Climate neutrality not just carbon neutrality: how the AIA is working are working to find out more about the non-CO2 effects of aviation

The aviation industry is increasingly under pressure from passengers, environmental groups, governments and policy makers to reduce its climate impact and become a more sustainable industry. The main focus has been on developing new aircraft and propulsion technology to reduce or eliminate greenhouse gas emissions or at least become carbon neutral. However, aviation's climate impact extends beyond carbon emissions. On clear days, aircraft flying in cold and humid conditions can be seen forming condensation trails, or contrails. In many cases these contrails disappear within a matter of minutes. However, if aircraft are flying in atmosphere where the relative humidity with respect to ice is greater than 100% (ice-supersaturated), contrails can persist for hours and may evolve into cirrus clouds. Like clouds, contrails reflect incoming solar energy back out to space creating a cooling effect, but they also absorb surface radiated energy creating a warming effect. The net effect is usually a warming of the atmosphere. In fact, one recent study suggested that between 1940 and 2018, the net **global warming impact of contrails, measured in terms of radiative forcing, may have been as much as three-quarters of that of the total net radiative forcing generated by aviation (Lee et al. 2021)** Therefore, although future aircraft operations may become carbon-neutral, they may not be climate-neutral if contrails are generated In recent months, engineers, scientists and industry partners working on the Aviation Impact Accelerator project (AIA) have been trying to estimate the climate impact of contrails now and in the future. But the science of contrails is relatively less well understood and their climate impact is highly uncertain.

Where do contrails come from? The uncertainty in the science of contrails

Contrails were first observed in 1915 and the theoretical framework for their formation was first presented in 1941. Contrails form when water vapour particles emitted from aircraft engines latch onto soot particles (also emitted by engines or naturally-present in the atmosphere). If the ambient temperature is less than approximately -40ºC the water freezes to form ice crystals. The shape and effect of the contrail depend on water vapour and soot concentrations in the fuel which varies depending on the fuel type.

