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Soaring into the Bluer Sky: Climate Change and the Green Aviation

Speaker: Dr. Kam K.H. Ng

Department of Aeronautical and Aviation Engineering
The Hong Kong Polytechnic University

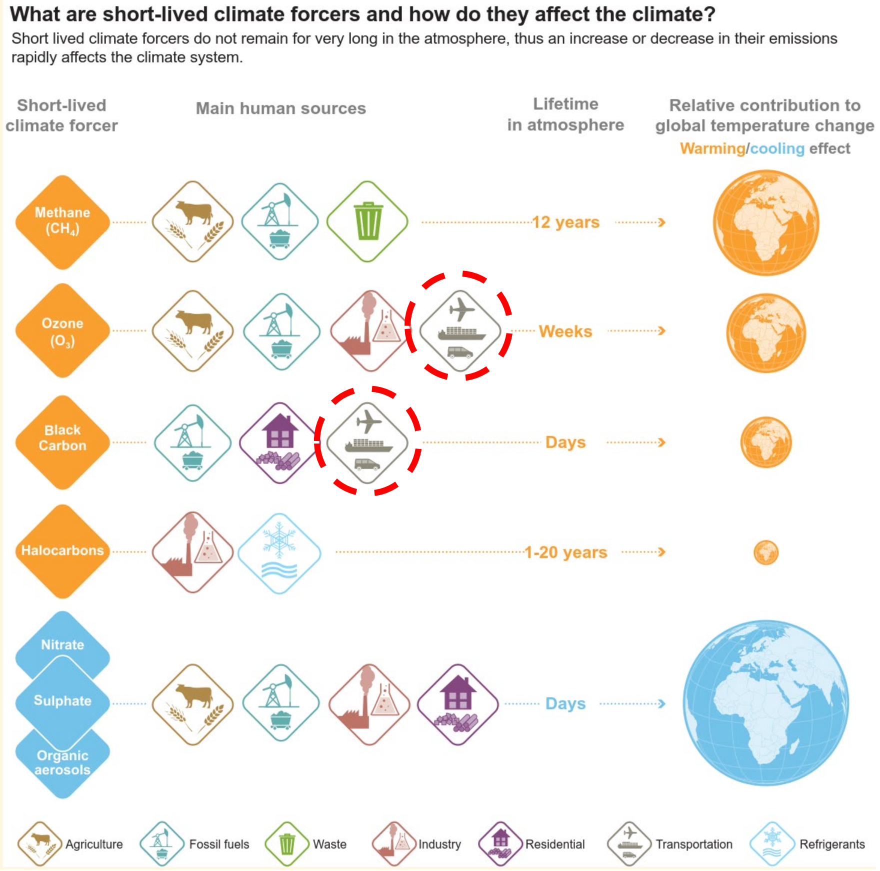
Aviation and climate changes

How Do Air Transportation Affect the Climate?

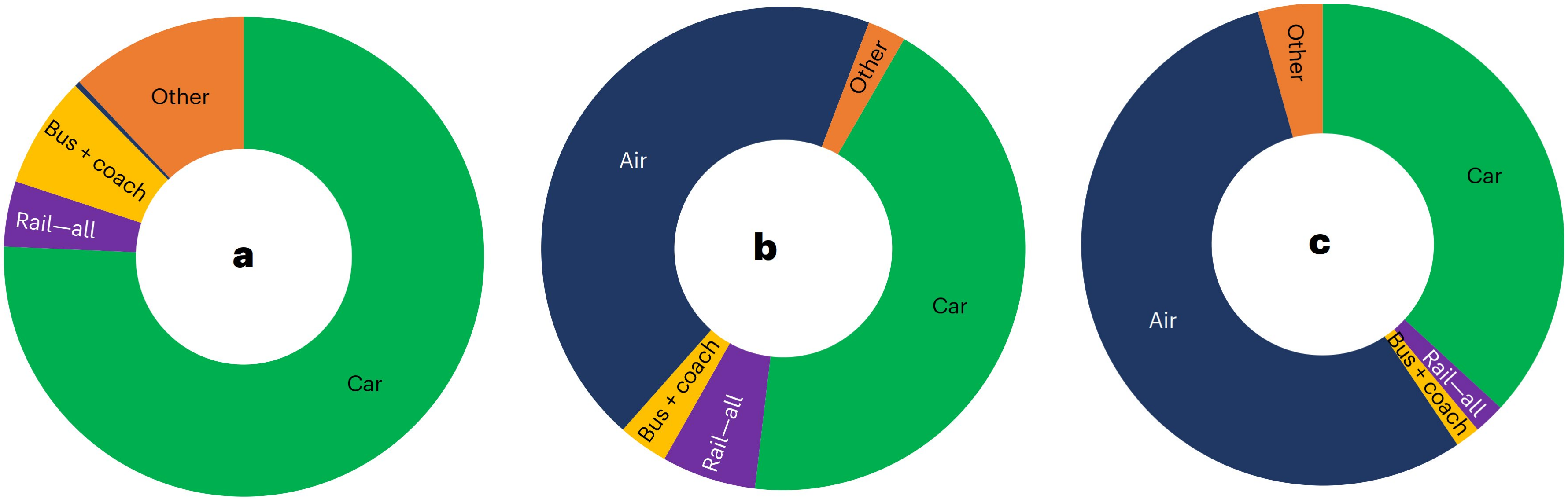
Air transportation affect in climate

Aviation is associated with a range of Short-lived climate forcers (SLCFs), in particular emissions of NOx and aerosol particles, alongside emissions of water vapour and CO_2.

The SLCFs can have a warming or cooling effect on the climate (Figure). Warming SLCFs are either greenhouse gases (e.g., ozone or methane) or particles like black carbon (also known as soot), which warm the climate by absorbing energy and are sometimes referred to as short-lived climate pollutants.

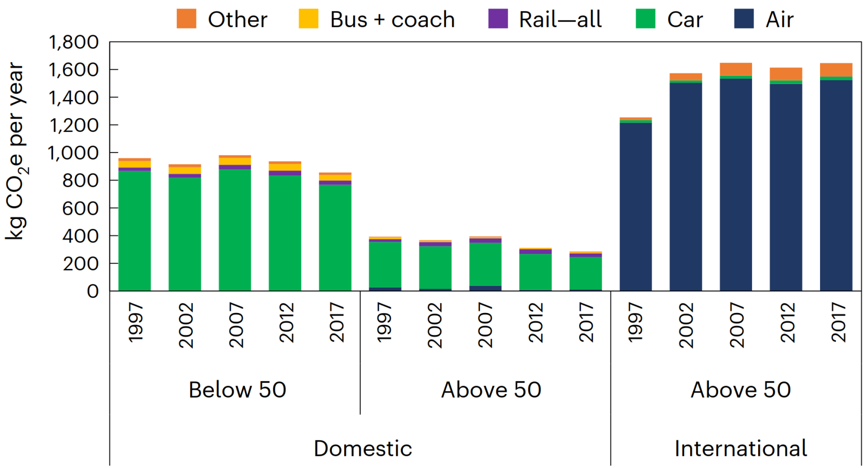


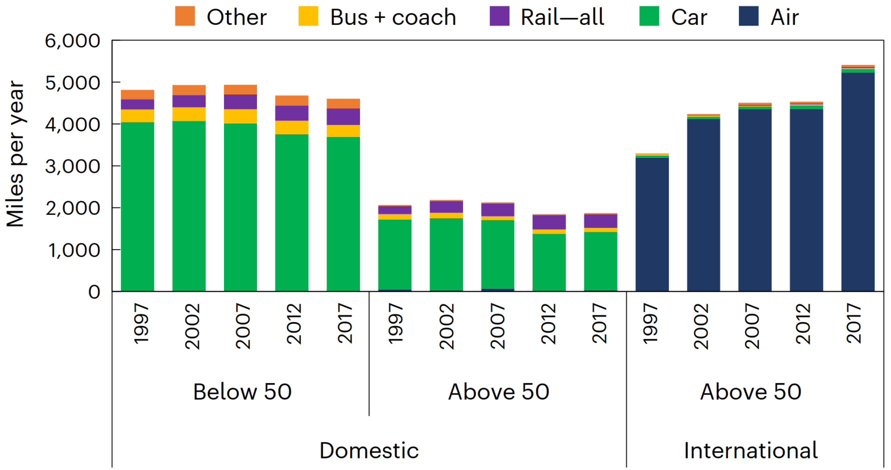
The Aviation Sector Plays the Major Role in Transport Emissions



An England resident flies only 2.9 times a year (**0.36%** of all trips) on average, but flying is the largest contributor to total passenger miles (5,255 miles, **44.2%**) and CO2e emissions (1,534 kg, **55.1%**).

The Aviation Sector Plays the Major Role in Transport Emissions





On one hand, the miles of aviation flights increased from 1997 to 2017. On the other hand, aviation accounts for the highest emissions.

The Aviation Sector Plays the Major Role in Transport Emissions

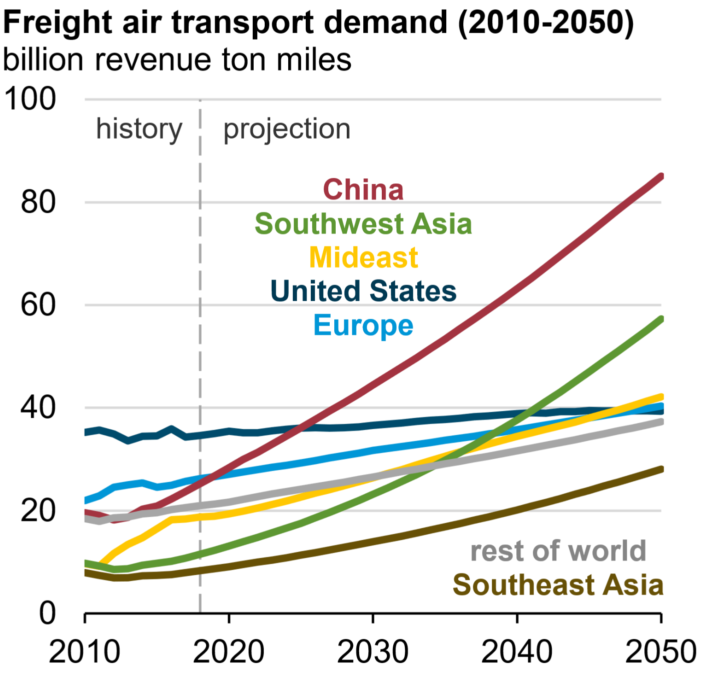
Mitigation potential of different modal shift and technological policy options

	Policy options	Reduction in miles (%)	Reduction in emissions (Em) (%)	Disrupted trips (Tr) (%)	Emissions reduction sensitivity[a] = Em/Tr
A	All car trips under 8 miles shifted to walking and bicycle	0.0%	9.3%	55.05%	0.17
B	All car trips under 8 miles shifted to walking and cycling, all car trips 8–16 miles shifted to electric bicycles	0.0%	16.9%	66.75%	0.25
C	Half of all LD car trips shifted to rail	0.0%	2.6%	0.90%	2.88
D	All LD car trips shifted to rail	0.0%	5.2%	1.80%	2.88
E	All flying trips under 1,000 miles shifted to rail	0.0%	5.6%	0.17%	33.2
F	All holidays involving flying abroad shifted to domestic holidays by car (300 miles one-way)	20.9%	27.6%	0.22%	122.9
G	All holidays involving flying abroad shifted to domestic holidays by rail (300 miles one-way)	20.9%	30.2%	0.22%	134.5
H	All holidays involving flying abroad halved, the rest shifted to domestic holidays by car (300 miles one-way)	7.9%	12.2%	0.11%	108.3
J	Reduce business flying trips by half	2.0%	2.6%	0.02%	129.8
K	Stop all business flying trips	4.1%	5.2%	0.04%	129.8
L	Maximum one return trip abroad is permitted per person per year[b]	27.4%	33.9%	0.21%	158.3
M	All car trips shifted to electric, using current grid mix for upstream emissions	0.0%	21.1%	0.0%[c]	–
N	50% fuel replacement with sustainable aviation fuel (with a 70% emissions reduction potential over replaced fuel on a lifecycle basis)[d]	0.0%	19.3%	0.0%	–

The Projected Global Growth in Air Transport Demand before COVID-19

Estimated air transport demands

Globally, air freight transport, measured in revenue ton miles, grows at **an annual rate of 2.6%** during the 2019 projection period and reaches **330 billion** revenue ton miles in 2050. Much of the increase occurs in **China and other Asian countries** where growth in certain goods results in increased air freight travel.

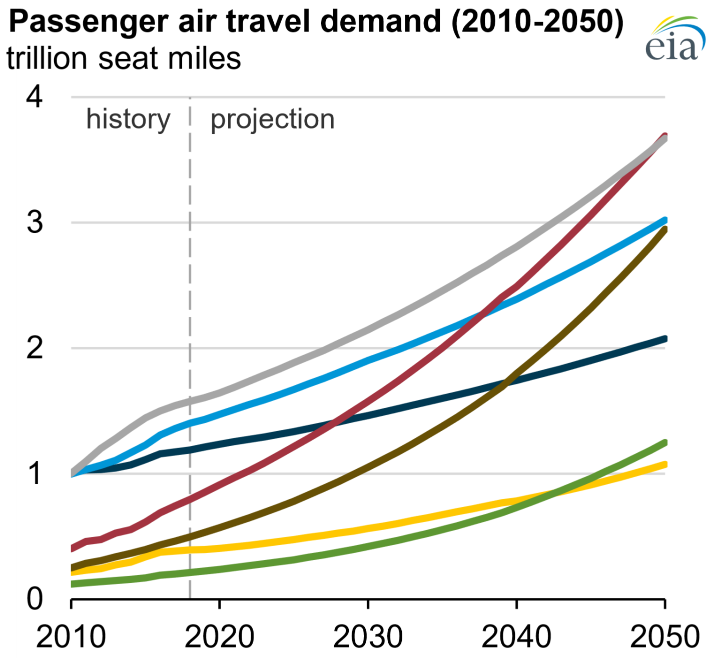


The Projected Global Growth in Air Transport Demand before COVID-19

Estimated air transport demands

Passenger air travel nearly triples during the 2019 projection period, from **6 trillion seat miles in 2018 to about 18 trillion seat miles in 2050**. It's expected that a growing global middle class will travel more both domestically and internationally as household incomes rise.

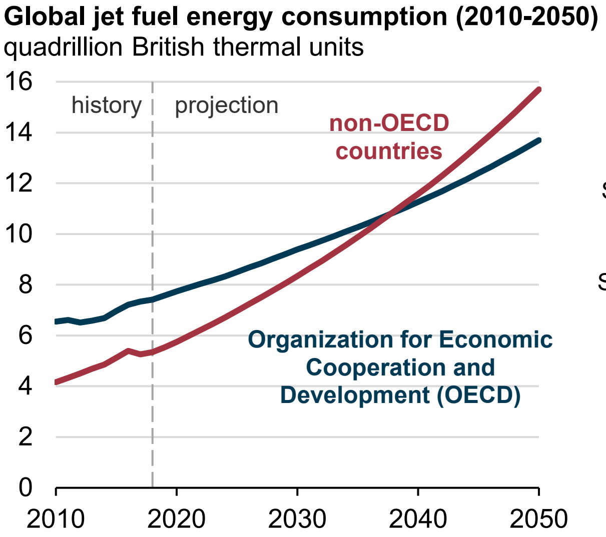
In particular, the projected **Asian** jet fuel consumption grows faster than in any other world region, **increasing to more than 40% of global** commercial jet fuel use in 2050.

