

Contrails:

Translating science into practice

ABC 2026

- Marc Shapiro
Executive Director, Contrails.org



- 1 What are contrails?
- 2 Why do contrails matter?
- 3 Contrail management
- 4 Challenges
- 5 Q&A



■ Global non-profit applied research organization

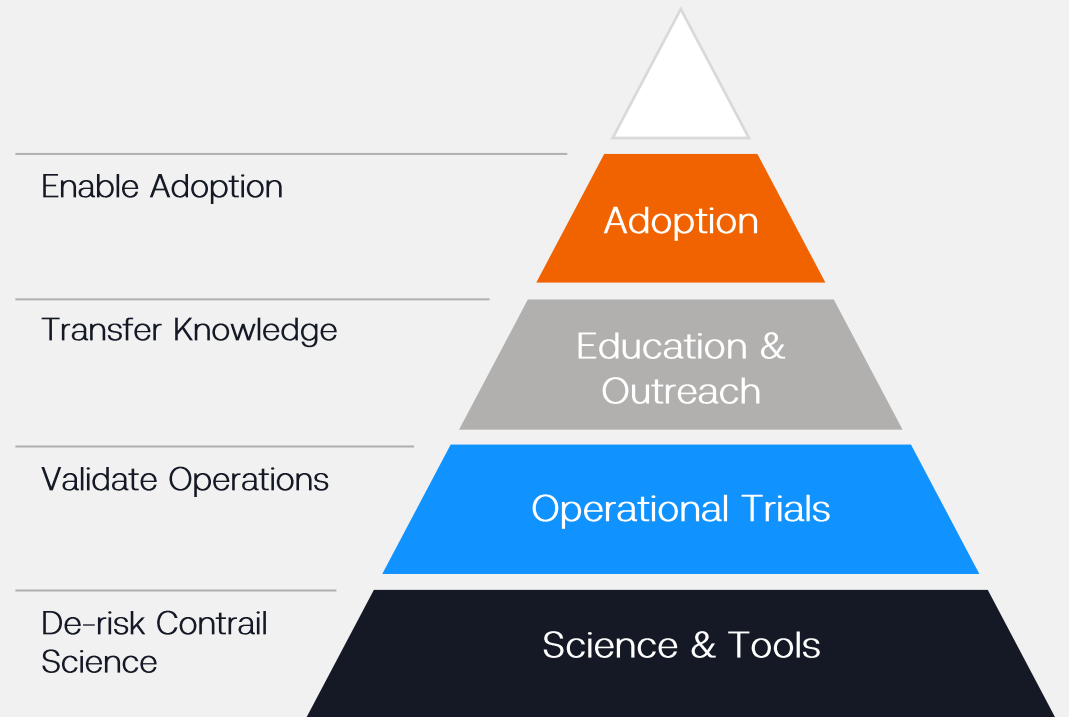
■ Mission

Drive the **development and deployment** of large-scale **contrail management** systems to reduce aviation's climate warming impact.

■ Vision

Intelligent route planning and management eliminates climate warming contrails with **near-zero** cost.

Focus Areas



Team

18 Core contributors
(10 US, 8 UK)



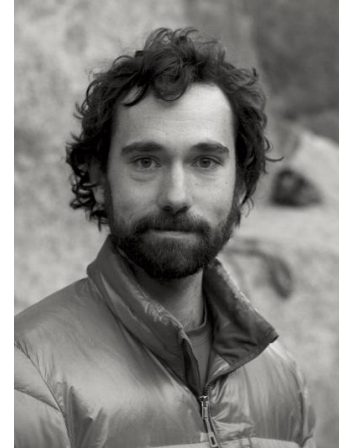
Marc Shapiro
Executive Director



Marc Stettler
Chief Scientist



Tom Dean
Research Director



Nick Masson
Engineering Director



Tyler Robarge
Trials Director

Key Advisors



Ian McKay
Orca



Ken Caldeira
Stanford



John Platt
Google



Annie Petsonk
Former Asst. Secretary
Transportation (Aviation)

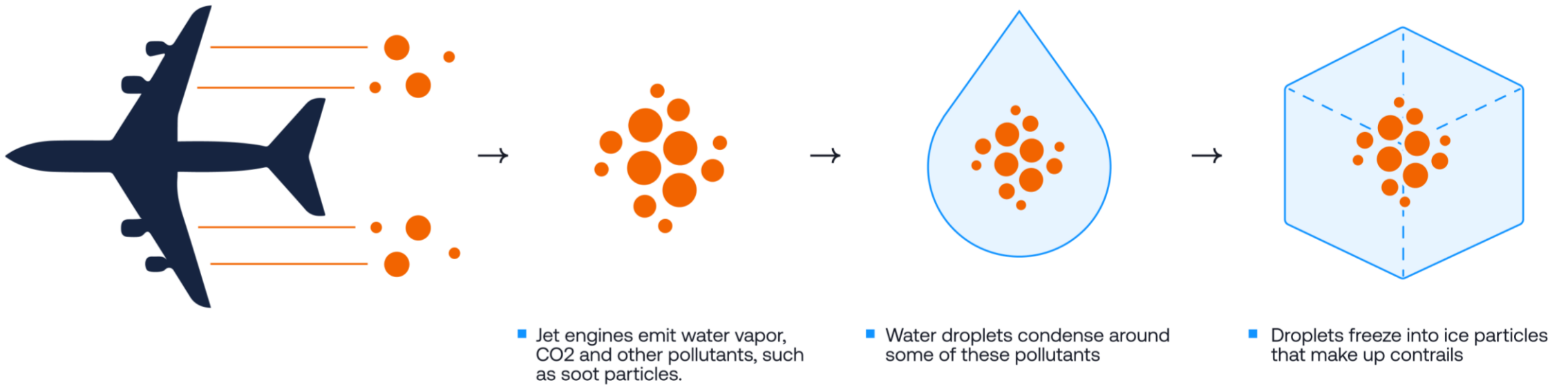


David Victor
UCSD

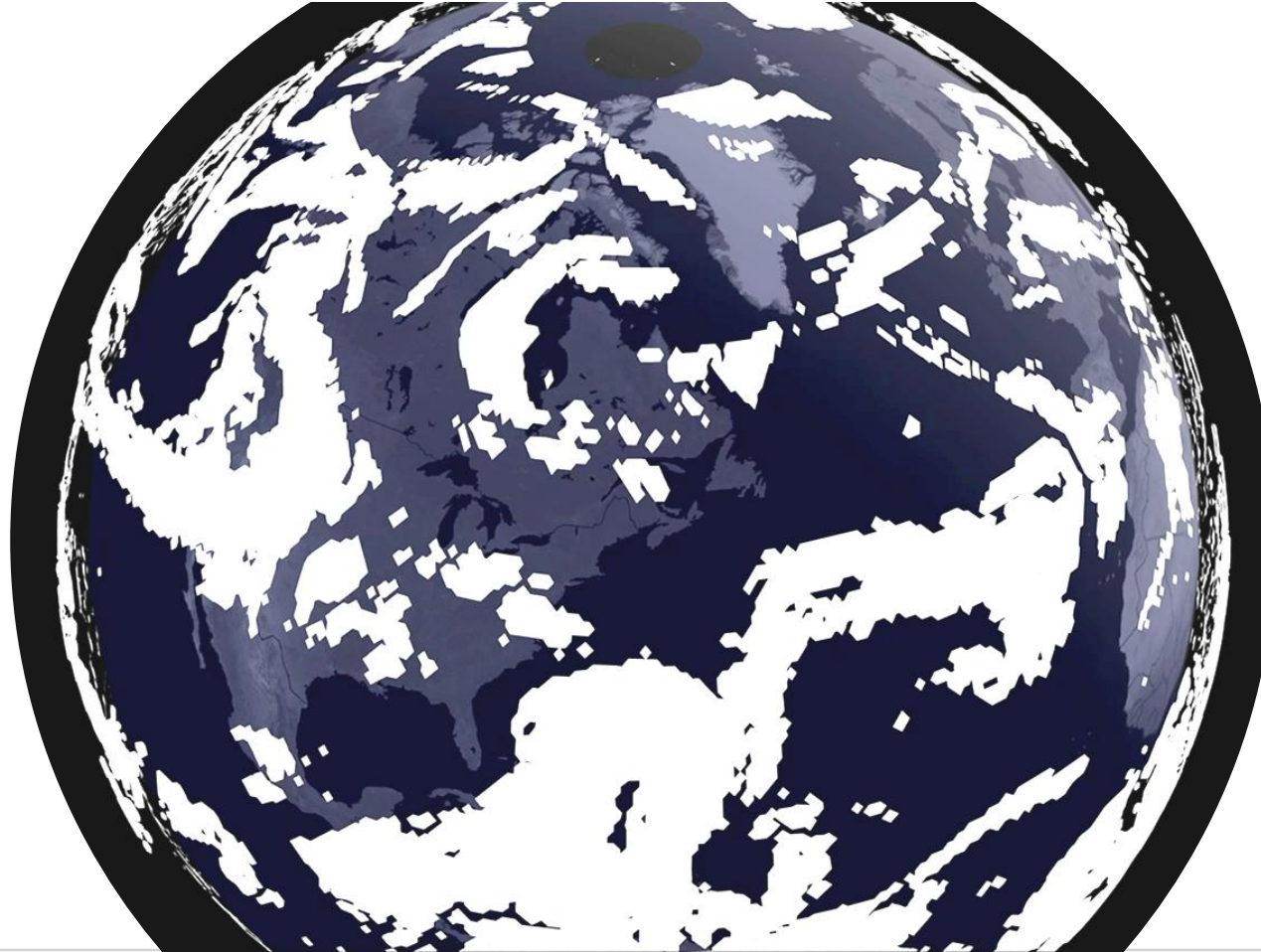
What are contrails?



Contrails form on jet engine exhaust

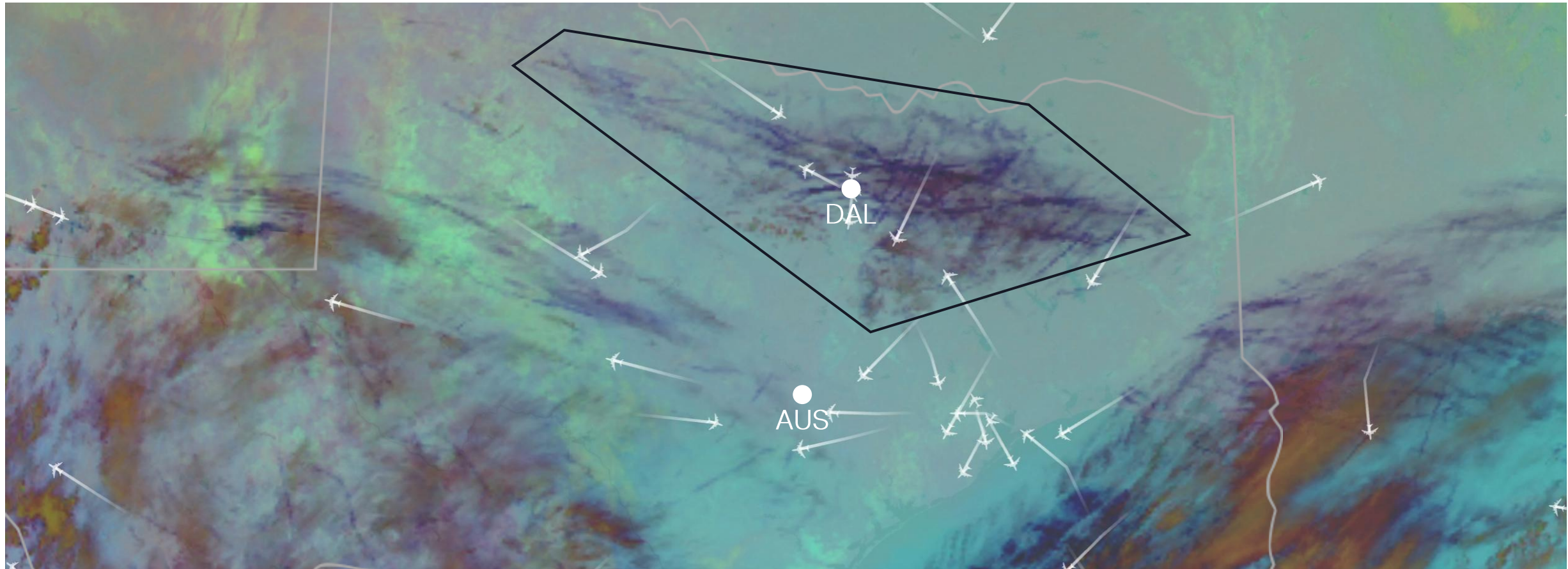


Contrails form in cold humid regions of the atmosphere



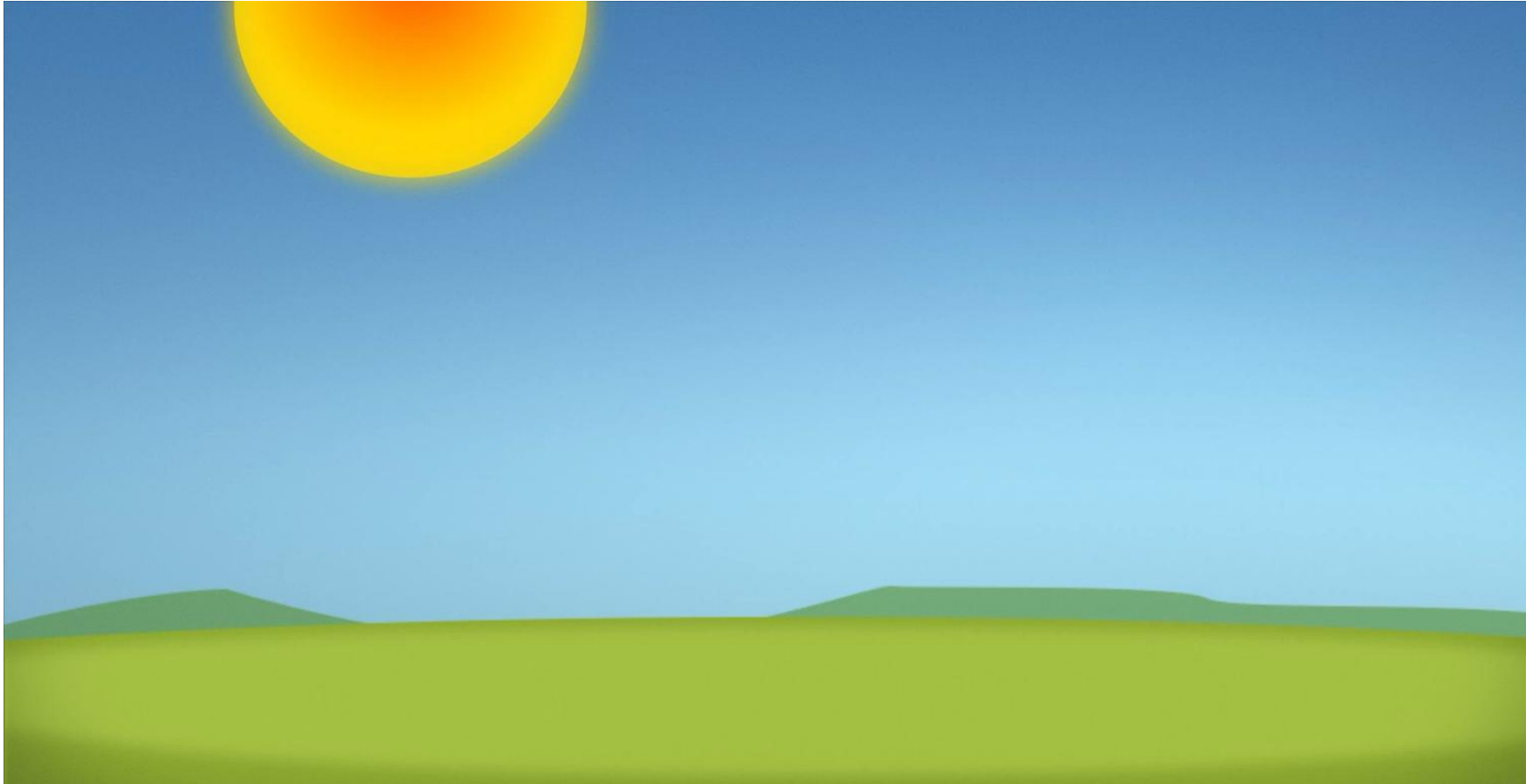
Contrails can persist and spread into synthetic cirrus regions