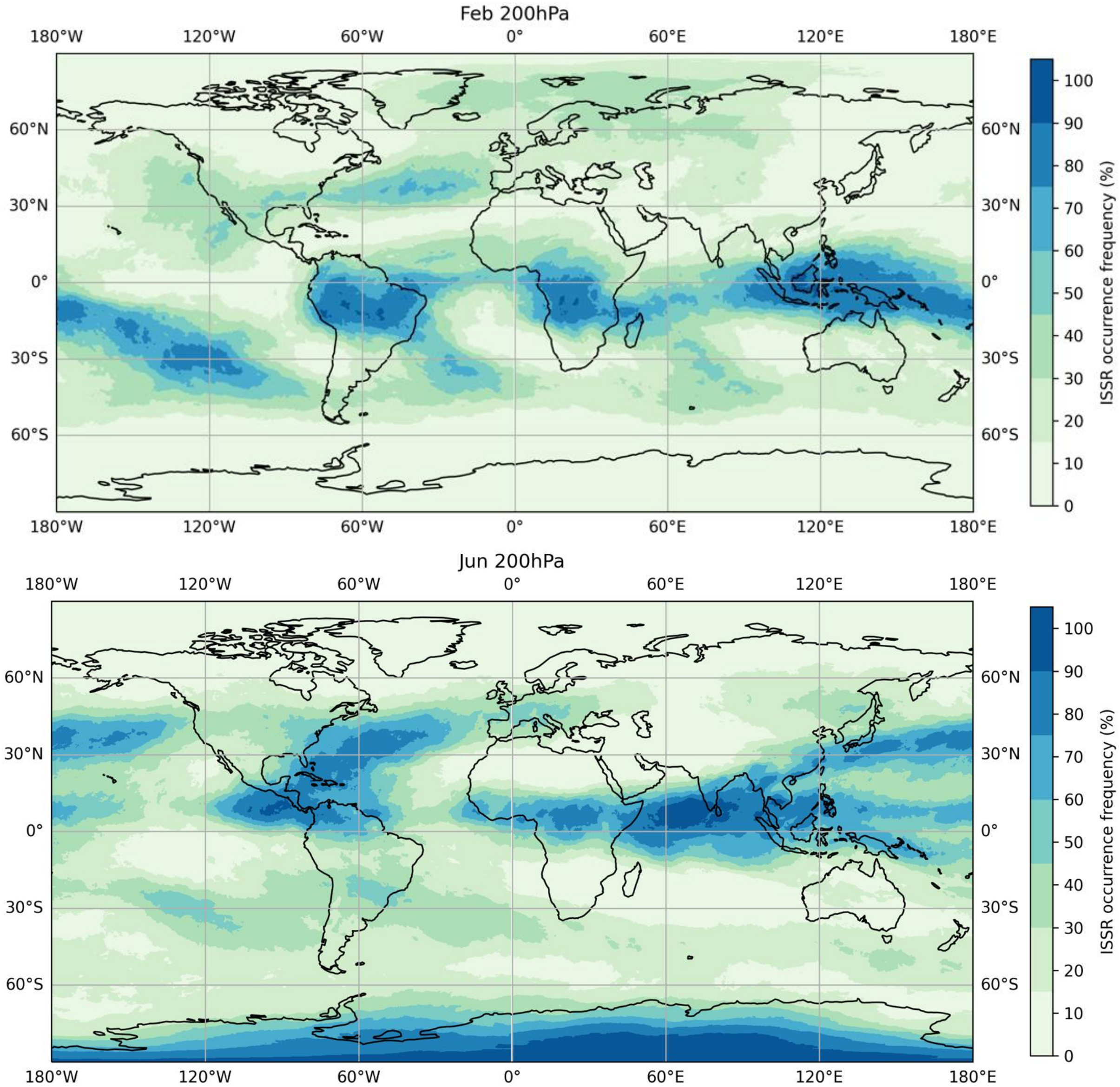
Predicting the formation of contrails is a complex challenge. The task requires not only detailed information about the relative humidity and temperature of the atmosphere but also aircraft and engine parameters such as the propulsive efficiency of the engines. In fact, **while more efficient jet-engines reduce fuel burn and carbon emissions, they are more likely to form contrails**. This occurs because, for more efficient engines, the temperature of the exhaust is lower for the same concentration of emitted water vapour. This causes contrails to form at higher ambient temperatures and over a larger range of altitudes in the atmosphere (Schumann et al, 2000).

This was observed during a flight test campaign in 1999 when two different aircraft were flown at the same altitude in identical atmospheric conditions as shown in the image below. The Airbus A340 aircraft on the left has relatively higher engine efficiency and is seen to generate contrails, compared to the Boeing 707 aircraft on the right which has relatively lower engine efficiency and no visible contrail formation occurring.

Photo of an Airbus A340 with contrails (left) and a Boeing B707 without contrails (right) at 10.5 km altitude. Source: Schumann (2000).

The greatest climate impact comes from long-lived, persistent contrails that occur in ice-supersaturated regions (ISSR) of the atmosphere. In these ISSR regions, ambient water vapour in the atmosphere deposit onto the initial ice crystals to sustain the contrail. These ISSRs can vary by time of year, altitude and region. The maps below show the occurrence frequency of ISSRs in February and June at a pressure level of 200hPA (approximately 39,000ft altitude), averaged over 5 years from 2014 to 2018. The likelihood of persistent contrails for flights between Europe and North America and the Caribbean is far greater in June compared to February. Once persistent contrails form, the rate at which they spread depends on the characteristics of the aircraft wake. The speed, size and geometry of the aircraft all play a part. Furthermore, the contribution of individual contrails to atmospheric warming is dependent on the presence of naturally-occurring clouds above and below the contrail, contrail overlapping in busy airspace regions and the albedo of the surface and atmosphere.

