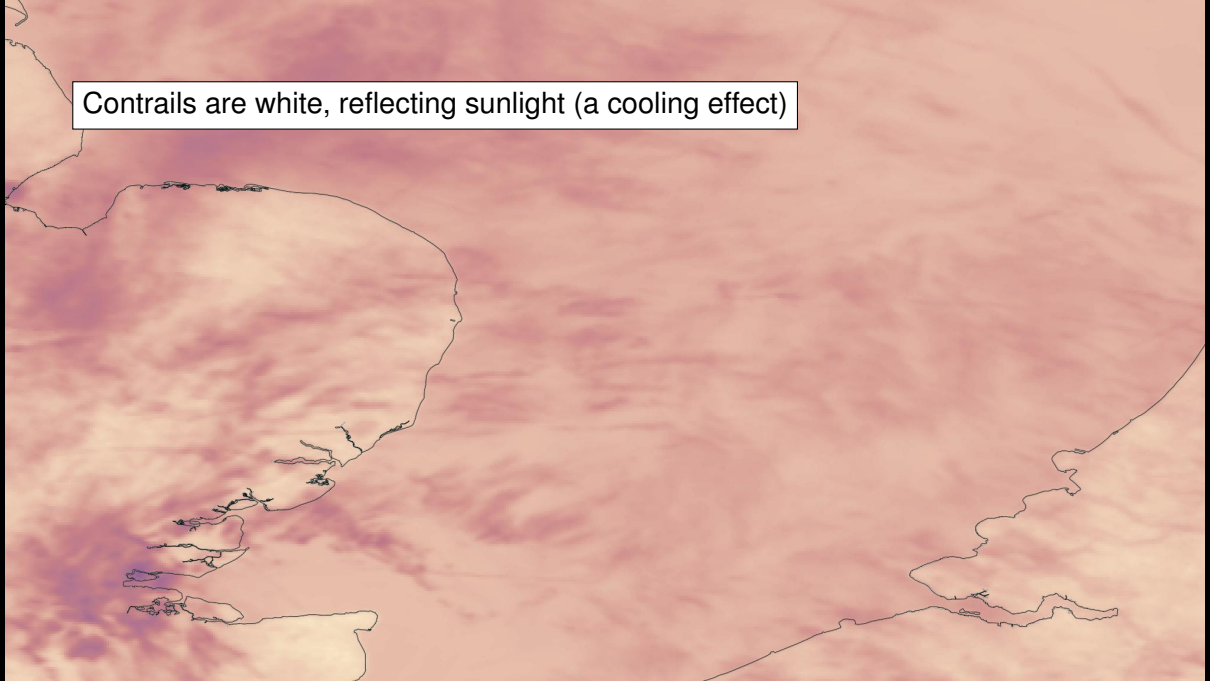
Mitigating the climate impact of aviation

Sajedeh Marjani, Edward Gryspeerdt,
Lindsay Bennett, Oliver Driver, Ryan Neely, Marc Stettler, Chris Walden


Contrails are white, reflecting sunlight (a cooling effect)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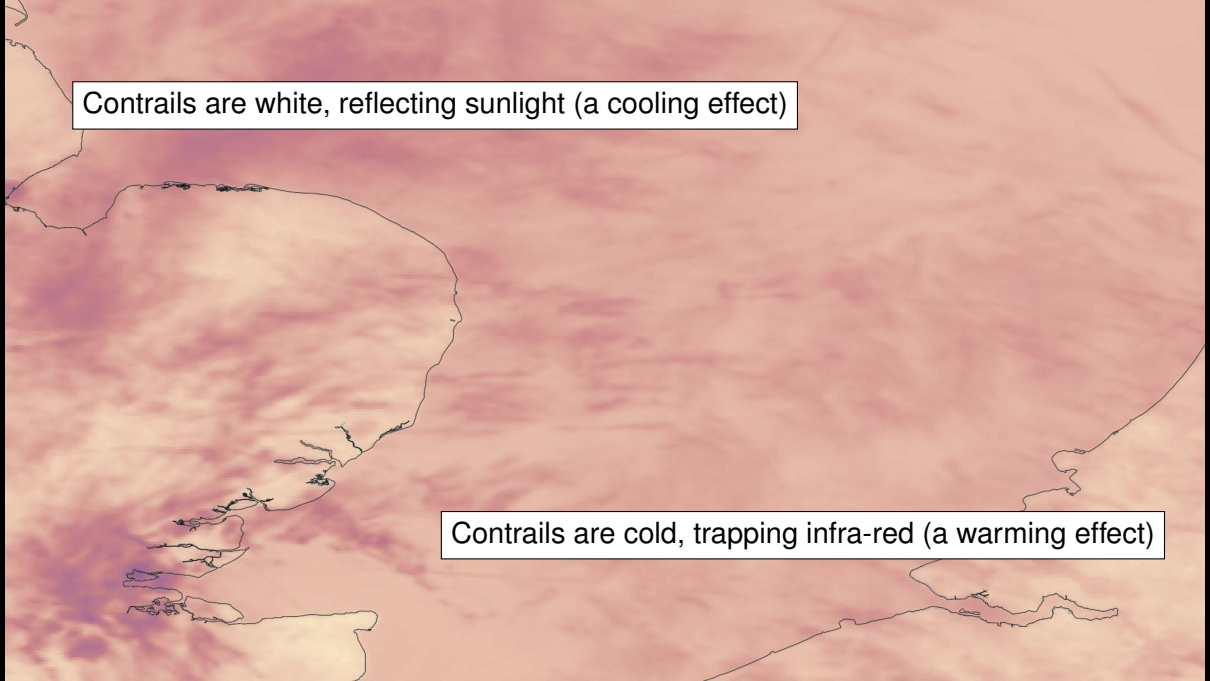
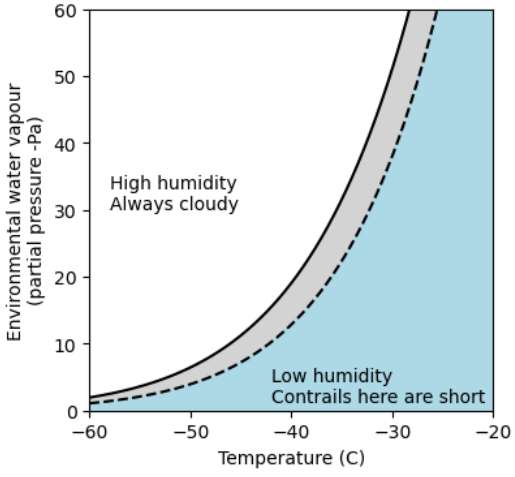