■ Cirrus cover

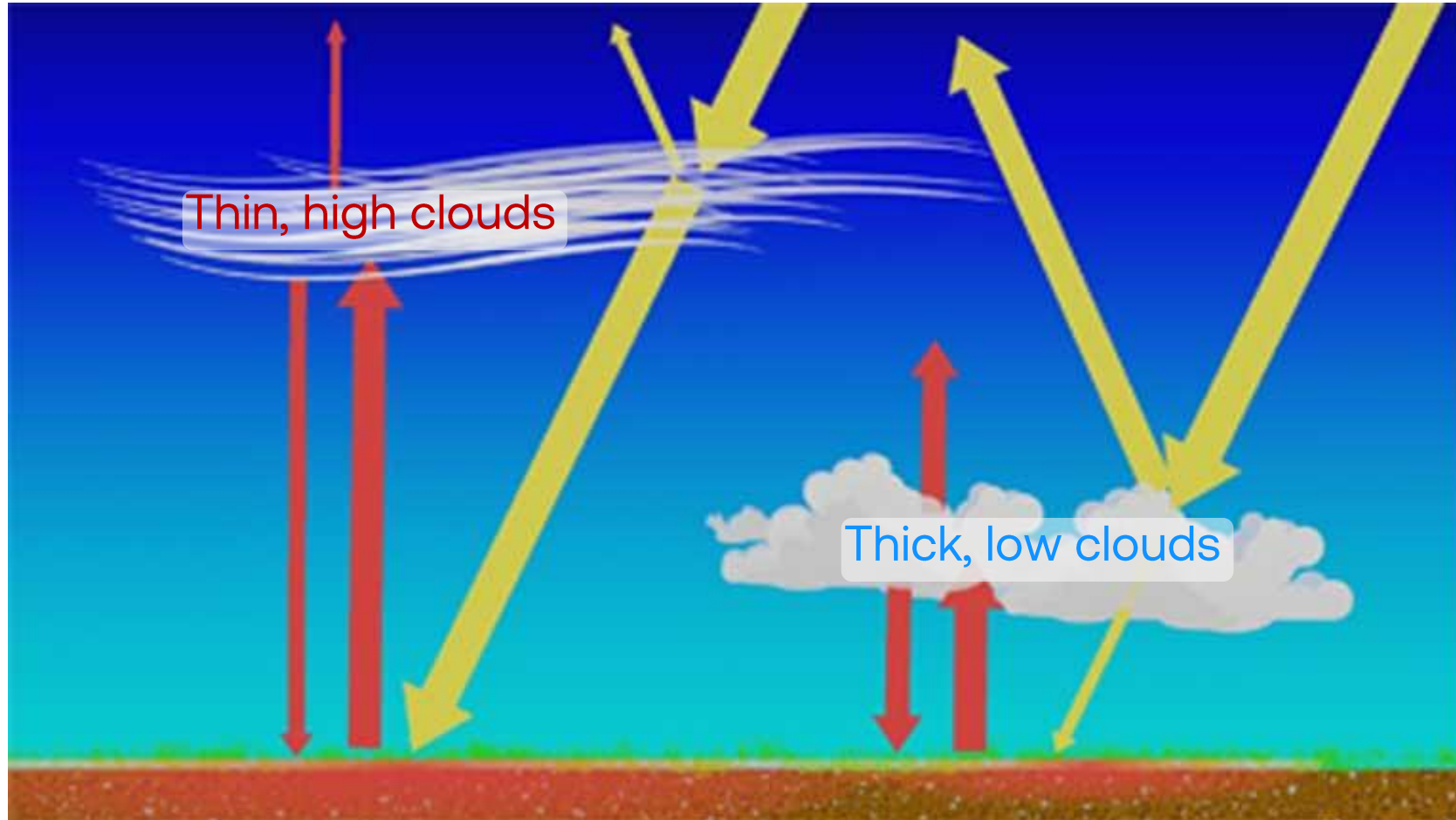


Why do contrails matter?

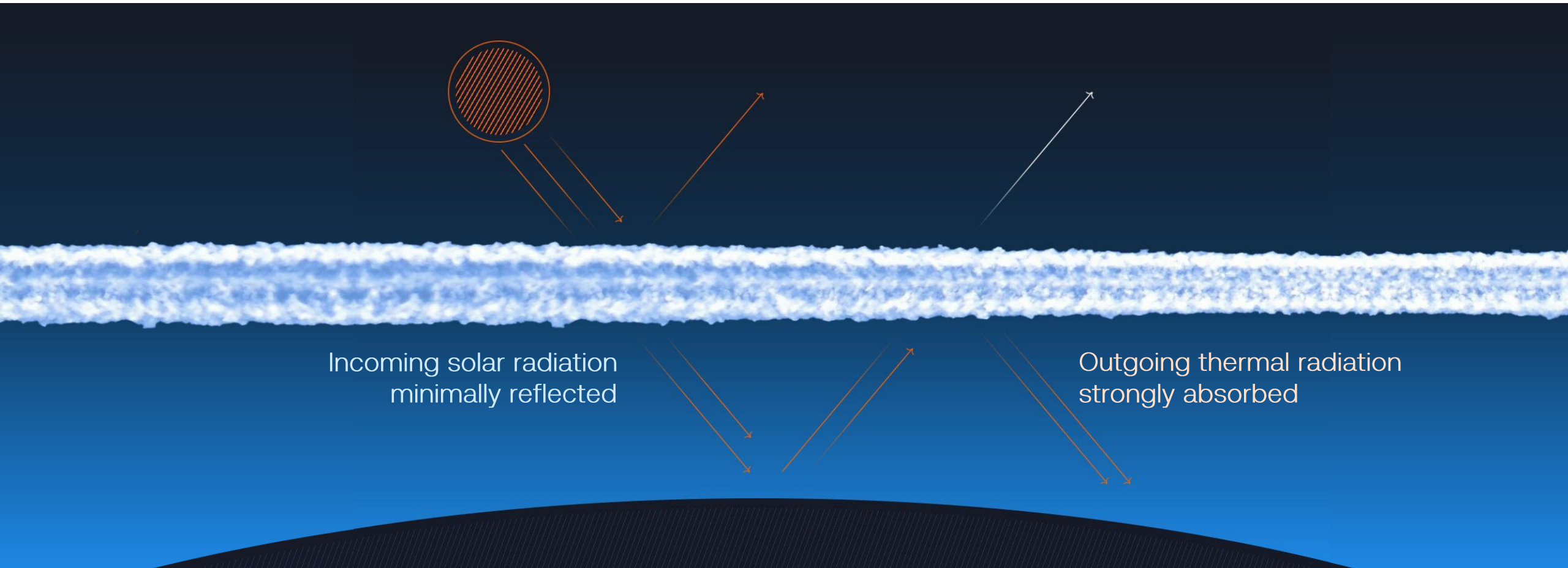
Earth's energy budget is a balance of incoming and outgoing radiation



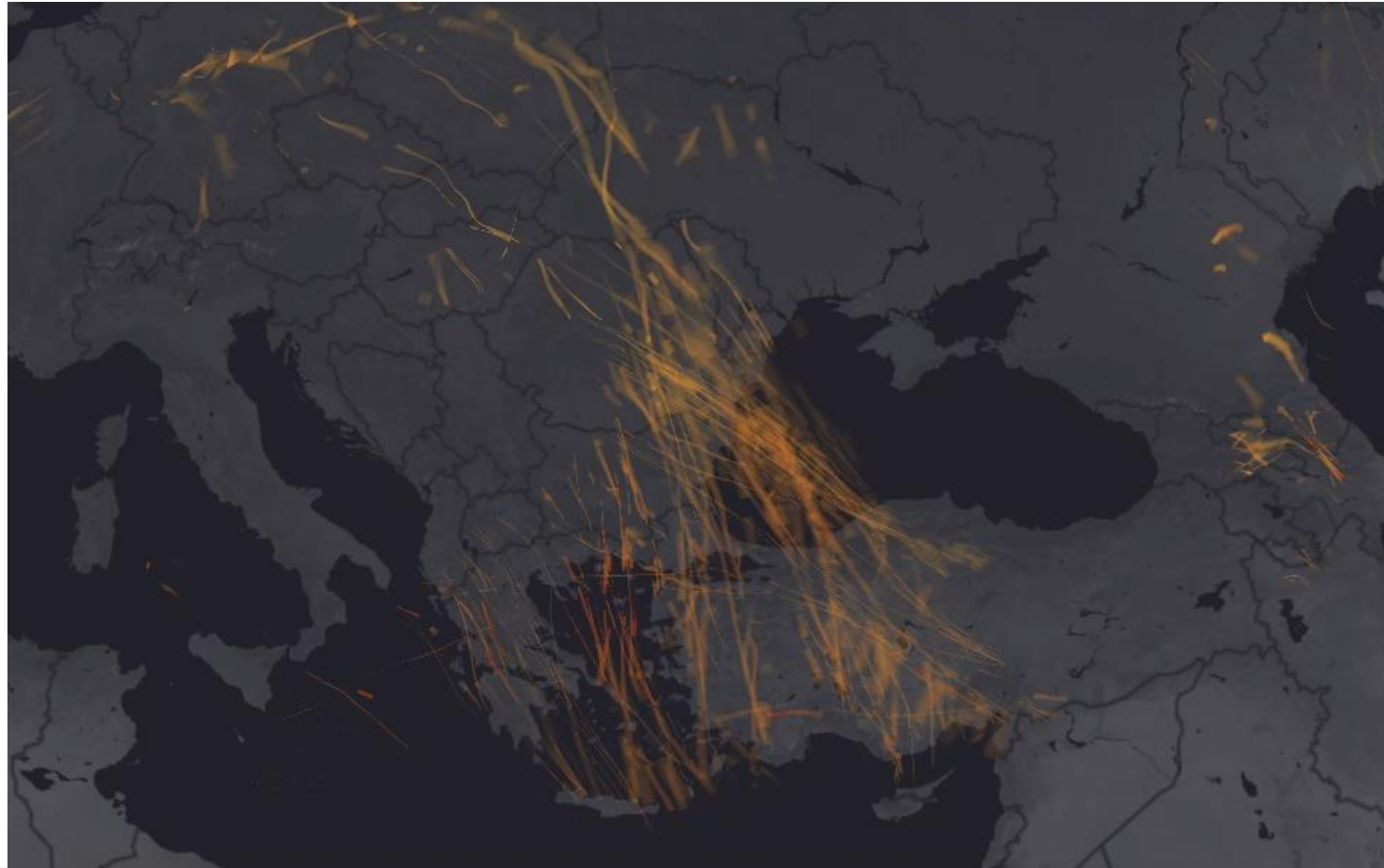
Clouds have a major influence on Earth's radiation budget



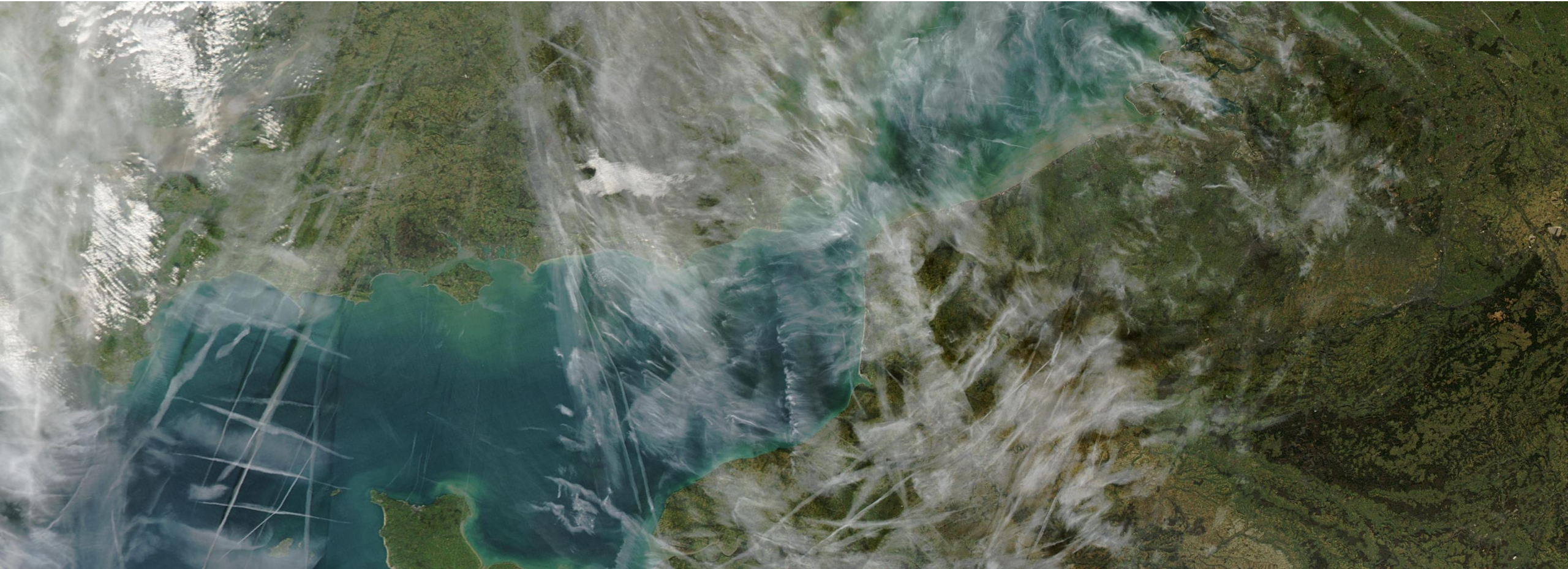
Overall, contrail cirrus is strongly warming



Contrail radiative forcing depends on space and time



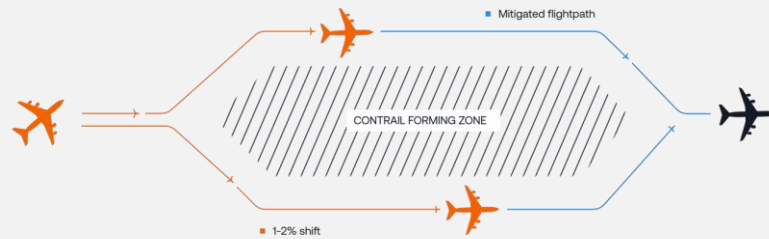
Contrails cause 1 – 2% anthropogenic radiative forcing



How do we reduce contrail forcing?

