

Addressing non-CO2 impacts of aviation on climate change

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MIT LABORATORY FOR
**AVIATION AND
THE ENVIRONMENT**

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Addressing the non-CO₂ impacts of aviation

Florian Allroggen

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MIT

1

What are the non-CO₂ impacts of aviation? What do we know about the magnitude of these impacts?

2

What can we do to mitigate these impacts – specifically the impacts of contrails?

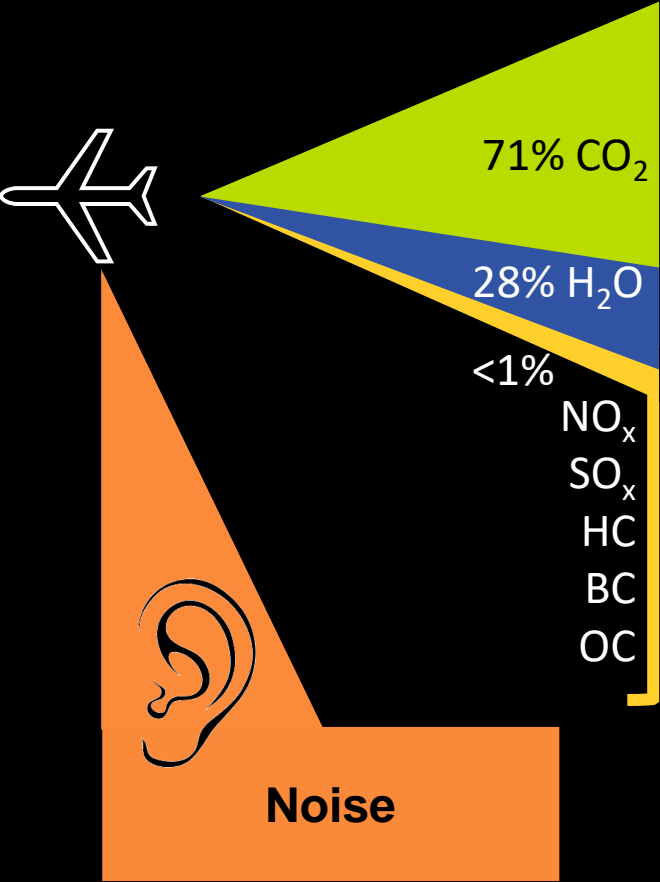
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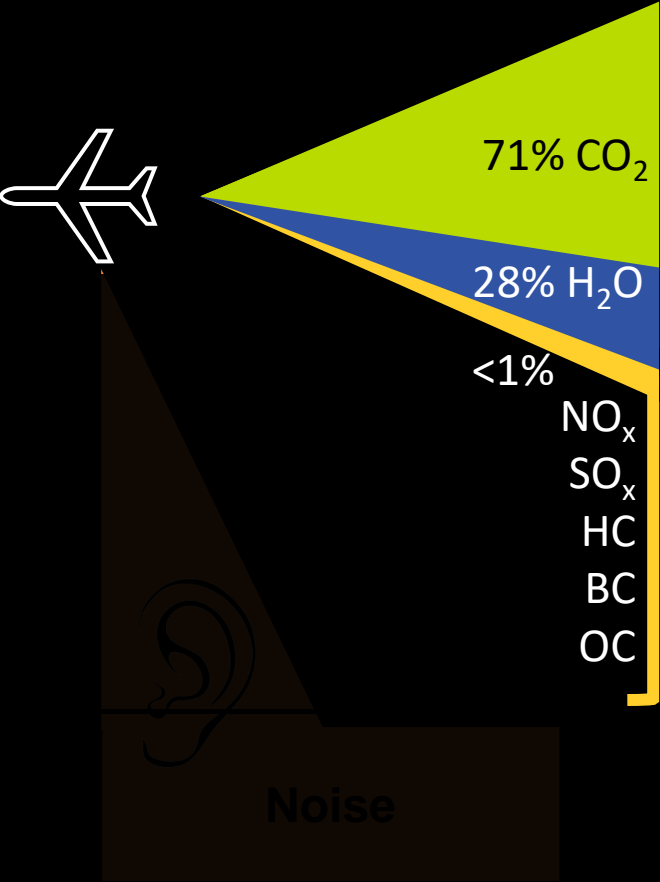
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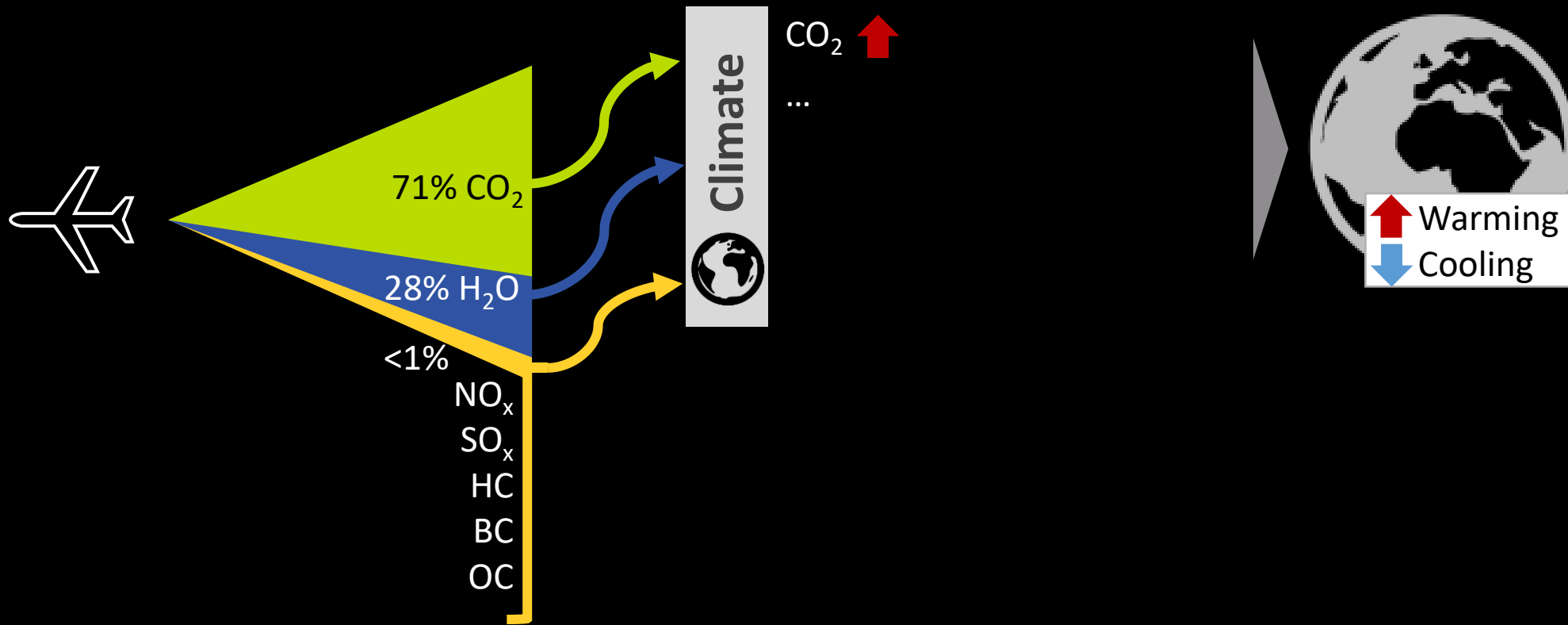
Aircraft are associated with emissions...



