Contrails and Their Impact on Climate

May 2, 2023

Aviation Noise & Emissions Symposium 2023

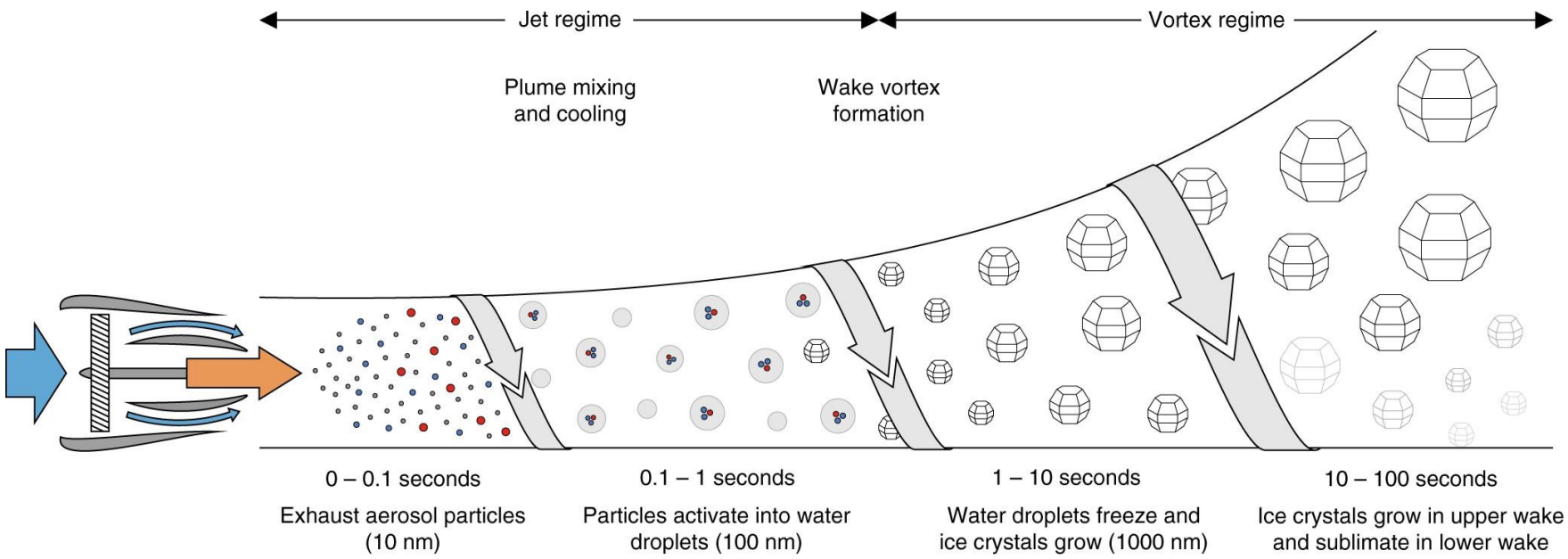
The Questions We Will Address Today

- What are contrails?
- Why do we care about them?
- How do we measure their environmental impact?
- What solutions exist for managing that impact?
- How is Delta working on those solutions?

What are contrails?

Contrails, short for condensation trails, are line-shaped clouds produced by aircraft engine exhaust or changes in air pressure.

Illustration of mechanisms and timeline behind contrail formation



This is not what always happens during flight. This is an illustration of contrail formation.

Why do we care about them?

There are **3 different types of contrails**, and they have been researched for different reasons.

Types of contrails:

Short-Lived	Persistent Non-Spreading	Persistent Spreading
		

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Early interest in contrails was from militaries. Contrails revealed the locations of aircraft, which was a surprise in the early 20th century.