1. Navigational Avoidance

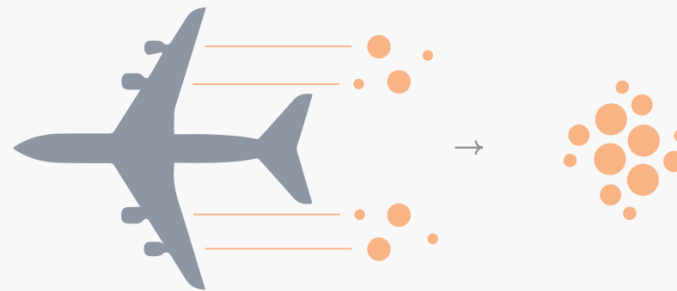
Avoid persistent contrail formation



Available now

2. Fuels

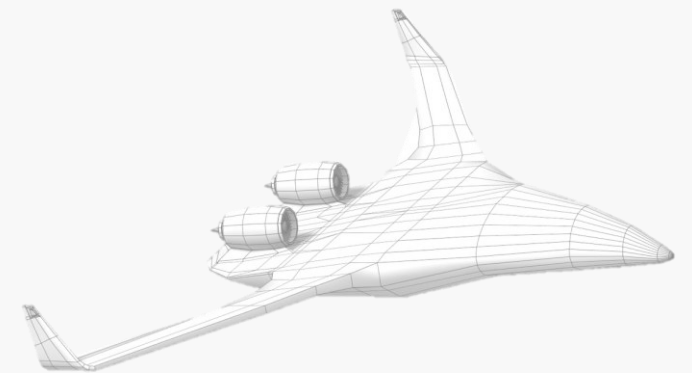
Change ice nucleation with fuels



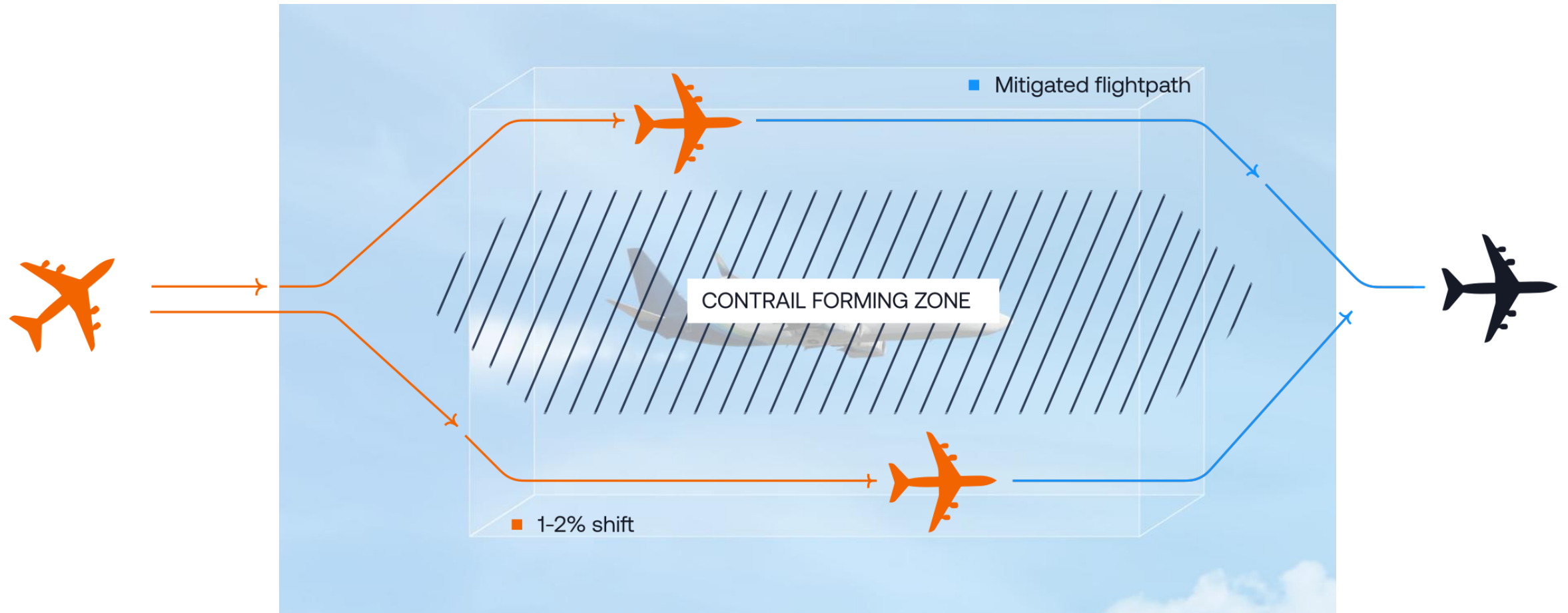
Potential future solutions

3. Propulsion

Remove ice nucleation with new aircraft

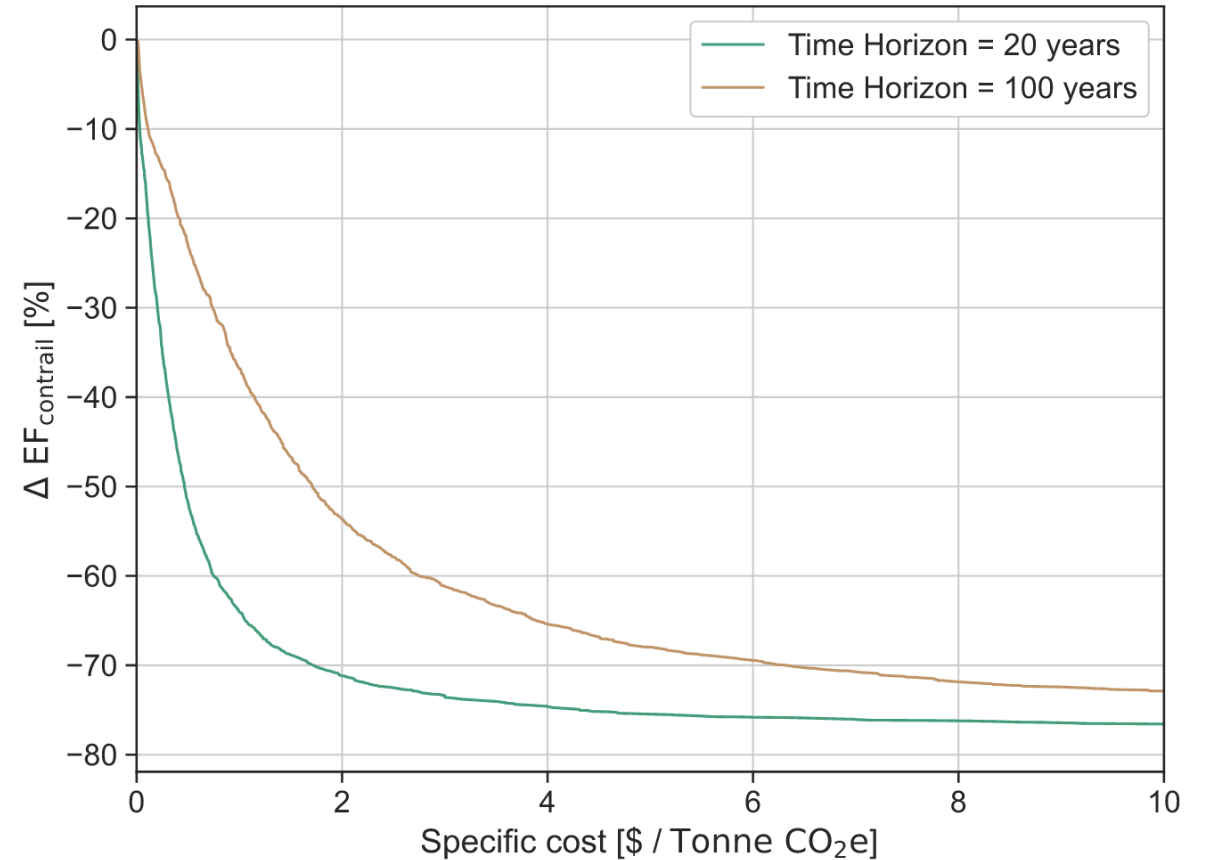


Aircraft can avoid forming contrails



Operational avoidance is low cost

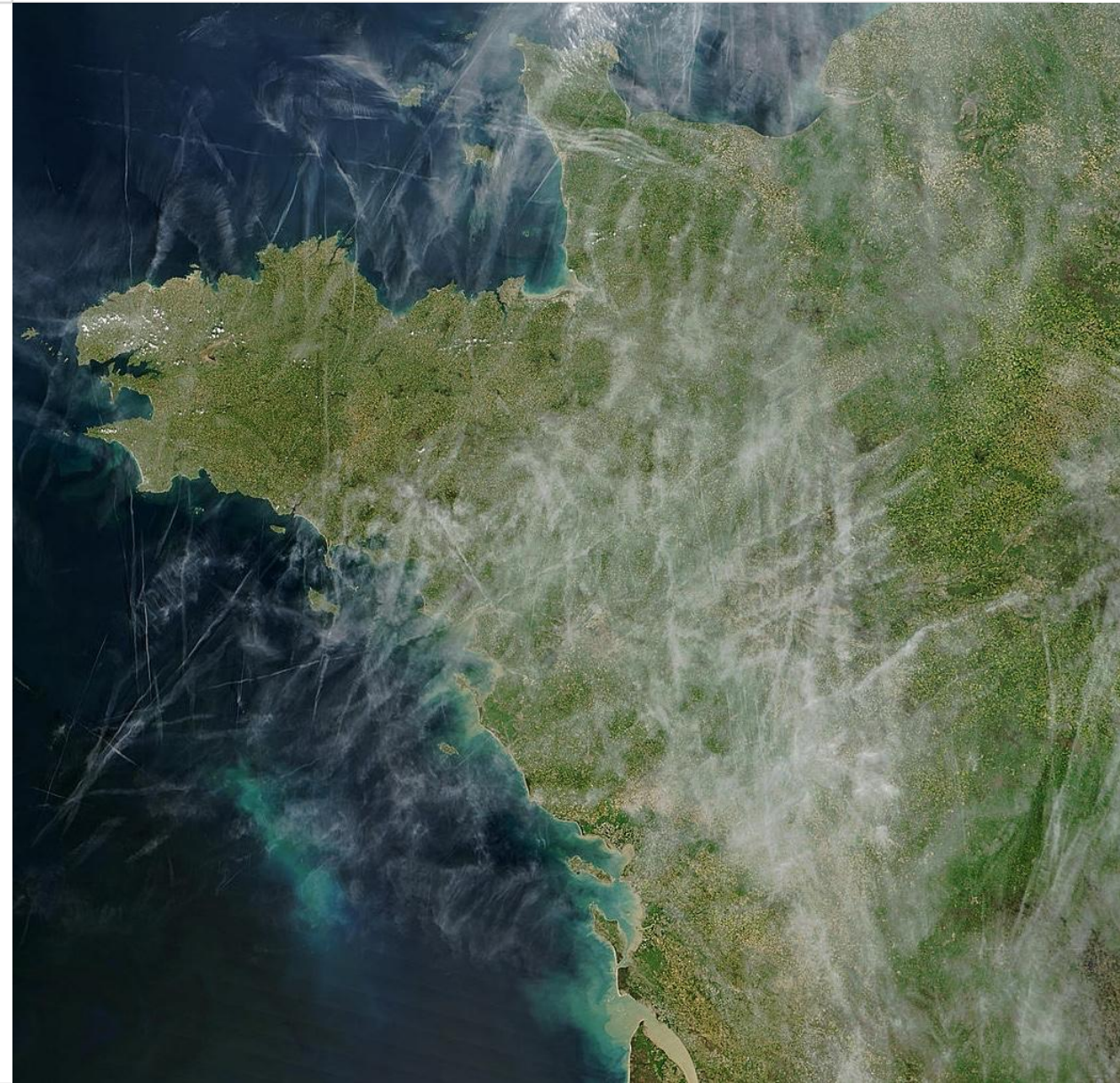
- <5% of flights cause 80% of the contrail forcing
- ~70% reduction in forcing = ~0.1% increased cost
- No new technology, **just another weather layer**
- At scale (estimate)
- ~\$1 – \$10 per tonne CO₂e abatement cost



The opportunity

- Contrail radiative forcing is $\sim 57 \text{ mW m}^{-2}$ ($\sim 33 \text{ Gt atmospheric CO}_2$, $+50 \text{ mK}$ by 2050)
- Avoidance will cost $\sim O(\$100\text{M})$ per year at full scale

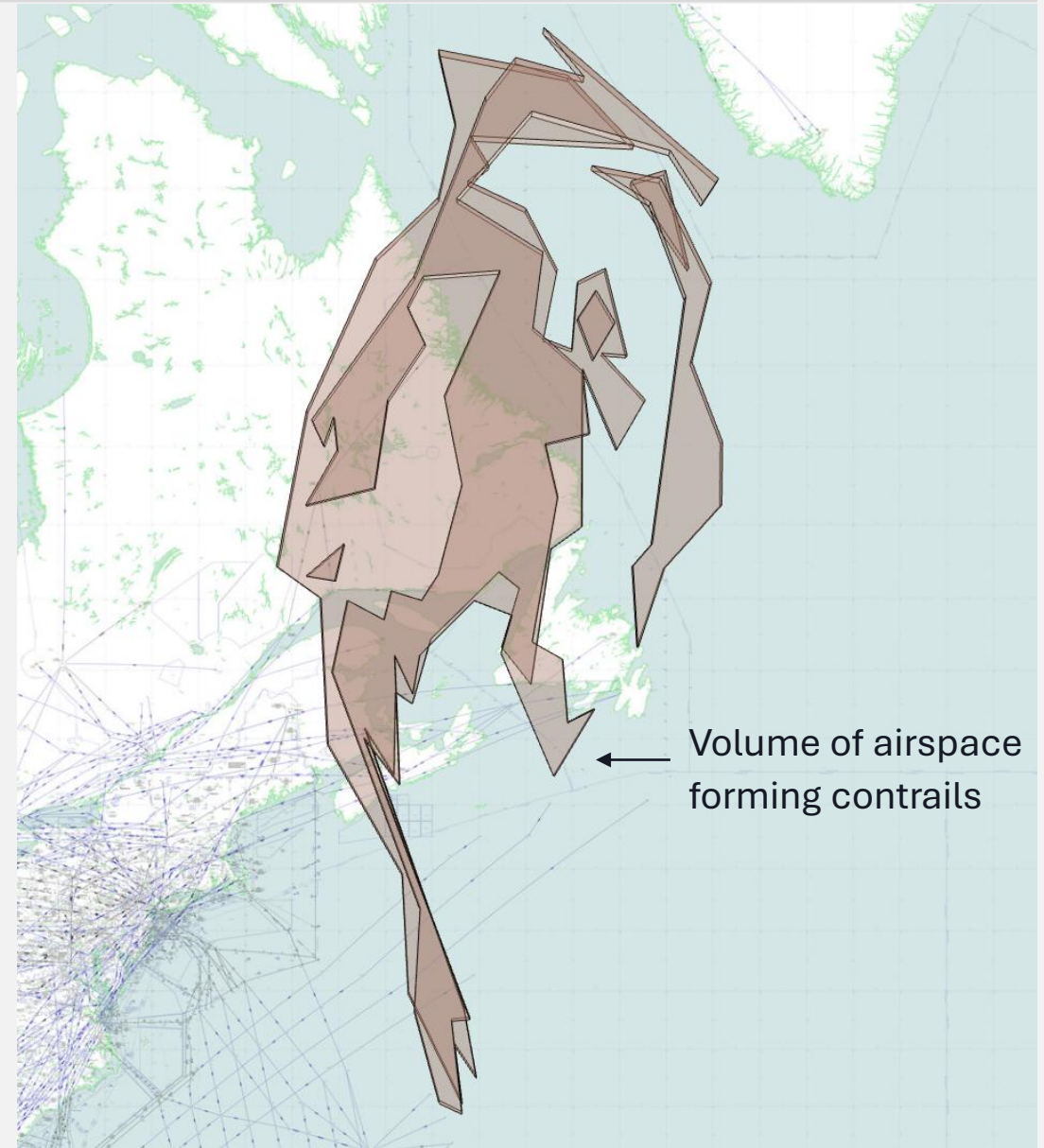
Remove 1 – 2% of human caused warming at a cost of $\sim \$1 - \10 per tonne by 2035