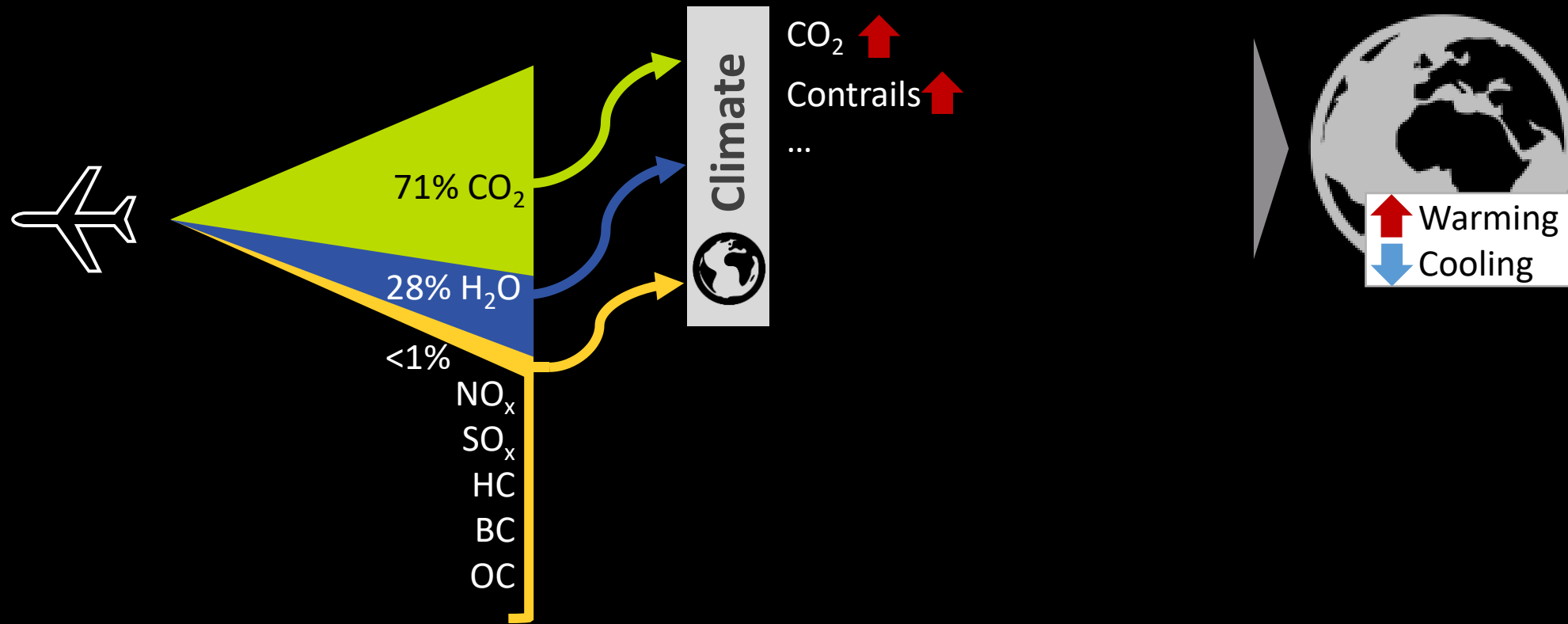
Aircraft are associated with emissions...



... and the emissions are associated with impacts



... and the emissions are associated with impacts



Contrail formation:

If air is sufficiently cold and humid, a contrail will form as water droplets freeze on particles in the plume.

Contrail lifetime

Seconds to minutes

**Non-persistent
contrail**



Minutes to hours

**Persistent
linear contrail**

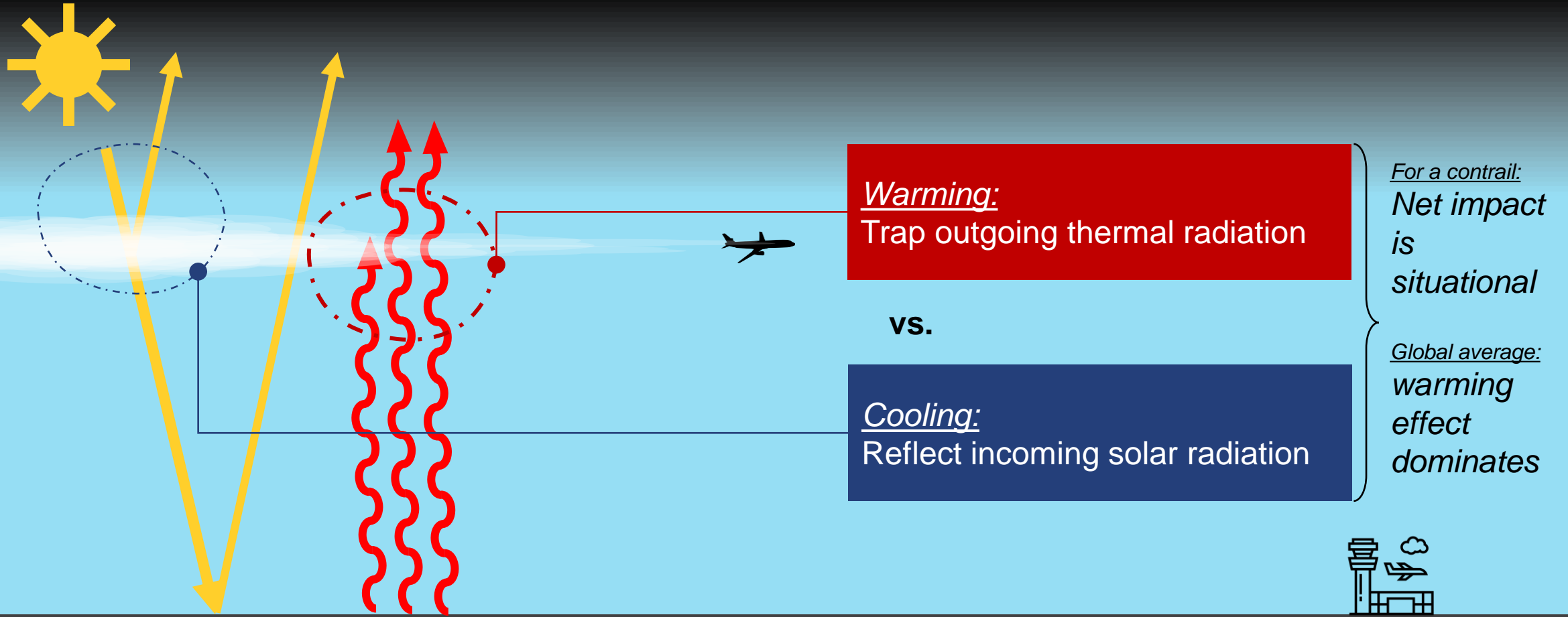


Hours (likely less than 6-8 hours)