Thus, the science of contrails consists of many aircraft and atmospheric variables which make them **difficult to model and predict**. Measuring some of these variables in-flight is challenging and costly and therefore modelling often relies on assumptions which lead to further uncertainties. Together this complexity and uncertainty has led to contrails often being left out of the conversation on the climate impact of aviation. However, with growing academic and industry agreement on their significant contribution to global warming, attention is growing on how to minimise their formation.



Global ISSR occurrence frequency (%) averaged over a 5-year period from 2014 to 2018. Data taken from the ECMWF ERA-Interim reanalysis data.

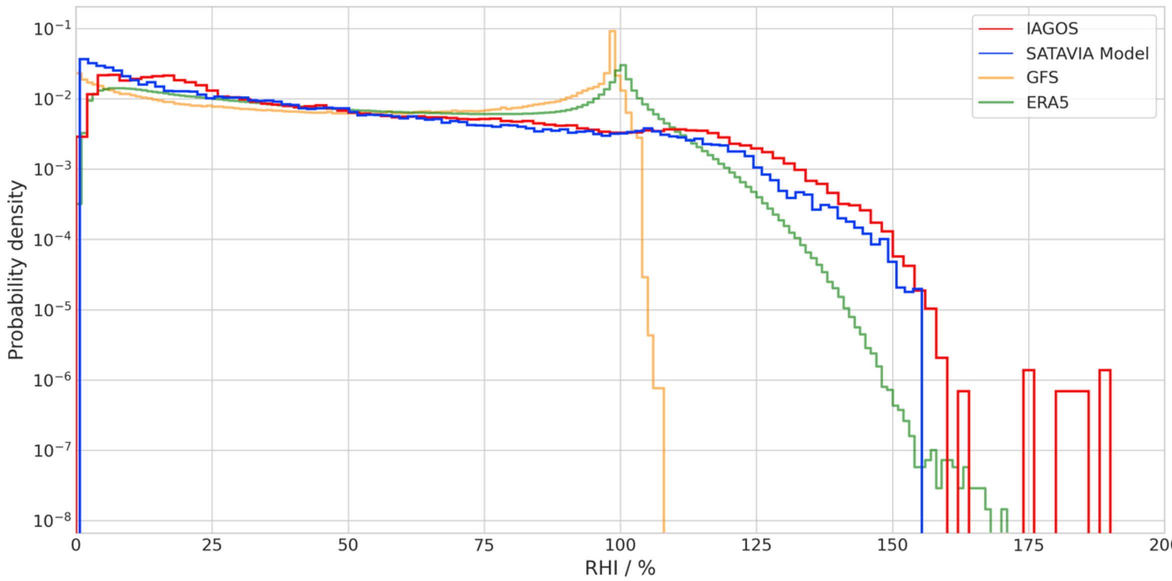
Operational solutions to minimise the occurrence of contrails

Since contrail occurrence depends on the time and location of flights, **a potential solution is to operate aircraft in regions of airspace where ISSRs are less likely to occur by adjusting flight paths** both laterally and vertically. This is operationally challenging and requires high resolution forecasting of the atmosphere and robust flight planning. Despite the operational and technical challenges, two of the AIA's industry collaborators, **SATAVIA and Etihad Airways, have been conducting trials to demonstrate that careful flight planning can reduce the climate impact of contrails**.
The ground-breaking SATAVIA/Etihad collaboration began with the **Etihad-operated EY20 Sustainable Flight in October 2021, which reduced overall per-flight climate impact by over 70% compared to 2019 equivalent flights**. As part of a suite of green aviation solutions, SATAVIA contrail intelligence prevented over 64 tonnes of carbon dioxide equivalent (CO_2e) on EY20 via flight plan optimisation. Following EY20 flight, SATAVIA and Etihad signed a world-first commercial agreement to undertake contrail prevention flight planning throughout 2022. SATAVIA and Etihad are currently

optimising at least one flight per week – and over 20 flights in the days leading up to Earth Day 2022 - to demonstrate the possibility of incorporation within mainstream commercial flight operations. Since the start of 2022, more than 40 Etihad-operated commercial flights have been undertaken with contrail-optimised flight plans, achieving a climate benefit equivalent to direct emissions from multiple days' continuous widebody jetliner flight. In line with published scientific research, the trial has also demonstrated that **significant climate benefits can be realised by optimising only a small proportion of flights (under 7% of scheduled flights).**

This Contrail forecasting and prevention is made possible by SATAVIA's [DECISIONX:NETZERO] platform, which at its core isa numerical weather prediction model optimised for high-altitude ice crystal formation, a key aspect of contrail formation and persistence.