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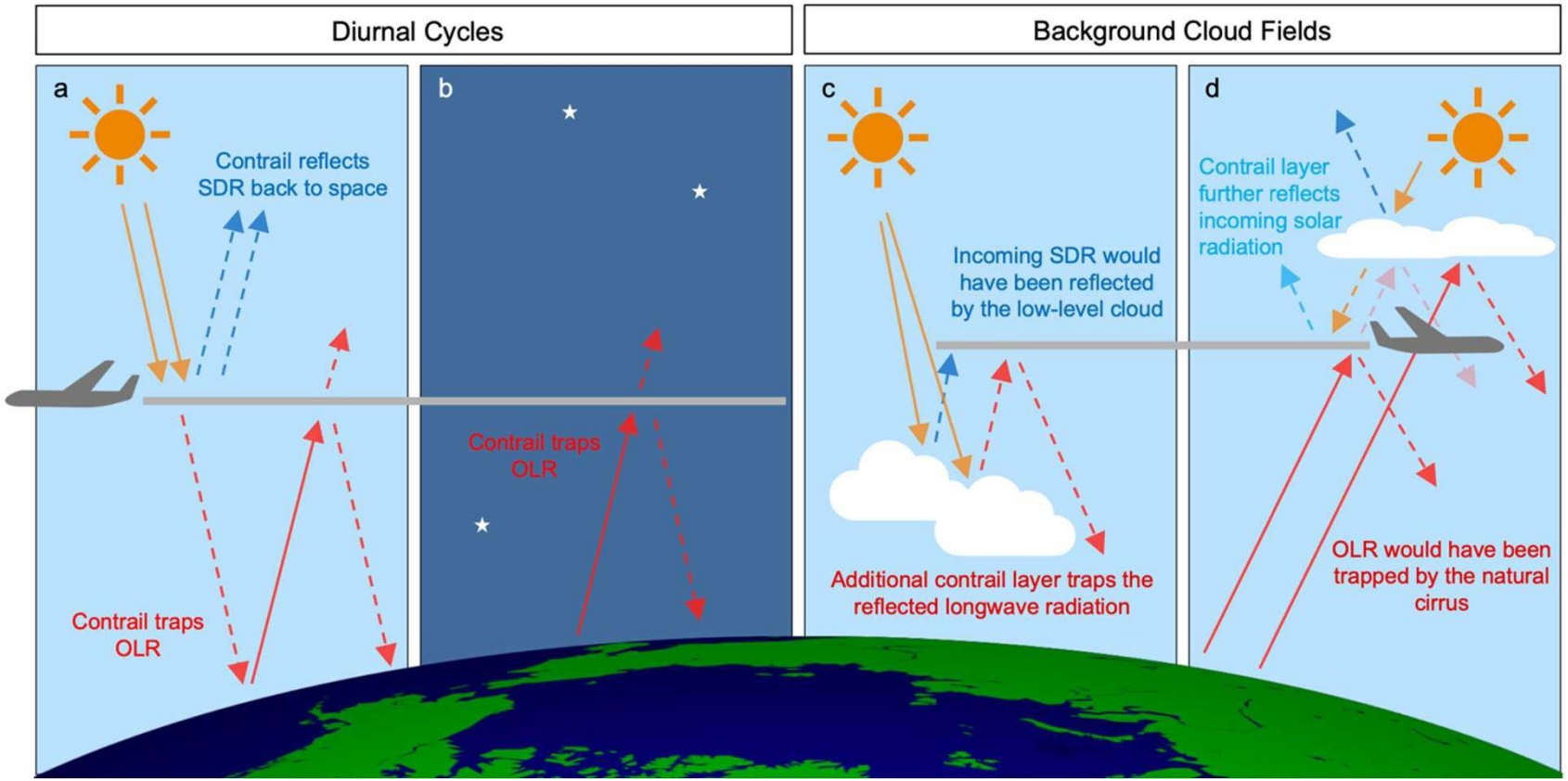
Today, research is focused on their environmental impact. In particular, persistent spreading contrails are widely considered a large portion of aviation's contribution to warming

Why do we care about them?

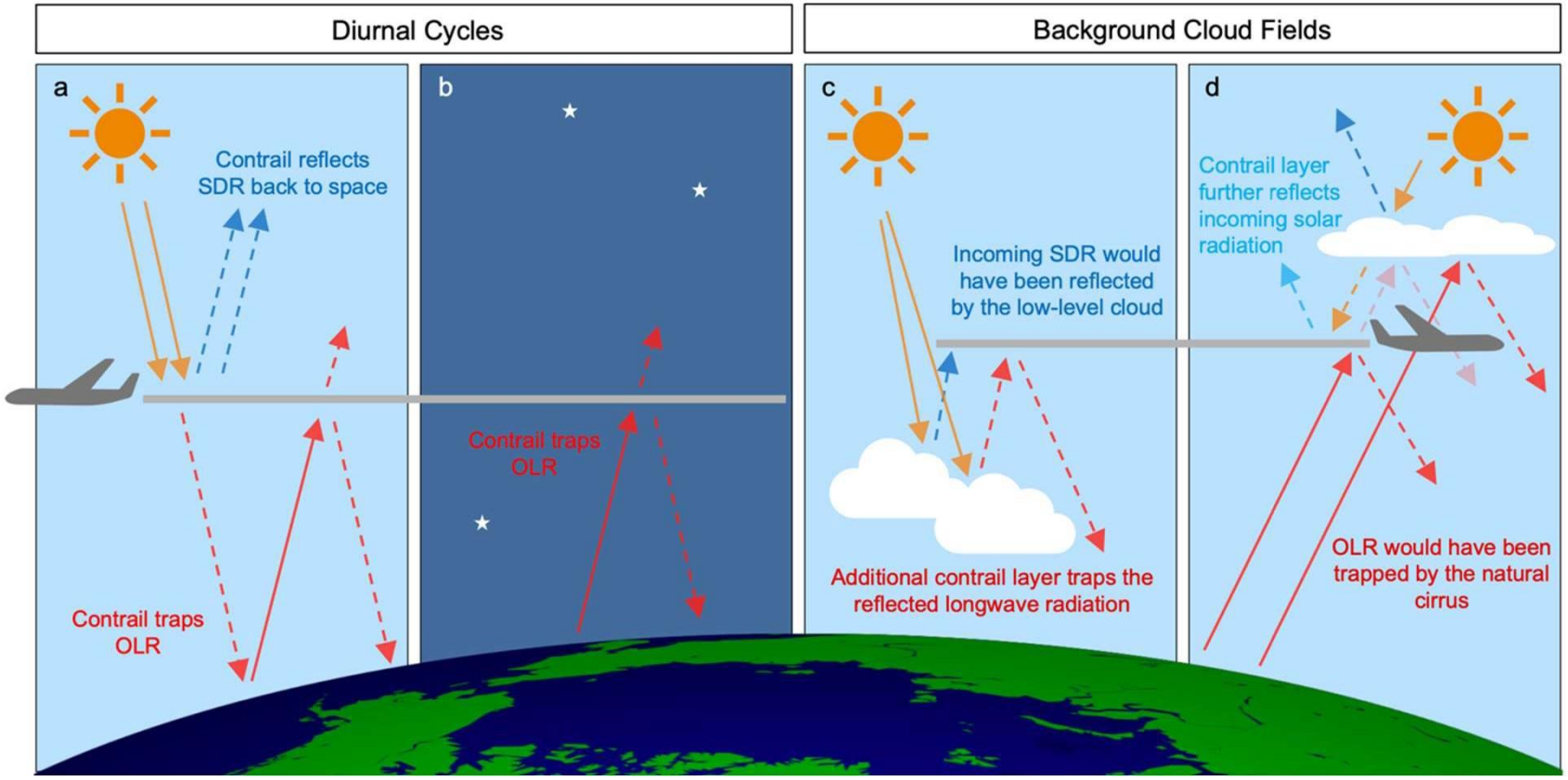
Persistent contrails have a **radiative forcing** effect that can be **warming or cooling** based on ambient conditions and time of day.