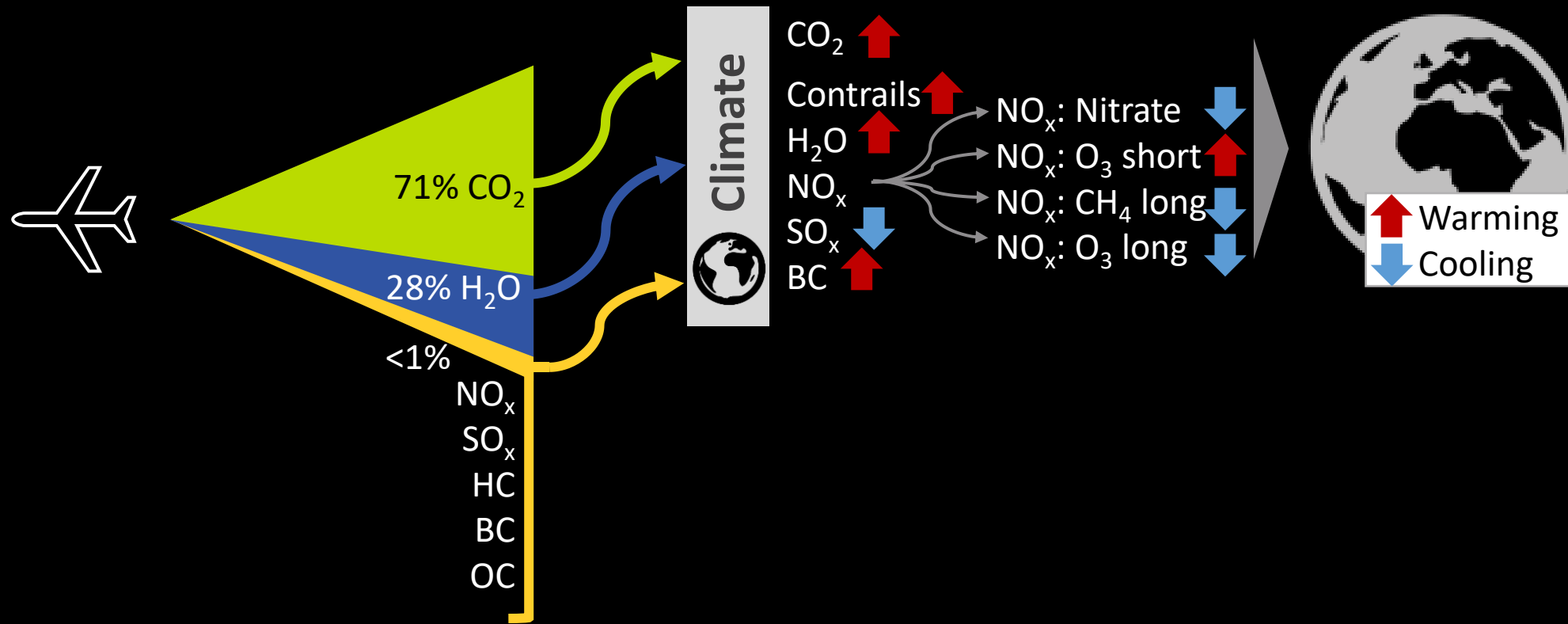
**Persistent
diffused contrail**



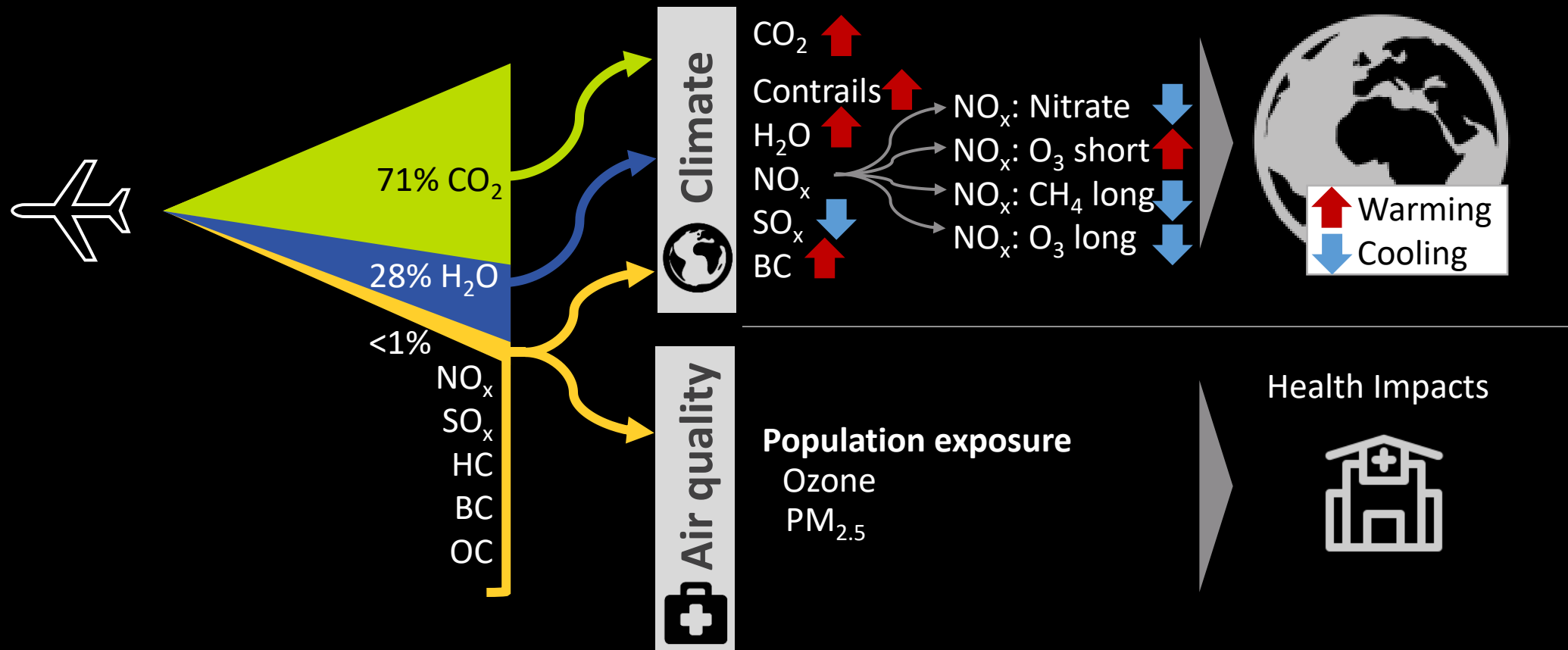
Climate impacts of contrails



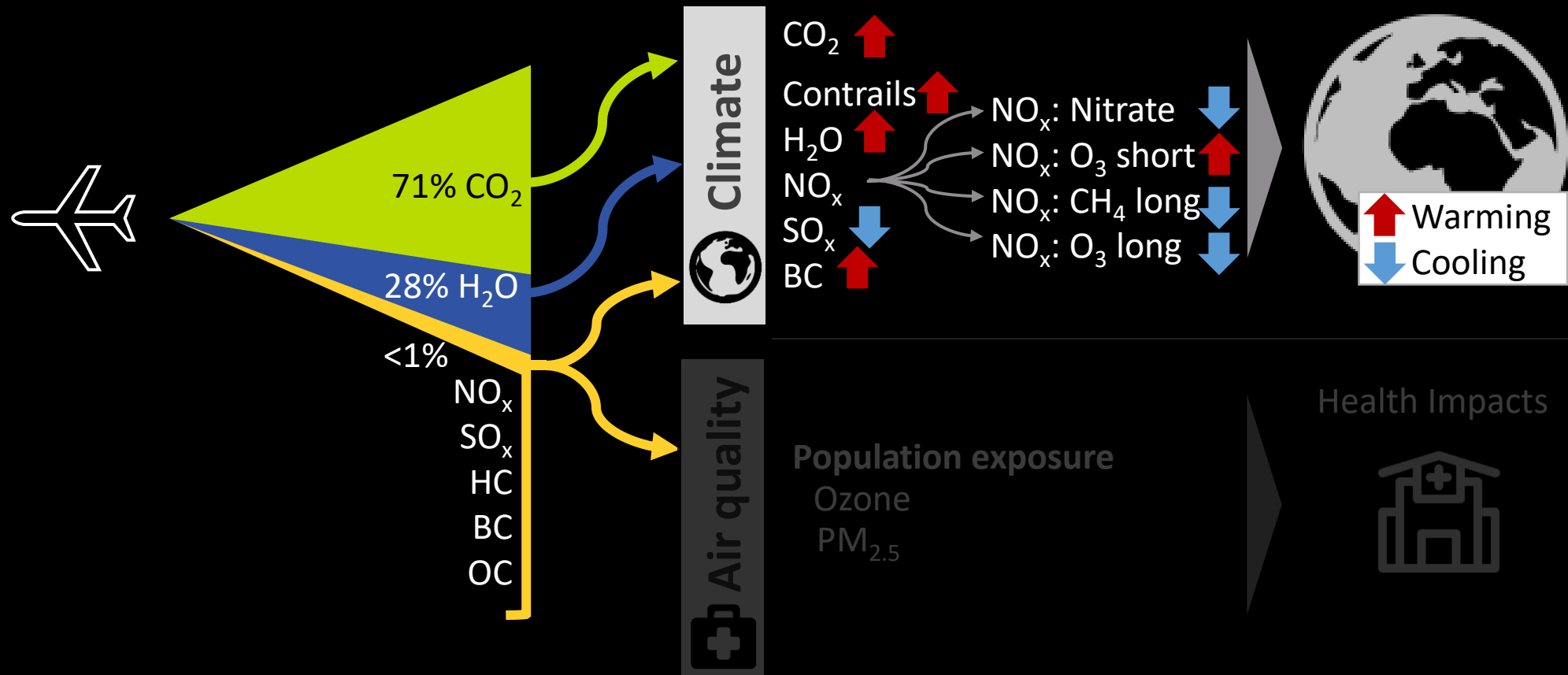
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Impacts
*(\$ per tonne of fuel
burn)*

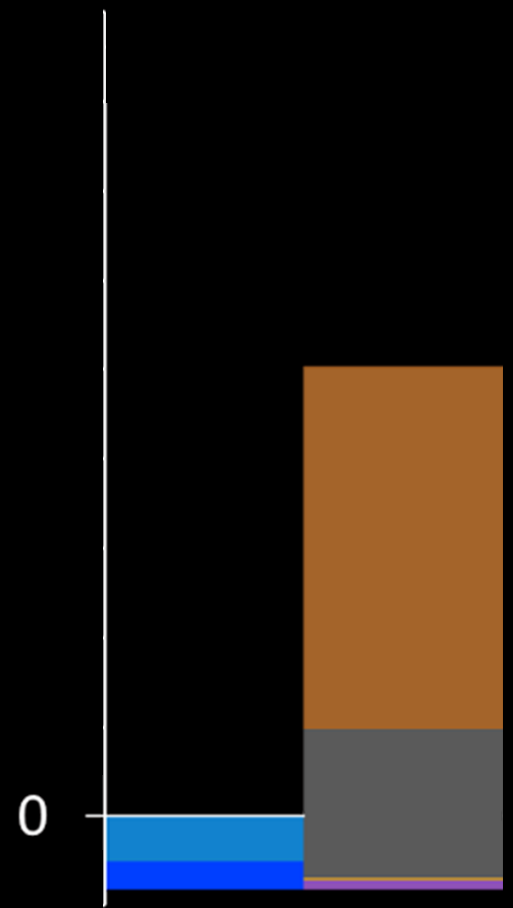