Contrails are white, reflecting sunlight (a cooling effect)
Contrails are cold, trapping infra-red (a warming effect)

How do contrails form?



Background
Cold, dry

Aircraft
Hot, wet

Red lines

Mix

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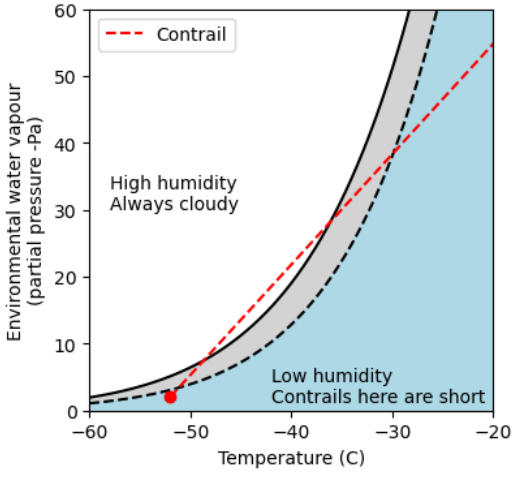

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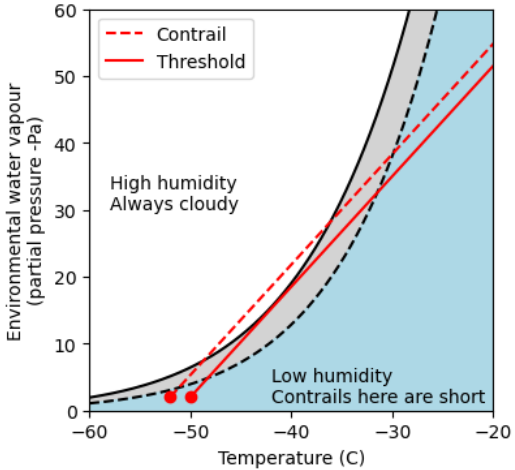

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Formation threshold

Mix

T<Threshold ?

Contrail!

T_{SAC}- Schmidt-Appleman-Criterion (threshold temperature for contrail formation)

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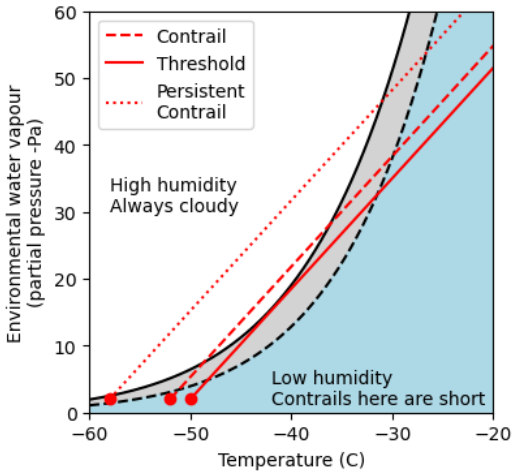

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Mix

Formation threshold

T<Threshold ?

Contrail!

