

# Contrail Mitigation Decisions

Friends and Partners in Aviation Weather, Fall 2023

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November 14, 2023

Public Release;  
Distribution Unlimited.  
Public Release Case Number 23-3751

# Aviation's Contribution to Climate Change

- IPCC 6<sup>th</sup> Assessment Report was clear:
  - “Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years.”
  - “Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO<sub>2</sub> and other greenhouse gas emissions occur in the coming decades.”
- **Aviation contributes to net warming with CO<sub>2</sub> and black carbon (particulate matter) emissions, as well as persistent warming contrail formation.**

Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling

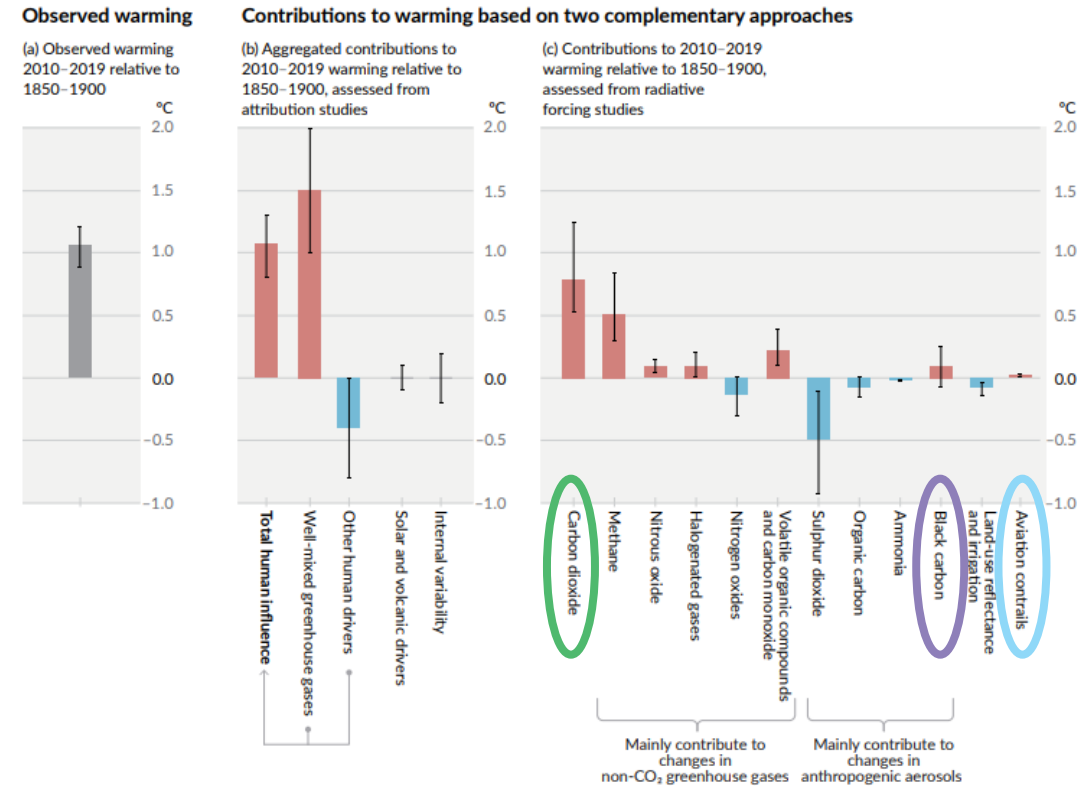


Figure SPM.2 | Assessed contributions to observed warming in 2010–2019 relative to 1850–1900

Source: IPCC WG1 6<sup>th</sup> Assessment Report Summary for Policymakers 2021  
[https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC\\_AR6\\_WGI\\_SPM\\_final.pdf](https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf)

# Europe Looking Beyond CO<sub>2</sub> Alone in Aviation Targets

European Union Emissions Trading System February 8, 2023 update:

- “Non-CO<sub>2</sub> effects on climate from aviation are at least as important as the impact of CO<sub>2</sub> alone. The agreement provides that the Commission will implement a monitoring, reporting and verification (MRV) system for non-CO<sub>2</sub> effects in aviation from 2025. By 2027, the Commission will submit a report based on the MRV and, by 2028, after an impact assessment, the Commission will make a proposal to address non-CO<sub>2</sub> effects.”