Radiative forcing is determined by observing the balance of incoming solar direct radiation (SDR) and outgoing longwave radiation (OLR)



How do we measure their environmental impact?

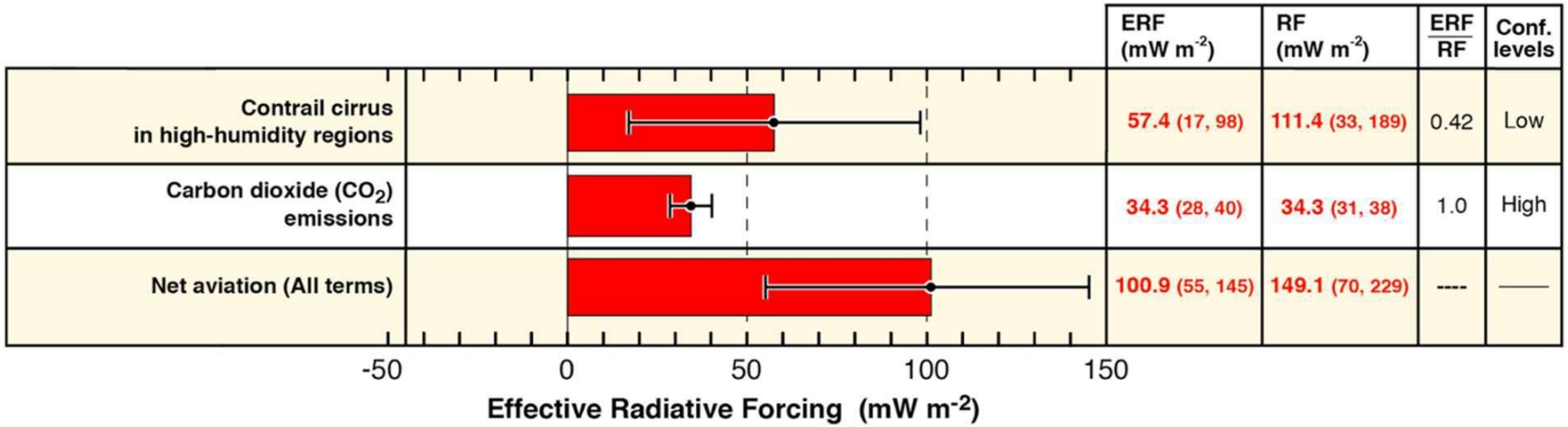
On a theoretical level, measurement is straightforward. You measure the balance of incoming solar radiation and outgoing longwave radiation.



How do we measure their environmental impact?

In practice, measurement relies on modelling and is **dependent on parameters that are up for debate.** Estimates of contrails' warming impact vary widely as a result.