Contrail management

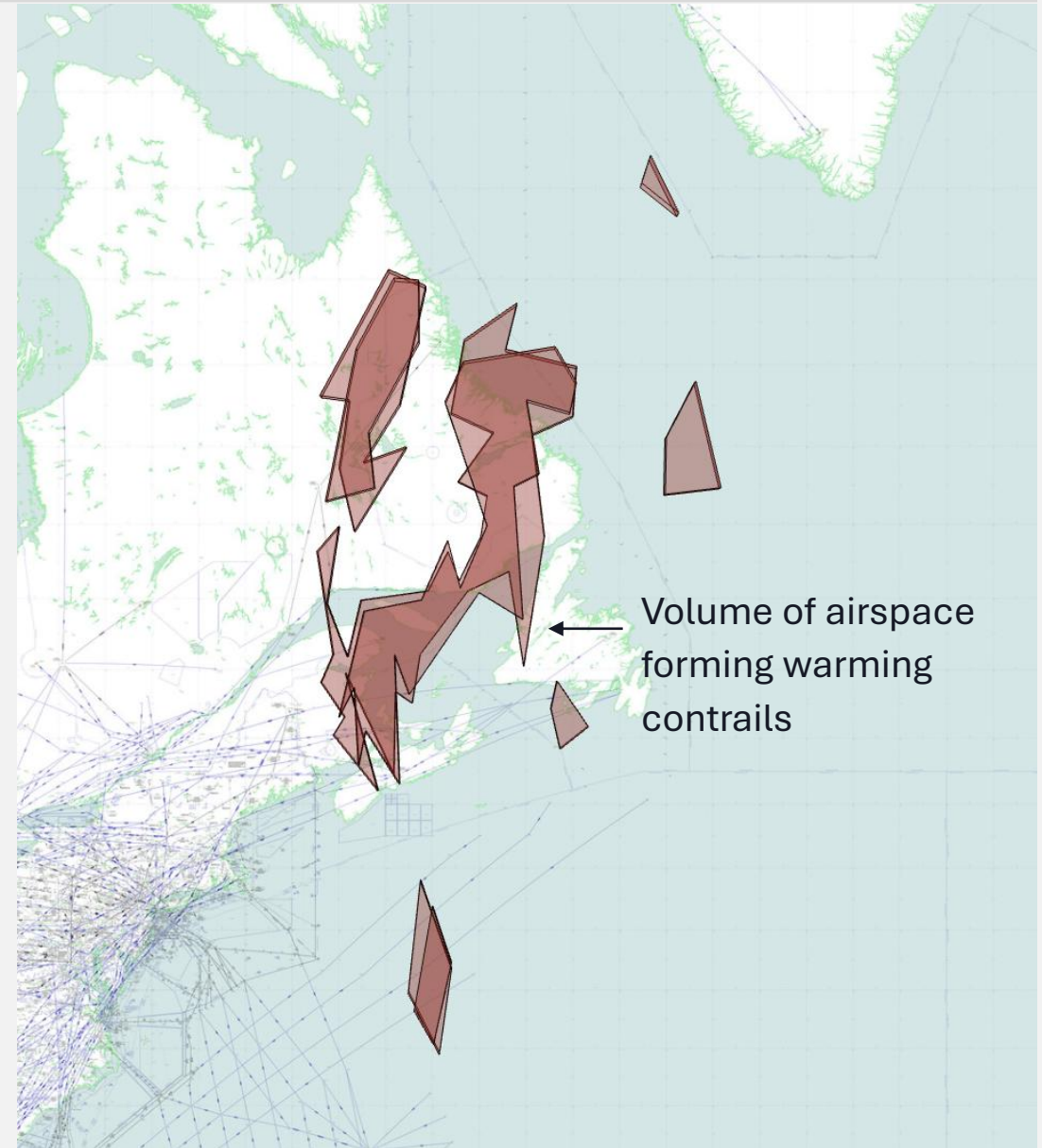
Navigational Contrail Avoidance

1. Predict where contrail-cirrus will likely form



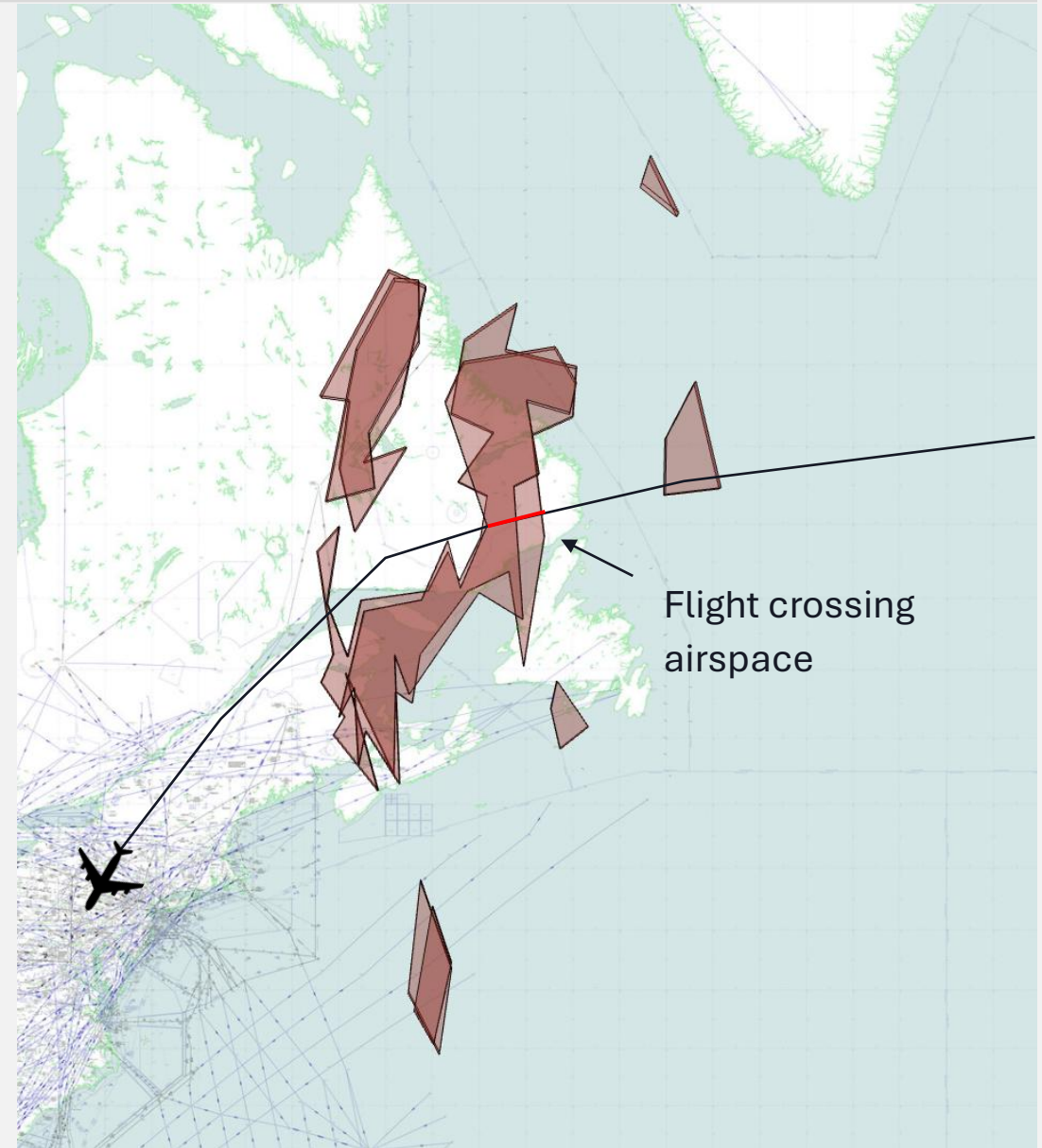
Navigational Contrail Avoidance

1. Predict where contrail-cirrus will likely form
2. Characterize the expected climate effects



Navigational Contrail Avoidance

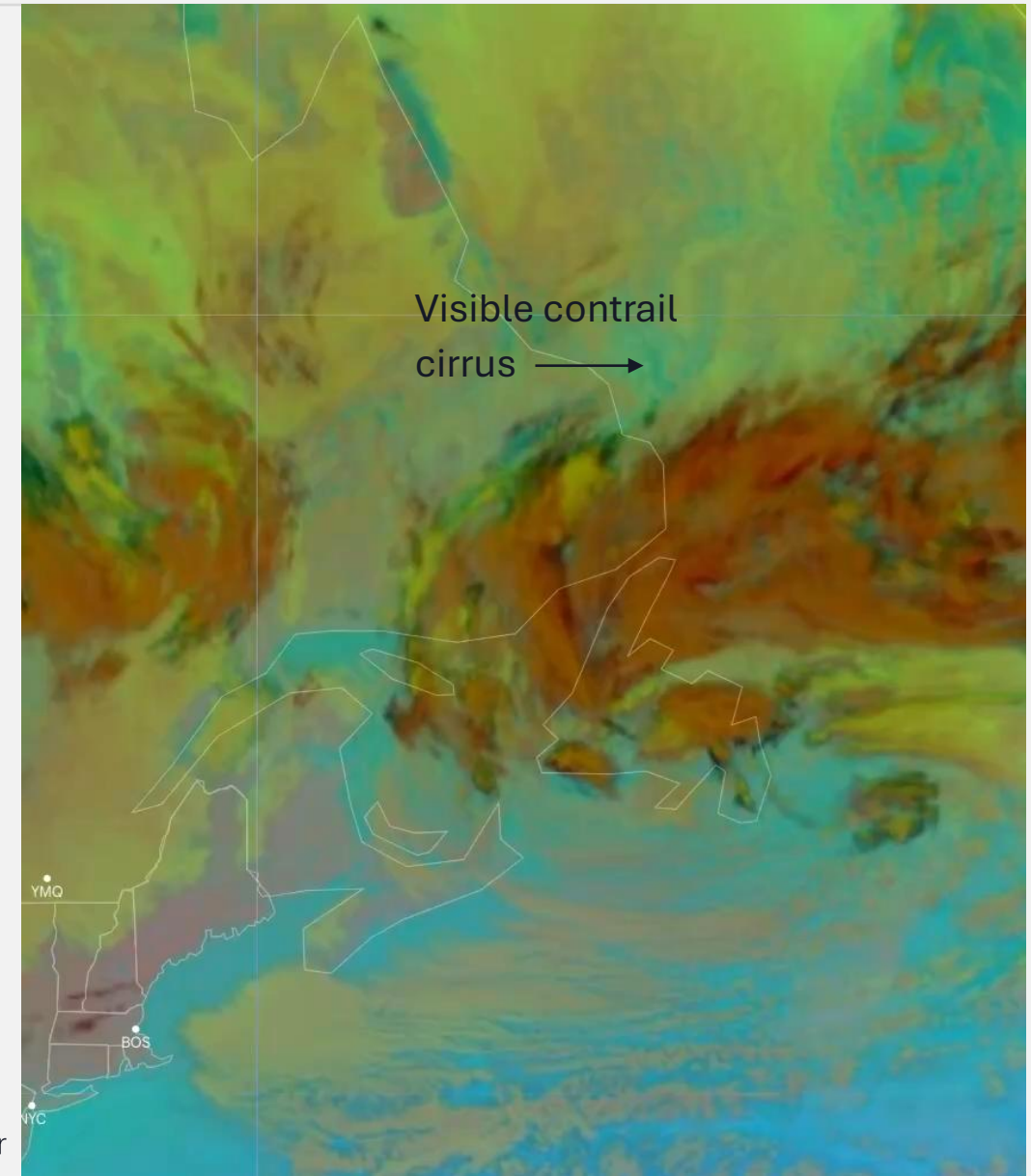
1. Predict where contrail-cirrus will likely form
2. Characterize the expected climate effects
3. Integrate into flight planning and management



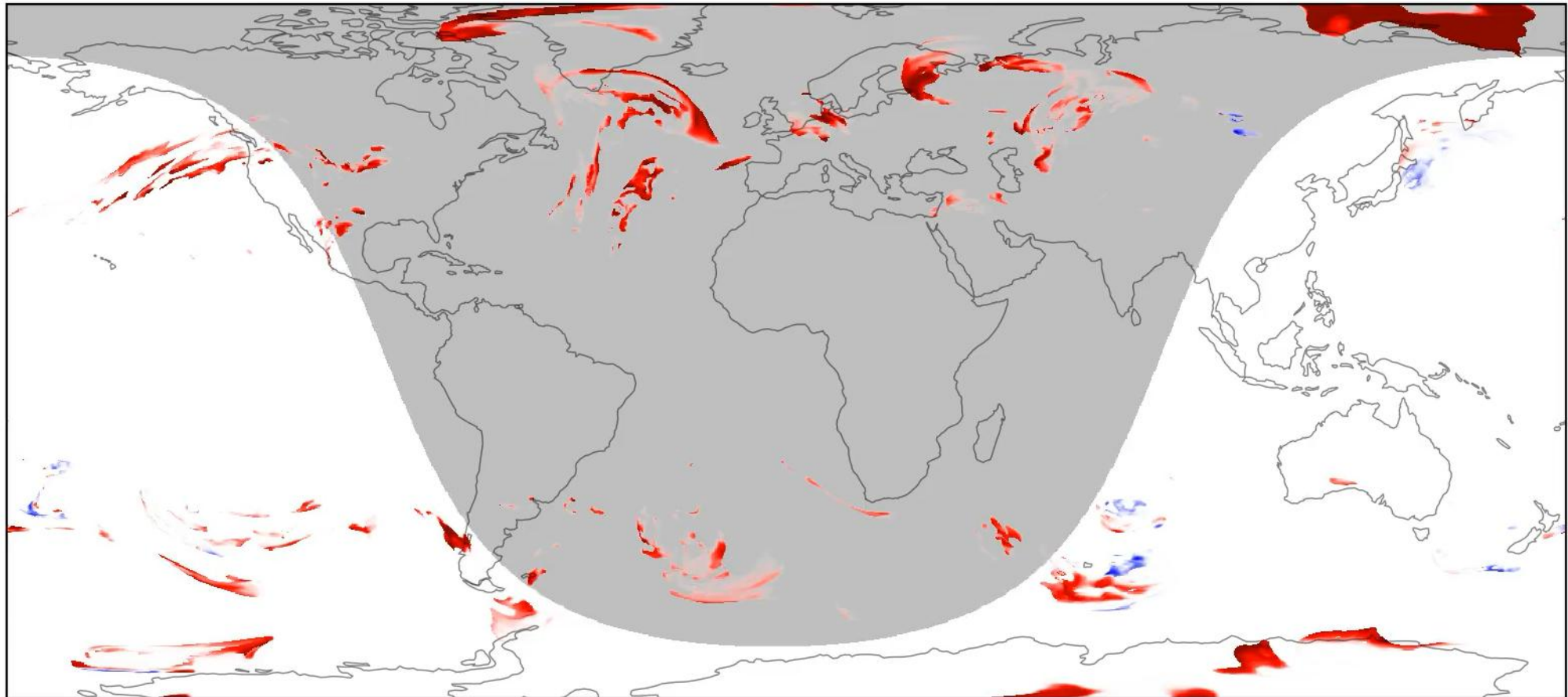
Navigational Contrail Avoidance

1. Predict where contrail-cirrus will likely form
2. Characterize the expected climate effects
3. Integrate into flight planning and management
4. Feedback observations

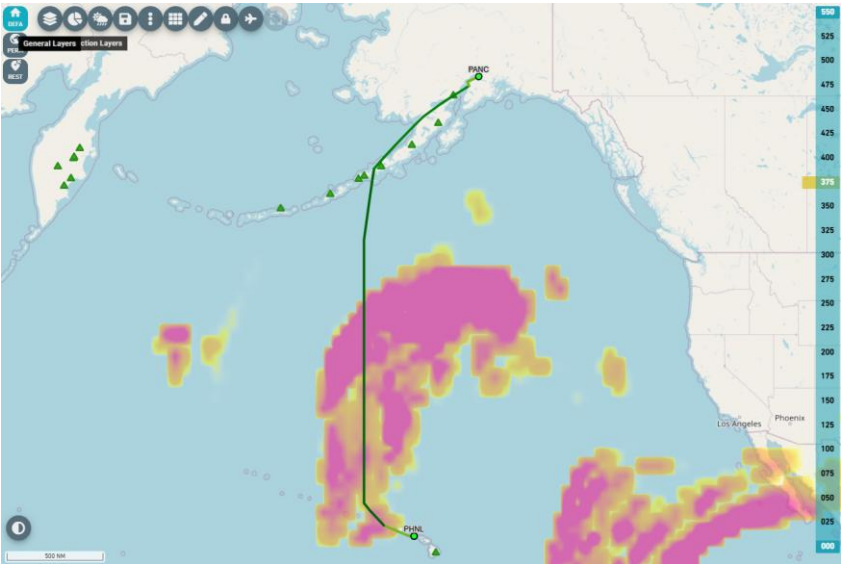
■ Cirrus cover



Contrail forecast enables trajectory co-optimization



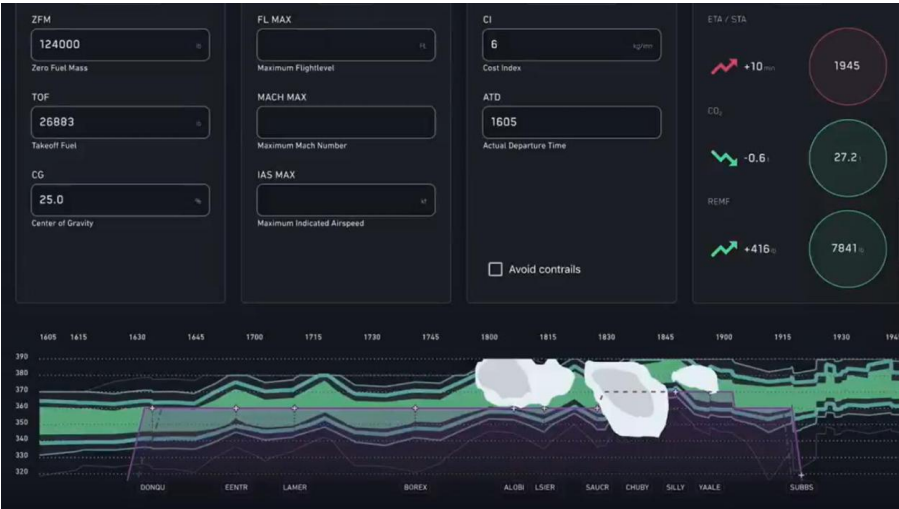
Distribute as aviation weather



Flight Planning



Air Traffic Control



Electronic Flight Bag (Cockpit Tablet)

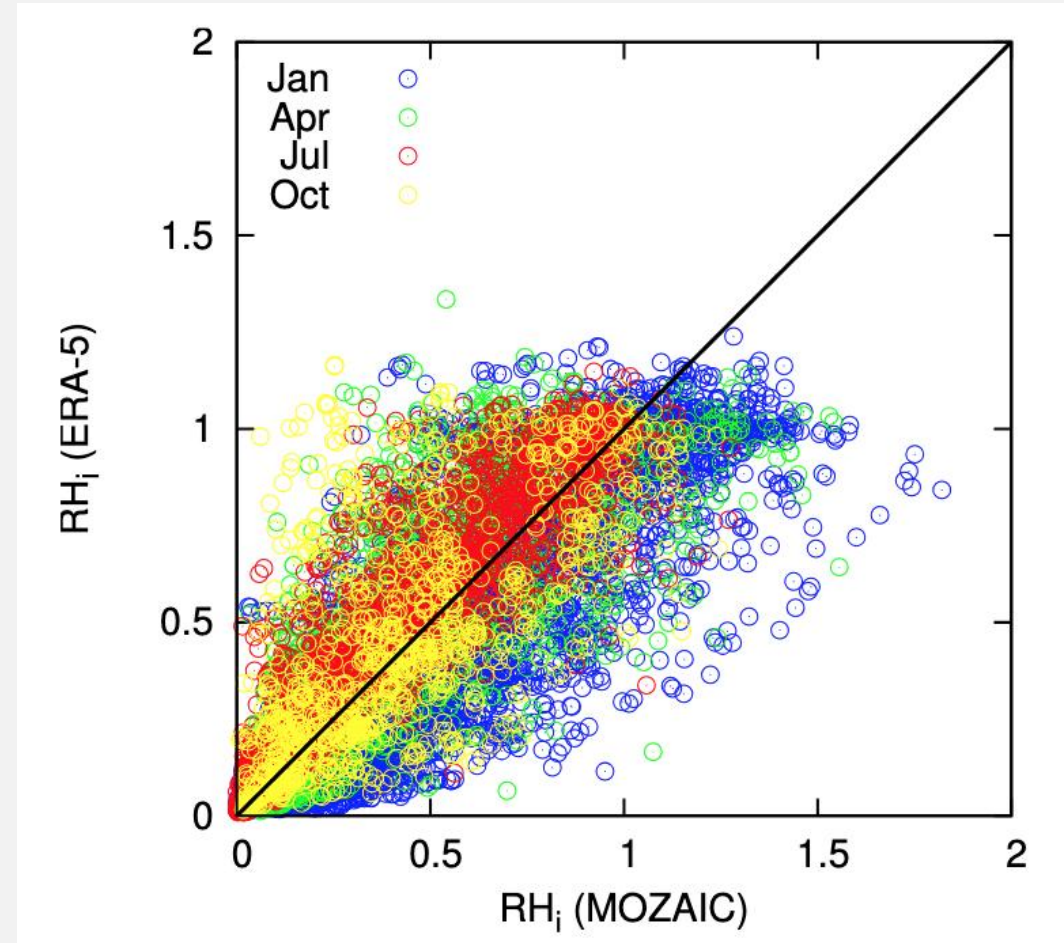
Contrail forecast & monitoring ecosystem