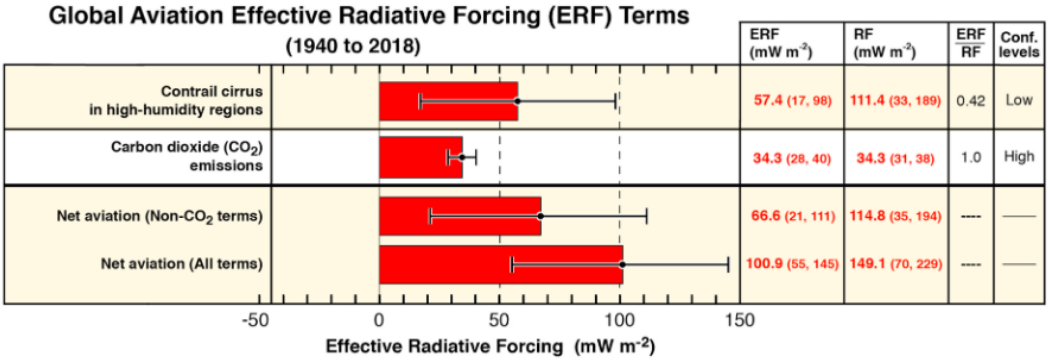
Persistence threshold

Humidity > 100%?

Long lifetime
Large climate impact

T_{SAC}- Schmidt-Appleman-Criterion (threshold temperature for contrail formation)

What is their climate impact?



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- Likely bigger than all the CO_2 emitted by every aircraft ever (but uncertain)

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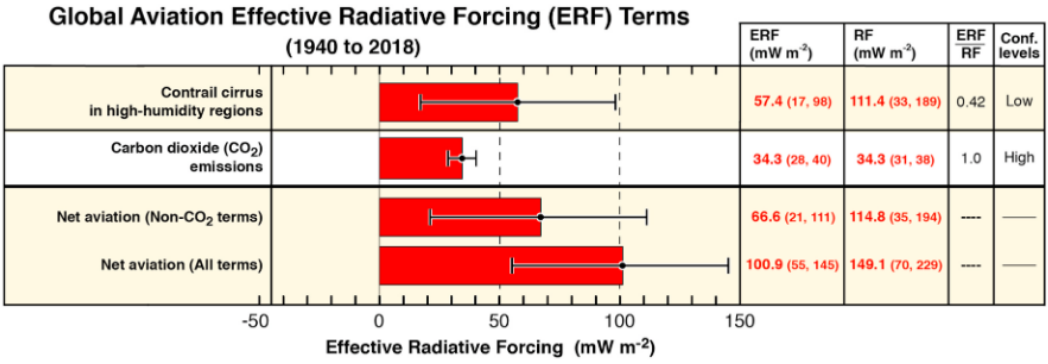

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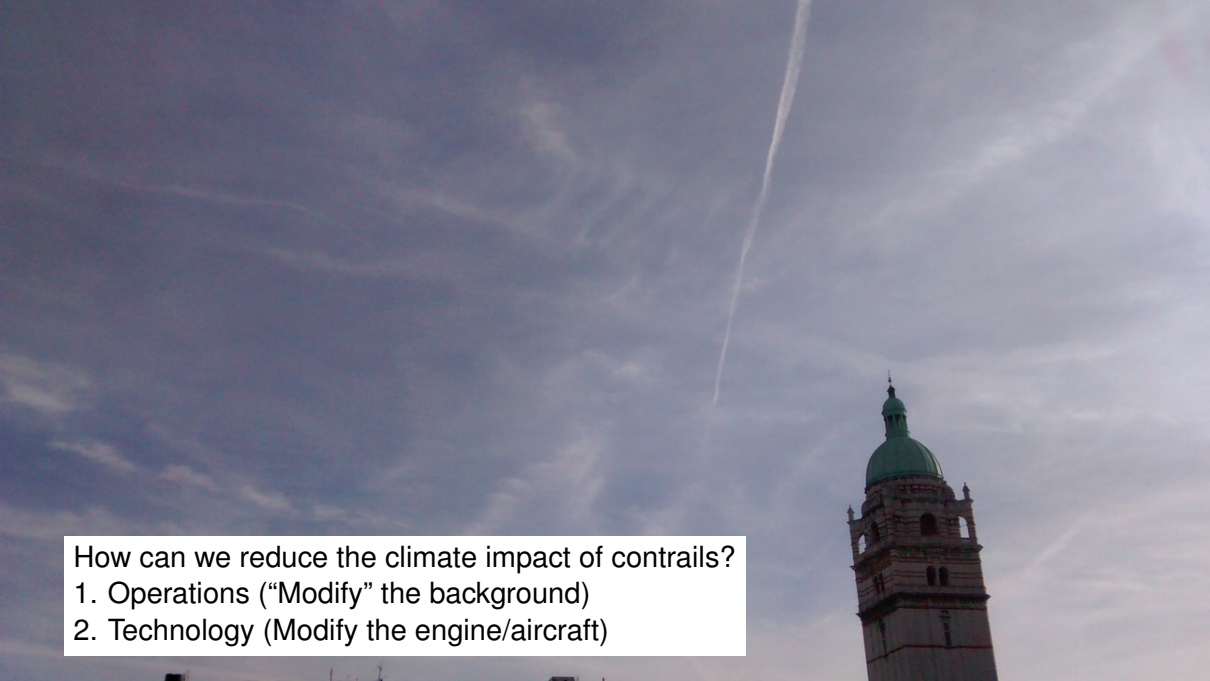
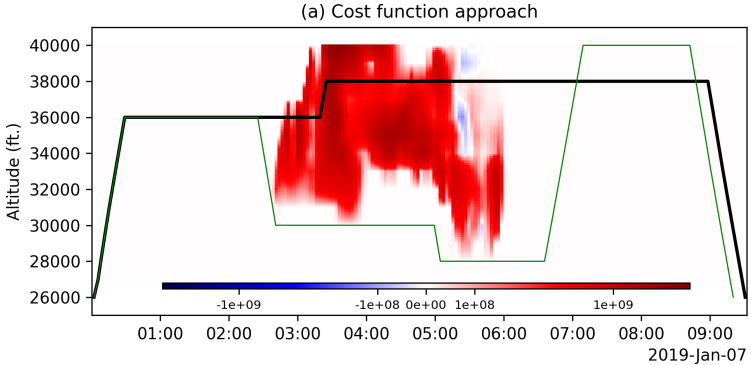
Provides a pathway for immediate reduction in the climate impact of aircraft