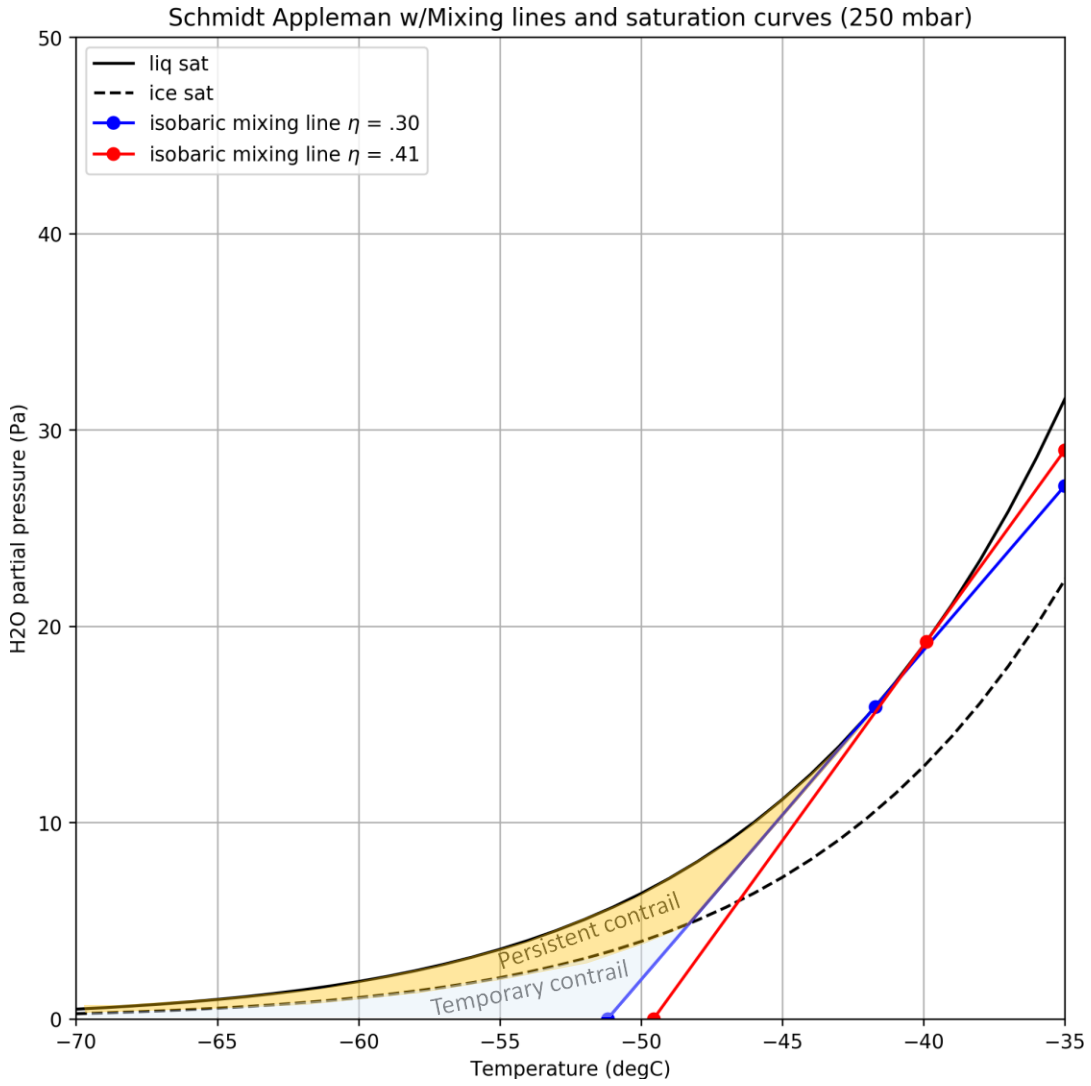
Effective Radiative Forcing is a measure that allows for comparison of different climate warming factors on a level playing field



Estimates of ERF for contrails varies heavily due to differences in assumptions about parameters like contrail size, ambient conditions, ice crystal shape

What solutions exist?

Persistent contrails form in **ice supersaturated regions,** where conditions are sufficiently cold and humid.



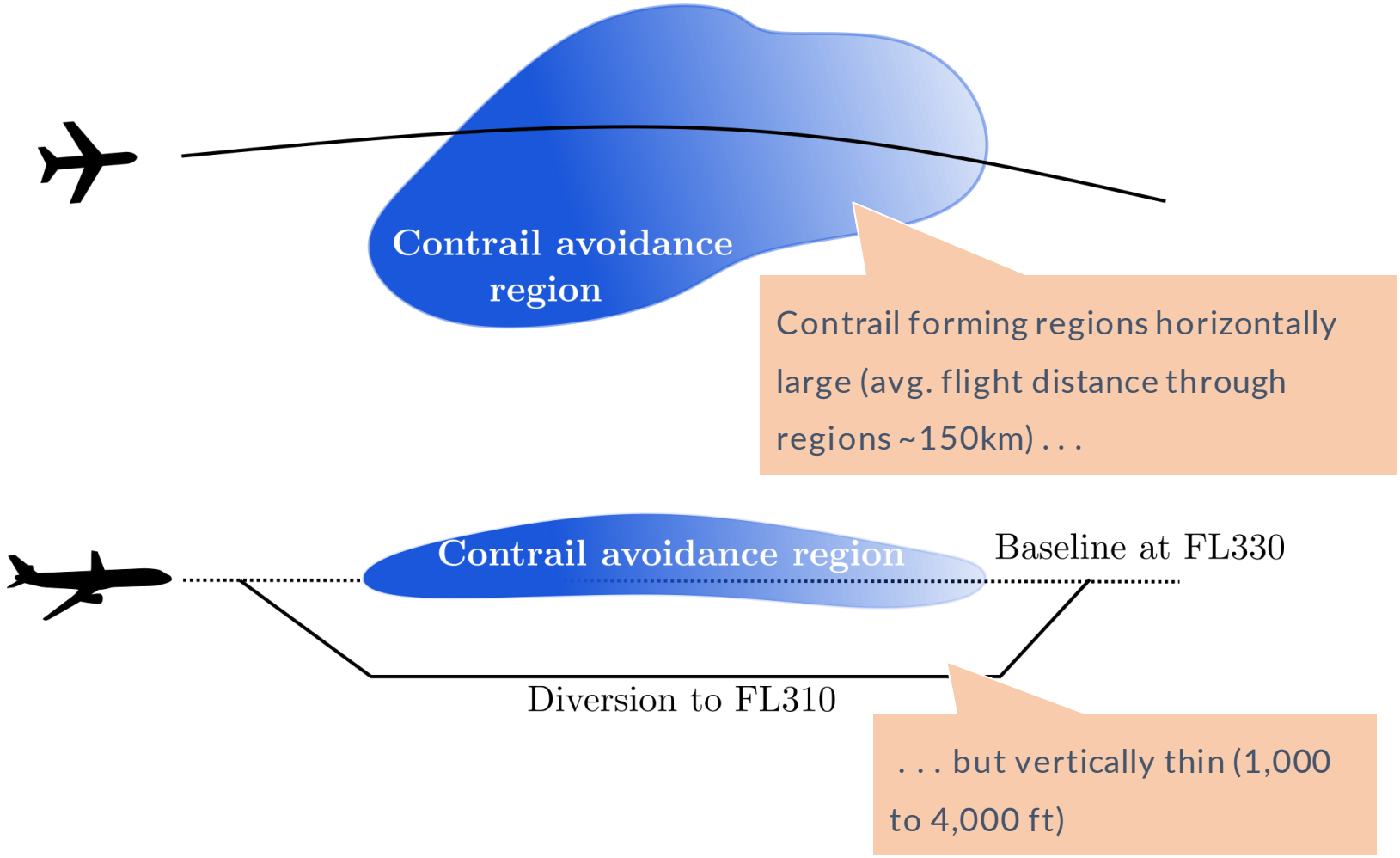
Shown here are example zones for persistent and temporary contrails, considering overall propulsive efficiency for 2 different engine/aircraft combinations (η=.30 and .41).