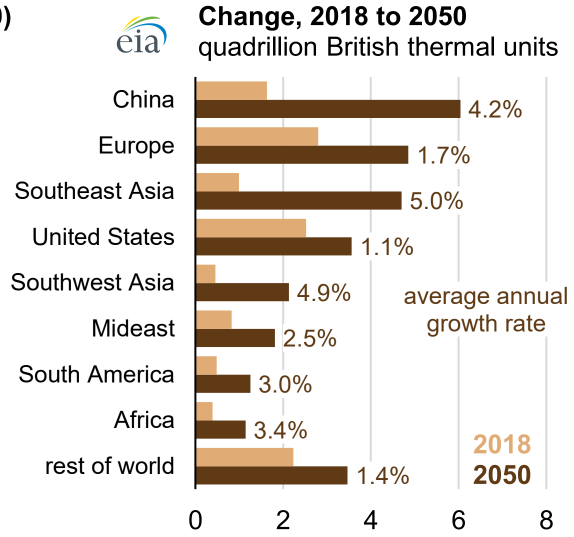


The Projected Global Growth in Air Transport Demand before COVID-19

Increasing jet fuel consumption

Global jet fuel consumption is expected to **more than double by 2050**, with demand growing fastest in **Asia**. **China and Southeast Asia** will account for 59% of this growth, driven by rising freight and passenger air travel.

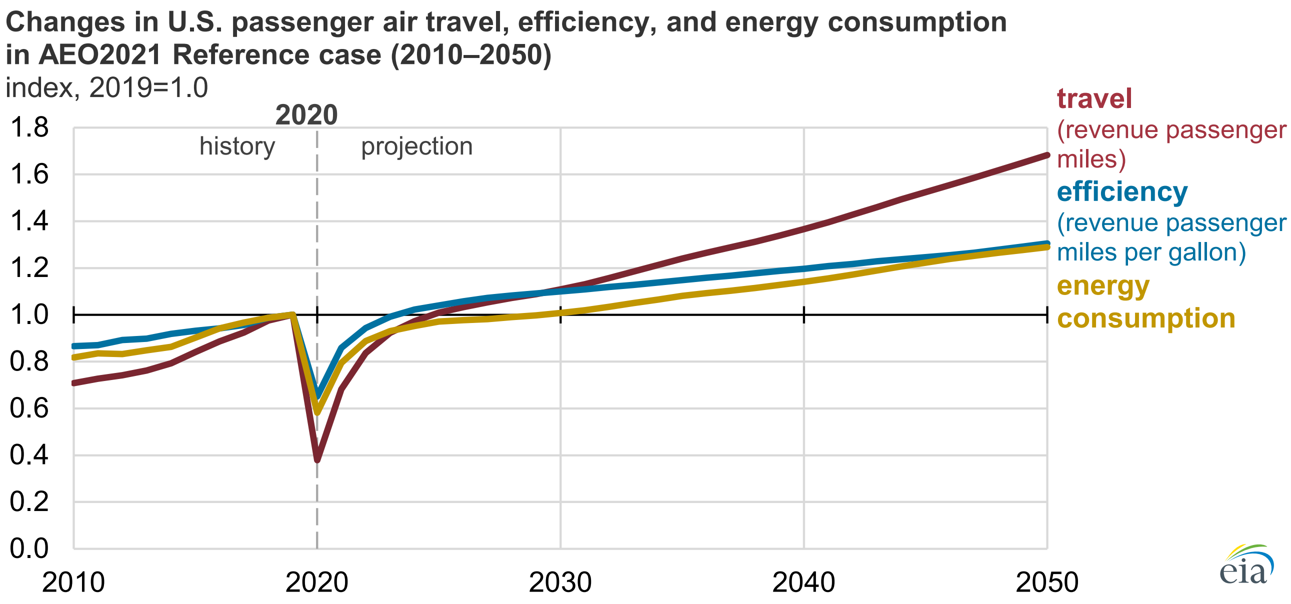




Updated Aviation Outlook after Pandemic

US

Air traffic will continue to grow, with **a 10-year lag** compared to pre-pandemic forecasts.



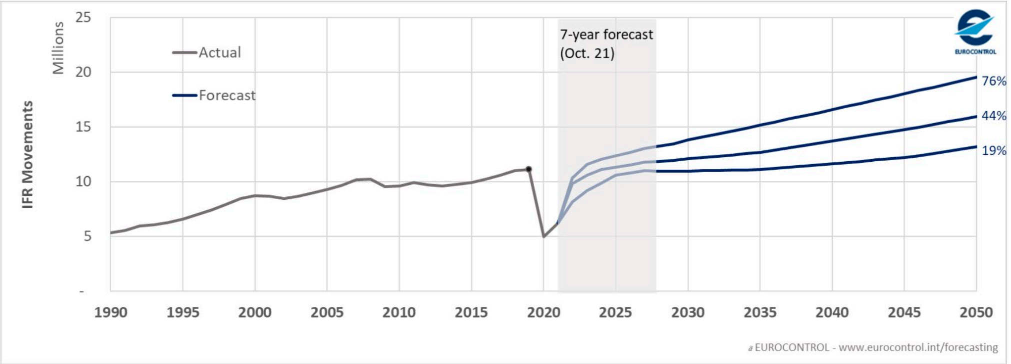
Updated Aviation Outlook after Pandemic

EU

High Scenario: Strong economic growth, globalized world, intense technology investment, and sustainable aviation growth with rapid expansion.

Base Scenario: Moderate growth, environmental regulations, steady progress toward sustainability, aligning with current and likely future trends.

Low Scenario: Slower growth, high fuel costs, limited technology investment, local travel, economic and environmental constraints shaping aviation.



ECAC	IFR Flights						
	2019		2050			2050/2019	
	Total (million)	Avg. daily (thousands)	Total (million)	Avg. daily (thousands)	Extra flights/day (thousands)	Total growth	AAGR
High scenario			19.6	53.6	23.2	+76%	+1.8%
Base scenario	11.1	30.4	16.0	43.7	13.4	+44%	+1.2%
Low scenario			13.2	36.2	5.8	+19%	+0.6%

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Aviation Carbon Emissions

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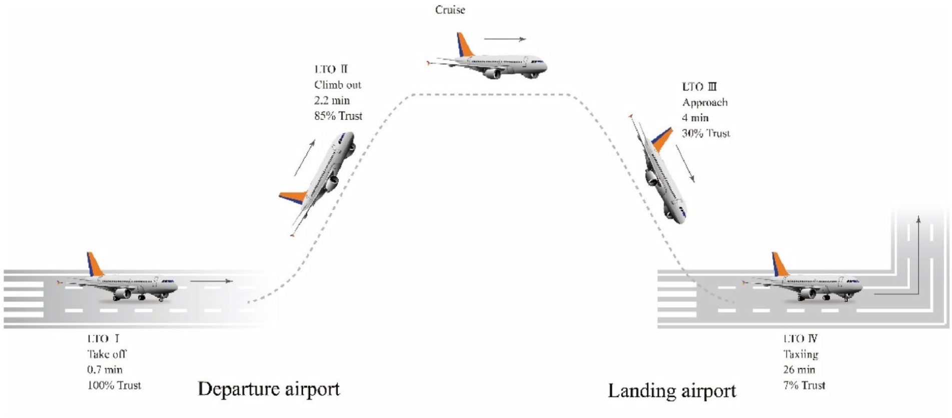
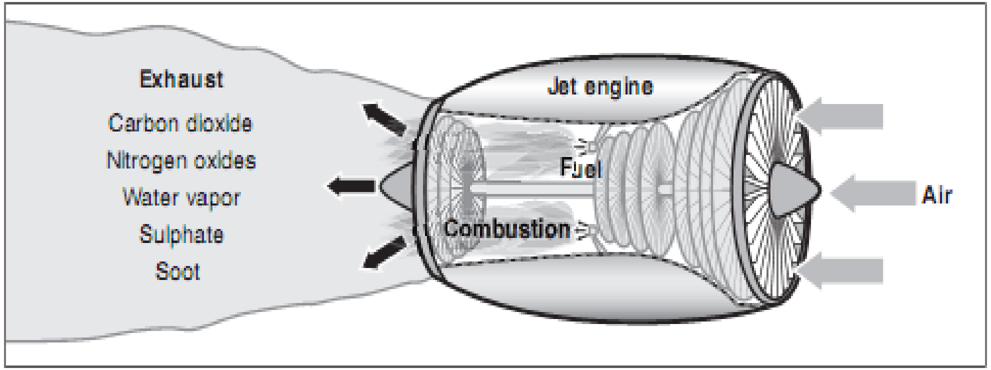
Aviation Carbon Emissions: Fuel Emissions

Aviation fuel **burns** in the engine, where carbon combines with oxygen to produce carbon dioxide (CO_2), the main greenhouse gas from aviation activities.

Factors such as **flight distance**, **aircraft type**, and **passenger load** directly impact fuel consumption, influencing CO_2 emissions. Longer flights and larger aircraft typically generate more carbon dioxide.



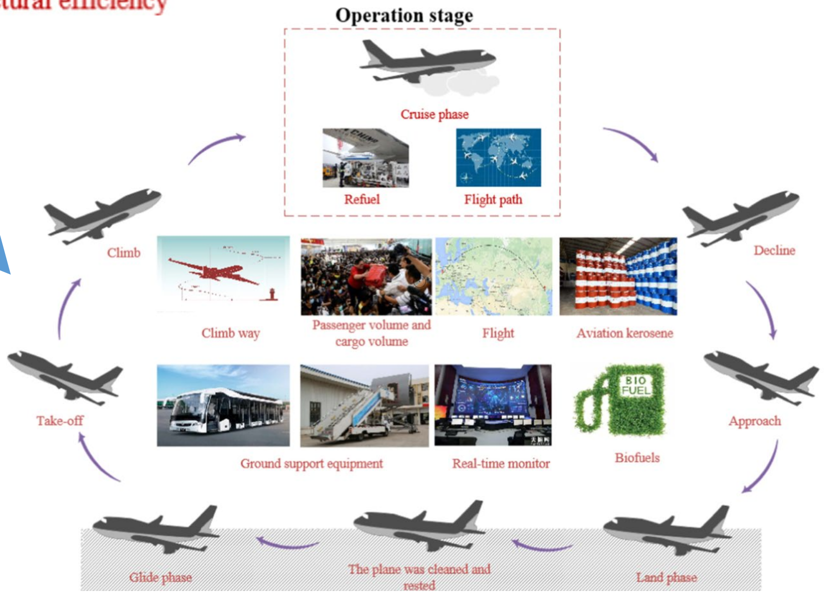


Source: GAO.

Aviation Carbon Emissions: Lifecycle Emissions

Design and manufacturing

Operation



Recycle

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The Global Scale, Distribution and Growth of Aviation Emissions

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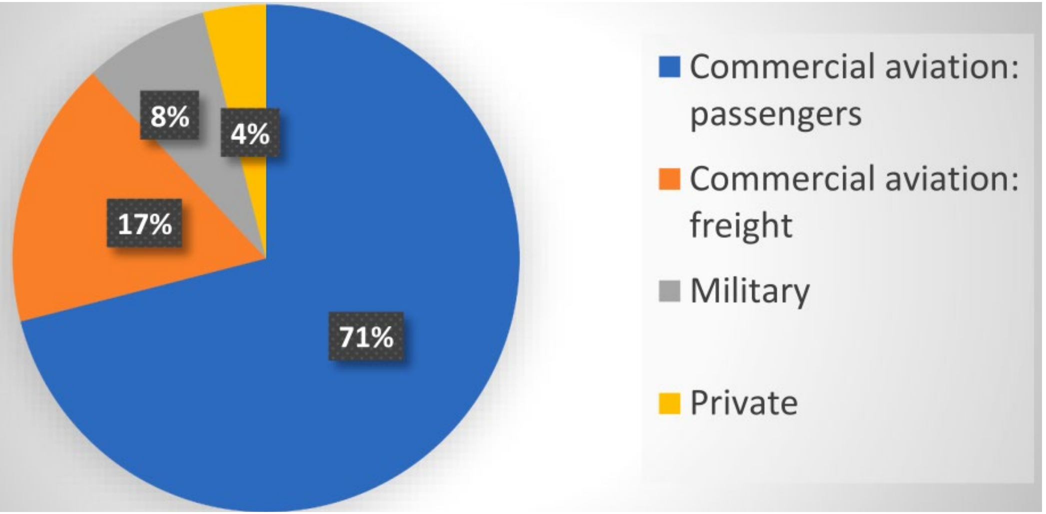
Global Distribution of Aviation Fuel Use

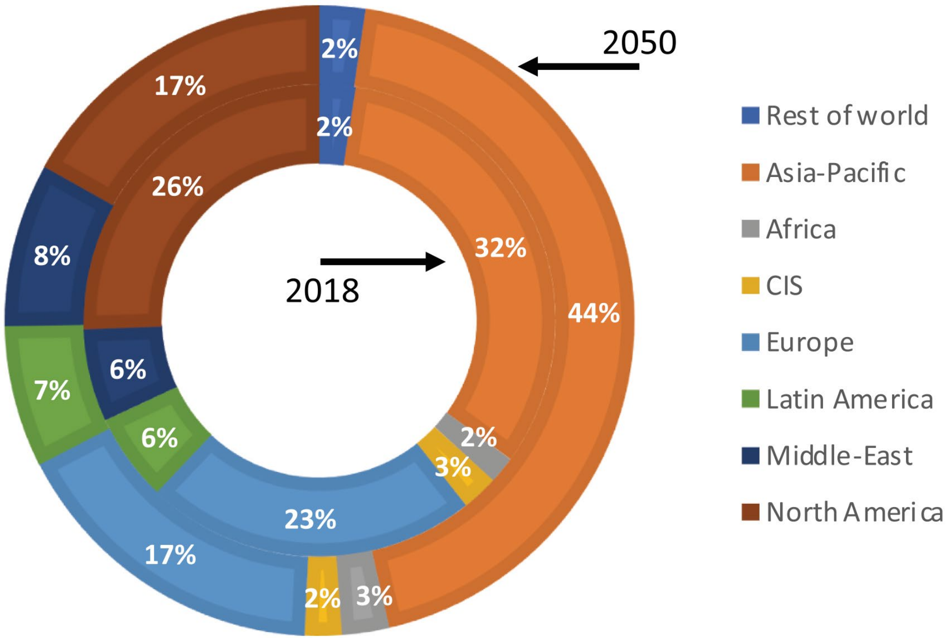
The estimate for 2018 is that global aviation burned approximately **320 Mt** of fuel, and emitted one Gt CO2, of which **88%** fell on commercial aviation, **8%** on military operations, and **4%** on private flight. For commercial aviation, fuel use can be further divided into passenger transport (**81%**) and freight (**19%**).