Challenge: Forecast Confidence

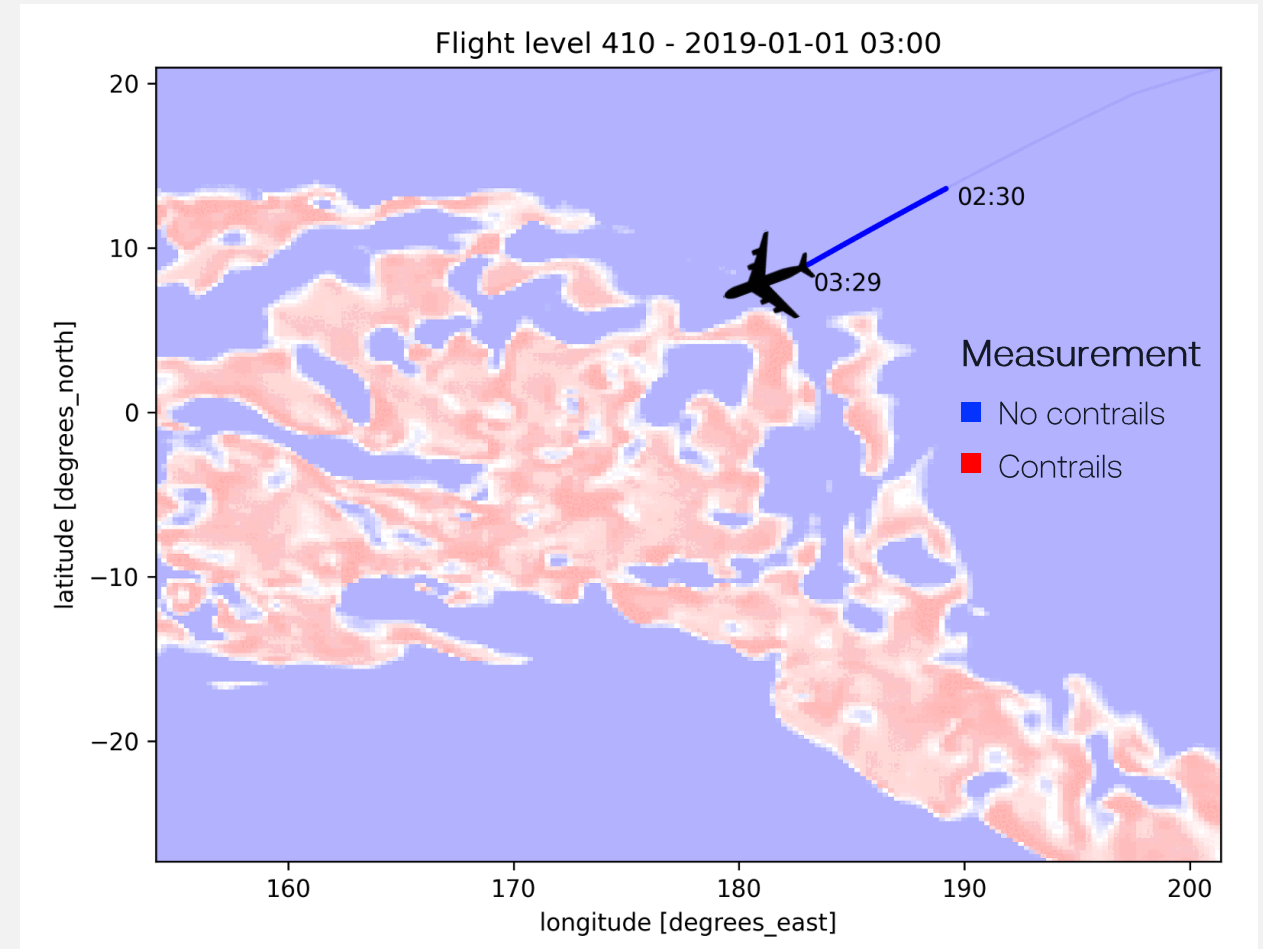
If we are spending money (and CO2), we need to get it right

- Humidity forecasts in the upper atmosphere have low pointwise accuracy



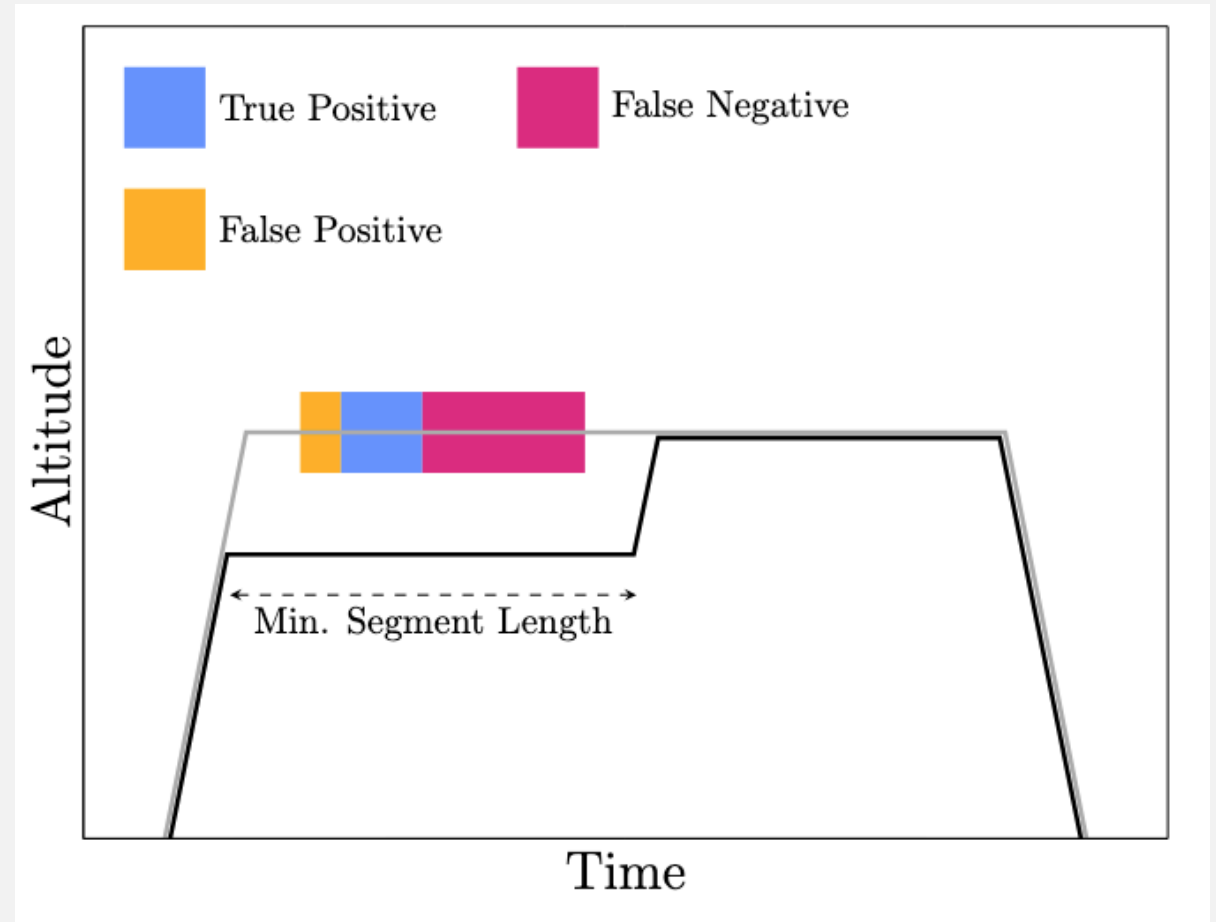
If we are spending money (and CO2), we need to get it right

- Humidity forecasts in the upper atmosphere have low pointwise accuracy
- But contrail forecasts often get the morphology right



If we are spending money (and CO2), we need to get it right

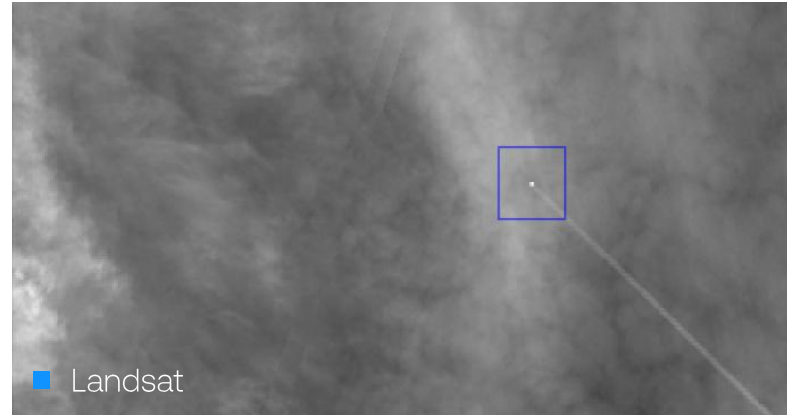
- Humidity forecasts in the upper atmosphere have low pointwise accuracy
- But contrail forecasts often get the morphology right
- And aviation operations naturally constrain interventions



How we evaluate forecasts?

- Measurements (point)
- Cameras (area)
- Radar / LiDAR (line)
- Heat detectors (area)
- (Reanalysis data)

Good for measuring **contrail formation** and **initial persistence**



How we evaluate forecasts?

- Measurements (point)
- Cameras (area)
- Radar / LiDAR (line)
- Heat detectors (area)
- (Reanalysis data)

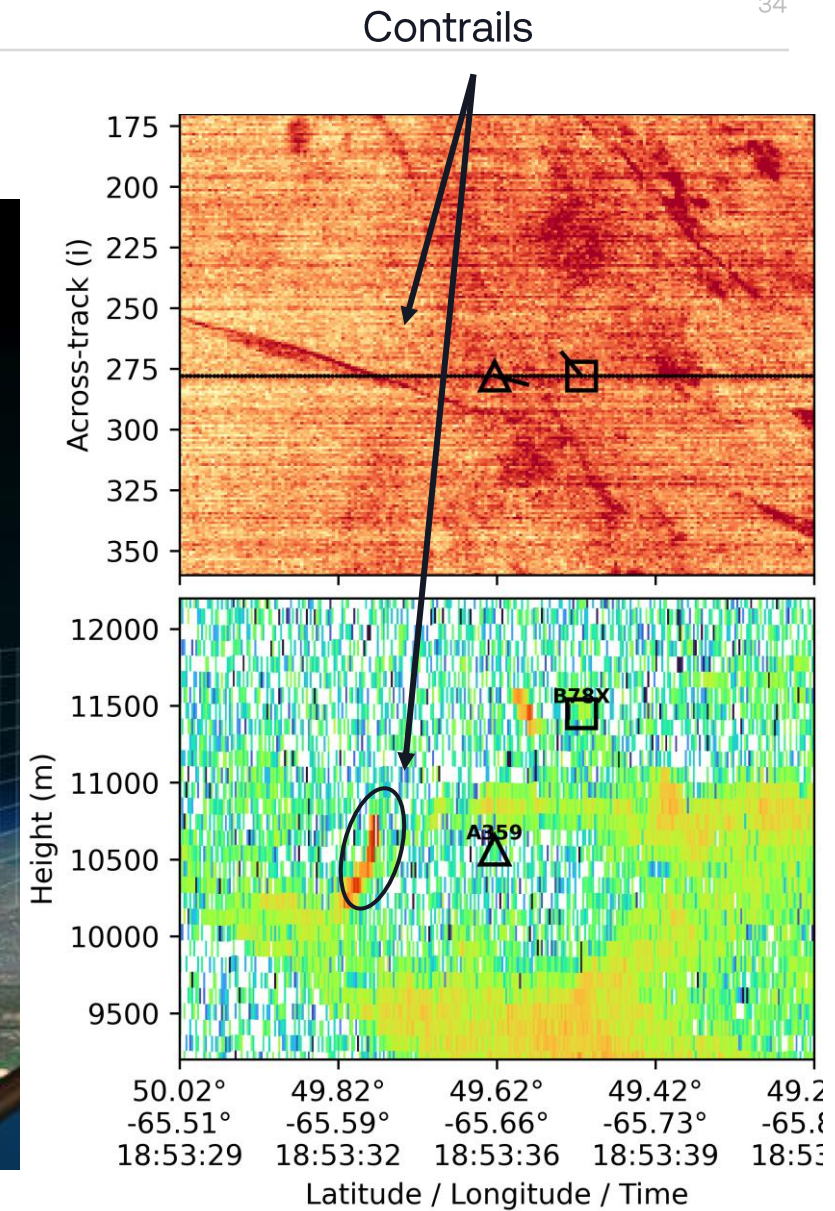
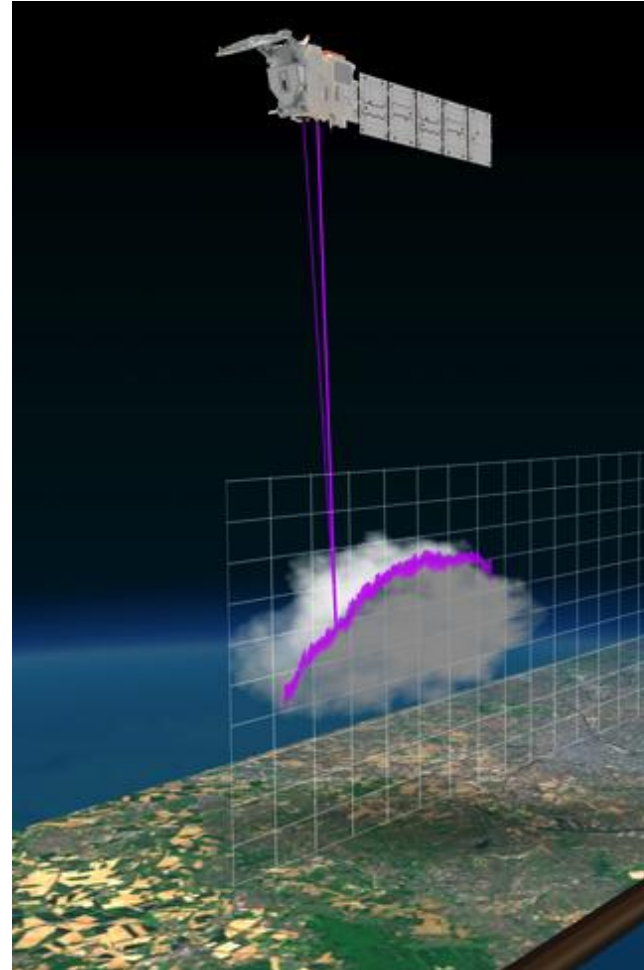
Good for measuring **contrail formation** and **initial persistence**



How we evaluate forecasts?

- Measurements (point)
- Cameras (area)
- Radar / LiDAR (line)
- Heat detectors (area)
- (Reanalysis data)

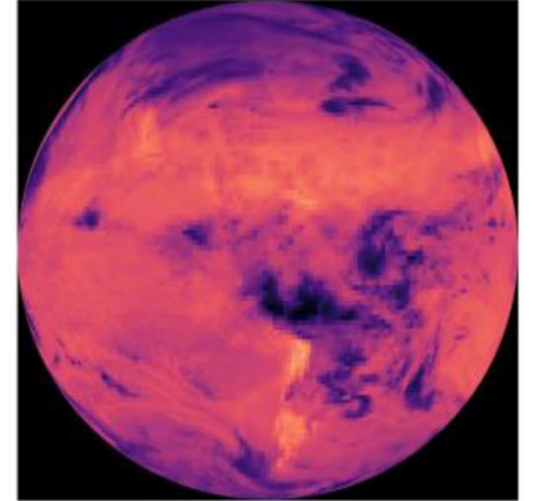
Good for measuring **contrail** properties and **cirrus coverage**



How we evaluate forecasts?