Source: Council of the European Union, <https://www.consilium.europa.eu/en/press/press-releases/2022/12/07/ets-aviation-council-and-parliament-strike-provisional-deal-to-reduce-flight-emissions/>

# A Matter of Timescales and Other Considerations



## Contrails

- Only cause warming at night.
- Do not always persist.
- Need to account for where they are created.
- Warming effects can last for hours.



## Black Carbon / Particulate Matter Emissions

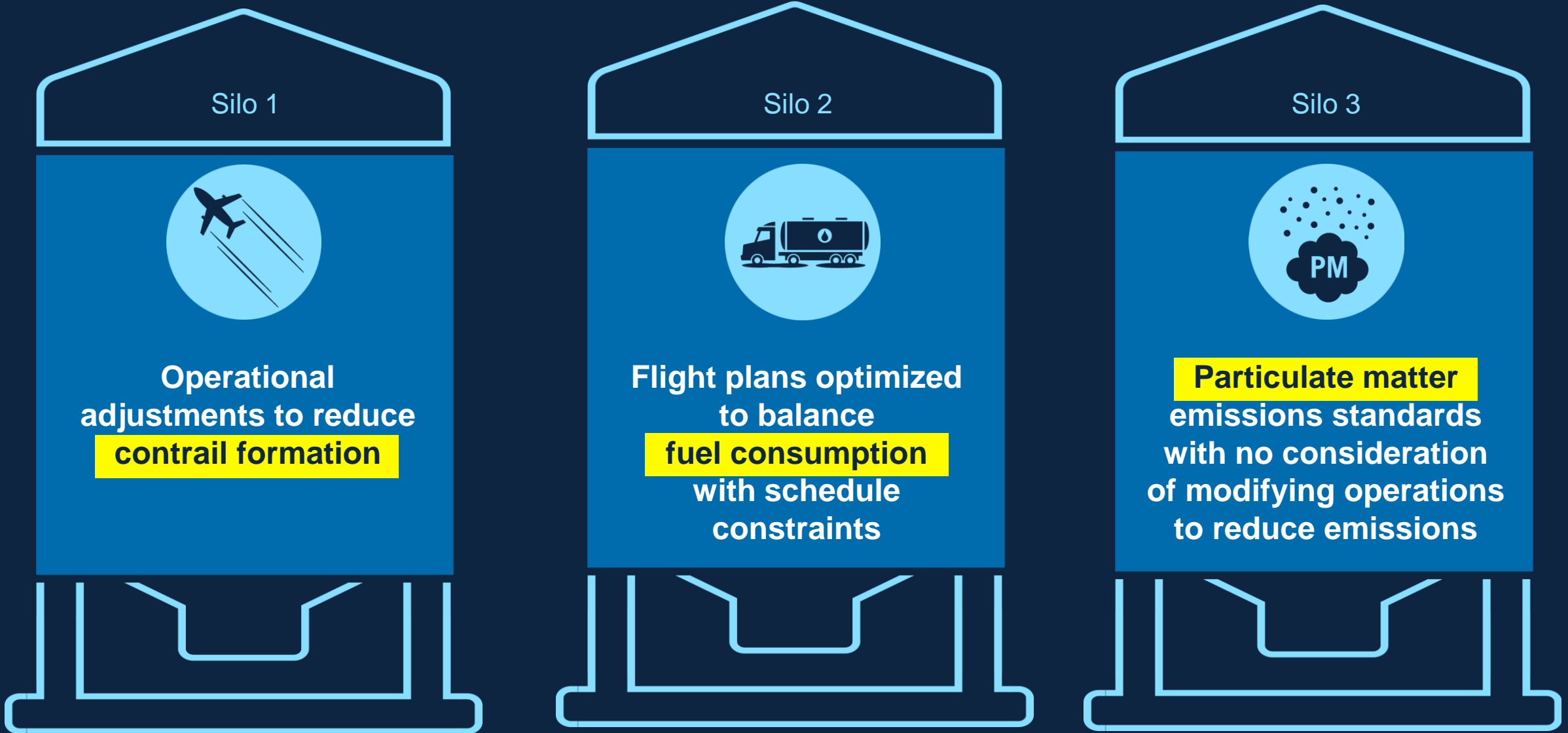
- Sensitive to fuel composition, engine design, and power setting.
- Need to account for where it is released.
- Warming effects can last for days or weeks.