Distribution of RPK by World region

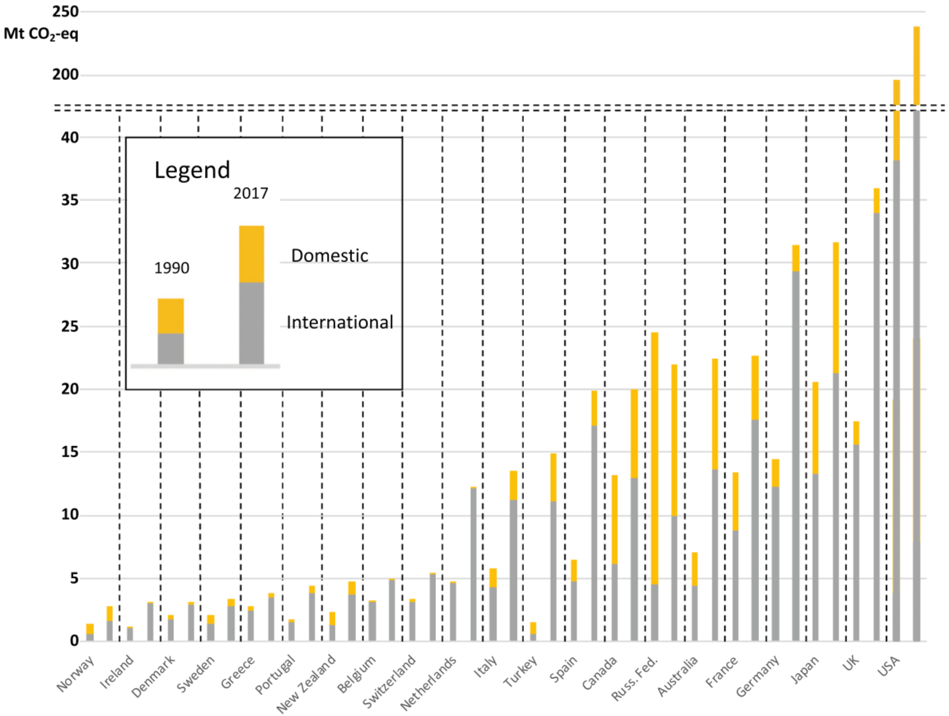
A quarter (**25.6%**) of global air transport takes place in North America, and another **22.7%** in Europe. The Asia-Pacific region accounts for **32.5%**. The remaining four regions, plus all countries not included in the seven regions, together account for **19.2%**.

Annual per capita air transport demand illustrates these regional differences, varying between **5,967** revenue passenger kilometers (RPK) in North America, **3,181** RPK in the Middle East and **2,867** RPK in Europe. In all other regions, and specifically Africa (**123** RPK), air transport demand is significantly smaller.

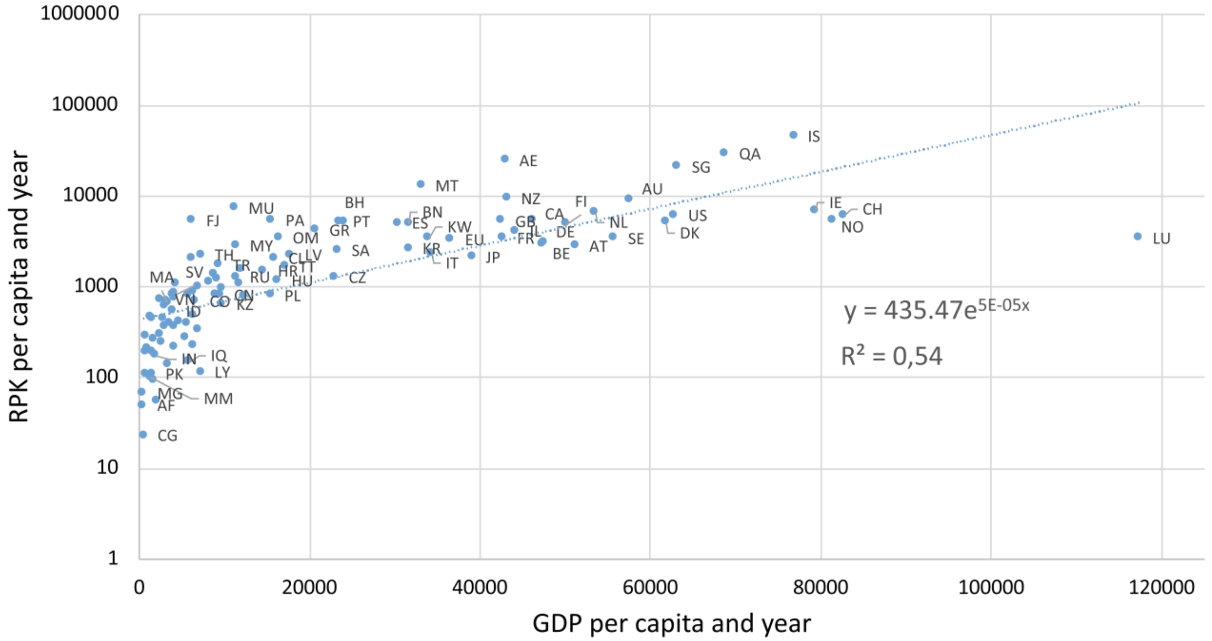


Aviation Bunker Fuel Emissions in the Annex Countries

UNFCCC (2020) data shows that a significant share of global emissions from air transport comes from a few countries, with only **12** countries emitting over **10** Mt of CO_2-eq annually. The USA alone emits more CO_2-eq than the combined emissions of the next 10 largest aviation fuel consumers. Two-thirds of US emissions (**67%**) are from domestic air travel (**161.5** Mt CO_2-eq), compared to **78.4** Mt CO_2-eq for international air transport. China, as the largest non-Annex emitter, reported **29.6** Mt CO_2-eq in 2014.

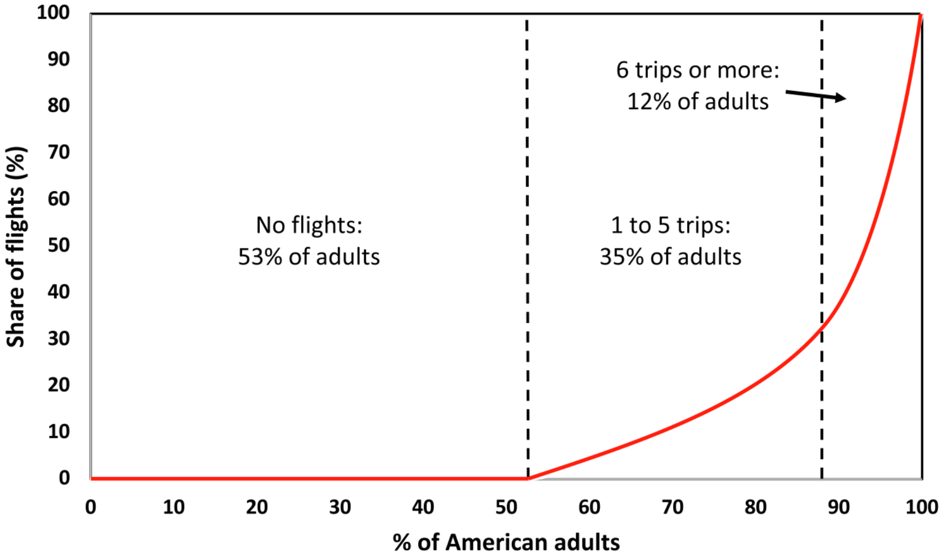


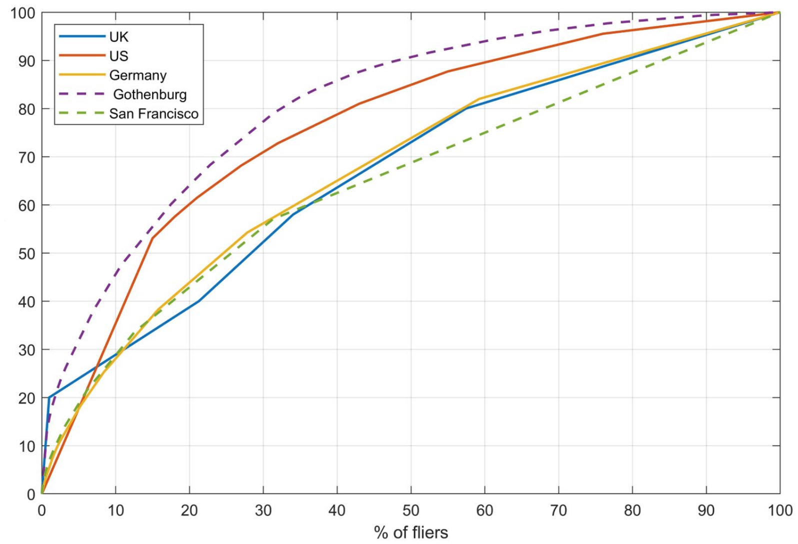
Interrelationships of RPK and GDP



A higher average GDP is linked to air transport demand. The lowest transport demand recorded in the Democratic Republic of Congo (**23** RPK and a GDP of US$**562** per capita per year), and the maximum, more than **45,000** RPK and a GDP of US$**76,856** per capita and year in Iceland.

Air Transport Demand Distribution

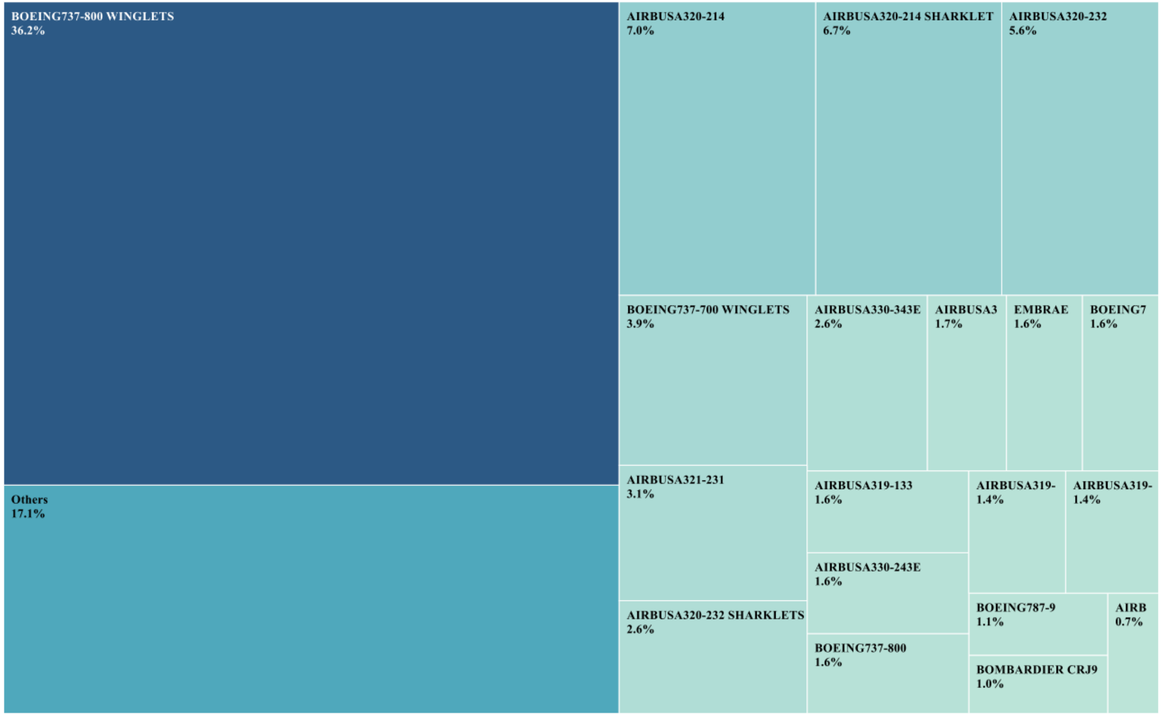




The distribution of air transport for the USA shows that more than half of adults did not fly in 2018, the most frequent fliers (6 flights or more), just **12%** of adults, accounted for **68%** of all flights taken. Surveys suggest that among commercial air travelers, the most frequent **10%** of fliers may account for **30–50%** of all flights taken. The share of the fuel used by these air travelers is likely higher, as more frequent fliers will more often travel business or first class.

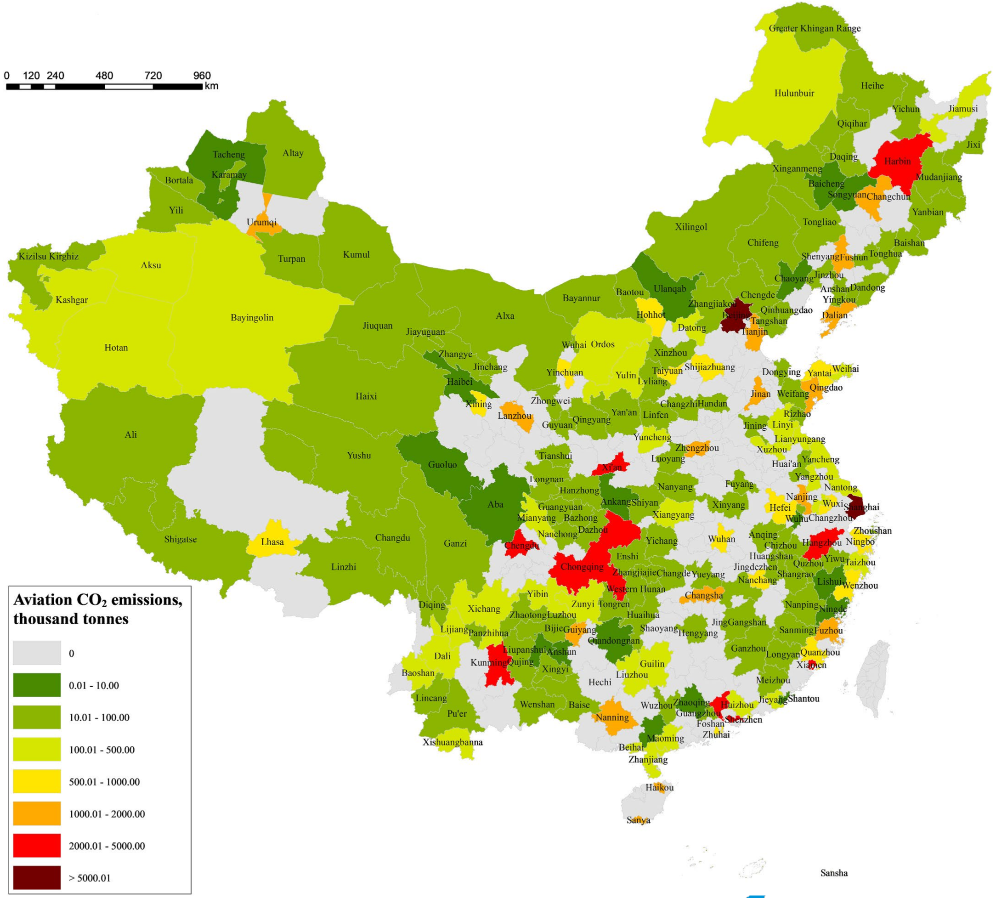
Most Used Aircraft of Chinese Civil Aviation

More than 100 types of aircraft were used by Chinese civil aviation between 2017 and 2020 mainly from Boeing, Airbus, Bombardier and EMBRAER. But more than **83%** flights used 20 types of aircraft. And **99%** flights used **46** types of aircraft, including different versions of the same model (e.g. BOEING737-800 and BOEING737-800 WINGLETS).



Aviation CO2 emissions of Chinese Cities

Beijing, Shanghai, and Guangzhou contributed about **24%** of China's total aviation CO_2 emissions. Overall, 35 cities accounted for **84%** of the total emissions. These include 4 municipalities (Beijing, Shanghai, Chongqing, and Tianjin), 23 provincial capitals (e.g., Guangzhou, Chengdu, Kunming), 4 independently planned cities (Shenzhen, Xiamen, Qingdao, Dalian), and 4 other key cities: Quanzhou (heavy industry), Zhuhai (manufacturing), Wenzhou (trade), and Sanya (tourism).