What solutions exist?

Fuel Switching	• **Approach:** Use fuels with lower soot emissions over certain areas to reduce contrail thickness • **Implementation:** Requires identification of regions and relevant fuels; fuel system changes required
Engine Modification	• **Approach:** Reduce soot emissions to produce thinner, shorter-lived contrails • **Implementation:** Adoption of lean burn / staged combustion
Convoying	• Wake-surfing has been shown to **reduce fuel burn and CO2 emissions** by up to 10-15% • **Substantial reductions in contrail optical thickness** may be possible (reduced available water content and overlapping contrails)
Deviation	• **Approach:** Avoid flying at regions and altitudes with high likelihood of contrail formation and persistence • **Implementation:** Identify regions with high humidity and low temperatures

What solutions exist?

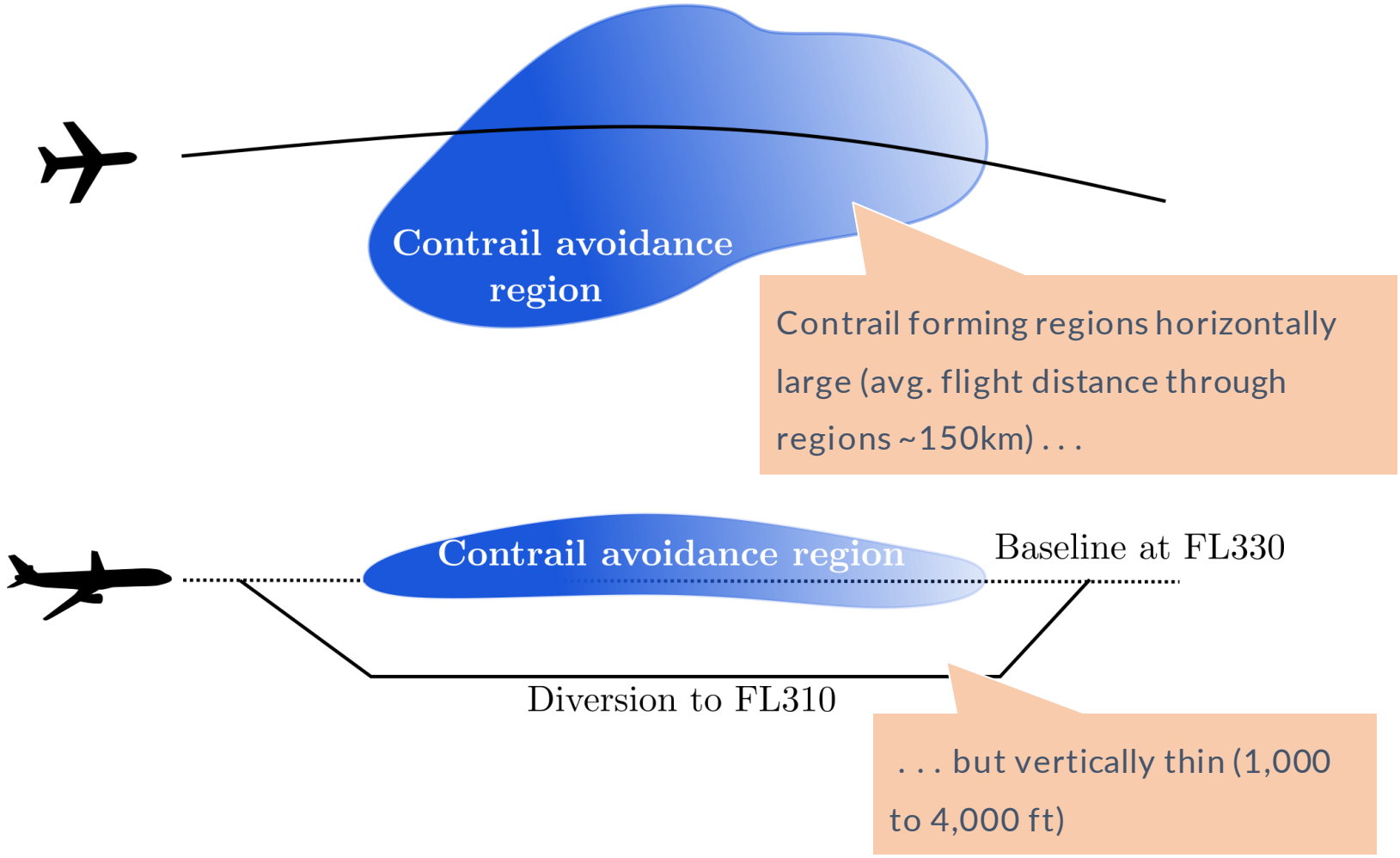
These ice supersaturated regions tend to be **horizontally wide but vertically thin.** Researchers estimate these regions **can be avoided with minimal fuel burn**