0

Impacts
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0



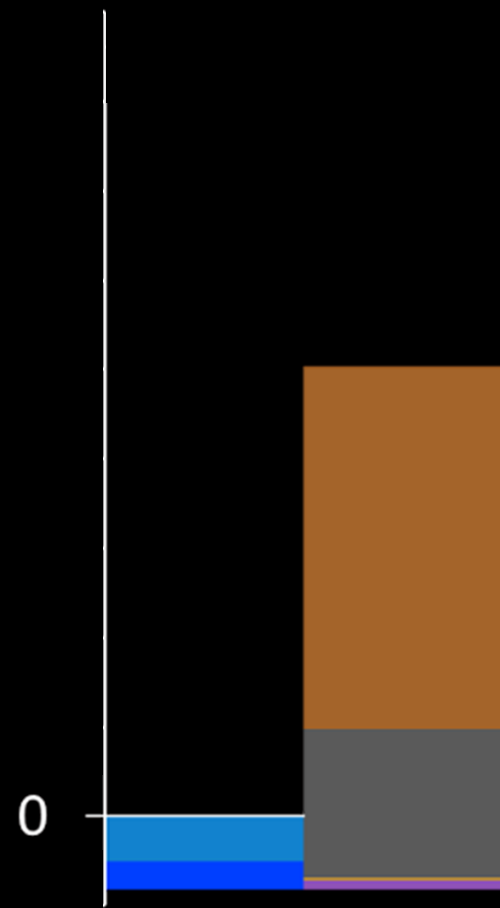
Impacts
(\$ per tonne of fuel burn)



- CO₂
- NO_x
- Contrail-Cirrus
- Fuel Sulfur



Impacts
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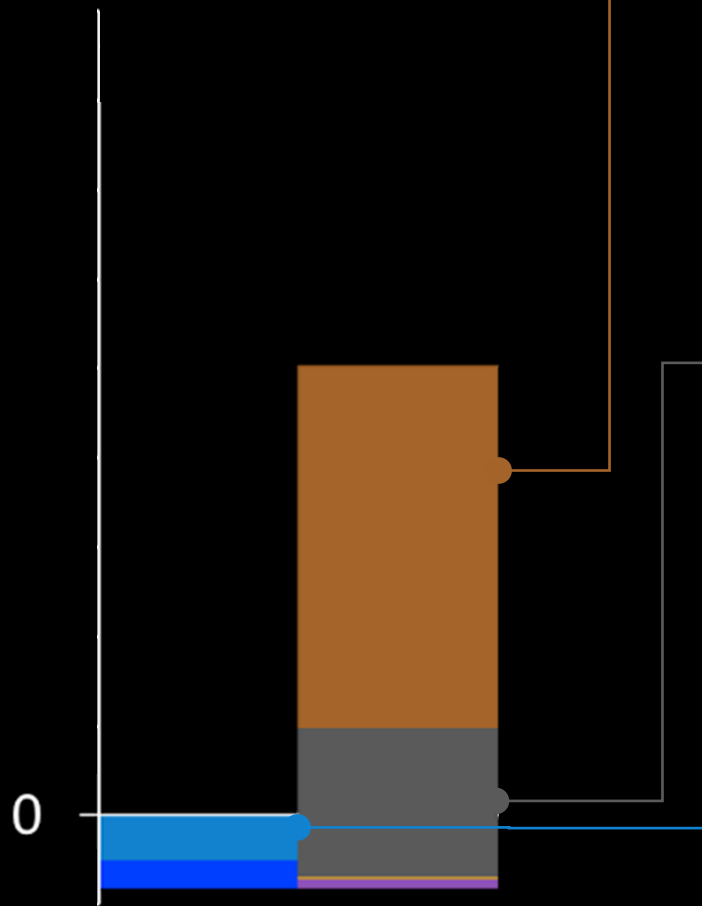