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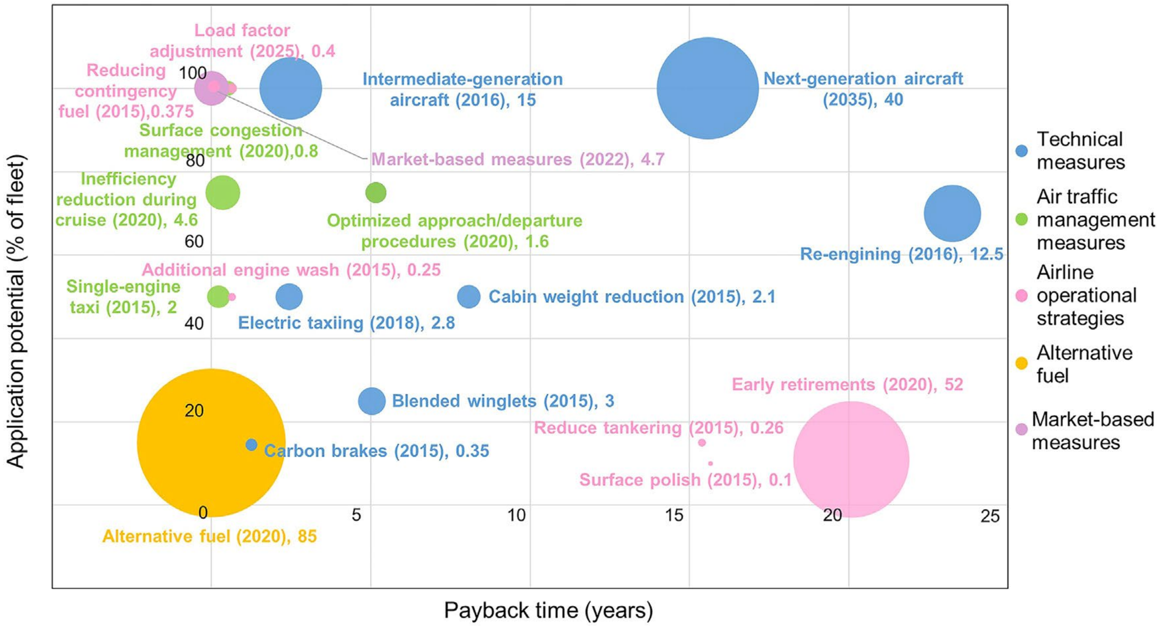
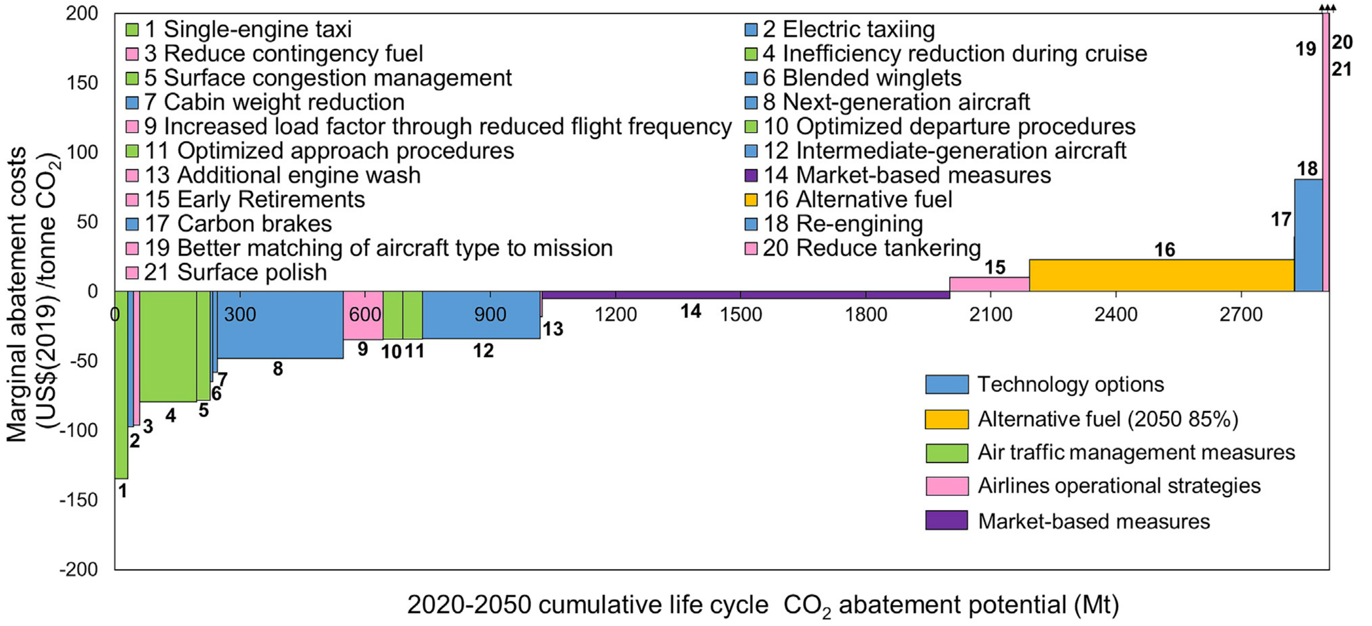
Aviation Emission Reduction Measures

Types of Aviation Emission Reduction Measures

Key mitigation characteristics of abatement options are displayed with investment payback time on the horizontal axis, application rate on the vertical axis, and mitigation rate represented by bubble size. Bubbles in blue, green, pink, yellow, and purple denote technical abatement options, air traffic management measures, airline operational strategies, alternative fuels, and market-based measures, respectively. The year of introduction is shown in parentheses, with the number following the comma indicating the mitigation rate (unit: %).



Cumulative Abatement Potential and Marginal Abatement Costs



The potential for abatement varies among options. Market-based measures are the largest contributors, providing over **one-third** of the potential. Technical abatement options, particularly next-generation aircraft, account for about **one-fourth**, mitigating **301.34** Mt CO_2. Alternative fuels offer the third largest potential, reducing emissions by **634** million tons. Airline operational strategies and air traffic management measures contribute the remaining 11% and 10%, reducing emissions by **323** million tons and 293 million tons.

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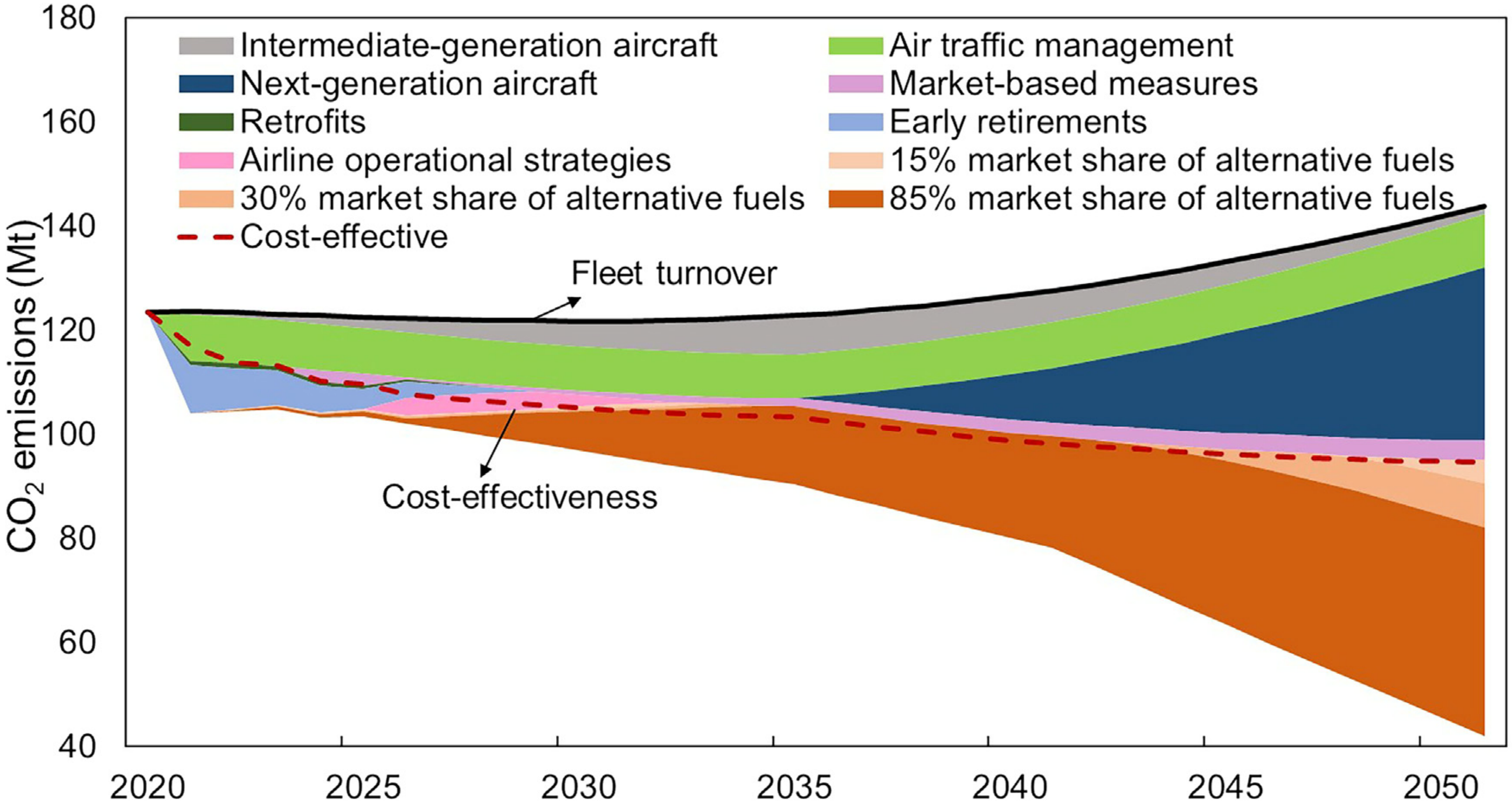
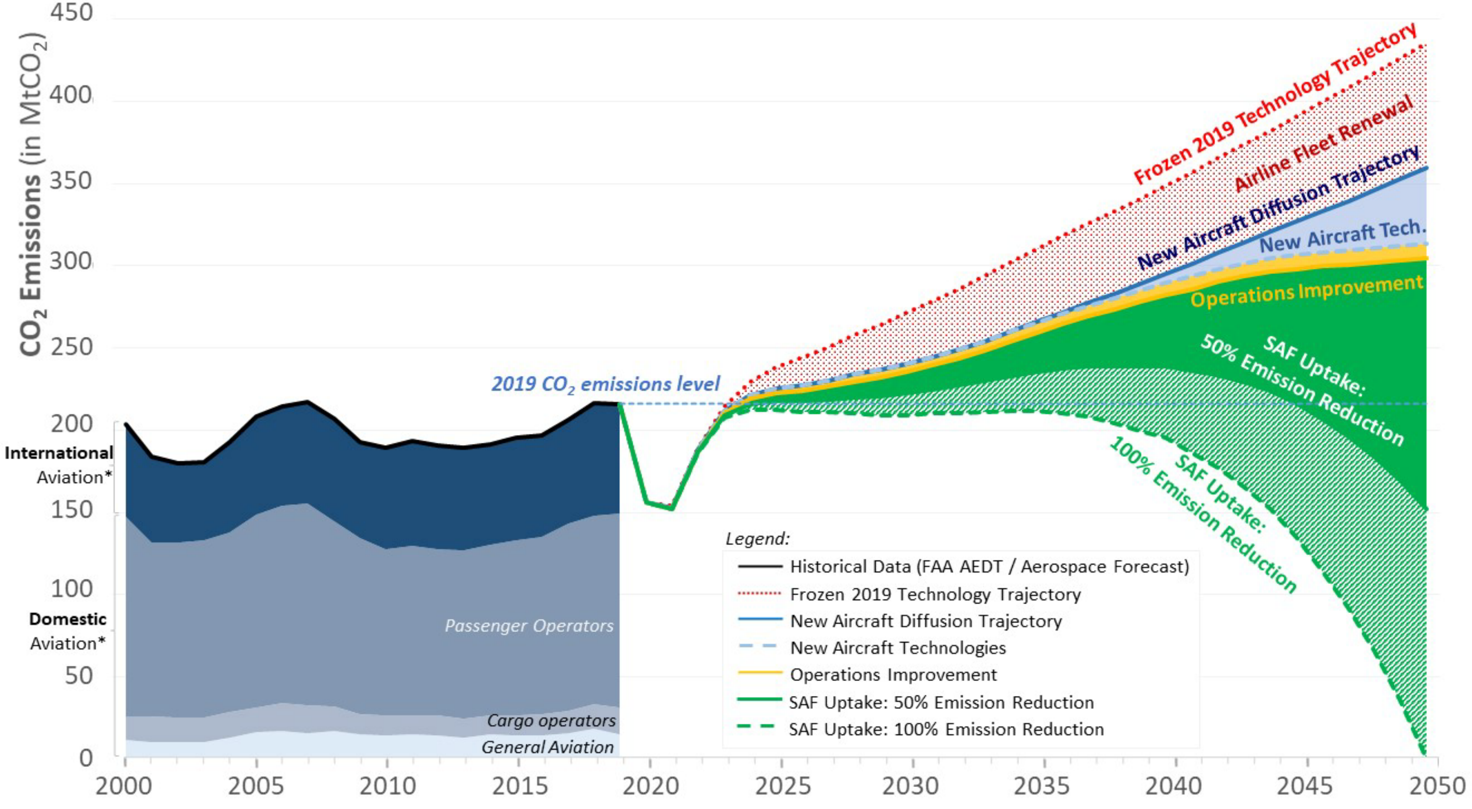
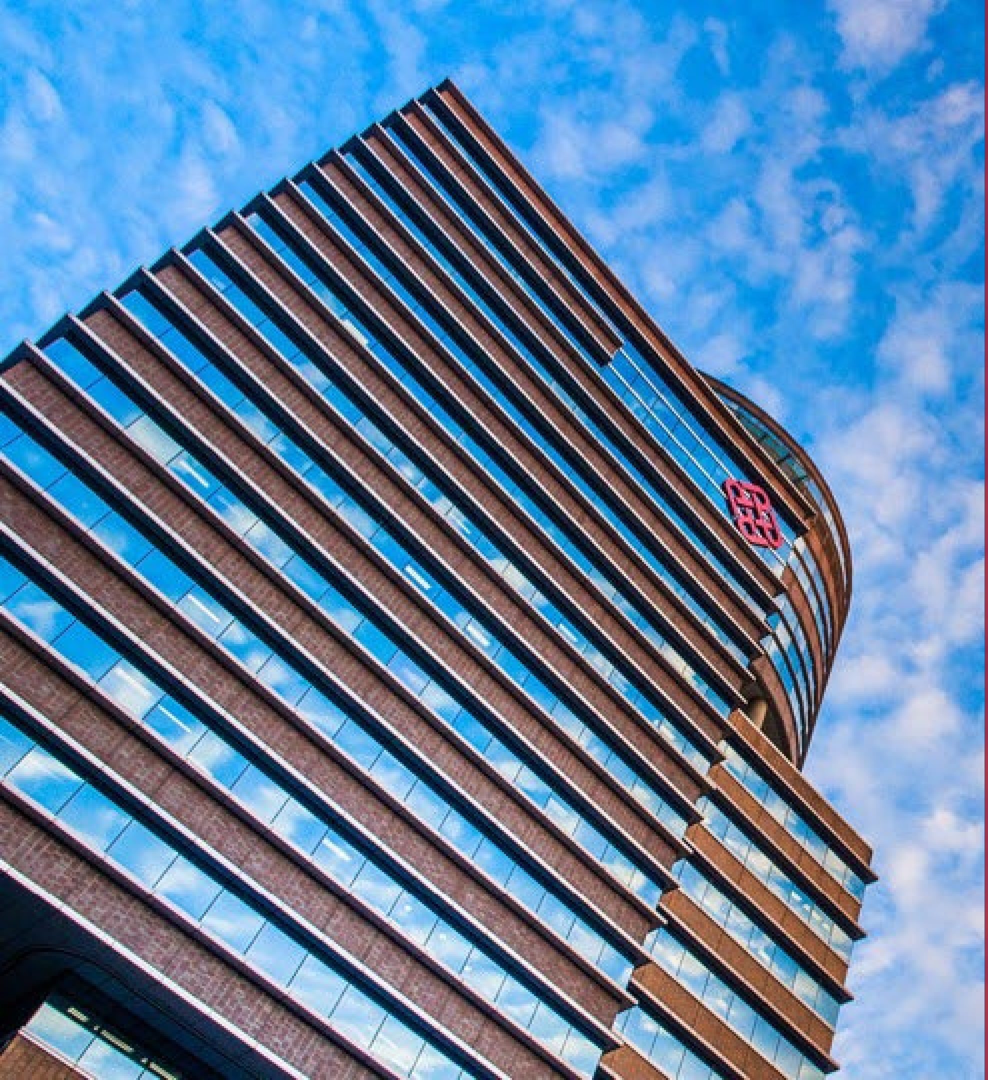
Effects of Aviation Carbon Emission Reduction Measures (China)



Effects of Aviation Carbon Emission Reduction Measures (U.S.)