Gierens et al. 2000, Spichtinger et al. 2003, Teoh et al. 2020

What solutions exist?

But how well can we predict the regions we want to avoid?



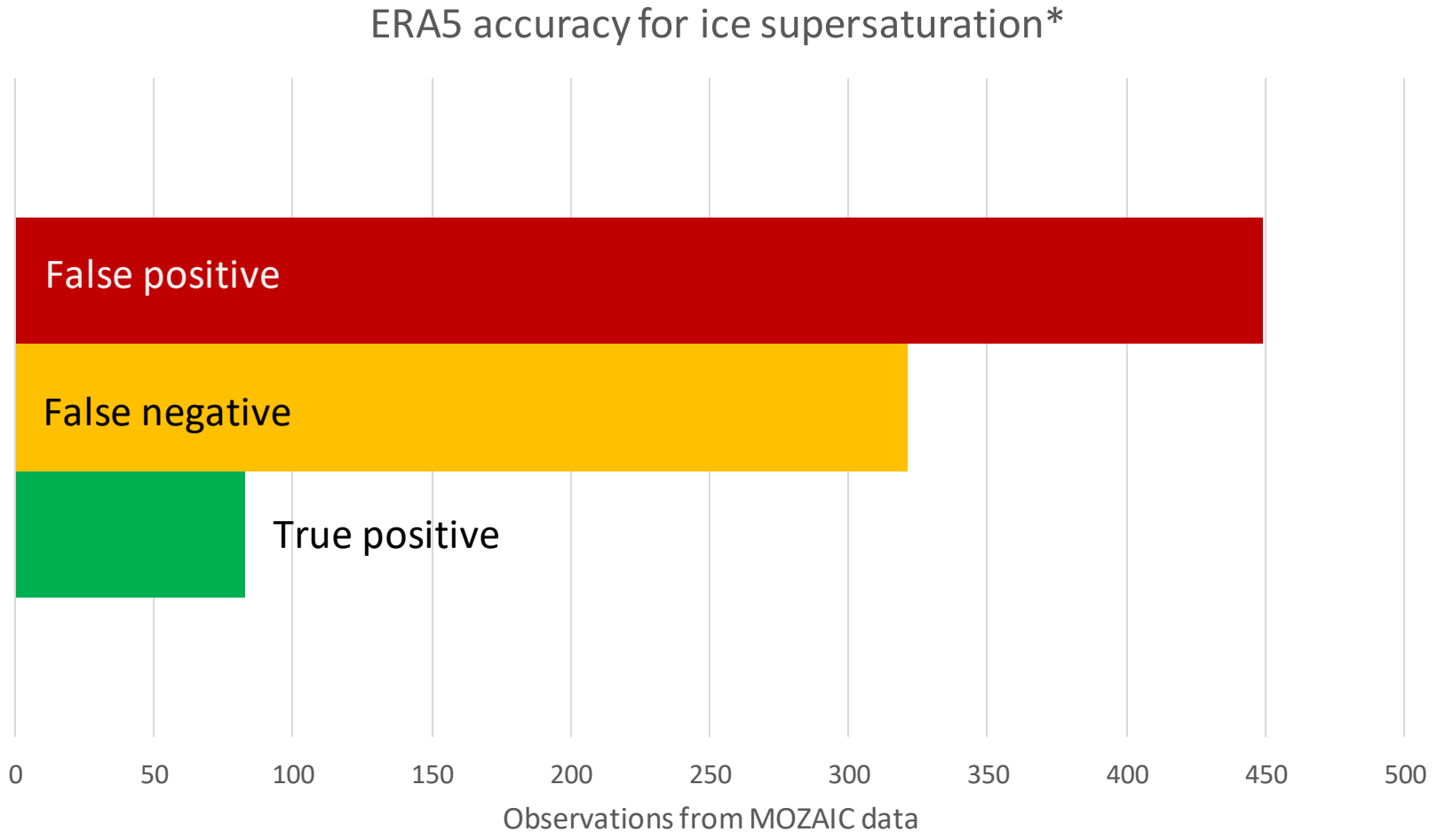
Gierens et al. 2000, Spichtinger et al. 2003, Teoh et al. 2020

What solutions exist?

But how well can we predict the regions we want to avoid?

Not that well.

Today's **forecast-based models** are not accurate enough.