How can we reduce the climate impact of contrails?
1. Operations (“Modify” the background)
2. Technology (Modify the engine/aircraft)

Operational contrail avoidance



Route aircraft around contrail forming regions

- Comes at fuel penalty - extra CO_2 emissions

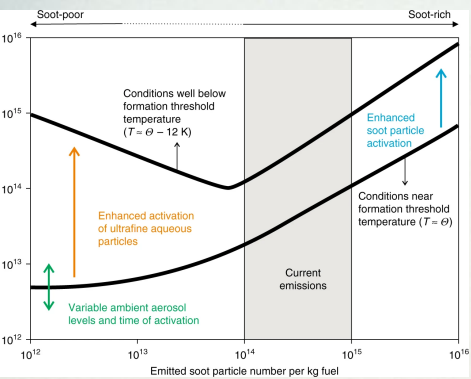
Need accurate contrail models to determine suitable tradeoffs

Engberg et al, ACP, 2025

USAF; Kärcher, Nat. Comm., 2018

More soot → More crystals → Smaller crystals → Longer lifetime

USAF; Kärcher, Nat. Comm., 2018



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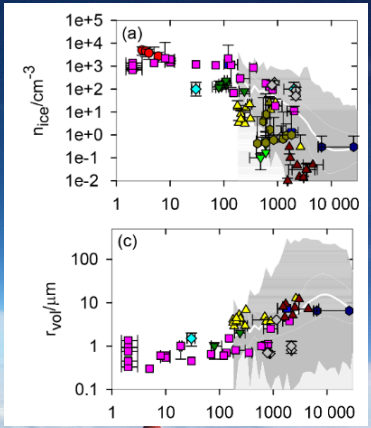
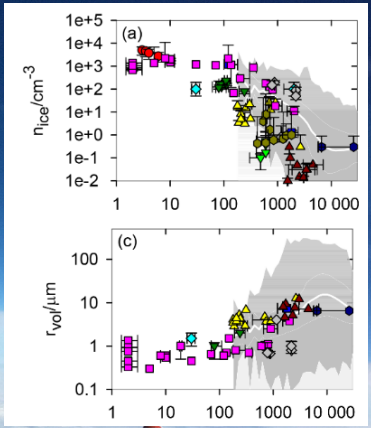
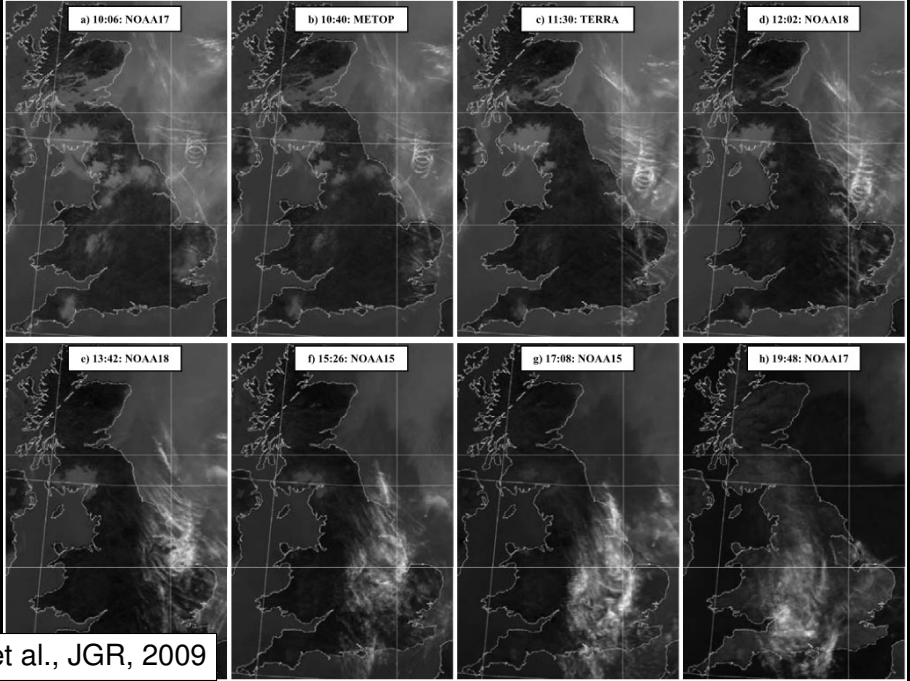