* Note: Domestic aviation from U.S. and Foreign Carriers. International aviation from U.S. Carriers.



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Next Aviation

An introduction based on Aviation in Europea.

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Next Aviation

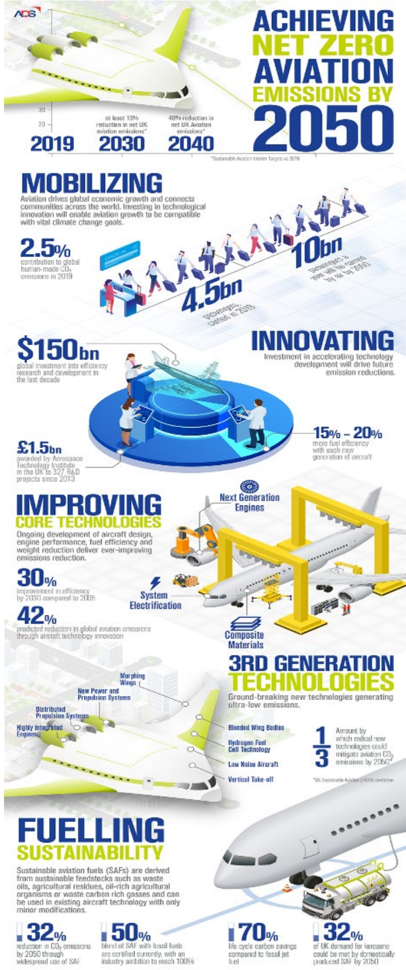
No single solution will enable aviation to achieve net zero CO_2 !

1. Sustainable Aviation Fuel
   A key contributor in achieving long-term emission reduction.

2. Advanced Technology and Design
   Mitigating nvPM emissions in new engine designs.

3. Sustainable Air Traffic Management
   Addressing fuel inefficiency in current operational networks.

4. Campaigns in Airlines
   Coordinated action from airlines to promote scientific studies.



Sustainable Aviation Fuels

Sustainable aviation fuels will be crucial in achieving long-term CO_2 reduction.

Sustainable Aviation Fuels

SAF Supply and EU Mandates

- Current SAF supply is less than **0.05%** of total EU aviation fuel use, aiming for gradual increase: **63% by 2050,** requiring 28.6 million tonnes of SAF.
- SAF plays a key role in decarbonizing aviation due to compatibility with the existing fleet and infrastructure and in **long-haul flights** where other technological advancements, like electric aircraft, are limited.
- SAF remains more expensive than fossil jet fuel, but future economies of scale are expected to reduce costs.

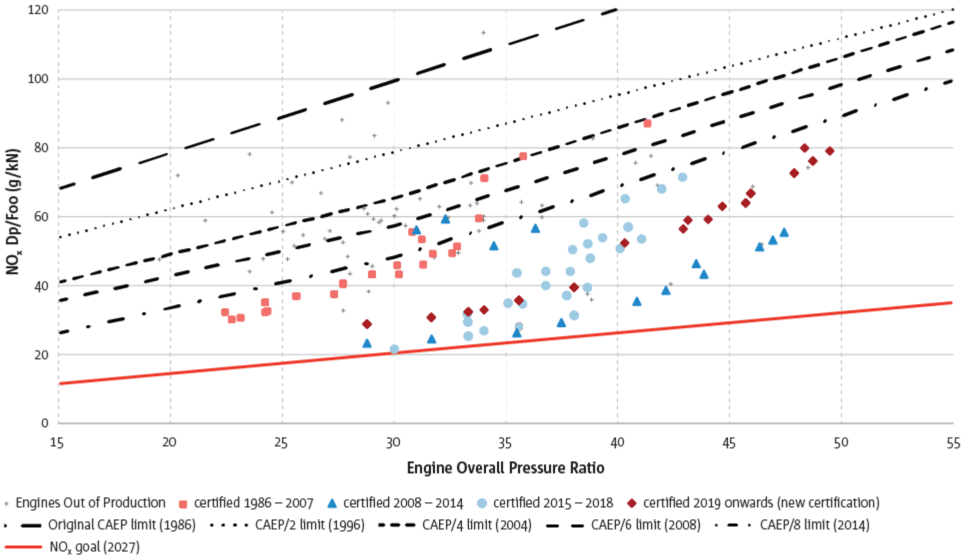
Airbus is raising the bar for sustainable aviation fuel

Advanced Technology and Design

The reduction in fuel burn and related CO2 emissions continues to be the overriding factor in engine technology developments.

Engine Technology and Emission Standards

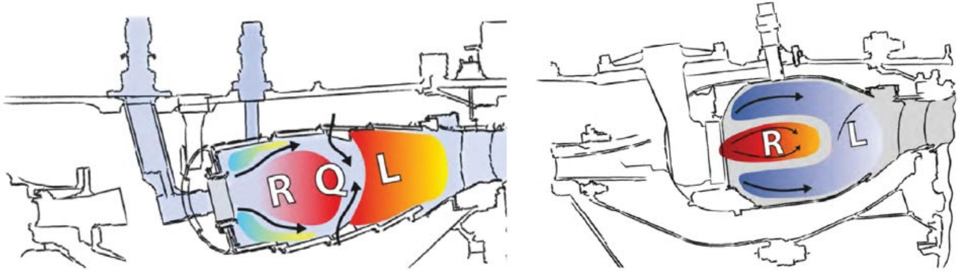
- Engine technology focuses on reducing fuel burn and CO_2 emissions, but higher efficiency can lead to increased NO_X emissions.
- Regulatory NO_X and non-volatile Particulate Matter (nvPM) standards, alongside aircraft noise and CO_2 standards, guide designs to address noise, air quality, and climate change.
- Most new engines comply with CAEP/8 NO_X limits, but high-pressure engines have less margin to meet these limits.



Certified turbojet and turbofan engine NO_x emissions performance

Non-Volatile Particulate Matter (nvPM) and Mitigation

- New nvPM standards aim to reduce particulate emissions, replacing the original Smoke Number standard.
- As of 2020, a mass concentration nvPM standard applies to in-production engines, with mass and number standards effective from 2023.
- Combustor designs, such as lean burn, show better performance for nvPM reduction, but further technical data is needed to assess climate and air quality impacts.



Left: Rich burn-Quick quench-Lean burn (RQL)
Right: Dual Annular Combustors (DAC) lean burn.

Sustainable Air Traffic Management

Developing technological solutions that can deliver a “perfect flight” in terms of carbon emissions reduction and create a fully connected airspace, to achieve Short-term emission.

The European Green Deal and Aviation’s Climate Challenge

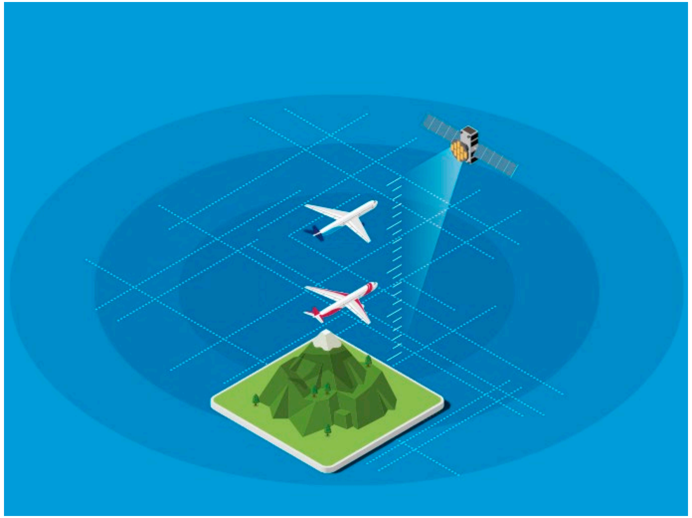
- The **European Green Deal** requires a comprehensive approach involving all stakeholders to accelerate greener aviation operations.
- In 2019, **excess fuel burn** on an average flight-by-flight basis within the Network Manager area was estimated to be between 8.6% and 11.2%, significantly contributing to CO_2 emissions.
- **The European ATM Master Plan**, under SESAR 3, aims to reduce CO_2 emissions per flight by 5-10% by 2035 through enhanced cooperation and system modernization.

Green-GEAR

Sustainable Air Traffic Management

Challenges and Opportunities for Greener Operations

- Despite traffic reductions in 2020, many EU Member States missed their environmental targets.
- Sustainable practices, such as **dynamic airspace, route changing**, and **advanced separation**, can help retain efficiency gains as traffic returns to pre-pandemic levels.
- Forecasting and managing climate-sensitive areas and high-emission aircraft, will be essential to mitigating climate impact of aviation.



Aircraft efficiency starts with having the right altitude

Green Airport

The use of fully electric sustainable taxiing is expected to become the standard procedure by 2030.

Collaborative Environmental Management (CEM)

- CEM developed in 2014, updated in 2021 to address growing sustainability challenges.
- Keys:

✓ Integration of **Sustainable Aviation Fuel (SAF)** and inclusion of SAF providers.

✓ Preparation for novel **hydrogen aircraft** and their associated fuelling infrastructure, such as Airbus “Hydrogen Hub at Airports” .

✓ Developing various operational, infrastructure and technical challenges need to be addressed for **sustainable taxiing**.

✓ Reference to new legislation and voluntary industry schemes like Airport Carbon Accreditation.

Green Airport

SESAR Total Airport Management Project

- Target:

✓ Developing **real-time environmental performance management tools** for airports.

- Supports:

✓ Optimization of **gate/taxi route allocation**.

- Achieved **50% reduction** in fuel and CO2 emissions compared to standard procedures by using sustainable taxiing during 2020 Schiphol airport .
- Also reduce **NOx emissions** and noise.
- **Electric taxiing** expected to be the standard by 2030.

✓ **Runway configuration update**.

- Allowing aircraft to use a second aiming point for landing.
- Reducing runway occupancy.
- Facilitating a steeper 4.5-degree approach (vs. the usual 3-degree)

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Contrails: Aircraft-induced Clouds

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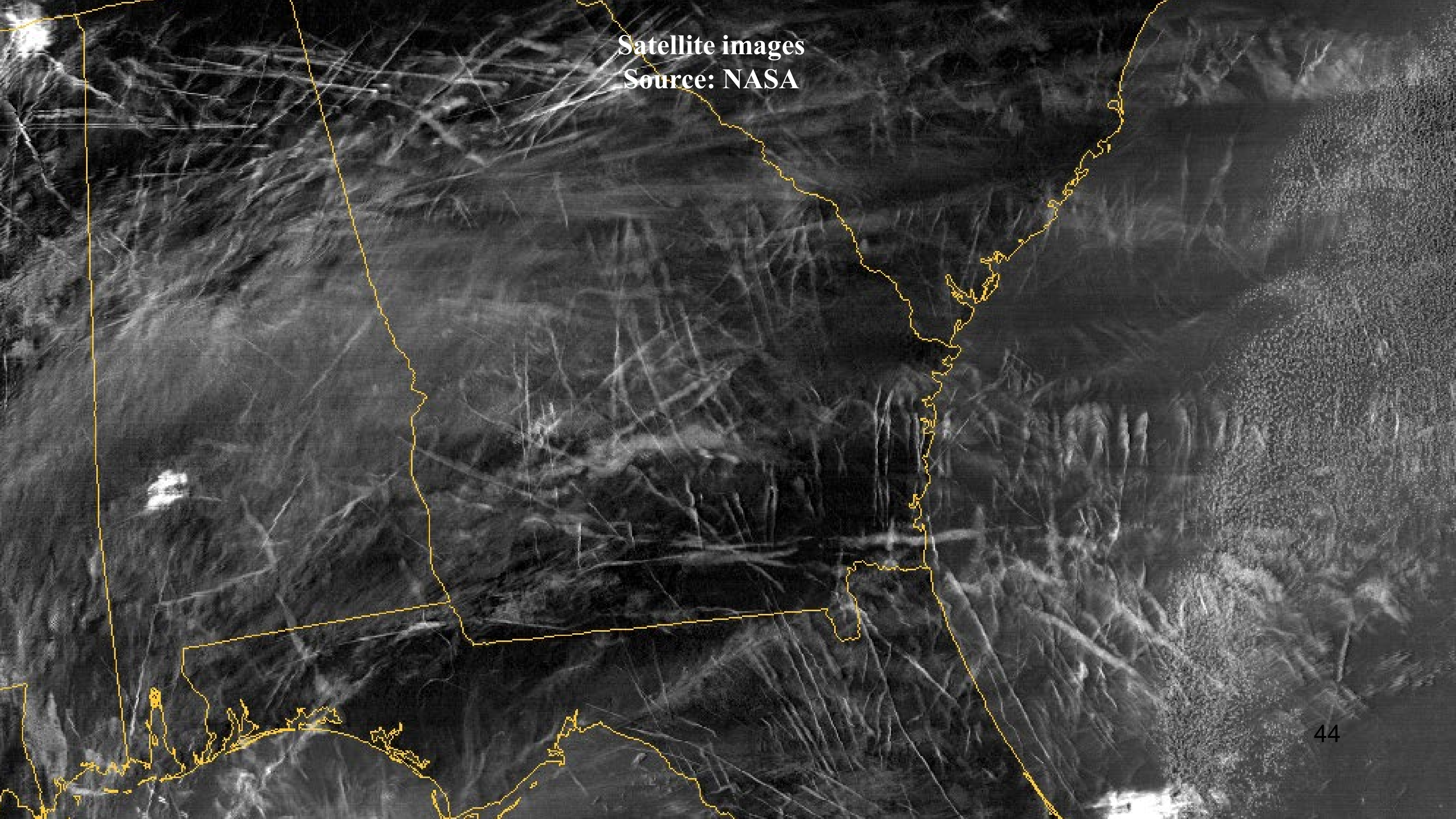
Toulouse, France


Portugal airspace

Toulouse, France



Satellite images
Source: NASA

Campaigns in Airlines

Humidity Sensors for Enhanced Contrail Understanding

- Civil aircraft lack accurate humidity sensors for detecting ice-supersaturated regions (ISSRs), key to forecasting contrails.
- Current data is limited, relying on scattered weather balloons, satellite data, and a small fleet of research aircraft.
- Improving in-situ **humidity measurements on commercial aircraft** could enhance contrail prediction and mitigation strategies.