## CO<sub>2</sub> Emissions

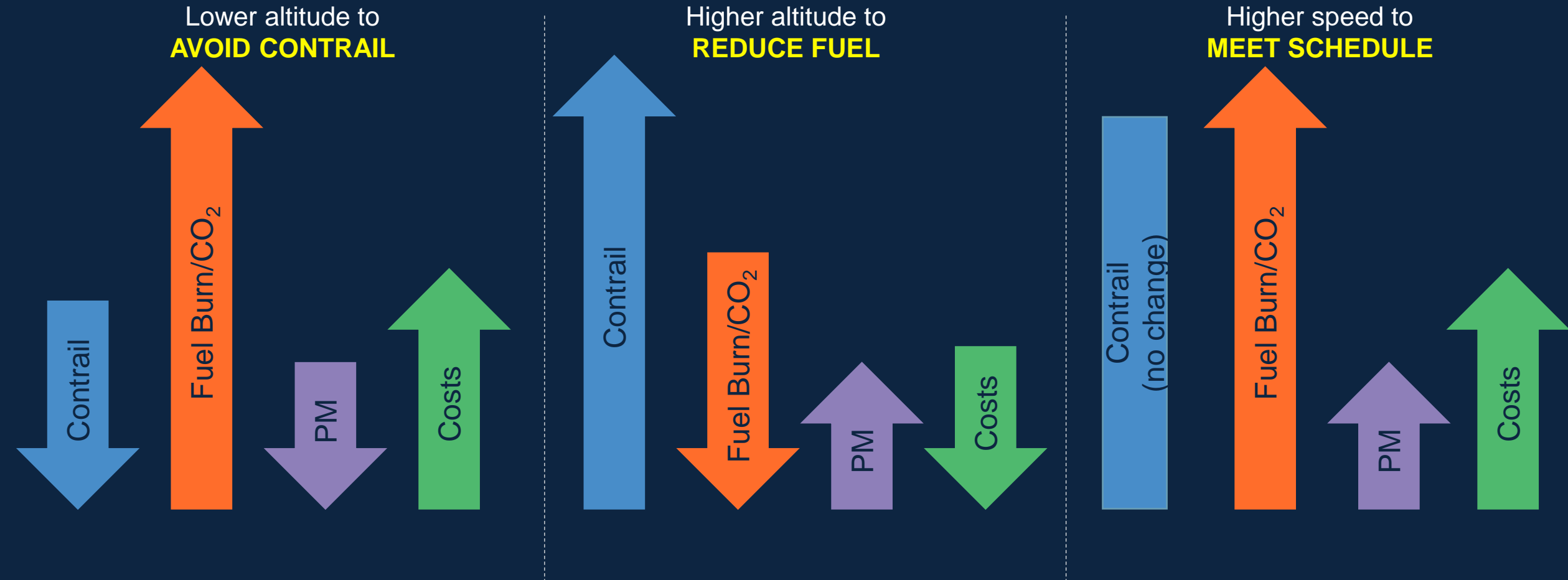
- Always cause warming.
- Well-mixed (does not matter where it is released).
- Warming effects can last for centuries.