Relative significance of impacts varies with the valuation of current vs. future impacts associated with a unit of emission today (i.e., discount rate)

- CO₂
- NO_x
- Contrail-Cirrus
- Fuel Sulfur



Impacts
(\$ per tonne of fuel burn)



CO₂ impacts:

Uncertainties specifically in the quantification of impacts

Contrail impacts:

- Significantly more uncertain than CO₂, but agreement on warming impact
- Uncertainty remains when modeling a contrail for a specific flight

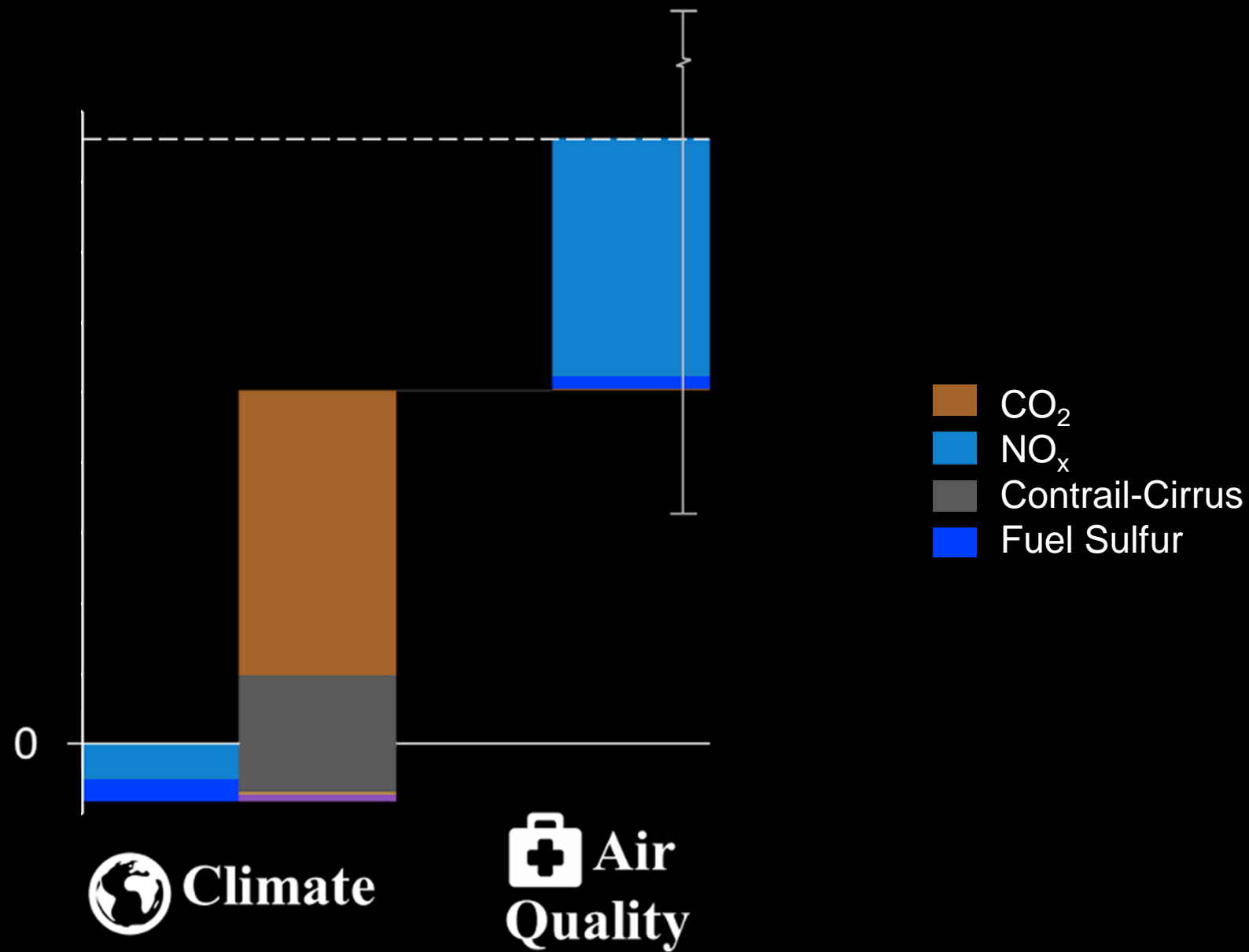
NO_x impacts:

- Integrated NO_x climate impact generally agreed to be smaller than CO₂ or contrail impact
- NO_x causes air pollution impact

- CO₂
- NO_x
- Contrail-Cirrus
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Impacts
(\$ per tonne of fuel burn)



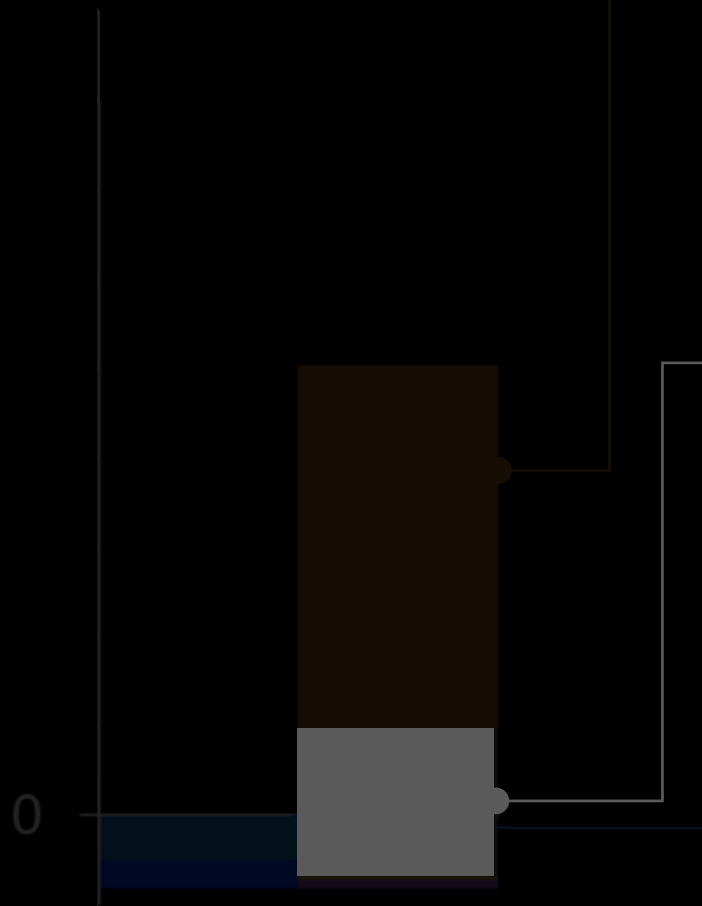
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 **Climate**

 **Air Quality**

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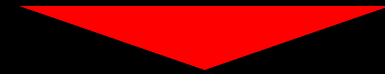
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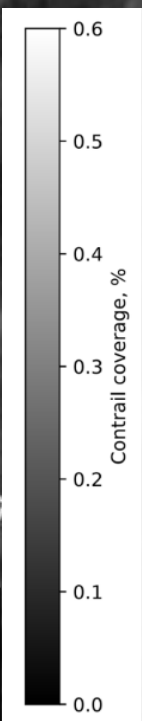


Contrail impacts:

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- Uncertainty remains when modeling a contrail for a specific flight



Can we improve our understanding using observational data?