- Measurements (point)
- Cameras (area)
- Radar / LiDAR (line)
- Heat detectors (area)
- (Reanalysis data)

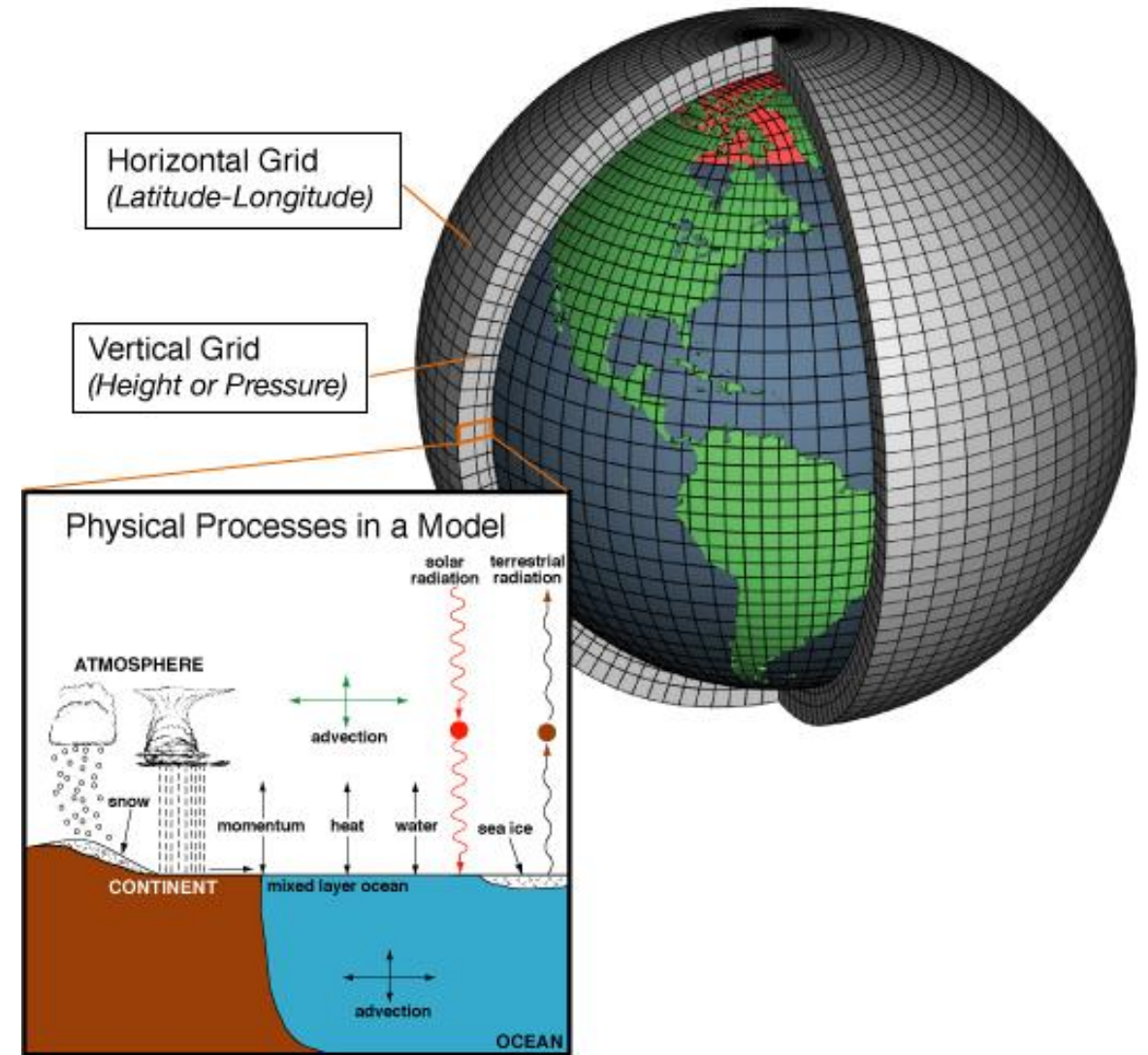
Good for measuring **radiative impacts**



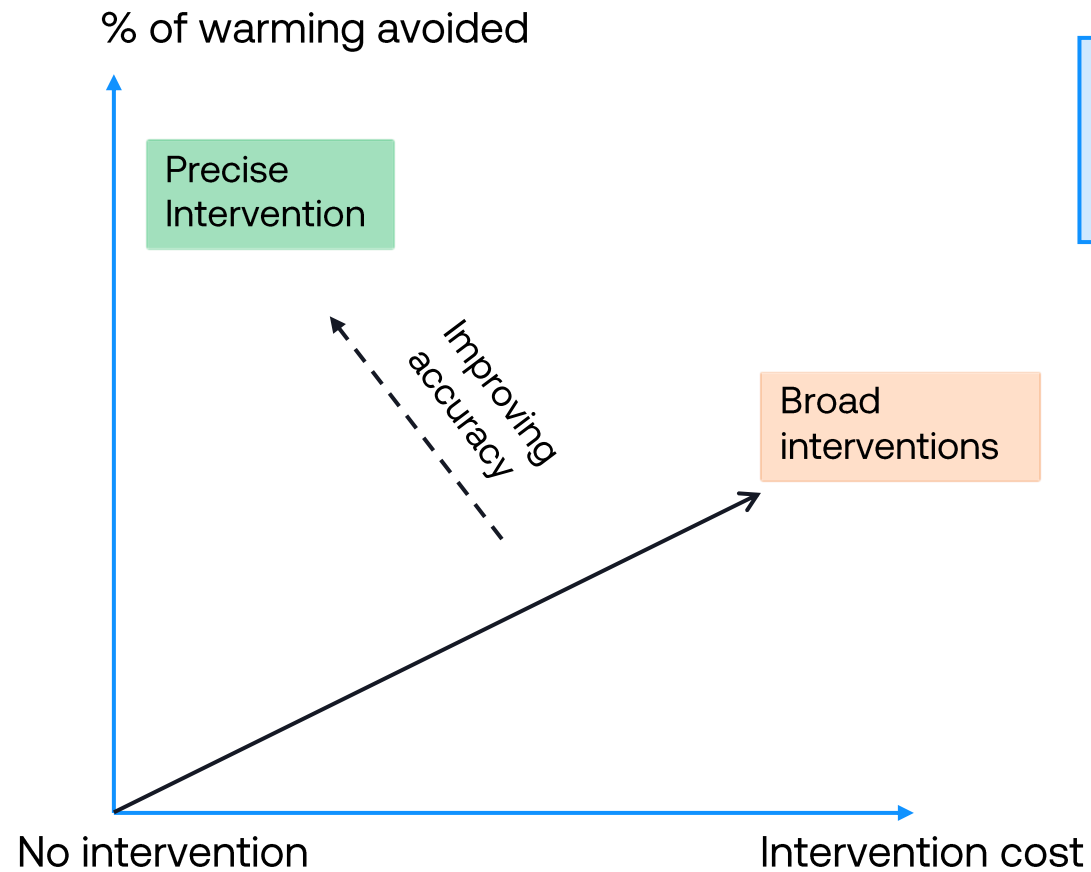
How we evaluate forecasts?

- Measurements (point)
- Cameras (area)
- Radar / LiDAR (line)
- Heat detectors (area)
- (Reanalysis data)

Good for filling in the gaps



Integrate observations to build confidence and reduce cost

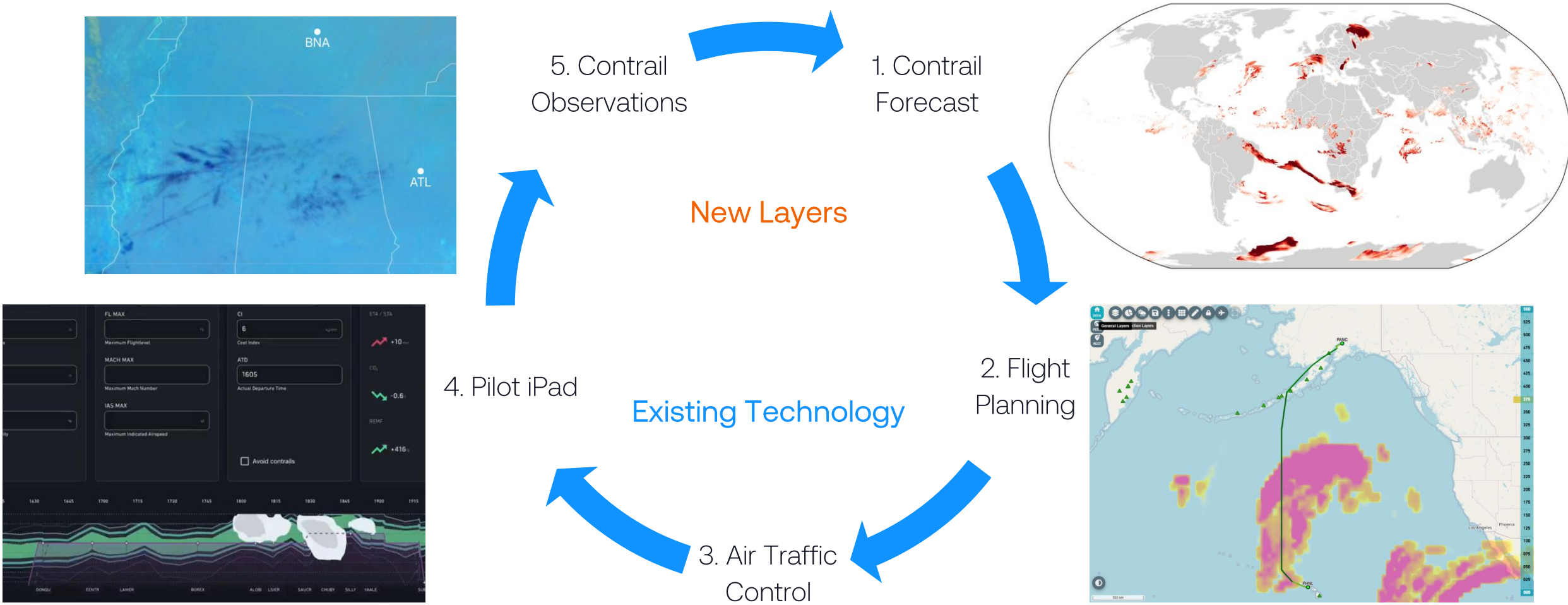


Read about ContrailBench!
bench.contrails.org

#

Challenge: Integrate into Operations

Contrail forecast & monitoring ecosystem



Simulations & Trials are the key next step

- **Build capability**

Incentivize service providers (planners, EFBs) to implement contrail features

- **Provide evidence**

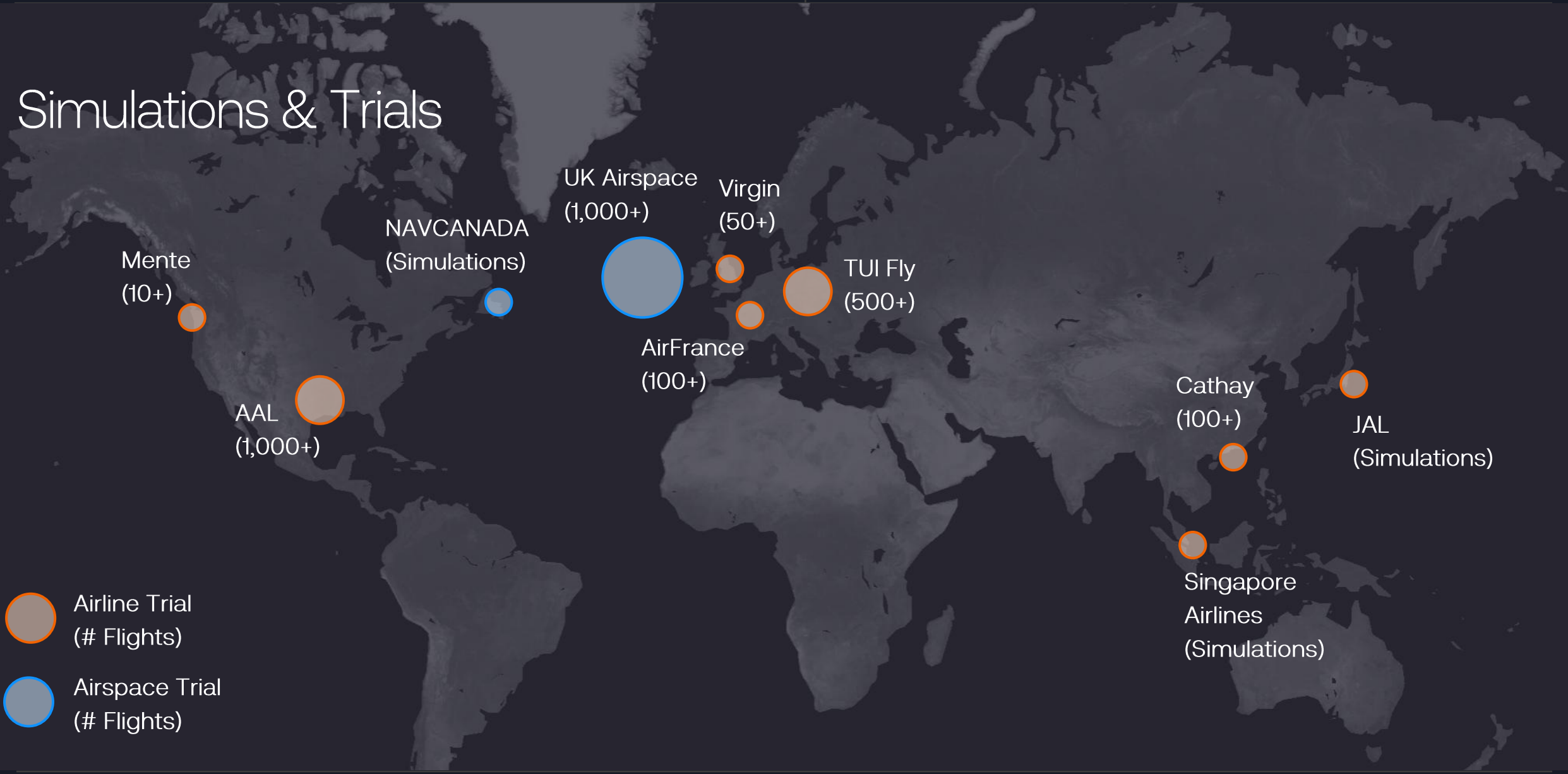
Measure actual operational impacts and effectiveness of interventions.

- **Inform protocols**

Airlines that implement trials now can inform the protocols that get adopted.

- **Provide immediate climate benefit**

Simulations & Trials

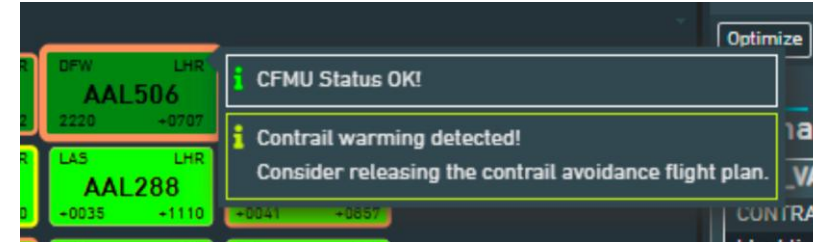


-  Airline Trial
(# Flights)
-  Airspace Trial
(# Flights)



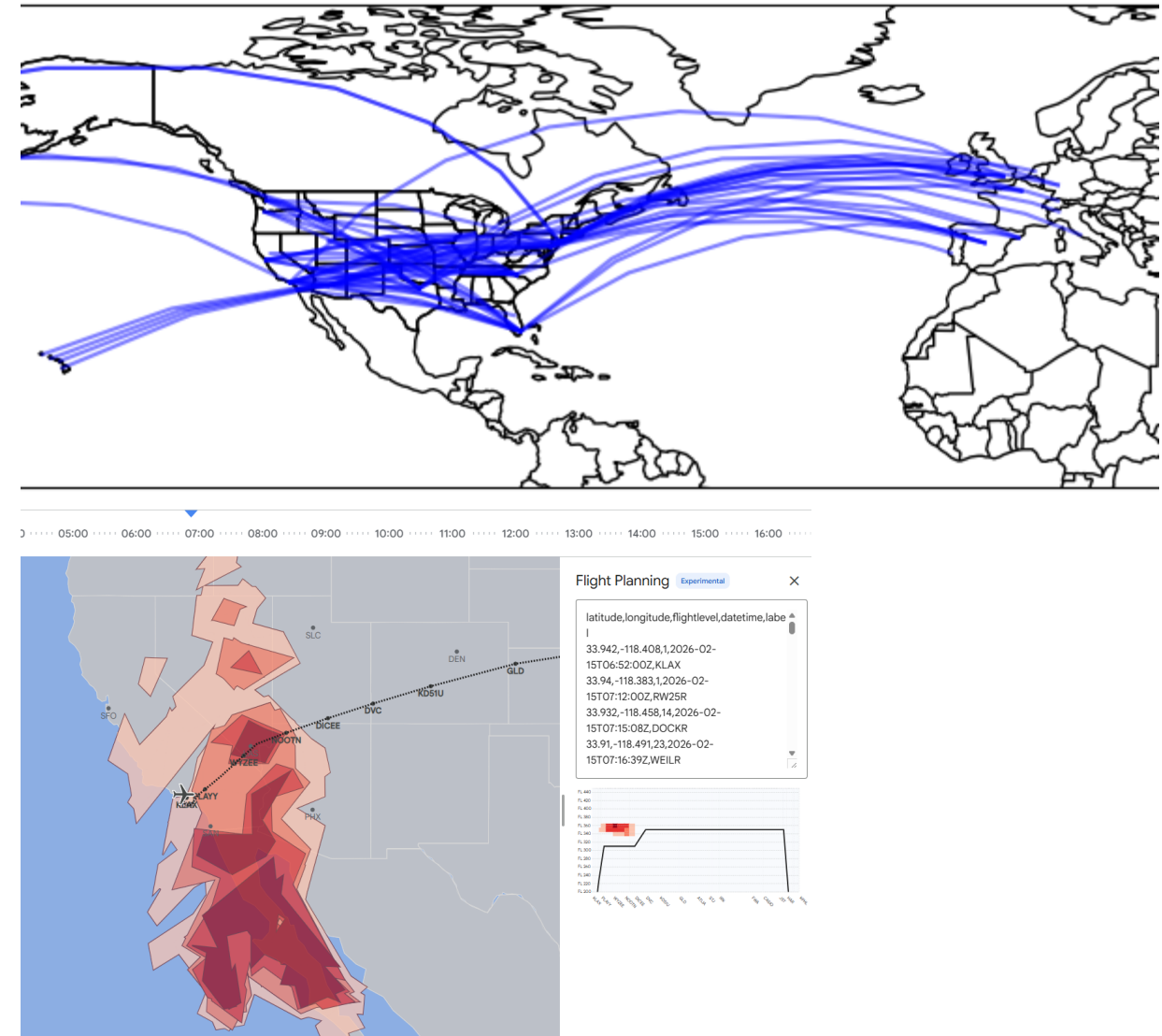
AA Scientific Trials (2025)