Temperature sensor attached to the humidity sensor installed aboard the Airbus A340-300[]

Campaigns in Airlines

Aircraft as Research Laboratories

Currently, with around **10** wide-body aircraft globally equipped for accurate ISSR detection at cruise level in **IAGOS.**

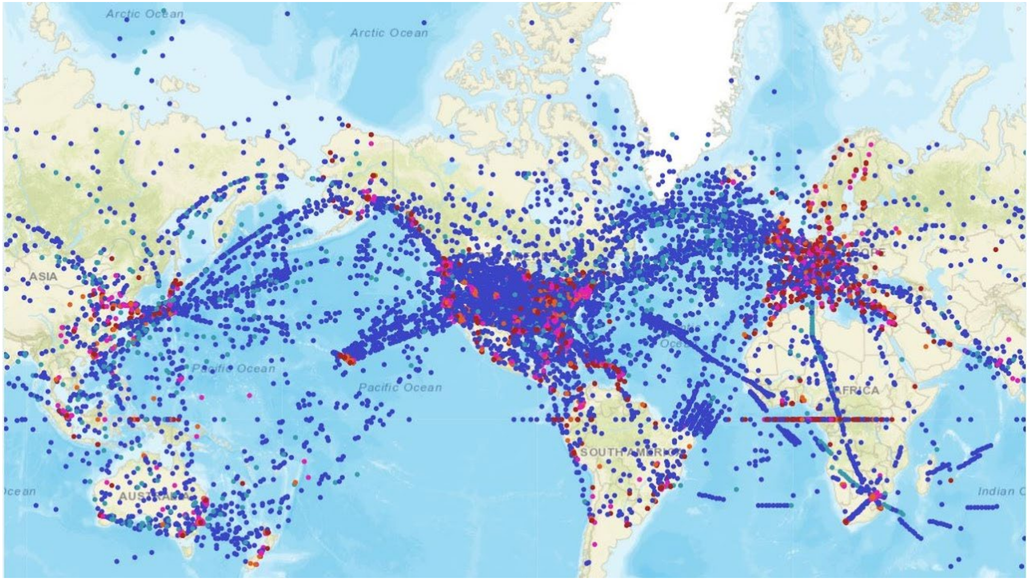
World map showing the IAGOS flights of the 8 participating airlines and Air Namibia as co-operation partner.

Aircraft installed: Airbus A340, Airbus A330, and there are plans to expand the program to Airbus A350.

Aircraft as Research Laboratories

- **In the AMDAR program**, about **140** narrow-body aircraft are equipped with humidity sensors which provide readings during climb and descent.

- Research into **advanced humidity sensors**, like the Chilled Mirror, aims to improve accuracy at cruising altitudes for better ISSR detection and contrail mitigation.



Indicative AMDAR data coverage map on 16 July 2019.

Benefits and Costs of Implementing Sensors

- Installing humidity sensors can create **minor drag penalties** and require additional power, but the effects are negligible for aircraft performance. Research into optimizing sensor weight and packaging is ongoing, ensuring minimal fuel consumption impact.

- Costs for sensor installation range from $20,000 to $180,000, with additional certification and maintenance expenses. However, these sensors could significantly benefit airlines and the scientific community by improving weather forecasting and contrail avoidance strategies.

Contrails: Aviation-induced Clouds

What are contrails we observe in sky?

Contrails or Condensation trails, are white line-shaped cirrus clouds which form behind the aircraft at cruising altitudes in high humidity areas known as **ice super-saturated regions (ISSR)**, where the temperature is cold enough, and water vapor emitted from the aircraft's engines and present in the atmosphere condenses onto the unburned carbon particles that are left behind by the engine's exhaust, to form trillions of tiny ice crystals for every kilogram of jet fuel burned.

Contrails: Aviation-induced Clouds

Contrail Formation Criteria (Schmidt-Appleman):

Temperature(below ~235 K ≈−38 °C);

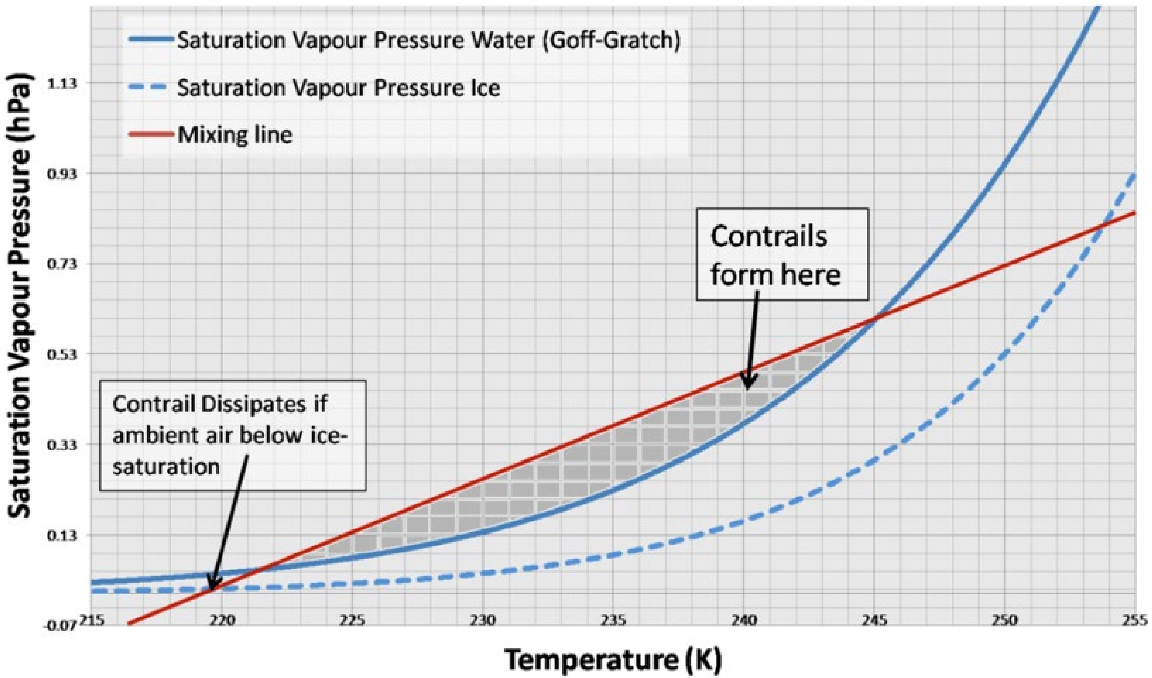
Relative humidity;

Water vapour;

Pressure;

Heat emissions;

Efficiency of aircraft engines.



The Science of Contrail Formation

Ambient conditions, engine efficiency and fuel properties are key factors influencing contrail formation.

The Science of Contrail Formation

1 Engine Exhaust

Aircraft engines emit hot exhaust gases containing water vapor and particulates.

2 Rapid Cooling

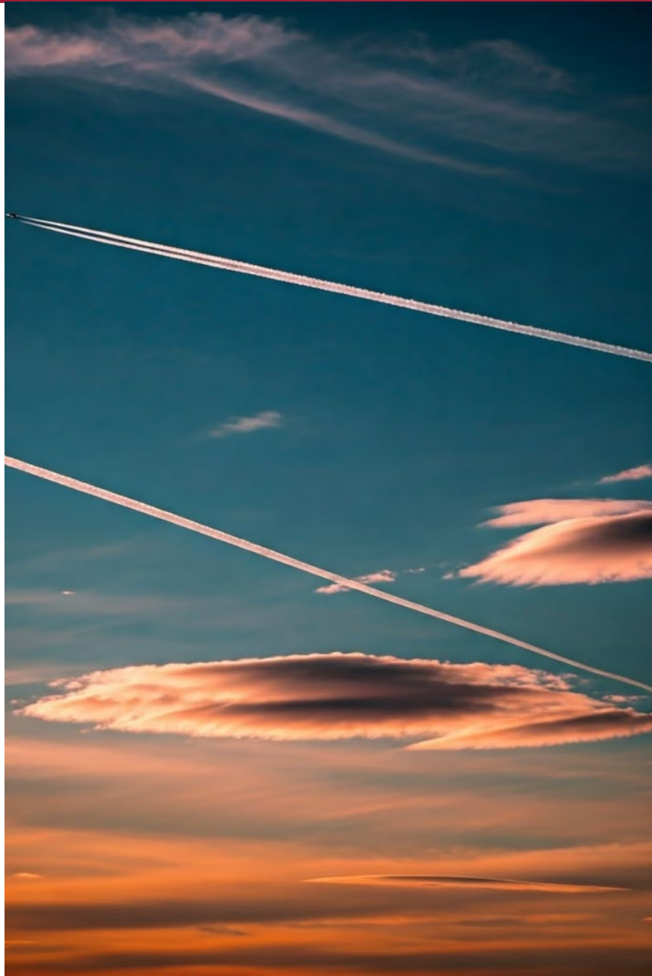
The hot exhaust mixes with cold ambient air, causing rapid cooling and condensation.

3 Ice Crystal Evolution

Water droplets freeze into ice crystals, forming visible contrails behind the aircraft.

4 Persistence or Dissipation

Depending on atmospheric conditions, contrails may persist and spread or quickly dissipate.

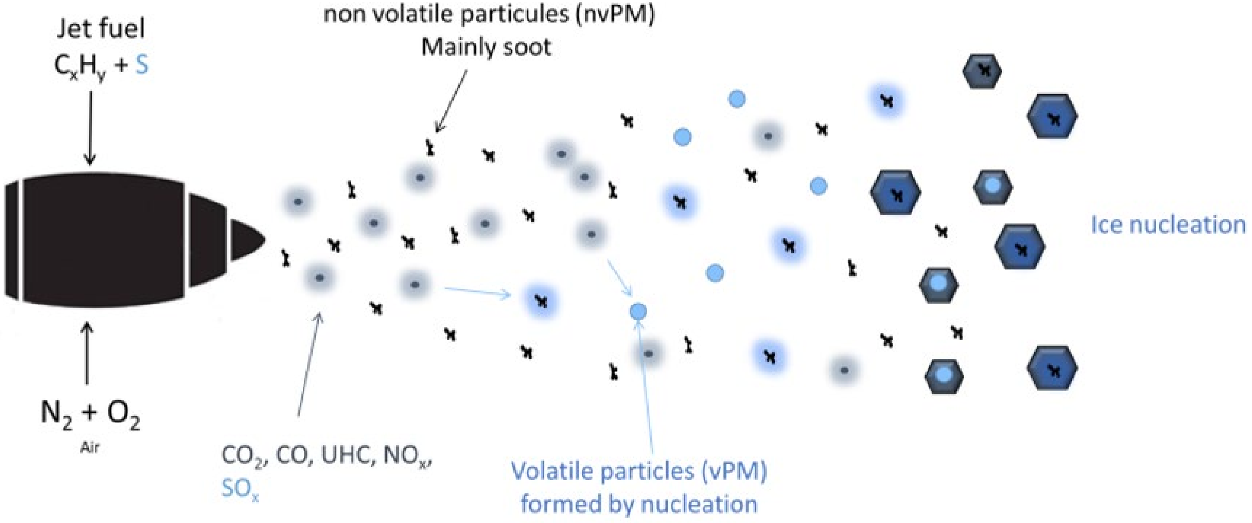


The Science of Contrail Formation

1

Engine Exhaust

Jet engine exhaust plumes contain **water vapor and particulate** emissions, which mainly consist of ultrafine soot or black carbon emissions, called Non-Volatile Particulate Matter (nvPM).

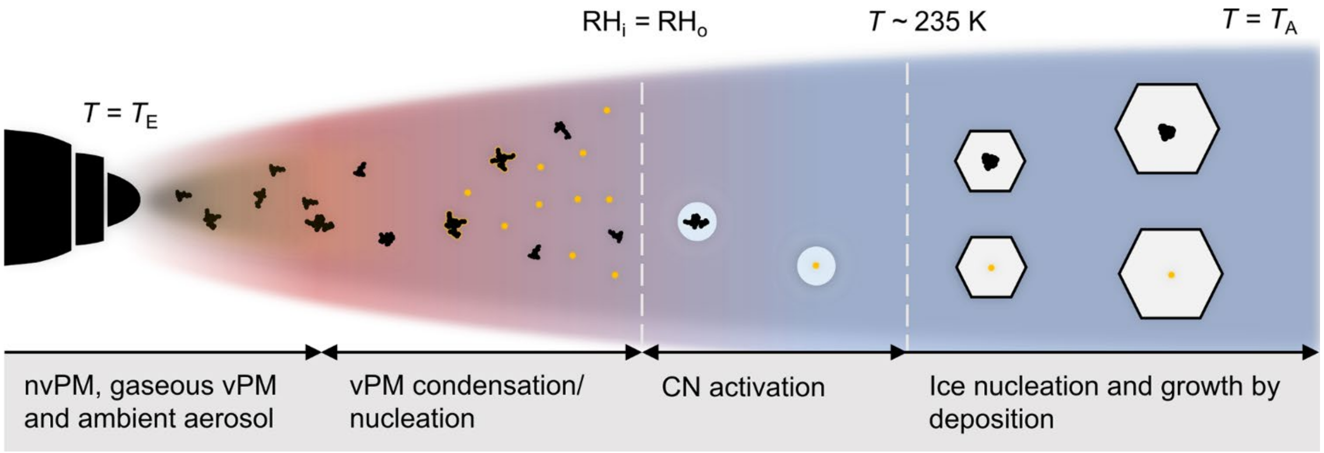


The Science of Contrail Formation

2

Rapid Cooling

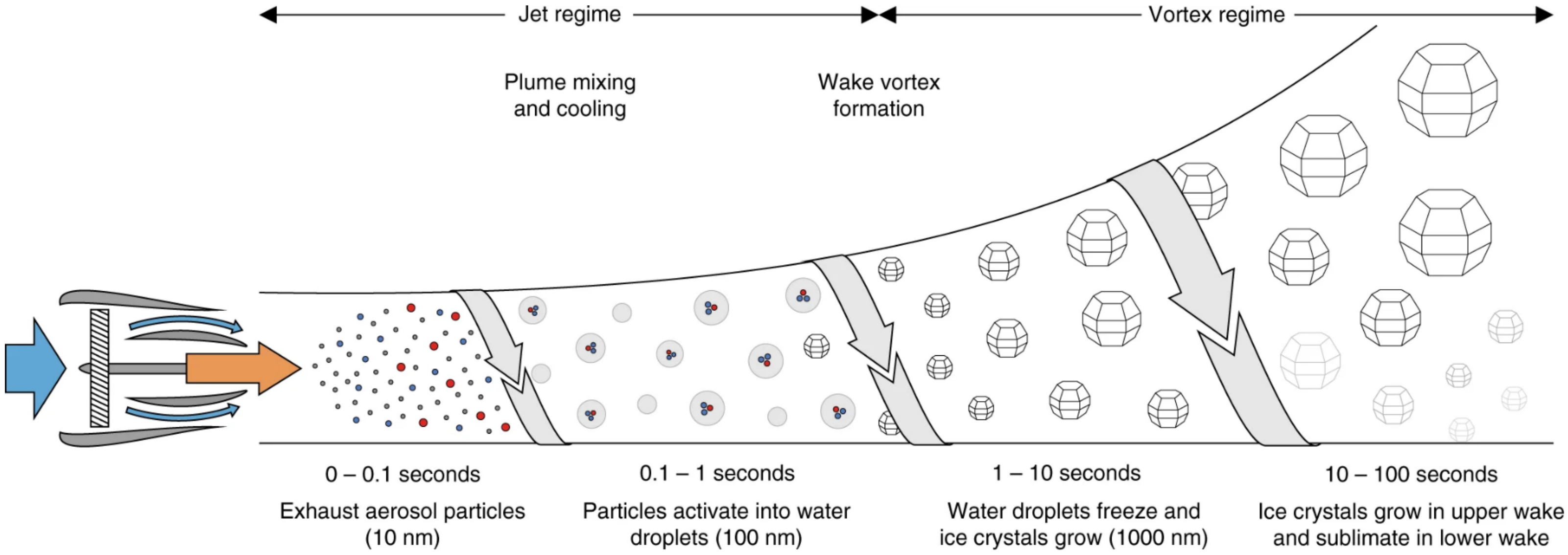
Contrails form when water vapor reaches supersaturation and cools, creating ice crystals, which initially form as unobservable water droplets containing soot particles, potentially resembling hexagonal prisms, and freeze rapidly as the plume cools in the atmosphere.