Average year 2018/19 contrail coverage of U.S. airspace
(MIT algorithm is entirely observational and has no information about flight routes)

Formation and persistence of contrails is the result of two criteria:

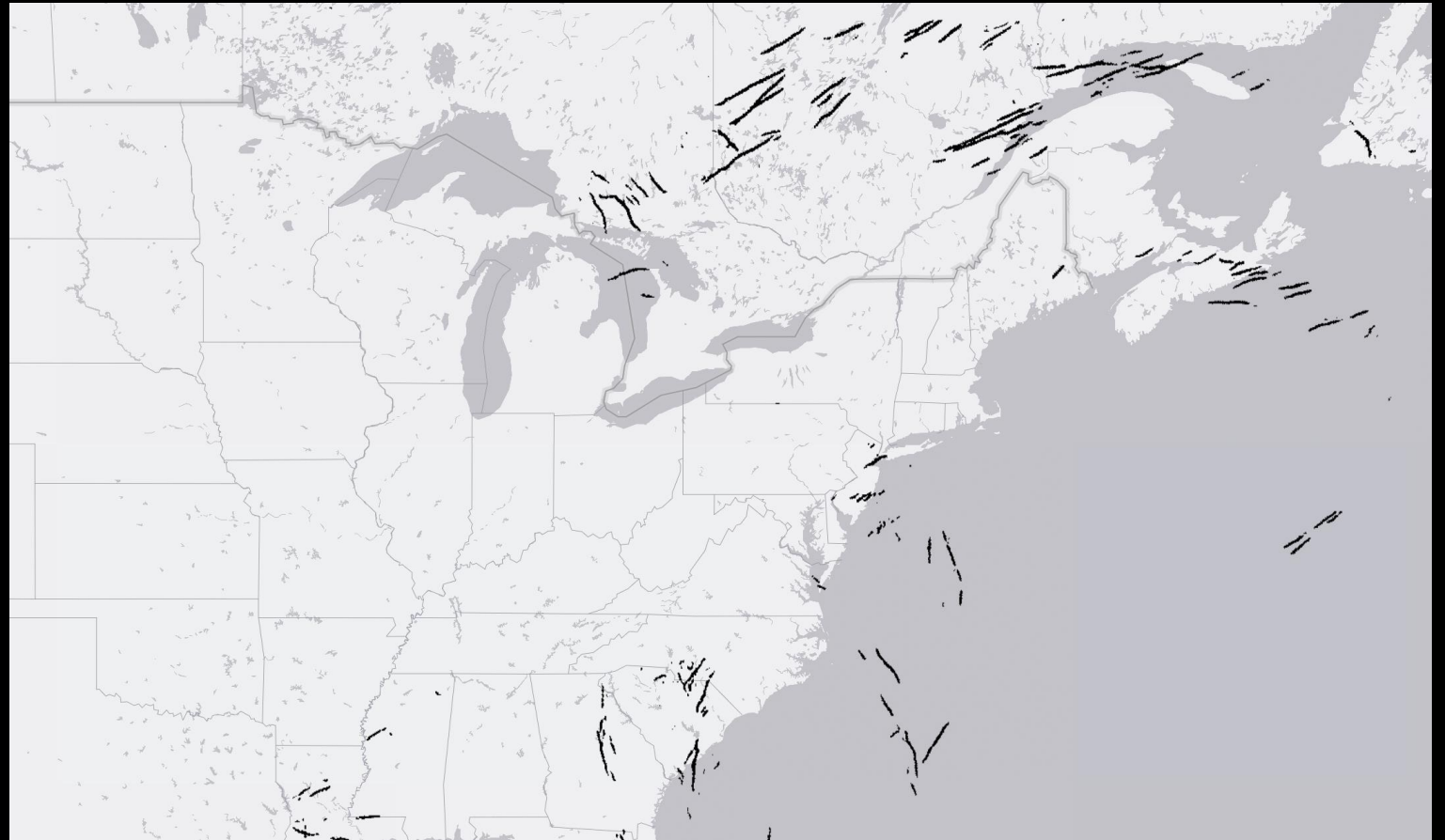


Temperatures are sufficiently low



The air is sufficiently humid

Contrails only form in a fraction of airspace at any given time, *detections April 16, 1630 UTC*