(a)
n_{ice}/cm^{-3}
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
1e-2
1
10
100
1000
10 000
(c)
r_{vol}/µm
100
10
1
0.1
1
10
100
1000
10 000



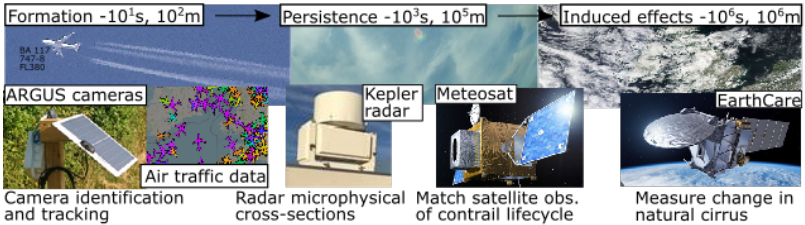
What is the impact of individual aircraft?

- Chase-planes can measure contrails at formation.
- Long-lived contrails have the largest climate impact...



Haywood et al., JGR, 2009

Contrail OBservations And Lifecycle Tracking (COBALT)



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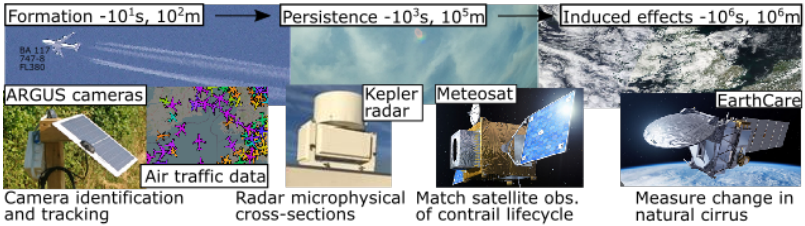

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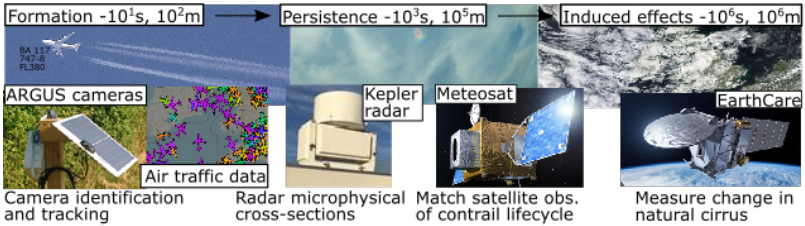

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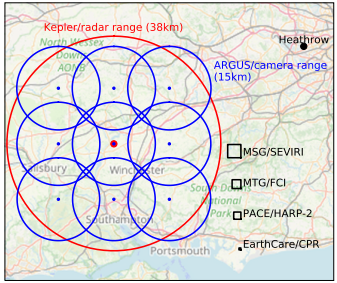


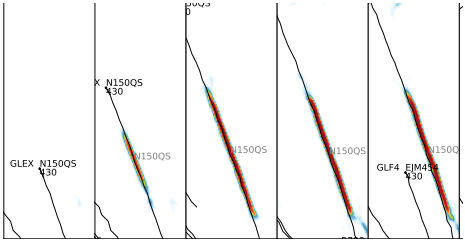
COBALT observations region Southern UK (2024-2025)

With Chris Walden (STFC), Ryan Neely, Lindsay Bennett (NCAS/Leeds), Marc Stettler (Imperial)

Matching to Models

Two types of measurements:

1. Tracking individual contrails from specific aircraft
   - Evaluate aircraft-level models (used for contrail avoiding rerouting)
   - Measure the impact of new fuels
   - Provide a test-bed region for industrial partners



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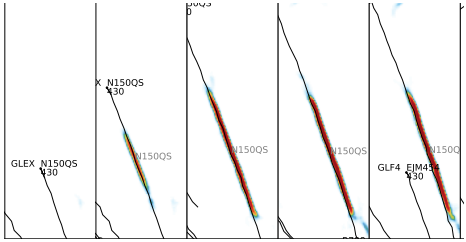