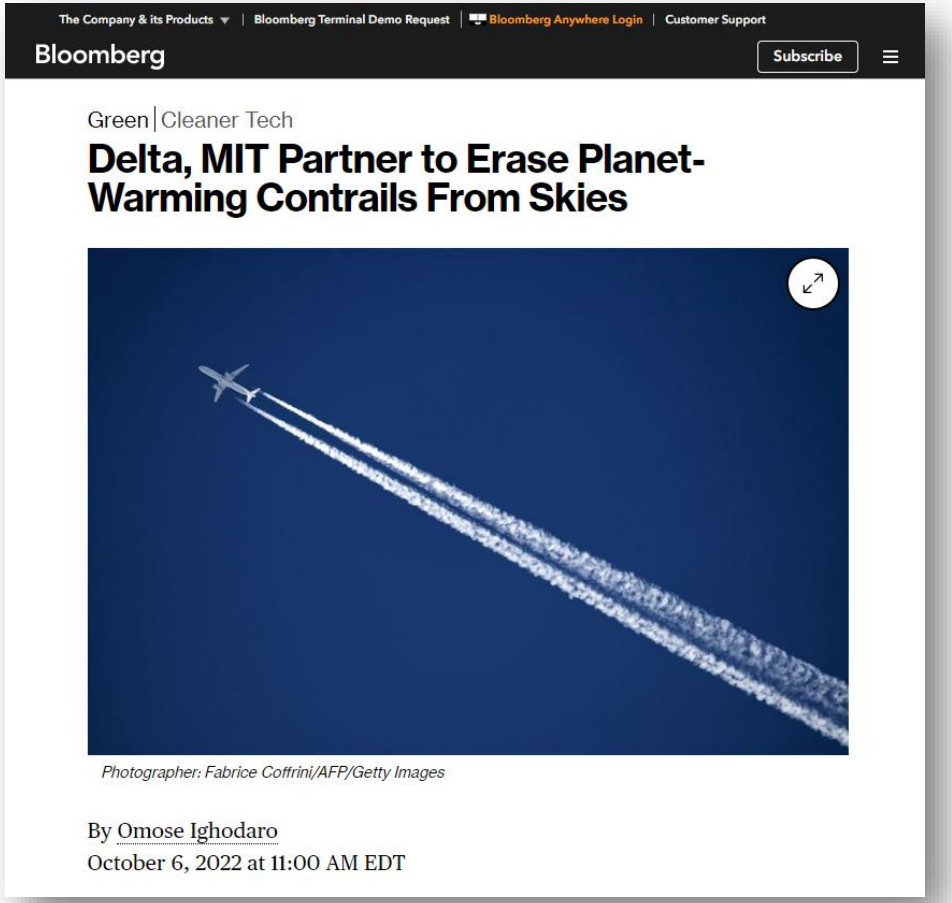
Gierens et al., 2020

Collaborating on Contrails Research

Delta and MIT are working to address fundamental obstacles to avoidance:

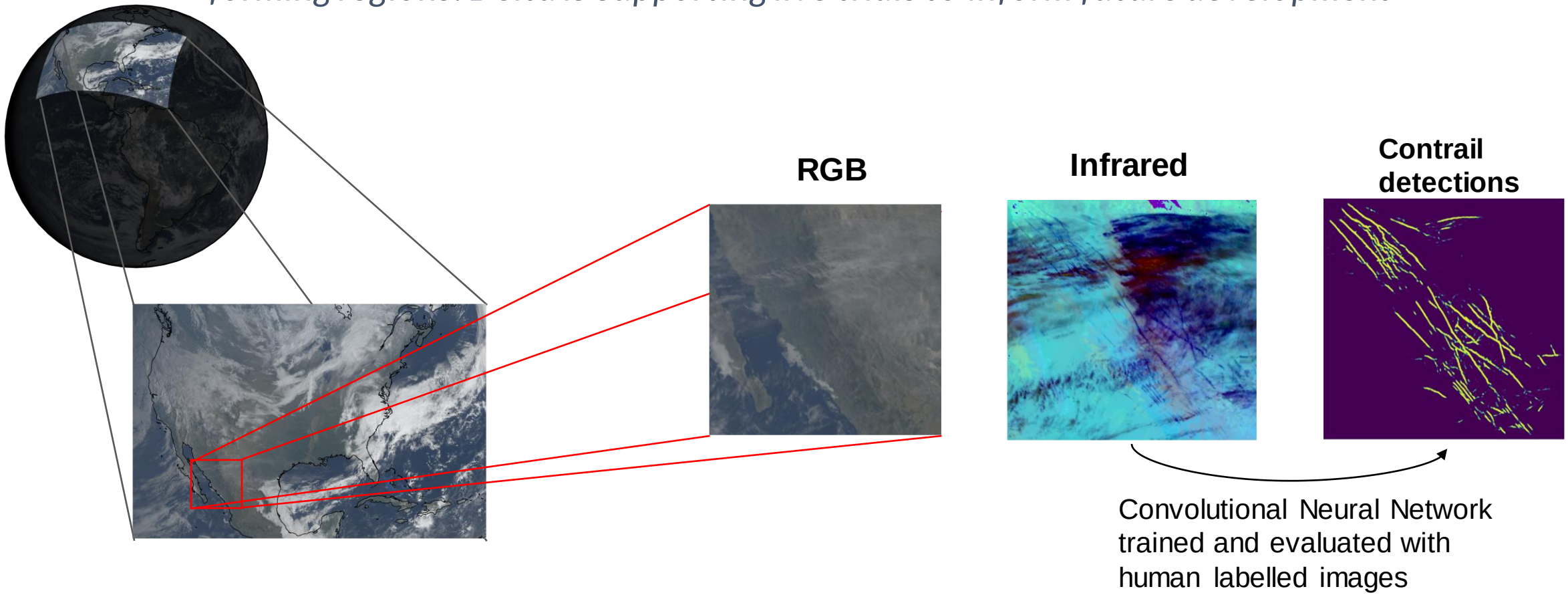
- Accuracy of predictive models for relevant persistent contrail forming regions
- Post-flight analysis methods and techniques