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Deviations

**Fuel
switching**

**Engine
modifications**

Convoying

Deviations

**Fuel
switching**

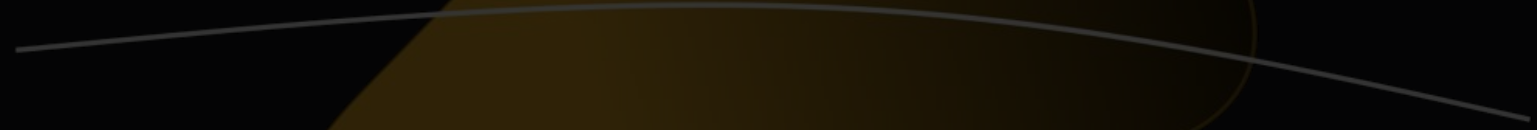
**Engine
modifications**

Convoying



Contrail avoidance
region





Contrail avoidance
region

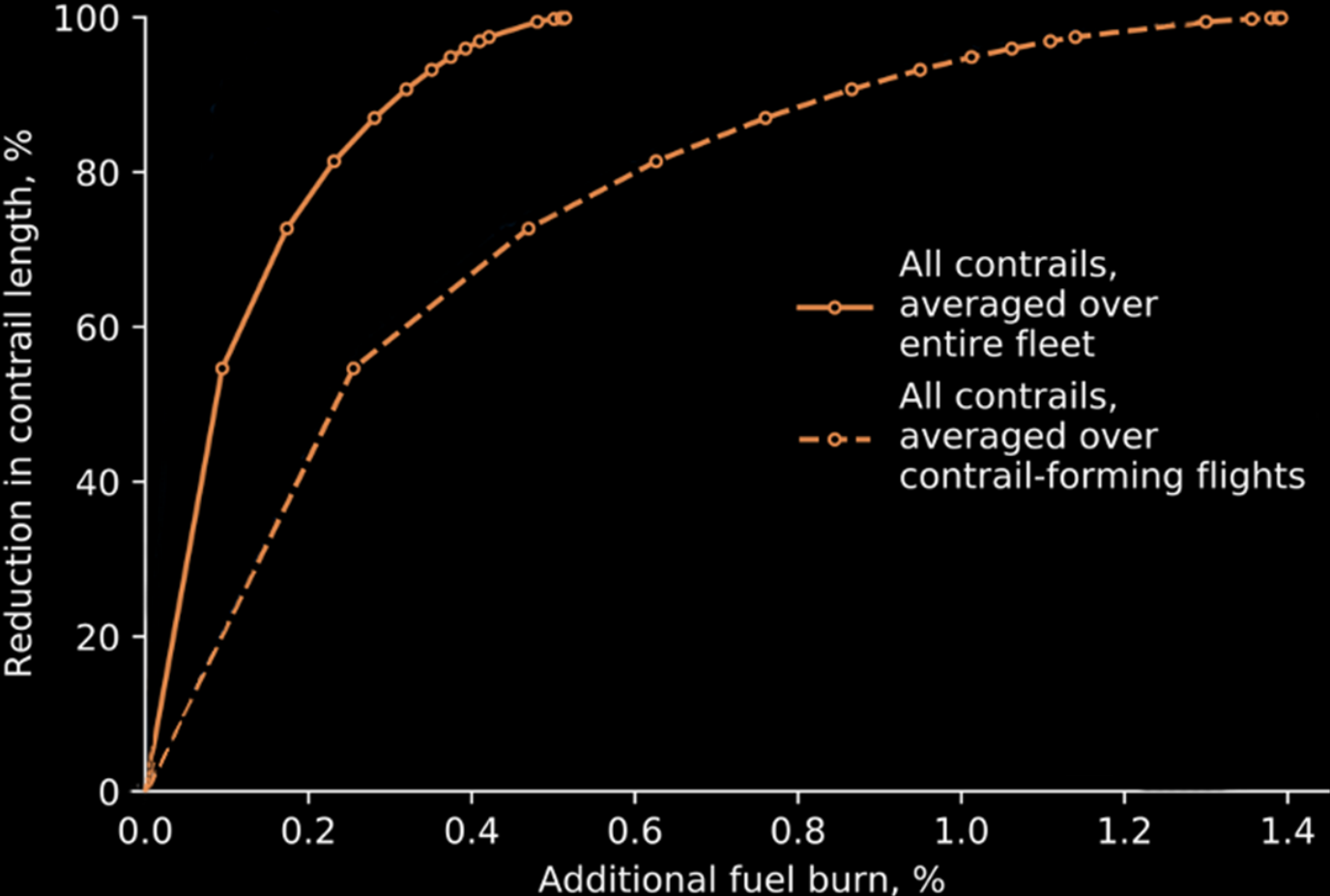


Contrail avoidance region

Baseline at FL330

Diversion to FL310

Model-based assessments of fuel burn penalties associated with operational contrail avoidance



Contrail avoidance for the purposes of climate impact mitigation is still a “tough” problem



Persistence of a contrail likely not observable from the forming aircraft via a “backwards looking camera”.



Lack of retrofittable sensors to detect contrail-forming conditions.



Off-the-shelf weather forecasting models not fit for purpose for detecting contrail forming regions.



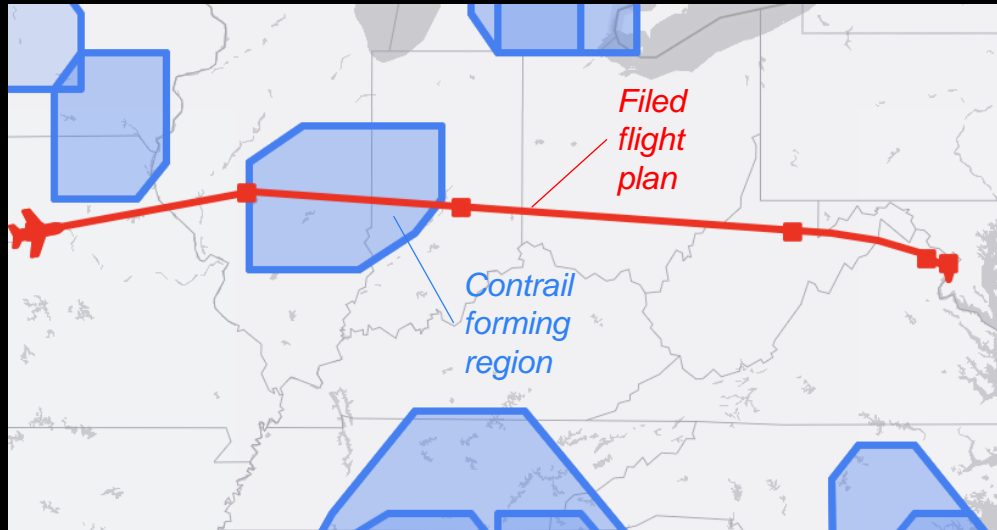
Impacts and required actions vary between flights.

Delta and MIT are developing and testing observation-based methods and tools to eliminate persistent contrails

Observe where contrails form along flight paths

DAL 380 (LAX-DCA), May 10

The pipeline

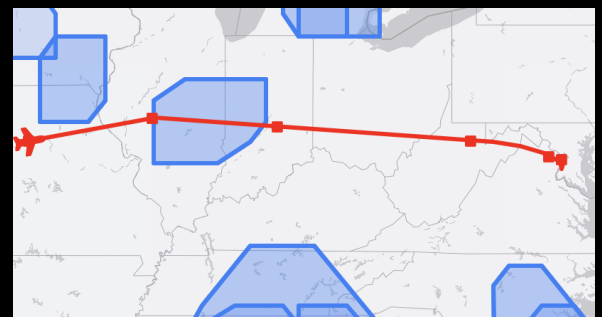


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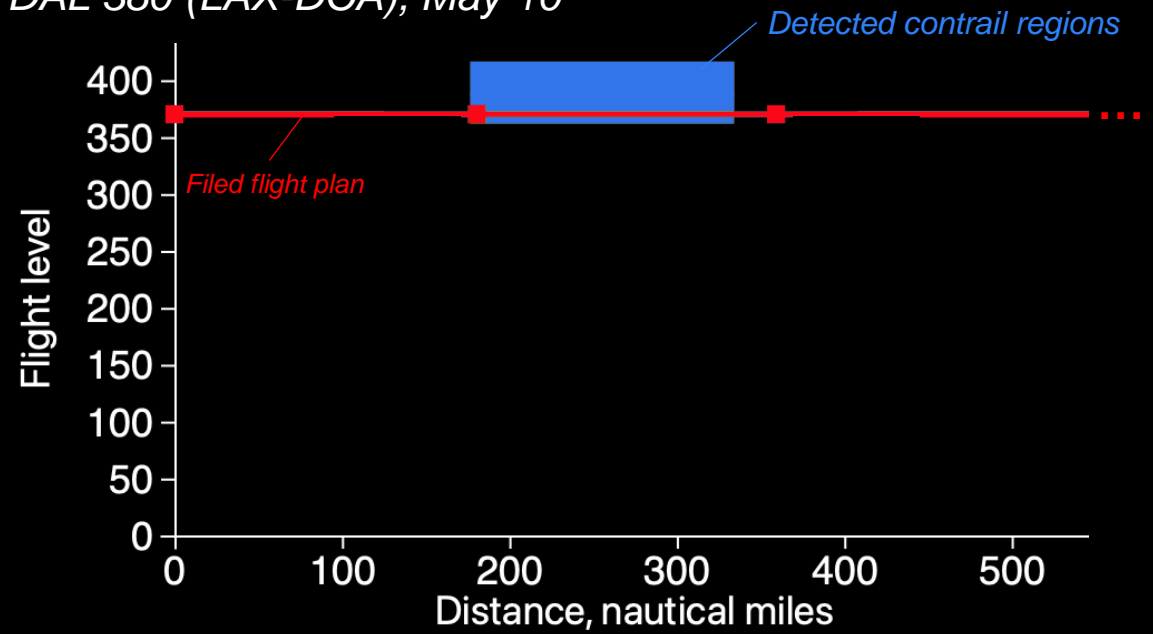
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Tactical action: Deviate around observed contrail forming regions