3

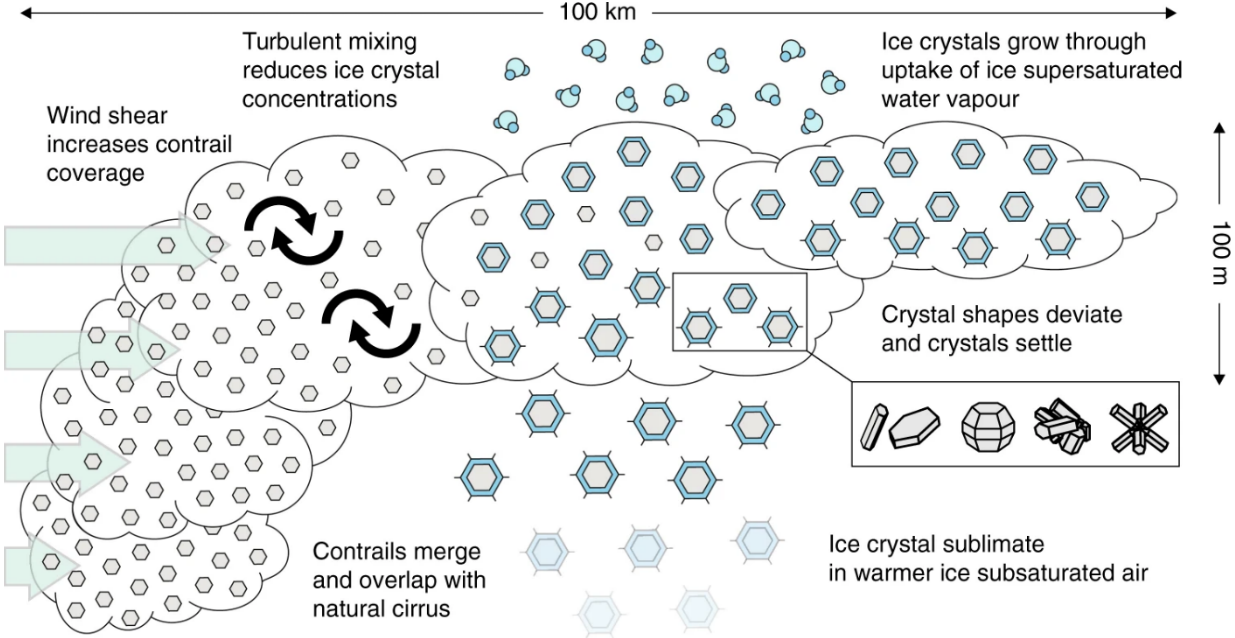
Ice Crystal Evolution

With exhaust plumes merging into wingtip vortices, ice crystals sublimate in warmer, lower wake regions but continue growing in the upper wake to be visible contrails.



4 Persistence or Dissipation

The microphysical and optical properties of ice crystals in contrails change as they evolve into contrail cirrus, influenced by meteorological conditions and microphysical processes.



The Science of Contrail Formation

4 Persistence or Dissipation

Initially linear contrails transform into extensive ice cloud layers, merging in high-traffic areas.

Contrails can persist from several minutes to several hours, with those lasting over 10 minutes classified as "persistent contrails."

Globally, contrail cirrus covers about 0.06% of the sky, but in high-traffic areas like the North Atlantic, coverage can reach up to 10%.

Contrails characterization

To take preventive actions, there must be a deep understanding of why they can cause net warming, where they are located, how large they are, and how long they could live.

Contrails Characterization

Factors Affecting Contrail Climate Impact

1. **Time of Day**

   The angle of incoming solar radiation affects contrail impact.

2. **Cloud Properties**

   Optical thickness and surrounding atmosphere influence climate effects.

3. **Location**

   Whether over land or sea impacts contrail effects.

4. **Duration**

   The lifetime of the contrail in the atmosphere matters.

Contrails Characterization

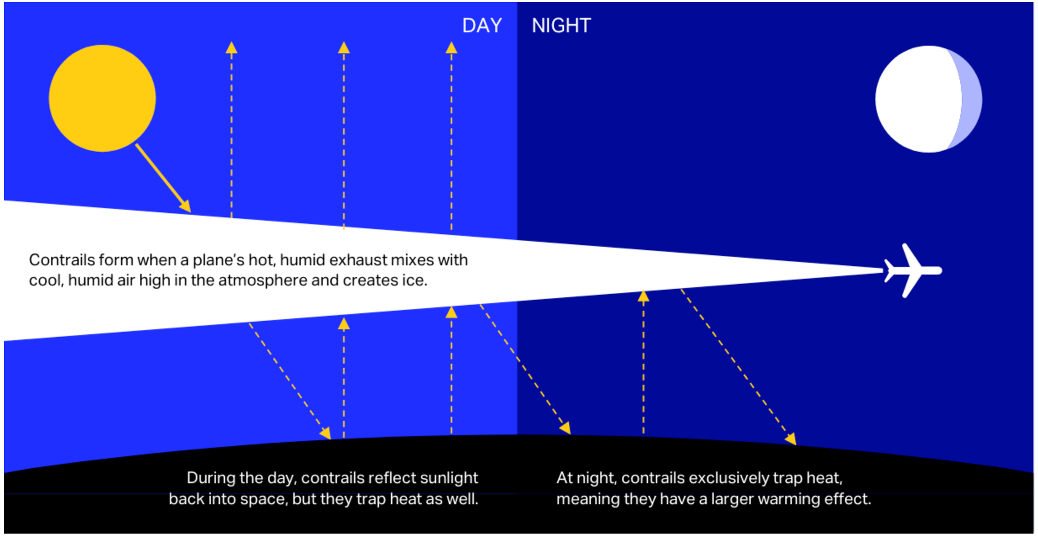
1 Day vs Night Contrails

Daytime Effects

Contrails reflect solar radiation (cooling) and trap thermal-infrared radiation (warming). For most contrails, the **warming effect predominates during daytime**, except for optically very thick contrails.

Nighttime Effects

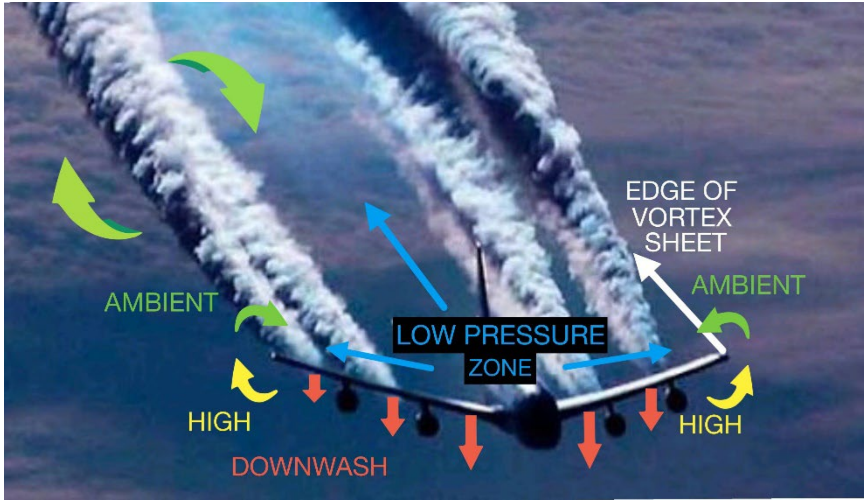
At night, there's no solar radiation. The cooling effect disappears, making **night contrails more warming on average**.



2 ISSR and Contrail Size

- Most Ice-Supersaturated Regions (ISSRs) are 100-400 km in horizontal extension, with an average around 150 km and less than 1% exceed 1000 km.
- Thickness of ISSRs ranges from 600-800 m, with extremes of 3000 m.

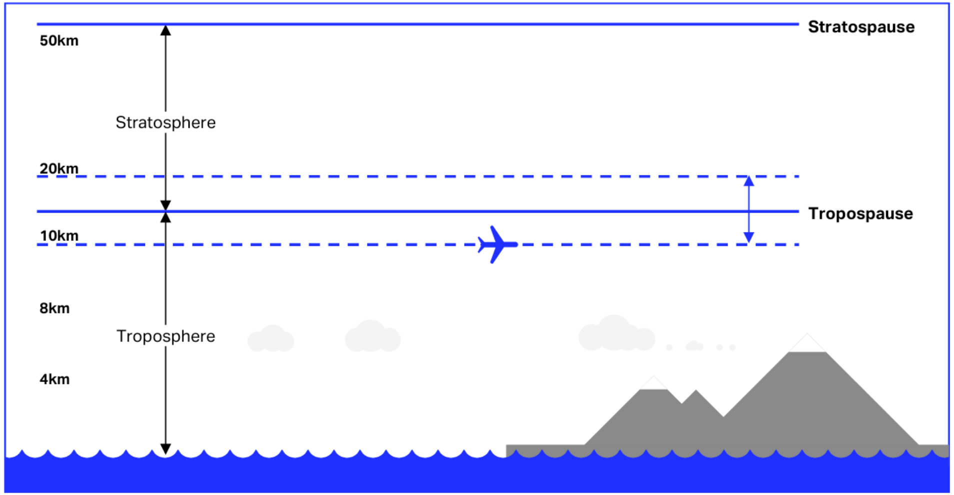
- Contrails form within ISSRs, typically with lengths matching the ISSR's horizontal size, averaging 150 ± 250 km.
- Contrails can expand as they absorb water vapor and are influenced by winds, reaching widths of 9-10 km.
- They also downwash vertically due to wingtip vortices.



Contrails Characterization

3 Contrail Location

- ISSRs: the upper troposphere and tropopause region at about **8-12 km altitude in the mid-latitudes**, and about 12-18 km in the tropics.
- Aircraft cruise level: at **9–12 km altitude**. This is why contrail formation is more common at mid-latitudes than near the tropics.
- Seasonal variation: contrail formation are **more likely during the winter** than during the summer due to climatological conditions favourable for contrail formation, such as weather frontal systems and jet streams.



Contrails Characterization

4 Contrail Lifetime

Contrail lifetimes are highly variable, with most lasting between 1 to 3 hours according to observations and weather models.

However, in regions with ice-supersaturated layers (ISSRs), contrails can persist longer, with ISSR lifetimes estimated between 6 to 24 hours, potentially extending up to a day depending on atmospheric conditions.

Non-persistent contrail

Persistent contrails and cirrus clouds

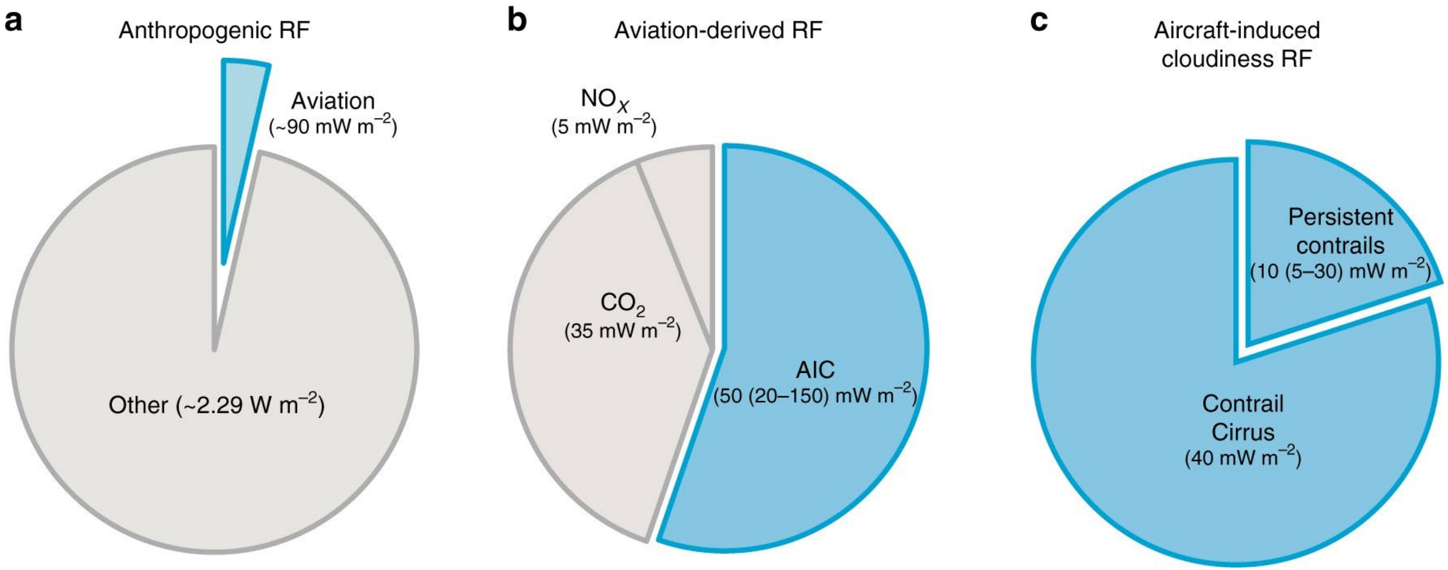
The Climate Impact of Contrails

While uncertainty remains high, studies estimate contrails have an overall warming effect on the planet.