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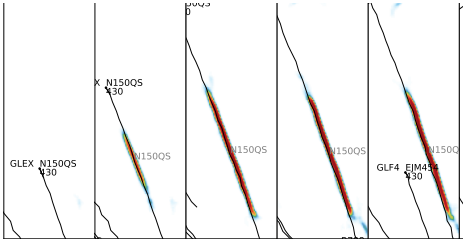

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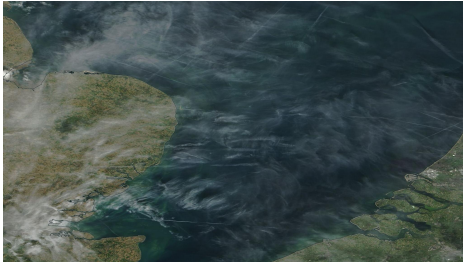
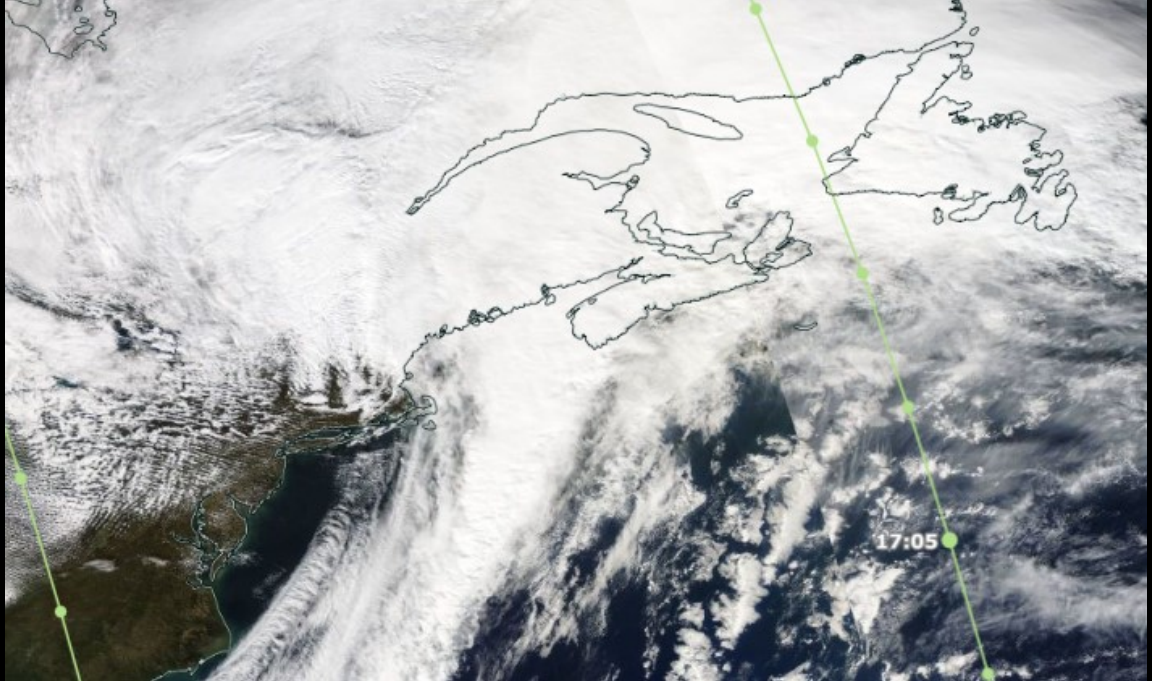
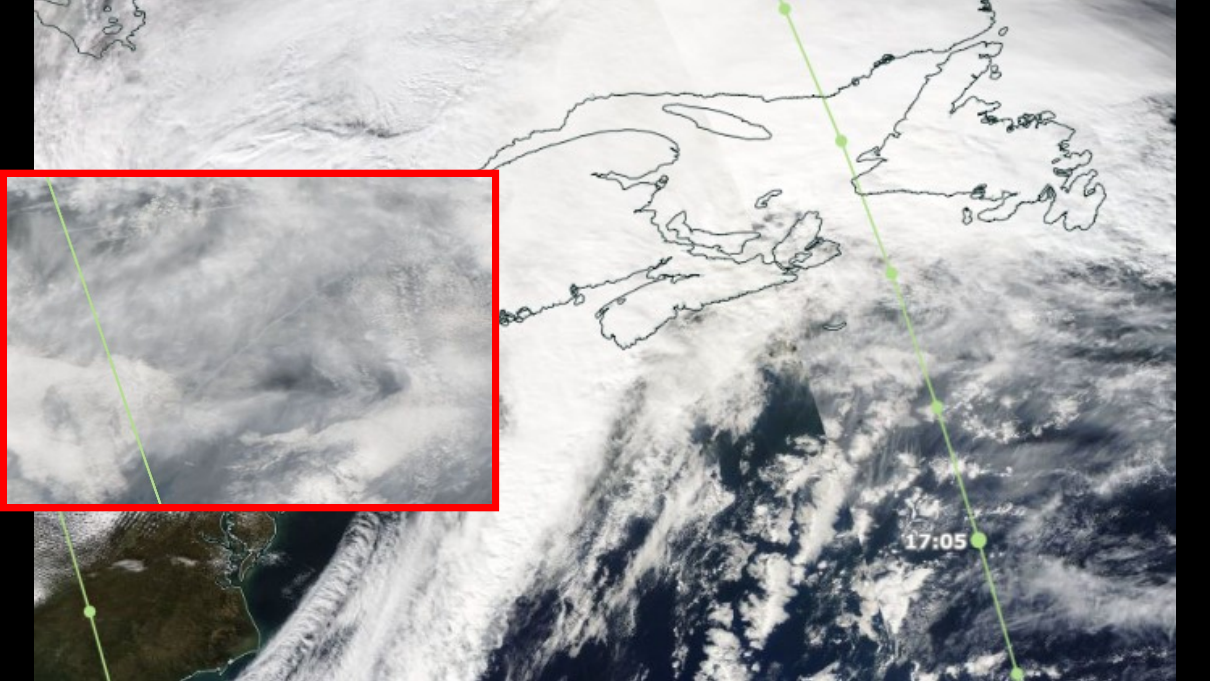