**Silos =**  Fundamental Research  Sustainability



# Context

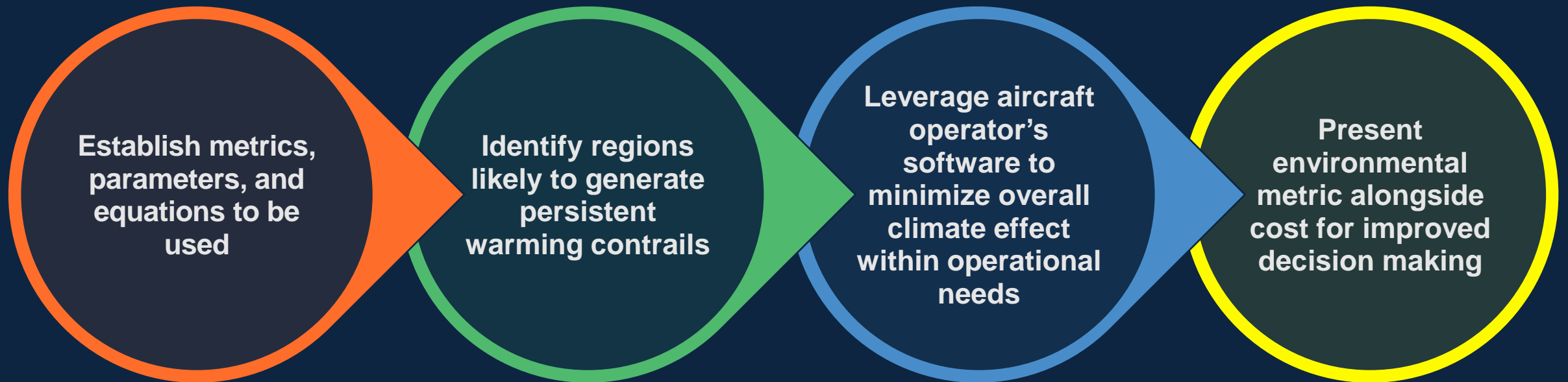
This can have unintended consequences.