The Climate Impact of Contrails

Aviation-induced Climate Effects

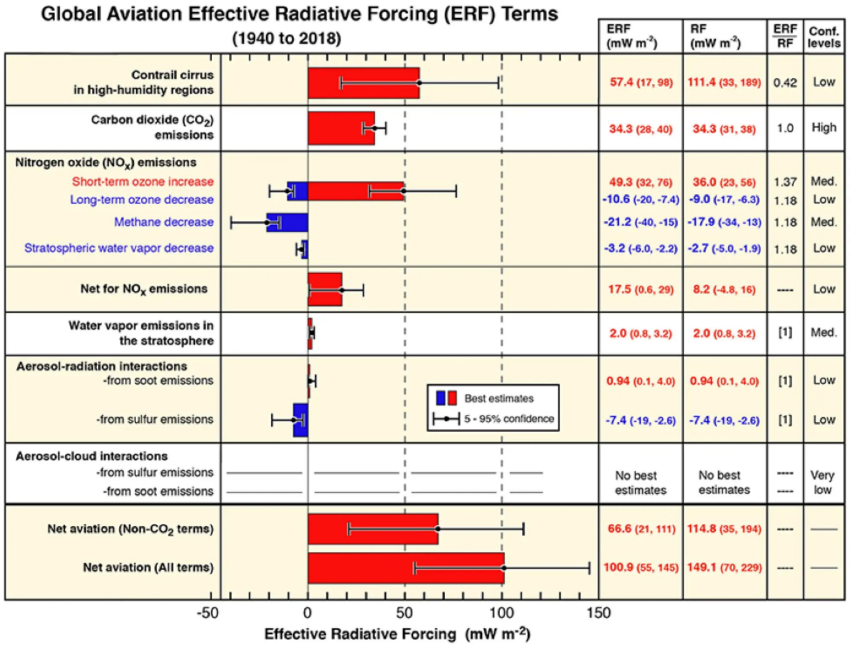
Aircraft-induced clouds (AIC), particularly contrail cirrus, accounting for the largest portion of aviation-related radiative forcing (RF), which represents 4% of the total global RF from human activities in 2011.



The Climate Impact of Contrails

Aviation’s Non-CO_2 Climate Effects

- Besides CO_2, aviation contributes to climate change through **contrails**, nitrogen oxides, and soot emissions.
- Non-CO_2 effects have complex interactions with the atmosphere, leading to significant short-term warming impacts.
- The recent studies pointed out that contrails (cirrus) have a **significant warming impact**, especially in the short-term, **of the same order of magnitude** as CO_2 emissions.



The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, Lee et Al

The Climate Impact of Contrails

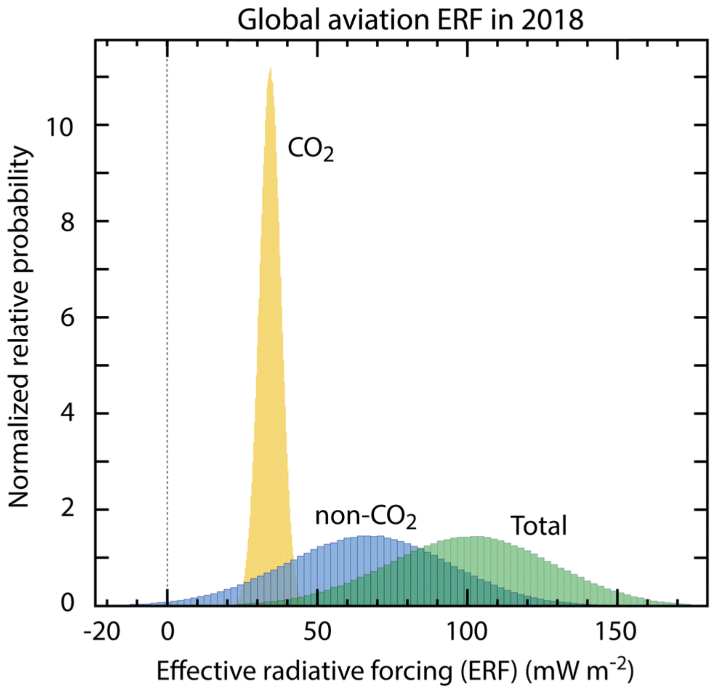
Radiative Forcing of Non-CO_2 Effects

- Radiative forcing (RF) measures the change in Earth's energy balance, a quantitative indicator to show how the warming effect could be.

- Non-CO_2 effects accounted for two-thirds of aviation's radiative forcing in 2018 but with far higher uncertainty than CO_2.

Item	CO_2 Emissions	Contrail-Cirrus
The best estimate	34.3 (±17%)	57.5 (±70%)
Range	28-40	17-98

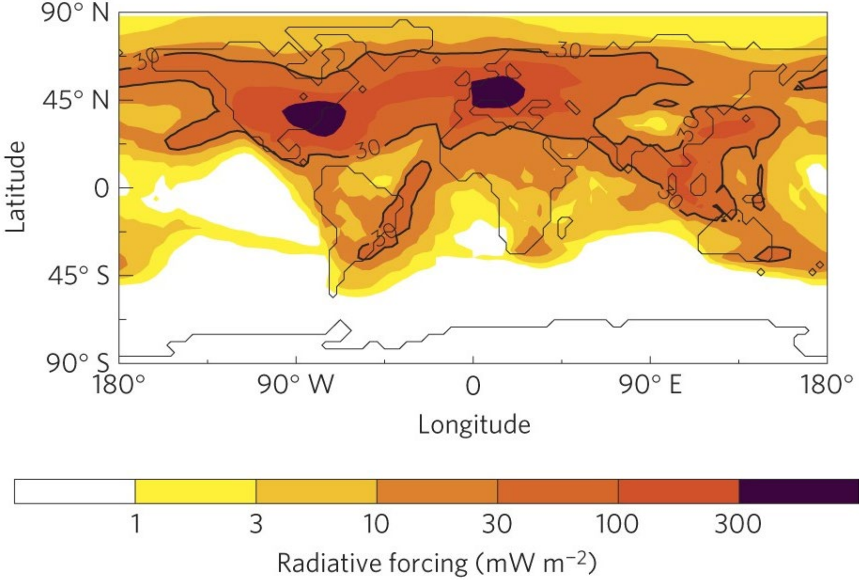
Unit (mW/m2)



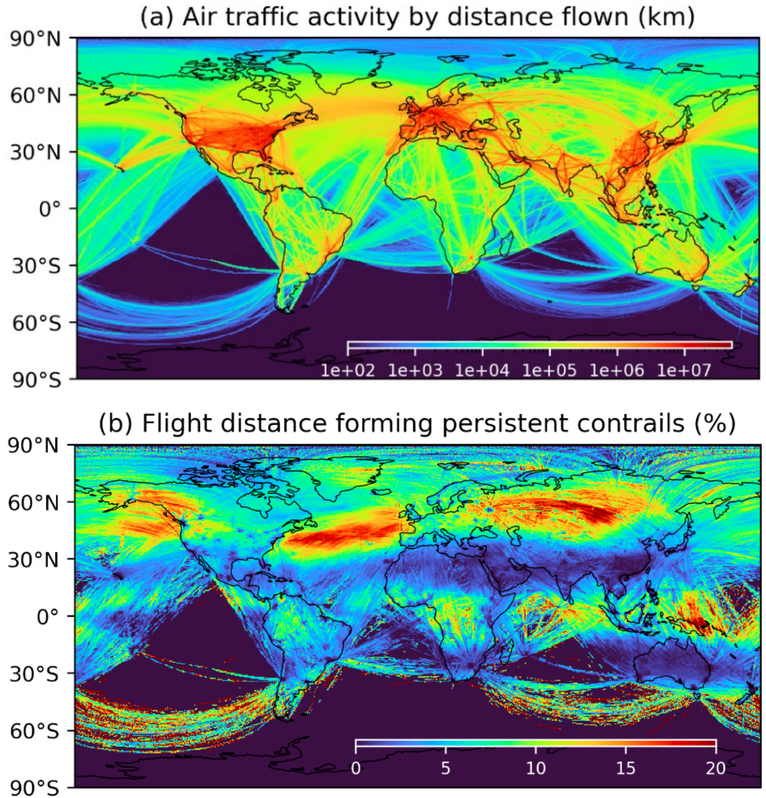
Probability Distribution Functions for Aviation ERFs in 2018: CO2, Non-CO2, and Net Effects

The Climate Impact of Contrails

Radiative Forcing Distribution for Contrail-cirrus



Net Contrail-cirrus radiative forcing at 250 hPa in the year 2002.



The 2019 global (a) annual flight distance flown, (b) percentage of flight distance forming persistent contrails.

The Climate Impact of Contrails

Challenges in Measuring Contrail Climate Effects

- Contrails affect climate depending on cloud thickness, location, time of day, and atmospheric conditions.

- Contrails can cause both warming and cooling. The total net effect will depend on the importance of each of these opposite effects during their lifecycle, a quite short lifespan which causes difficulties in measuring the climate impact.

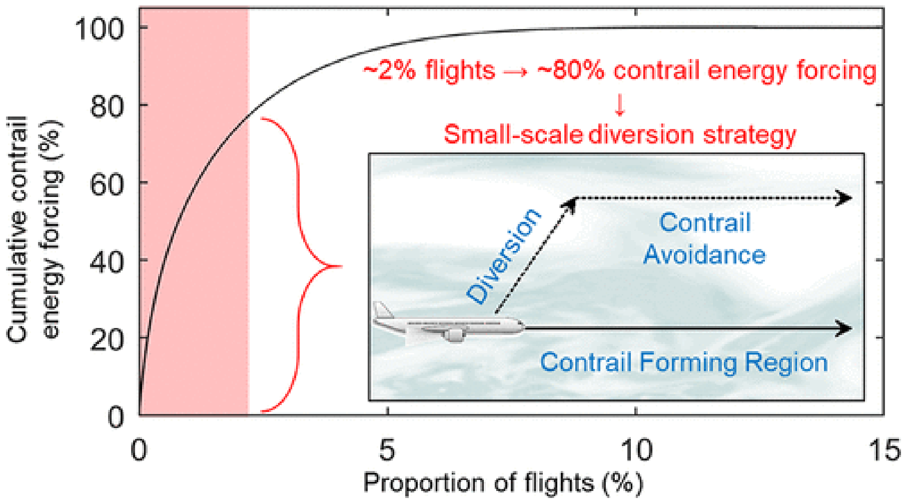
- Only a few global climate models can accurately simulate contrail formation and its effects, and there are less observational evidences to support the simulated results.

Contrails Avoidance

Two potential solutions are under study: changes in flight trajectory and improvement in fuel quality.

Avoiding Contrail Formation through Flight Path Adjustments

- One solution under study is **changing flight paths** to avoid forming contrails in climate-sensitive areas.
- **Trade-off**: avoiding contrails can increase fuel consumption, leading to additional **CO_2 emissions**.
- Decision-making: balancing **short-term benefits** of reduced contrail impact with the **long-term consequences** of higher CO_2 emissions.



Challenges: Operational Considerations

1

Prediction

Using numerical meteorological models and satellite observations to accurately predict where persistent warming contrails might form

2

Impact Assessment

Quantifying the warming impact of a single contrail. Meanwhile, understanding system-level climate impacts of avoidance strategies.

3

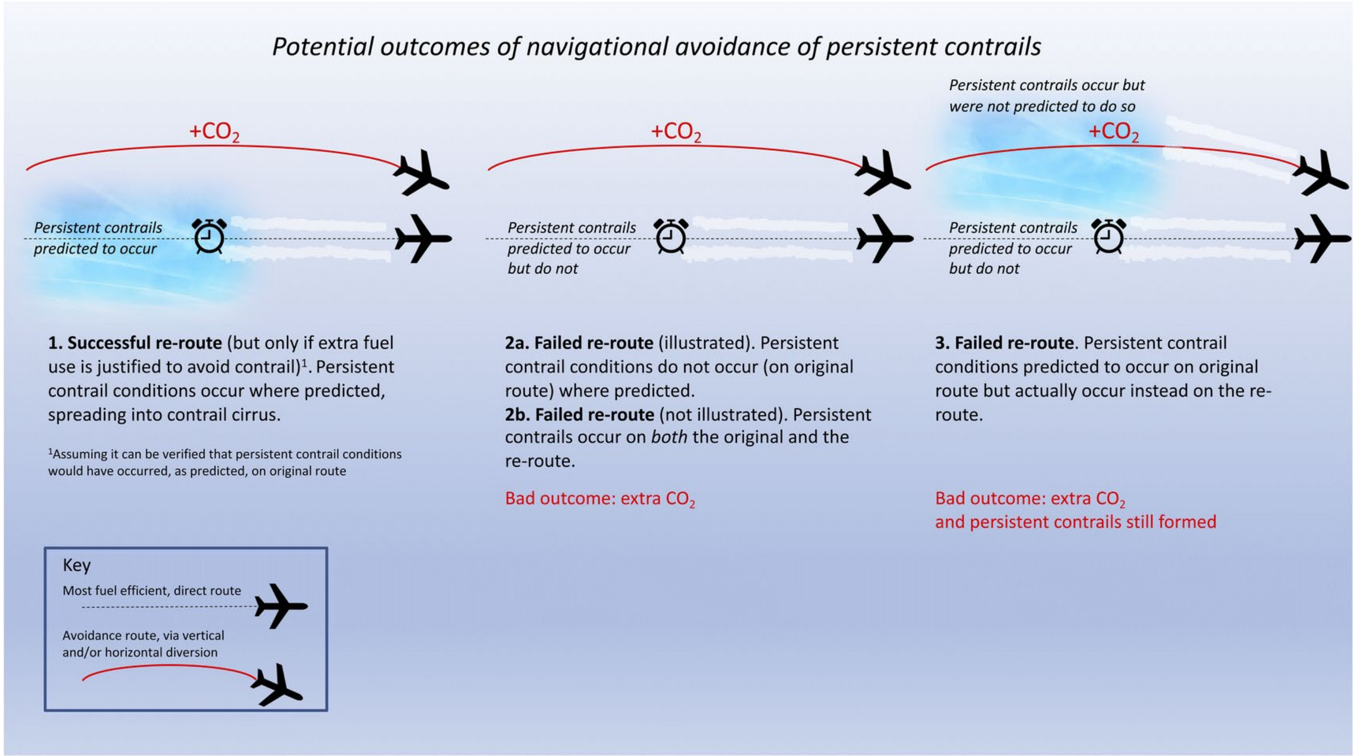
Safety Constraints

Ensuring deviations don't compromise flight safety, satisfying the requirements of fuel, capacity, and workload for crew and ATC.

- A small fraction of flights disproportionately contributes to the climate impact of contrails. In 2019, around **2% of global flights** were responsible for **80% of the climate impact** related to contrails.

Contrails Avoidance

Challenges: Operational Considerations



Contrails Avoidance

Improving Fuel Quality to Reduce Contrails

- Certain fuel components, especially **aromatics**, contribute to **soot production** which fosters contrail formation.
- **Sustainable Aviation Fuels (SAF)**, which have lower aromatic content, are being explored as a solution to reduce soot and ice crystal formation, to avoid contrails formation **fundamentally**.
- Experimental results show that using **low aromatic SAF** can lead to a **50-70% reduction** in soot and fewer ice crystals in contrails, reducing their warming impact.
- **Operational Challenges**: higher cost in comparison with jet fuel.

The Falcon 20E (small one using SAF) flew to within 100 metres of the A350 at cruising altitude.

Contrails Avoidance

Hydrogen Aircraft

- **Hydrogen-powered aircraft** present a promising alternative to conventional jet fuel, producing **water vapor** as the primary emission, reducing **soot** and **contrail formation**.

- **Benefits**: Hydrogen combustion doesn't release CO_2, offering **zero-carbon flight** and mitigating both **CO_2** and **contrail** impacts.

- **Limits**: Hydrogen aircraft face **technical challenges** such as the need for new engines, larger storage tanks due to hydrogen's **low energy density**, and the high cost of producing **green hydrogen**.

Airbus ZEROe Concepts

Photo credit: PolyU AAE AIAA DBF Team

Thank you!

We welcome you to join this adventure of flying ☺