Expecting to use EarthCARE observations for both


17:05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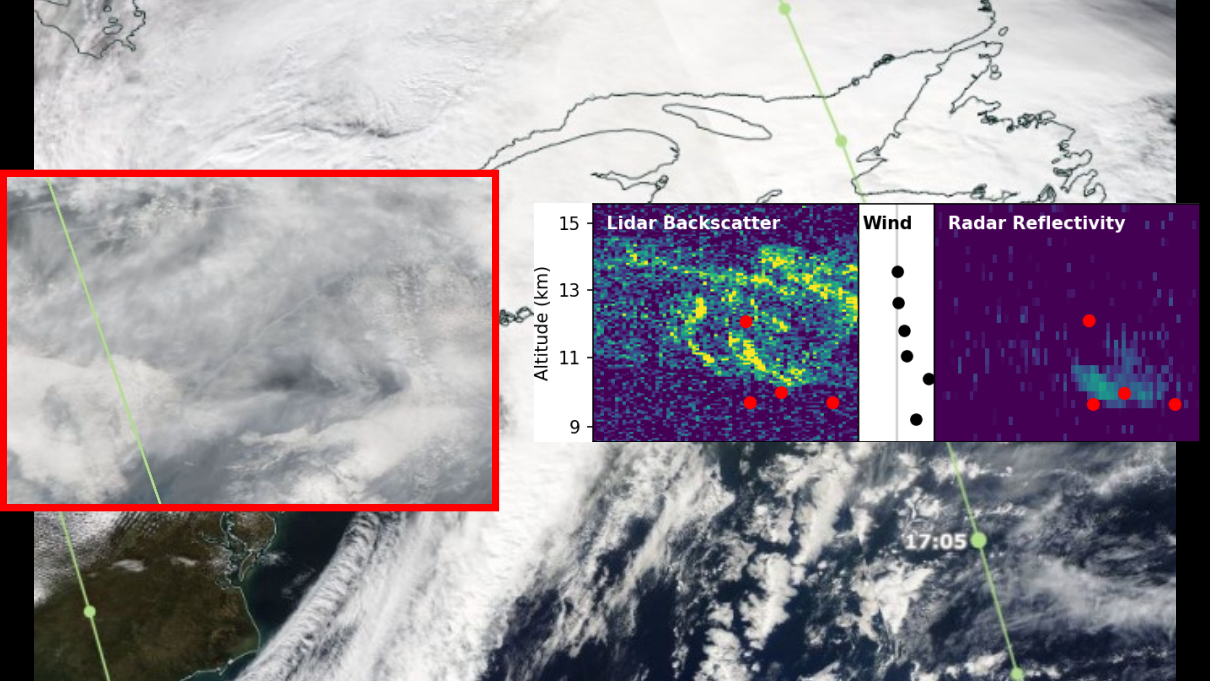
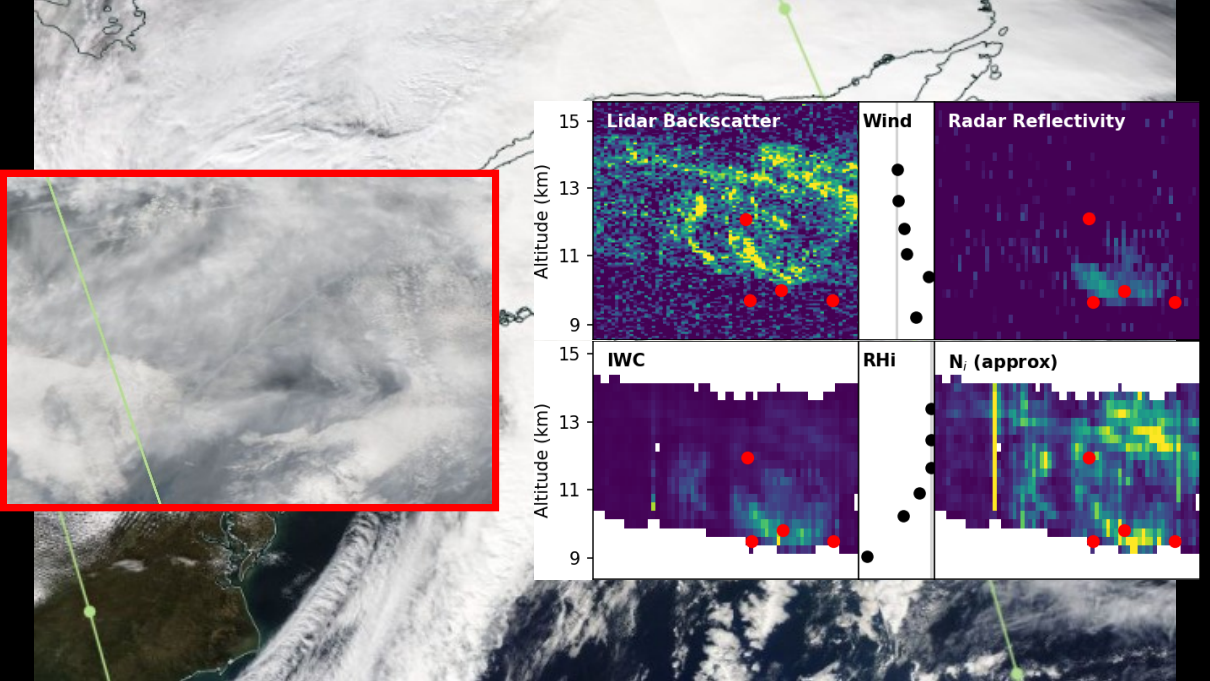
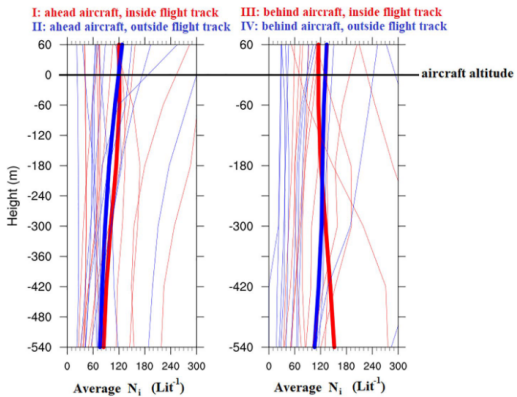