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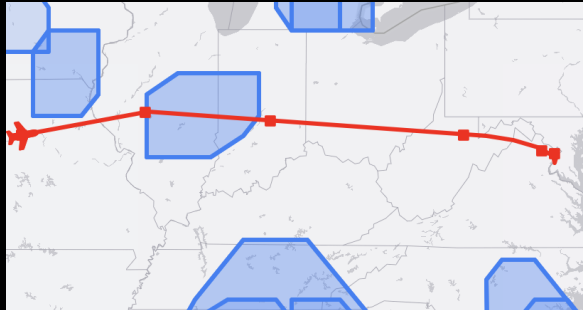


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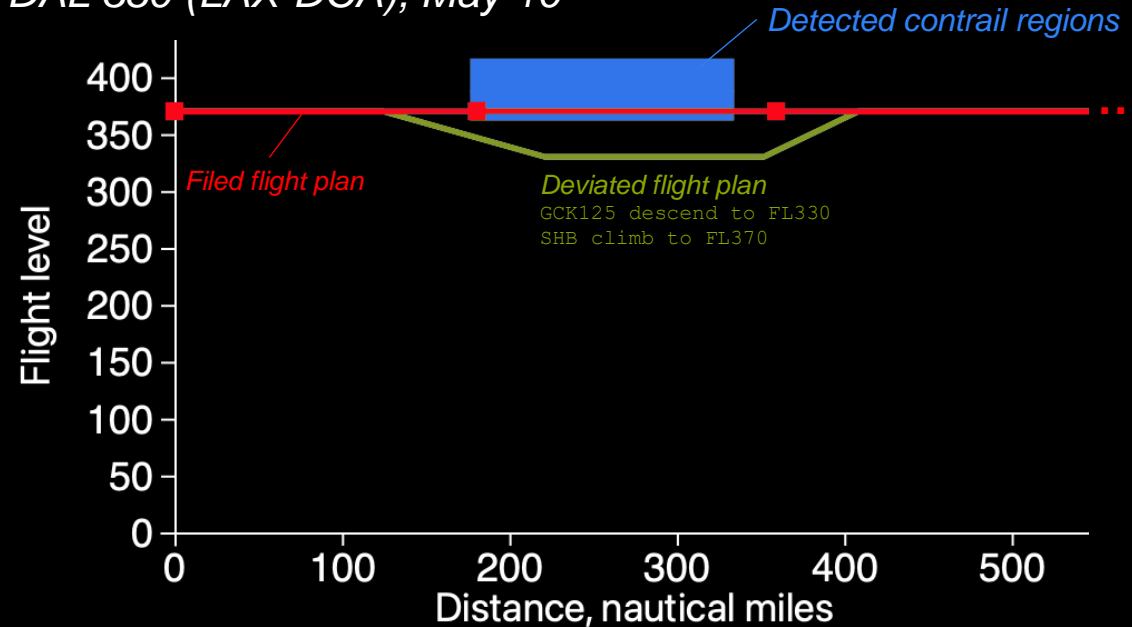
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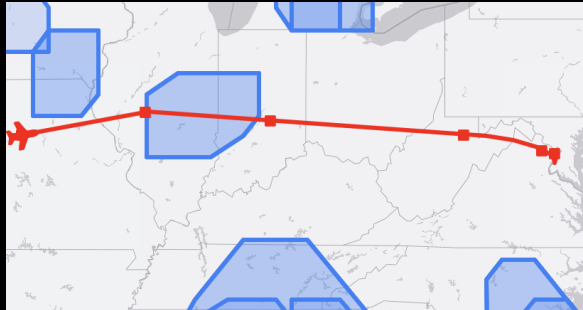


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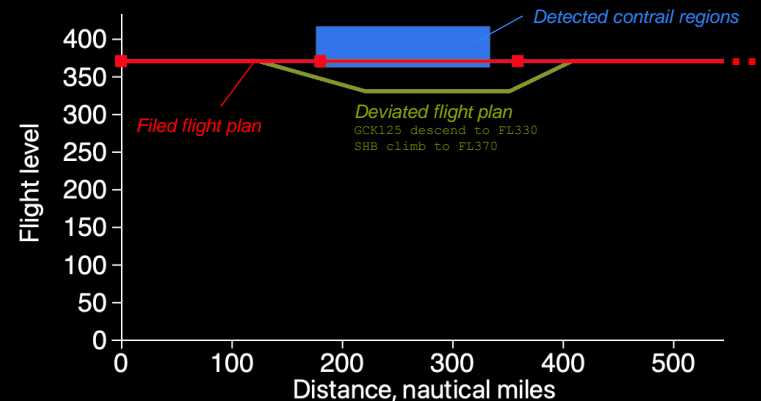
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Observe outcomes

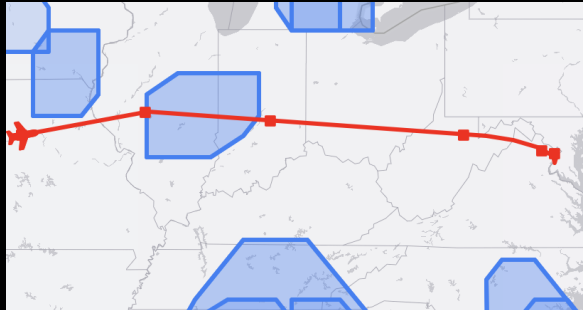
- Additional fuel burn
- Observed contrail formation for the flight
- Net climate impact

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The pipeline

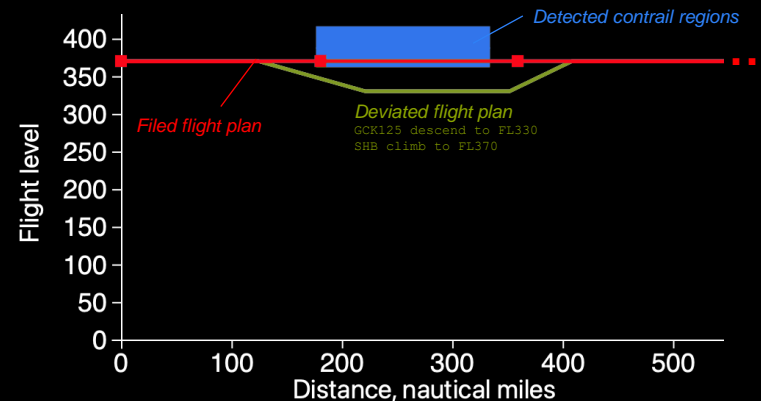
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DAL 380 (LAX-DCA), May 10



Tactical action: Deviate around observed contrail forming regions

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Observe outcomes

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Currently: Simulation of tactical avoidance actions

Goal: Large-scale observation-based study to assess costs and benefits of contrail avoidance

Steps towards verifiable contrail avoidance

1 Establish science and validate tools to observe contrail impacts by flight in a verifiable way.

2 Observation-based data to quantify costs and benefits.

3 Develop required sensors and modeling.

4 Concept of operations at scale.



Policy & incentive structures



Implementation

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