- 112 flights automatically filed by AA dispatchers
- Measure contrail formation length in satellite imagery
- Outcomes
 - >60% reduction in contrail formation length
 - No discernable added fuel (need larger sample)



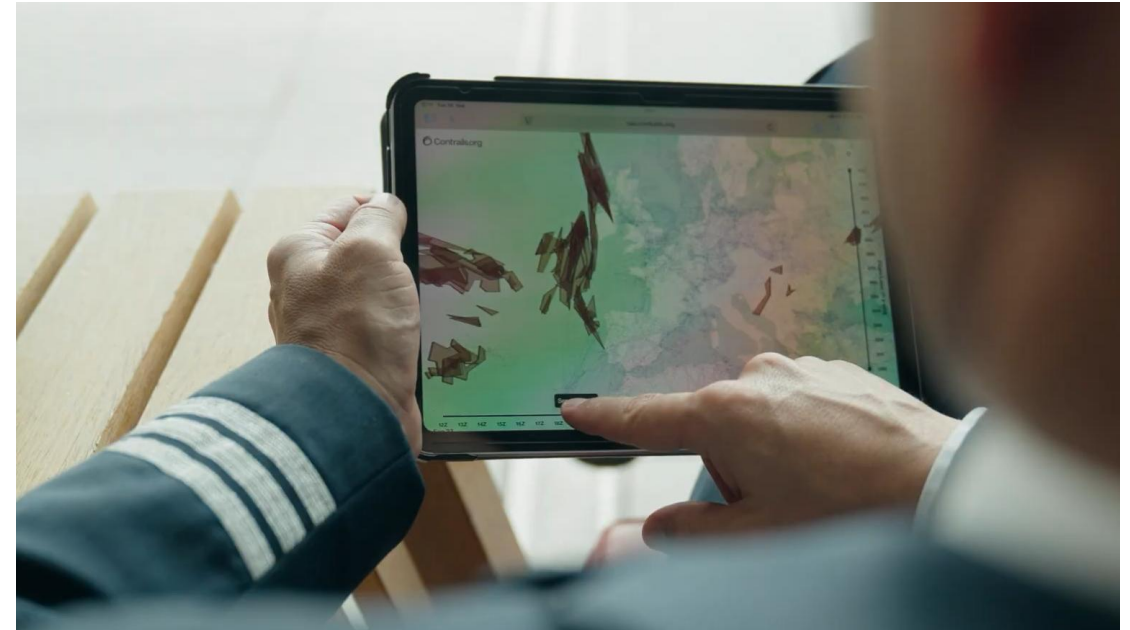
AA Scientific Trials (2026)

- Build on success of 2025 trial
- Targeting **1000** flown avoidance flights
- Focus on **warming** contrails, not just formation
- Goals
 - Largest contrail avoidance trial by 10x
 - Statistically significant warming reduction and quantifiable fuel impact



TUI Operational Trials

- >500 avoidance flights to/from Germany
- Includes 2 weeks of avoidance across all flights
- Outcomes
 - High response rate and engagement from pilots
 - 1.1% added fuel on avoidance flights
 - Saved 8,600 tonnes CO₂e (including 200t added fuel)
- Released [great video summarizing experience](#)



UK Operation Blue Skies

- Re-route all aircraft flying through trial regions
 - ~500 aircraft per region, per shift
- Winter 2026–2027 and 2027–2028
- Trial will cover 10,000+ aircraft, ~100,000 tCO₂e
- Detect contrails using geostationary imagery

 Contrails.org

NATS

IMPERIAL

 Google

 Met Office

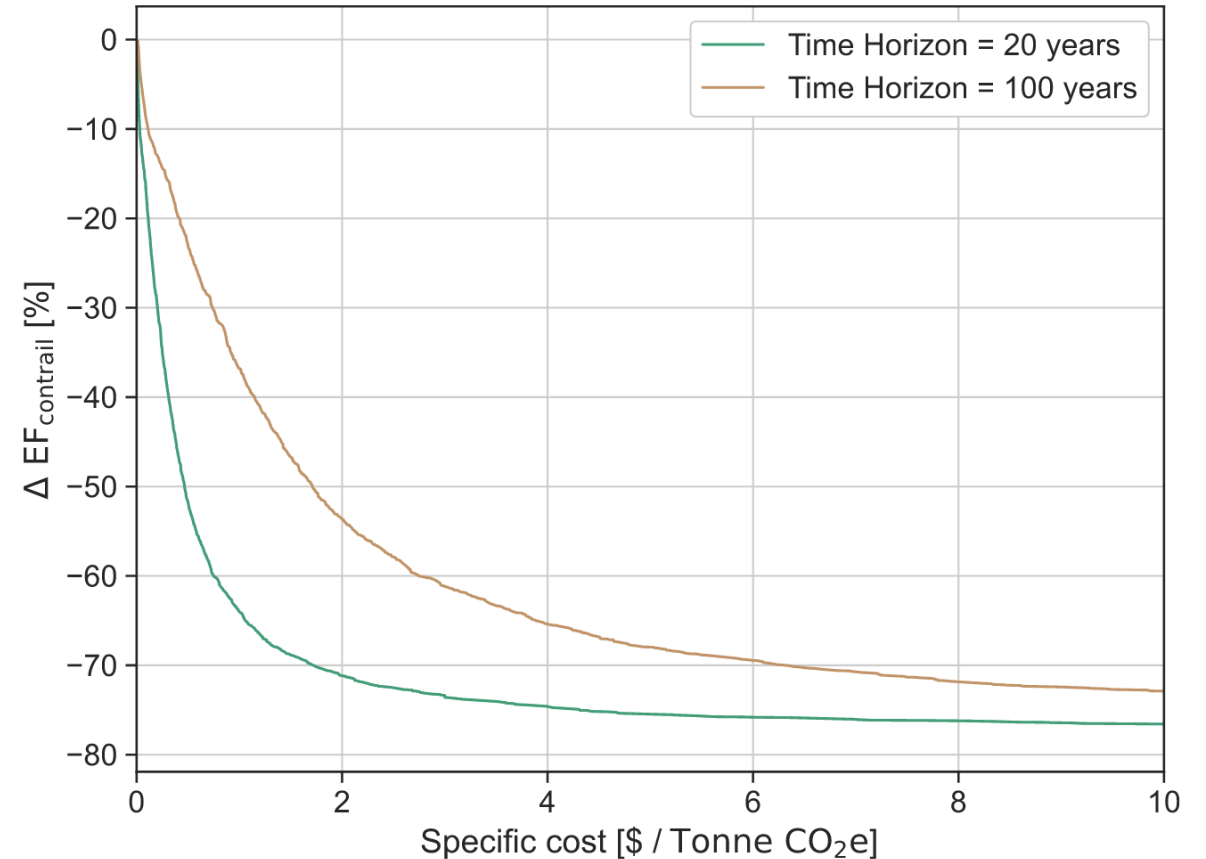
 UNIVERSITY OF
CAMBRIDGE



Challenge: Incentives for Adoption

Contrail avoidance will be cheap from a climate perspective

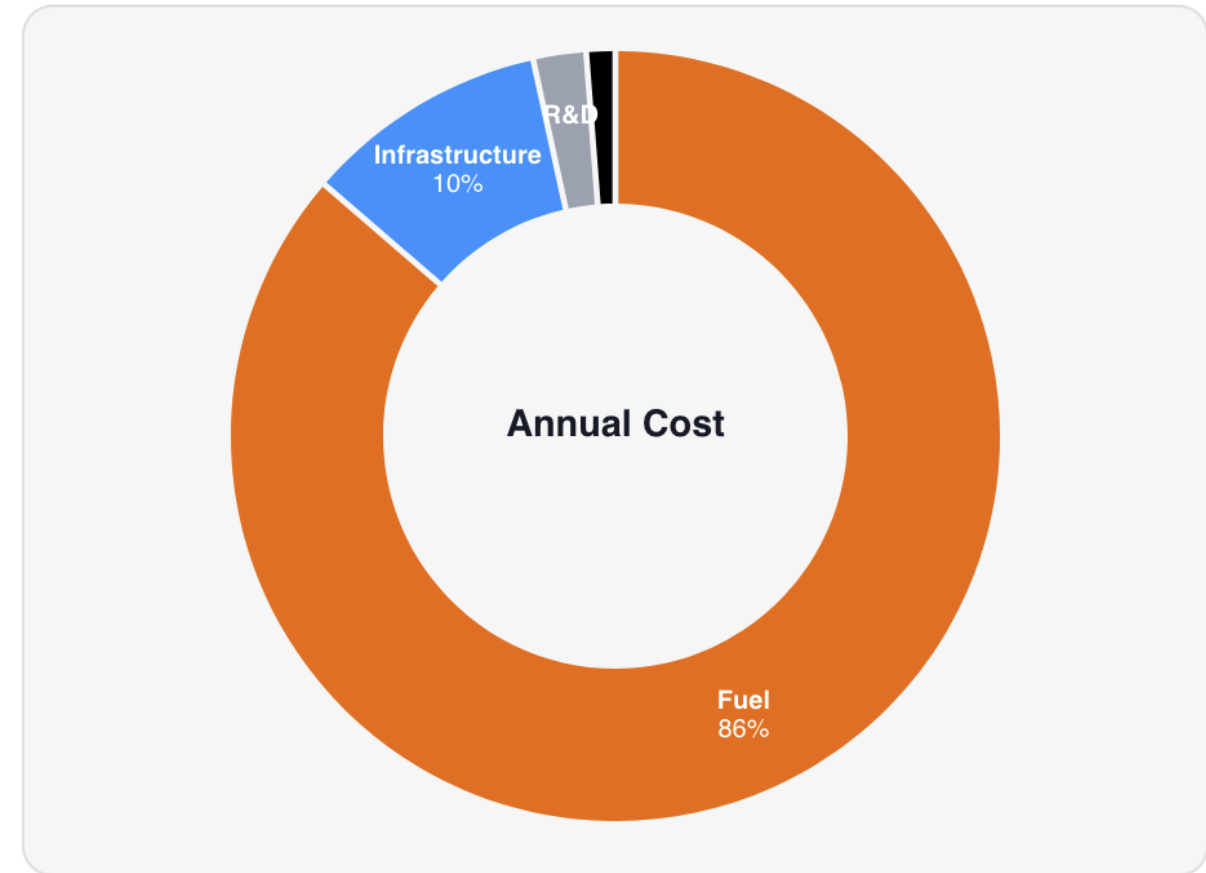
- ~5% of flights cause 80% of the contrail forcing
- ~70% reduction in forcing = ~0.1% increased cost
- At scale (estimate)
- ~\$1 – \$10 per tonne CO₂e abatement cost



This will still cost the airline industry money

- 0.1% added fuel to global aviation ~ \$230M / year
 - If SAF used, it will cost more
 - Air Traffic improvements will solve this

Need to develop incentives once tech has been refined and demonstrated at scale



The path forward

- The tools exist, but need more real-world validation and testing
- Early results are promising, but still small scale

The critical work moving forward

- 1. Large-scale airline and airspace trials
- 2. Benchmark contrail forcing with observations
- 3. Develop near- and long-term incentives to integrate contrail aware operations