Advancements in both are needed before considering integration of avoidance in the operation

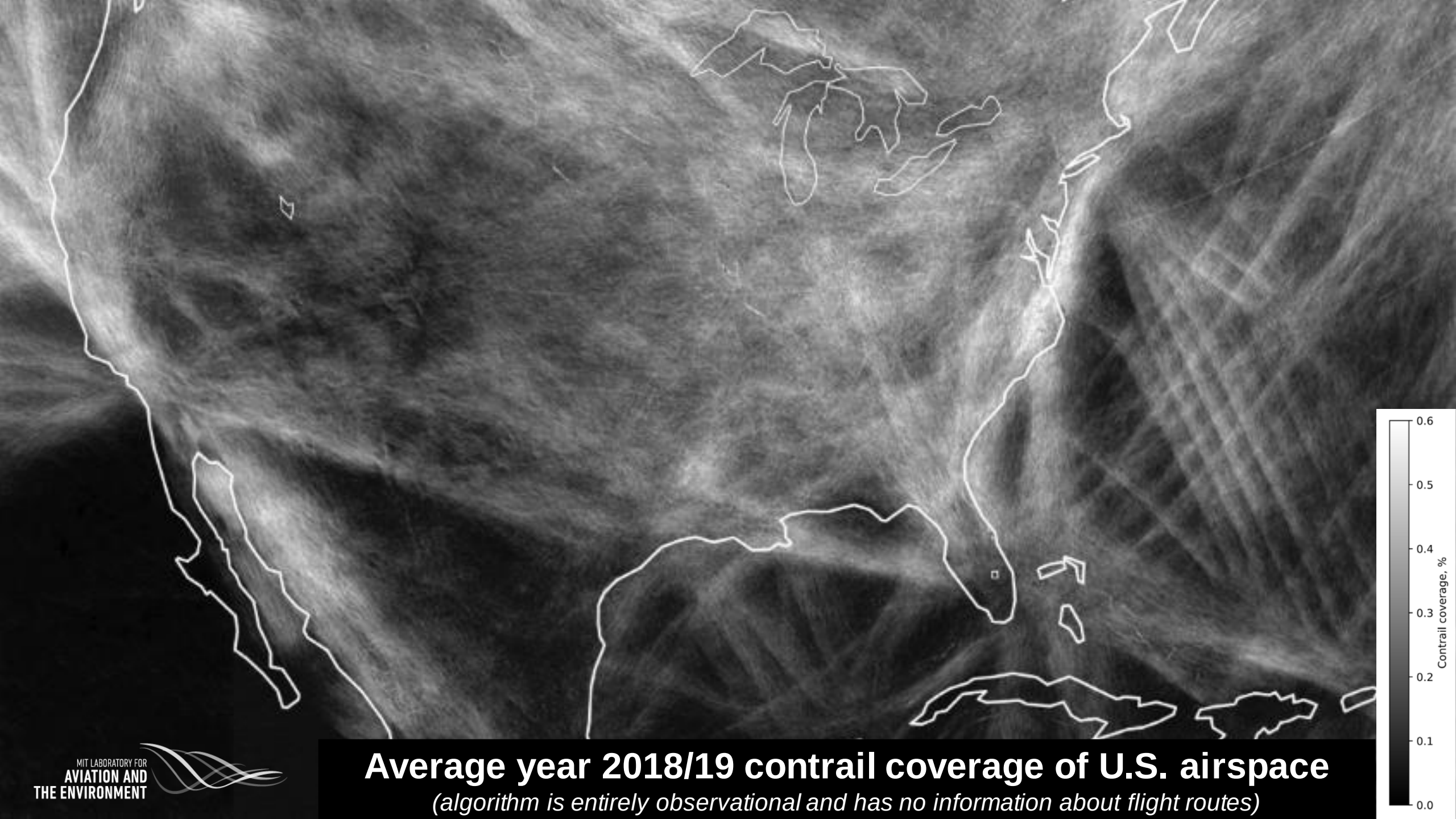


How is Delta supporting these solutions?

MIT has developed new capabilities to use observation-based methods for identifying contrail forming regions. Delta is supporting live trials to inform future development



Meijer et al. (2022), Contrail coverage over the United States before and during the COVID-19 pandemic



MIT LABORATORY FOR
AVIATION AND
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Average year 2018/19 contrail coverage of U.S. airspace

(algorithm is entirely observational and has no information about flight routes)

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Q&A