# Integration Has a Multiplicative Effect



# Initial Implementation: Pre-Flight Planning



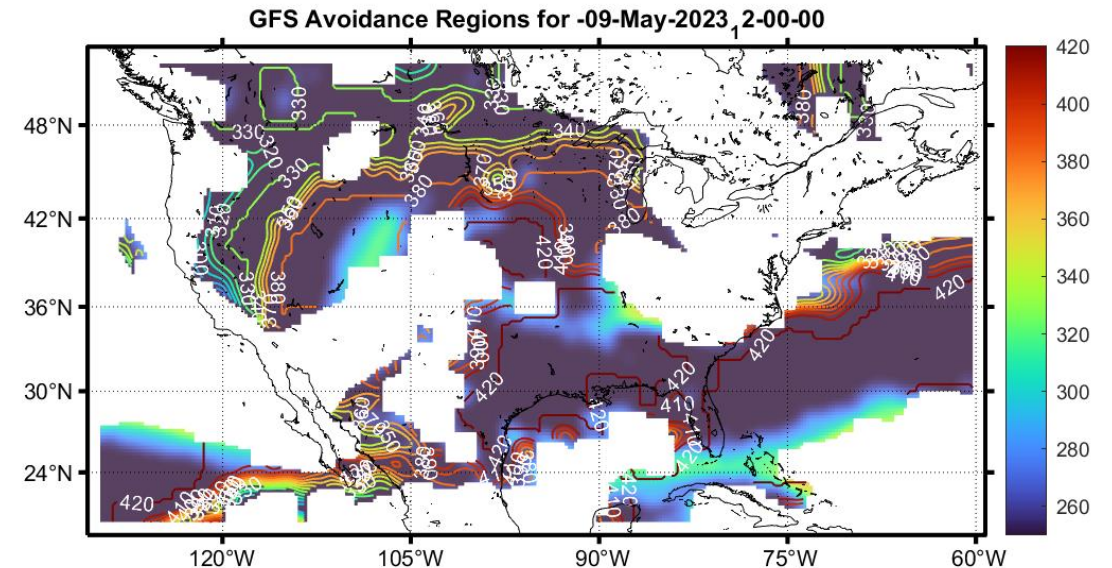


# **Airline Flight Planning Trial**

**Goal: To evaluate feasibility of approach**

# Airline Flight Planning Trial

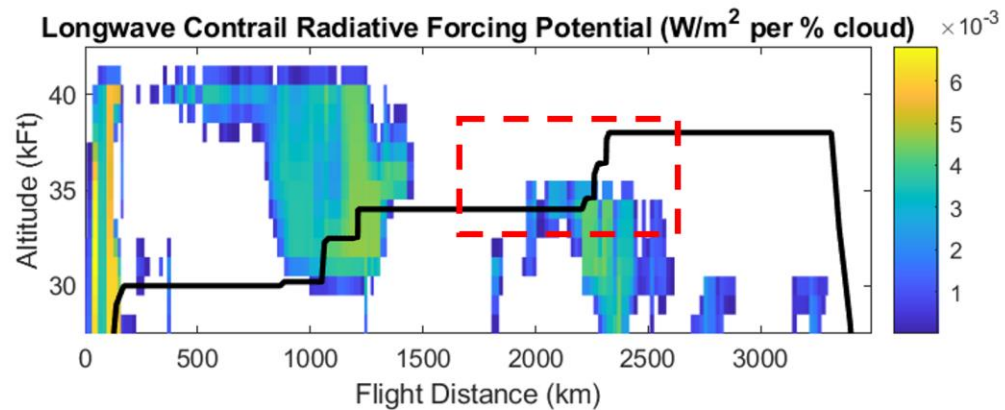
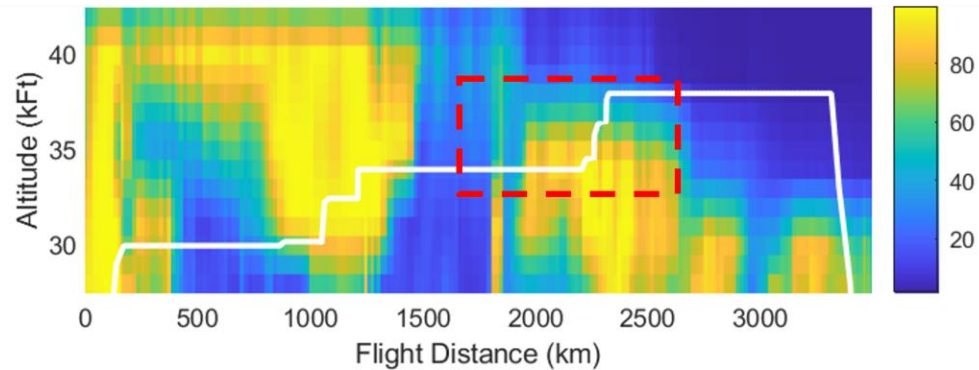
- At 2 to 4 hours pre-departure:
  - Identified flights that may form persistent warming contrails.
  - Contrail avoidance regions loaded into airline's turbulence avoidance system.
- The airline prepared flight plans for the flights as usual.
- The airline prepared alternative flight plans that exclusively used altitude changes to minimize time in the forecasted contrail-producing areas.