Lidar Backscatter
Wind
Radar Reflectivity
Altitude (km)
15
13
11
9
17:05


Lidar Backscatter
Wind
Radar Reflectivity
IWC
RHi
N_i (approx)
Altitude (km)
15
13
11
9

Embedded contrails



Marjani et al., GRL, 2022

Some observations of aircraft impacts on existing clouds

- impacts on optical thickness and ice number

Recent observations suggesting significant “in-cloud” flight time for commercial aircraft

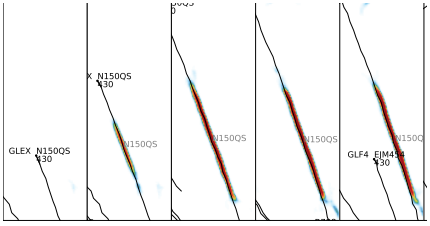
- Possibly as high as 50%

(Uncertain) indications of ice number changes during Covid

- An indicator of aerosol-cloud effects?

Where next with EarthCARE?

- Compositing EarthCARE data and matching to aircraft data, geostationary and ground-based observations for temporal context



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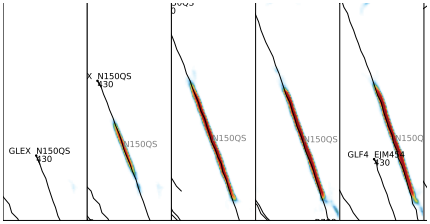

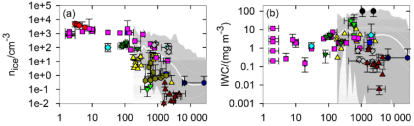

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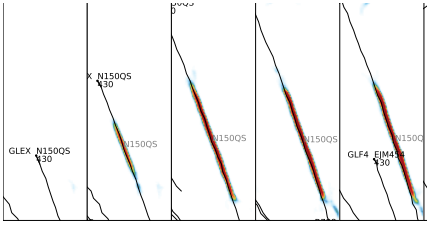

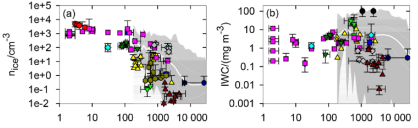

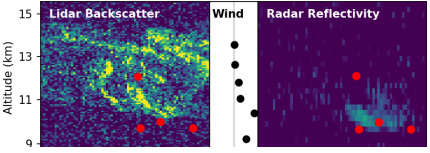

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