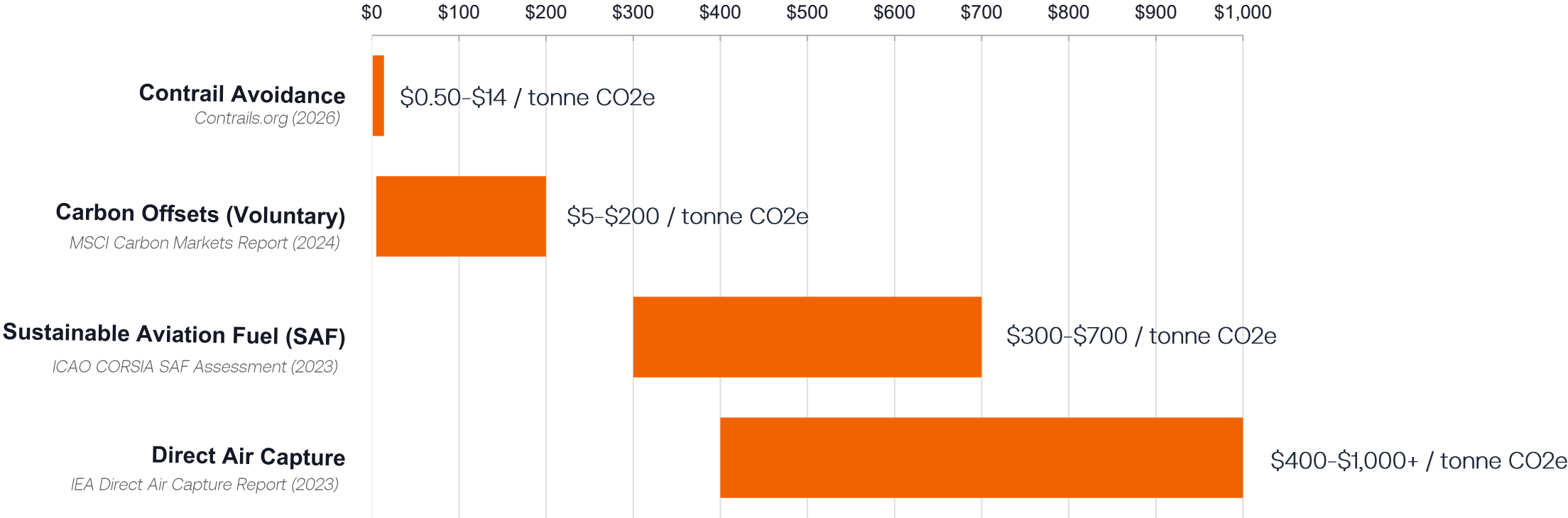
Thank you

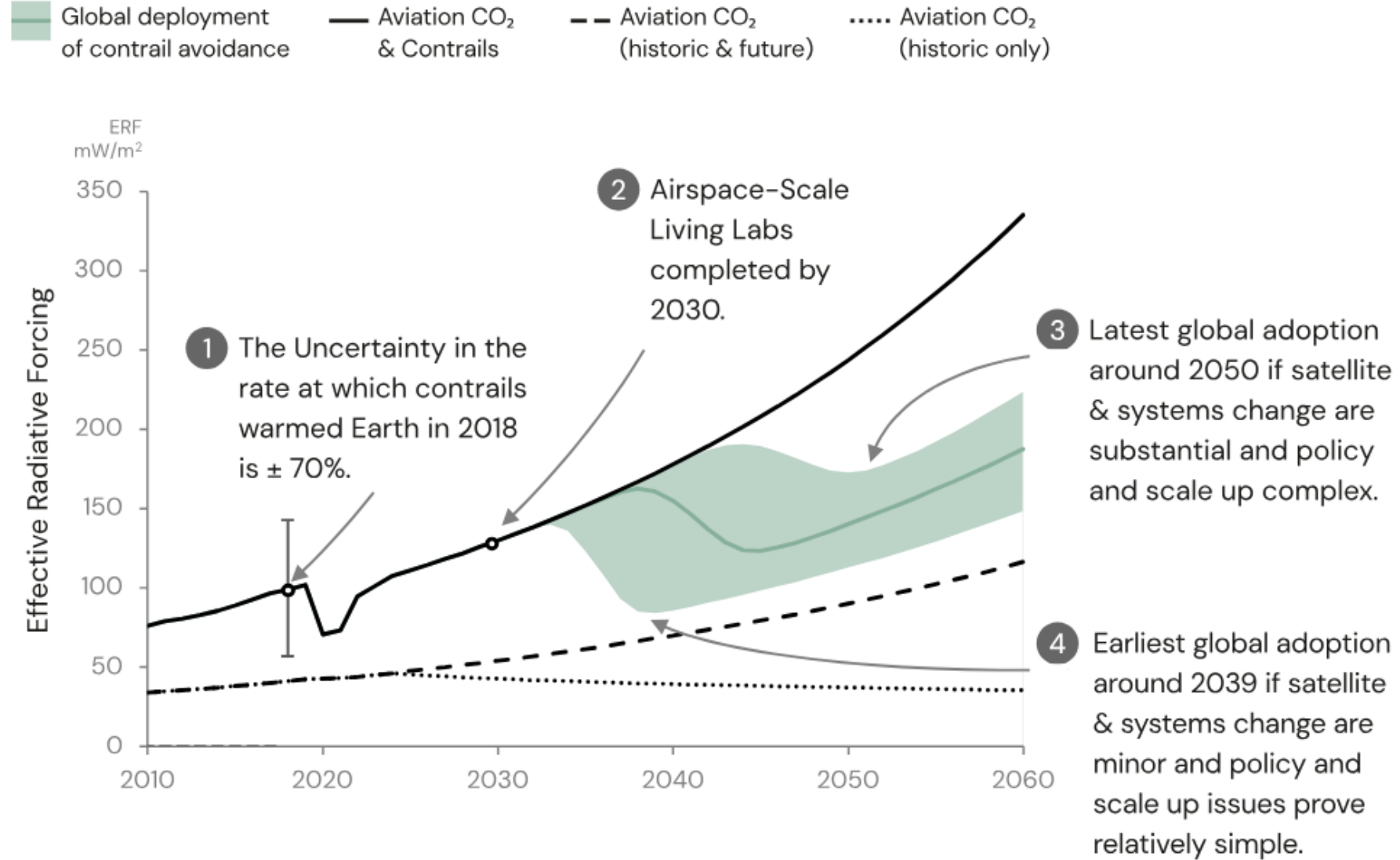
Contact

marc.shapiro@contrails.org



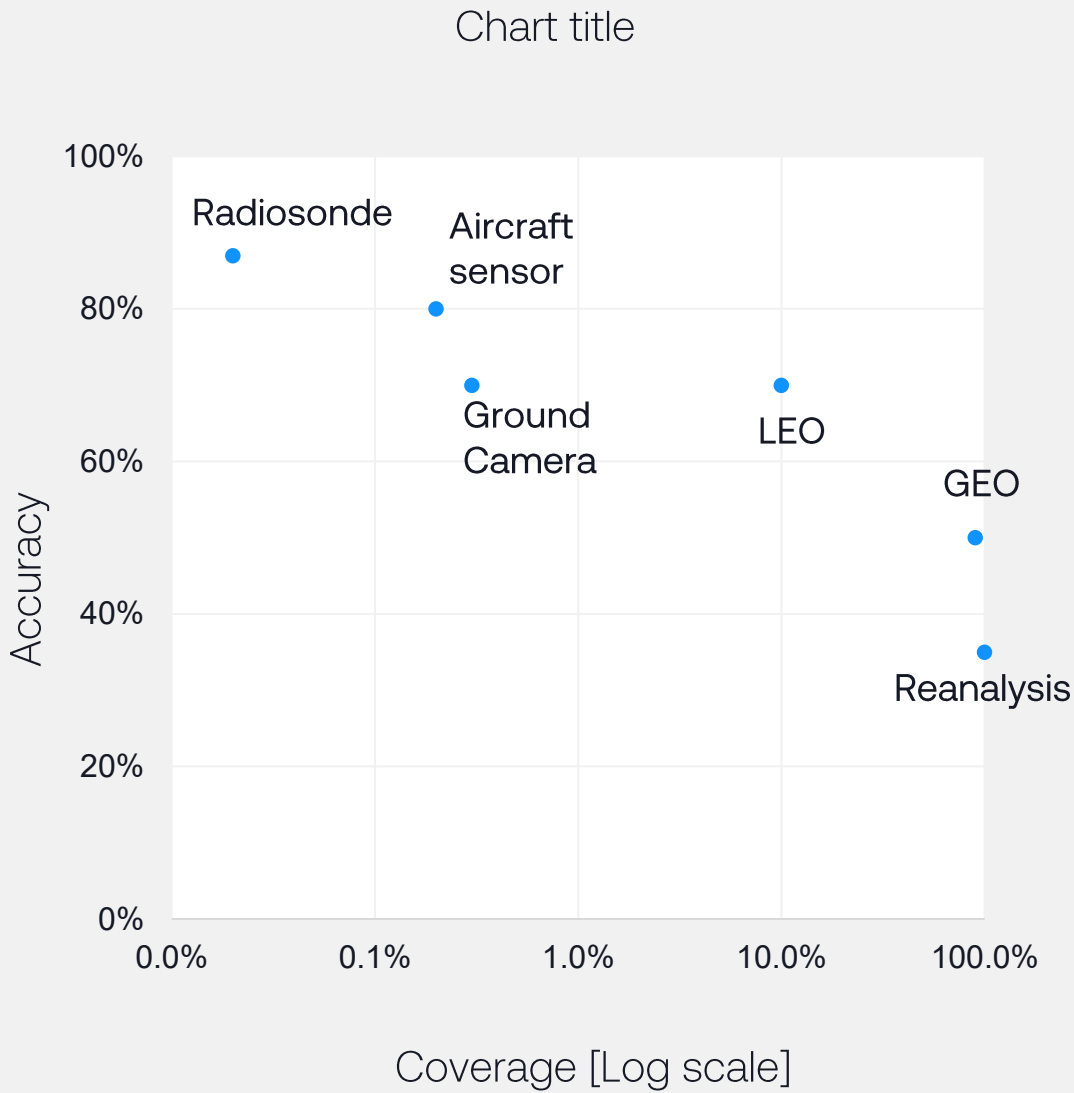
This among the lowest-cost climate interventions available





Observation limitations

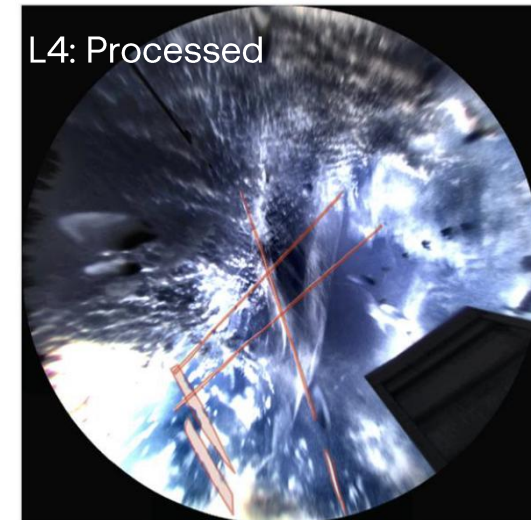
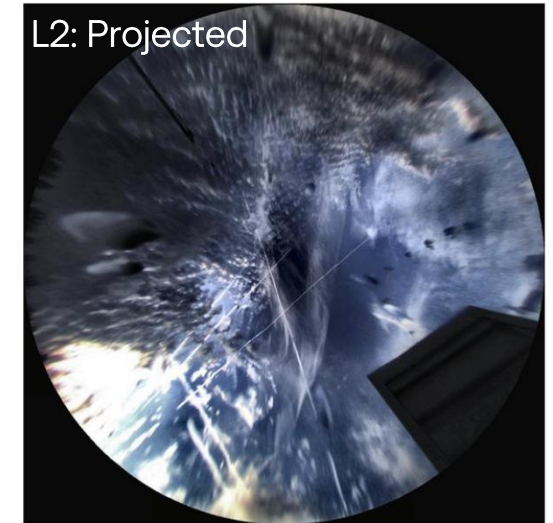
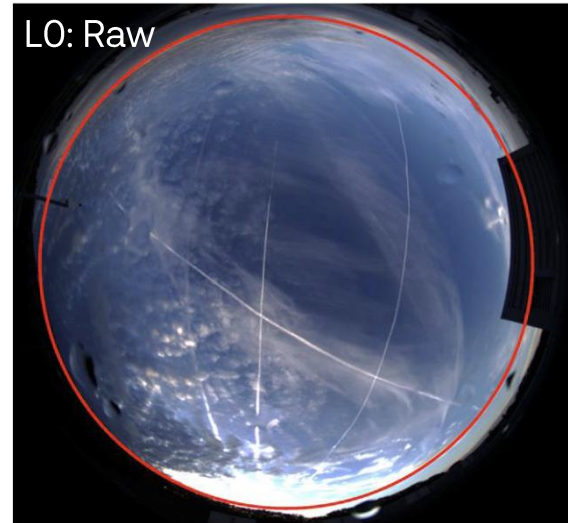
- High accuracy observations generally have low coverage



* Numbers either rough or placeholder currently

Observation limitations

- High accuracy observations generally have low coverage
- Observations have various levels of data processing
- Adopted a formal data process level hierarchy
 - L0: Raw, directly from the source
 -
 - L4: Outputs from models or analyses



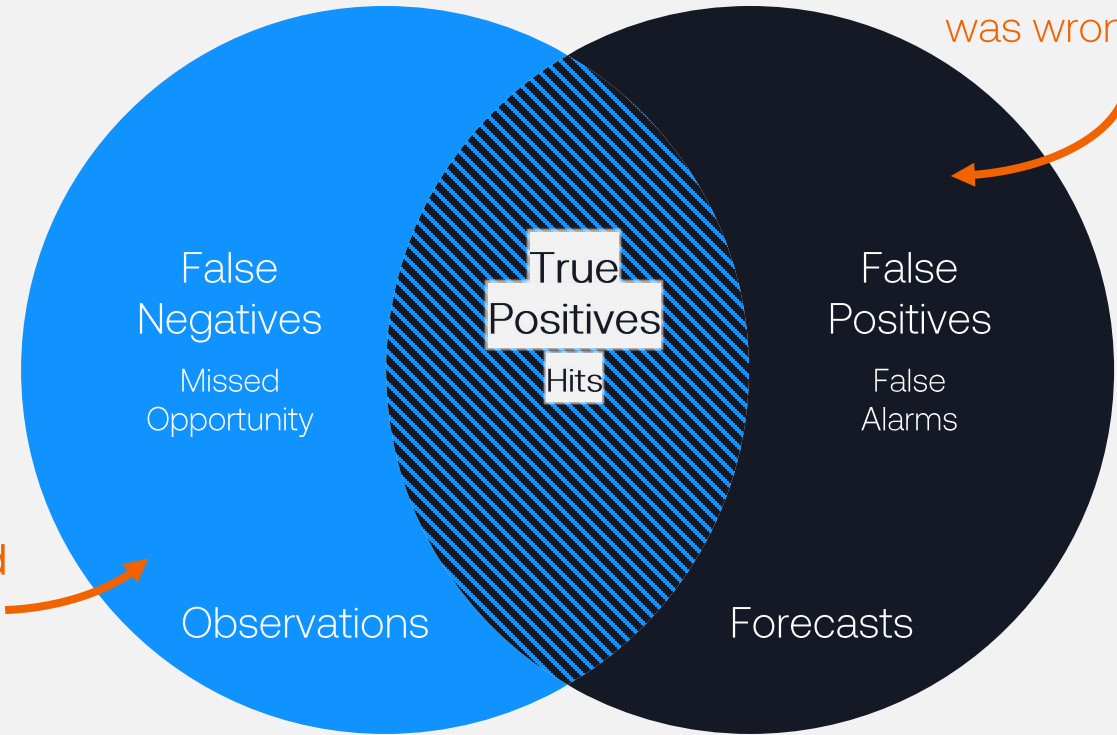
Consequence for contrail metrics

Observations can be used to measure hit rate, but not false alarm rate

● “Truth”: Observations of contrail regions

 **Hit Rate** (Recall)
% of contrail regions that are **observed** which were also forecasted

Observations **can** tell us about **missed opportunities**: we reliably detected a contrail, but never forecast one



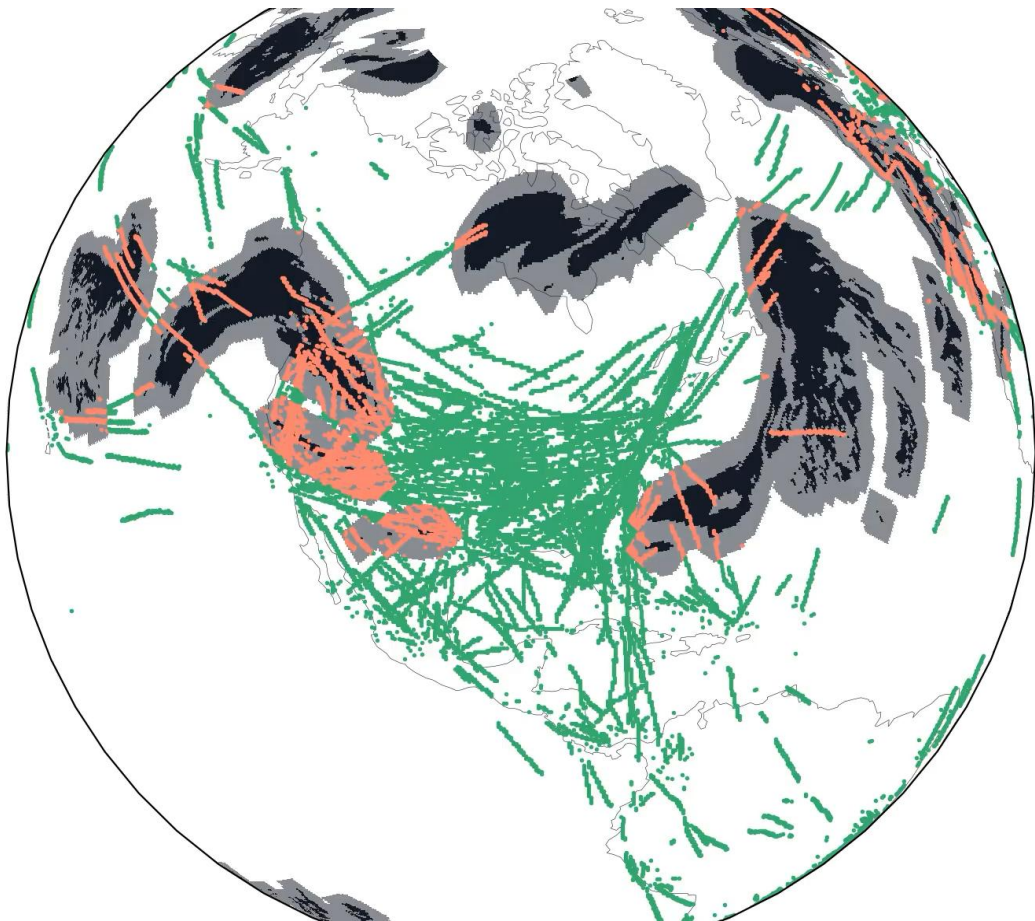
Observations **are poor** at confirming we made a **false alarm**: hard to tell if forecast was wrong or observation just missed it

False Alarm Rate
(1 – Precision)
% of contrail region forecasts that are false positives

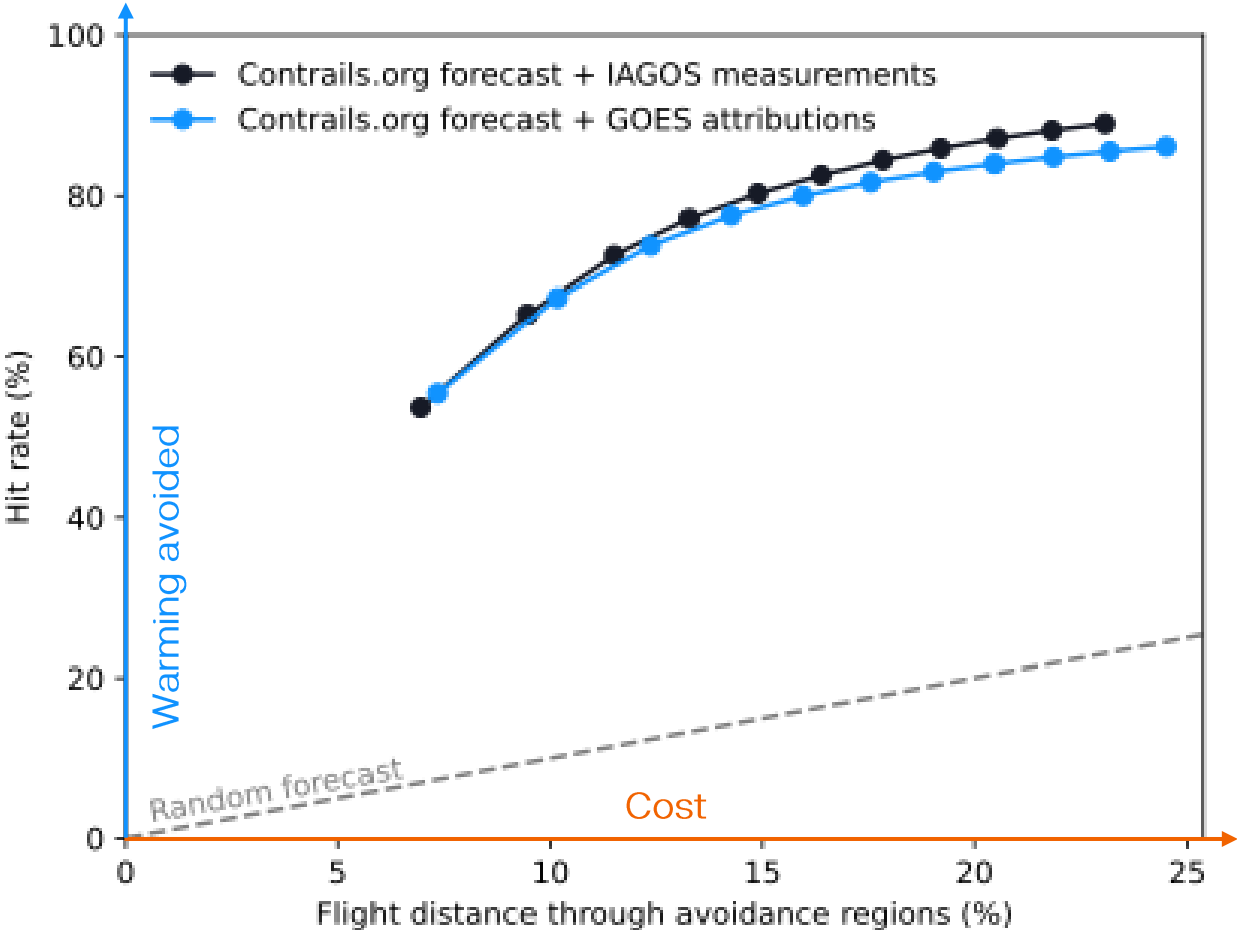


Forecast of Contrail Regions ●

Forecast benchmarking approach



■ Forecast region ■ Buffer



Trial Phasing