# Sample Result

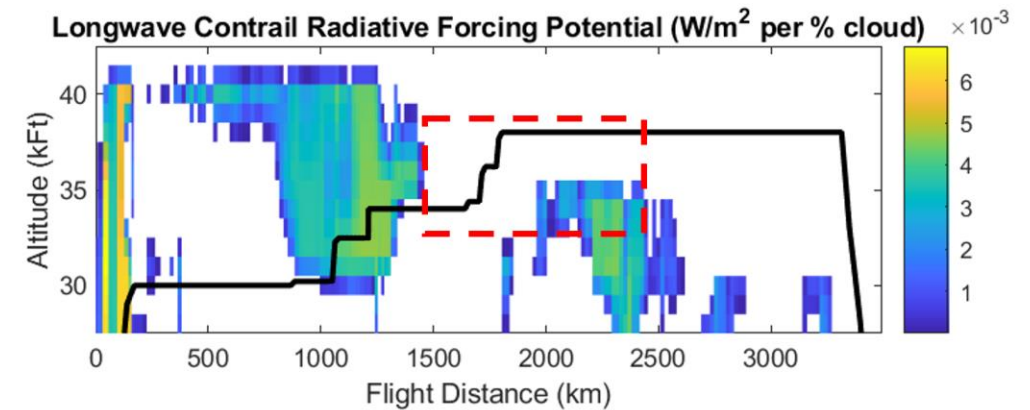
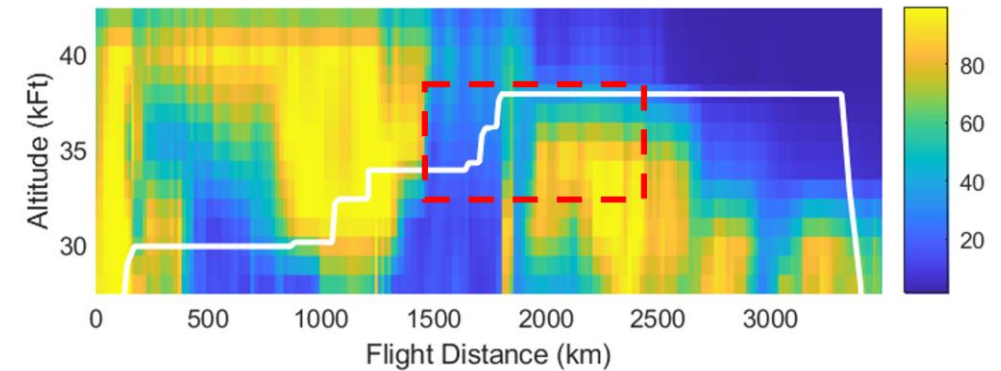
## Filed Flight Plan

Relative Humidity % (colors)



## Mitigated Flight Plan

Relative Humidity % (colors)



# Sample Result

	ENERGY FORCING BY COMPONENT					
	Time Scale 1 (20-yr)			Time Scale 2 (100-yr)		
Units: 1.0x10 <sup>13</sup> J	Contrail Cirrus (all time scales)	CO <sub>2</sub> (20-yr)	BC (20-yr)	Contrail Cirrus (all time scales)	CO <sub>2</sub> (100-yr)	BC (100-yr)
Filed Flight Plan	4.58	2.05	.0330	4.58	7.20	.0333
Mitigated Flight Plan	3.45↓	2.03↓	.0338↑	3.45↓	7.16↓	.0341↑
Total	6.66 × 10 <sup>13</sup> J vs 5.51 × 10 <sup>13</sup> J			11.8 × 10 <sup>13</sup> J vs 10.6 × 10 <sup>13</sup> J		
Mitigation Difference	-17.2%			-9.9%		

	Change in Cost	Change in Time
Mitigated Flight Plan	Negligible Decrease	+1 Minute

# Looking to the Future

# Further Integration Has a Greater Multiplicative Effect



+



+



Integrated  
Climate Metric

+



Costs



**= IMPROVED  
DECISION MAKING**

## TRAJECTORY-BASED OPERATIONS



# Thoughts for FPAW

- Mitigating aviation's effects on the climate needs an integrated approach.
- Physics and chemistry of how contrails form becoming better understood.
- Prediction is limited by the fidelity of forecast humidity data by pressure level.
- How can we make it better?
  - Few aircraft are equipped with humidity sensors.
    - Even fewer are using the most accurate instruments.
  - Radiosonde observations occur only twice daily and are sparse.
  - Can next generation satellites help?
  - Have we gone as far as we can with numerical weather modeling without improved humidity observations?

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