Recent data presented by SATAVIA at the TAC-5 International Conference on Transport, Atmosphere and Climate revealed significant improvements in predictions of relative humidity with respect to ice (RHi) for the SATAVIA model compared to other global models such as GFS and ERA-5, as demonstrated by close fit between SATAVIA RHi predictions and IAGOS in-flight aircraft observations. SATAVIA continues to work with the AIA and other academic partners to further develop and optimise its science-based contrail forecasting and climate impact modelling, alongside rigorous methodology development to support future accreditation of contrail prevention for voluntary carbon offsetting.



Comparison of relative humidity with respect to ice between models (GFS, ERA5 and SATAVIA) and observations (IAGOS). Data covers period January-June 2021, with 318 IAGOS flights measuring RHI in European/Middle East region.

Another operational solution could be to limit the number of night flights because at night contrails only have a warming effect. This would be most beneficial in regions where ISSRs are more likely to occur. Operationally, this could impact air cargo flights which tend to operate during the night when freight logistics is more convenient. Alongside engagement with consumer-facing climate footprint platforms, **further research into the climate impact of contrails is needed to** better inform passengers about the time of day, time of year and the routes they fly to minimise climate impact due to contrails. It is also important to note that solutions for mitigating contrails may result in some adverse operational and commercial impacts such as longer flight times and more fuel burn. Proving and validating that changes to flight trajectory and operations eliminates, or at least reduces contrail formation continues to be a key challenge. Future advances in the remote sensing of contrails from the ground and from satellite images may help to overcome this challenge.

The climate impact of contrails and alternative fuels

One of the many powerful outcomes of the work of the AIA is to model future aviation scenarios based on predicted improvements and introduction of new technologies. This includes new aircraft and fuel types and the associated impact on contrail formation and climate impact.
Much of the recent industry efforts to achieve a net-zero carbon aviation industry has been to introduce more sustainable aviation fuels (SAFs) such as biofuels. Some recent studies, based on a combination of in-situ measurements and modelling, have shown that **certain biofuels** (when blended with 50% jet fuel) **have lower emission concentrations of soot particles**. This reduces the concentration of ice particles by up to 40% compared to using 100% jet fuel. The optical depths of contrails are also reduced by 40-50% reducing their climate impact by 20-30%. Thus, in addition to reducing carbon emissions **SAFs may also reduce non-CO2 climate impact**. However, the number of studies on SAFs and contrails is very limited and further research is required.
The future introduction of hydrogen aircraft will eliminate in-flight carbon emissions altogether but the impact on contrail formation is less certain. The combustion of liquid hydrogen generates about 2.6 times more water vapour emissions. There are also emissions of nitrogen oxide particles. Theoretical results suggest that the threshold temperature at which hydrogen contrails form is 10°C higher than the equivalent scenario for kerosene fuel. Therefore, contrails produced by hydrogen aircraft may occur at lower altitudes and further south, closer to equatorial regions. However, the ice crystals are more likely to be larger, fall quicker into warmer altitudes and evaporate, therefore having a shorter lifespan and possibly lower climate impact. Since there are no liquid hydrogen aircraft currently operating, there are no emission measurement studies and all existing research is based on theoretical assumptions and modelling estimates.

A common misconception is that electric aircraft would not generate contrails because there are no direct emissions of water vapour or soot particles. While it is true that there are no emissions, contrails may still form due to aerodynamic reasons. There is evidence that turbulence generated by aircraft propellers can increase local relative humidity which can create the conditions for ice cloud formation and contrails. It is believed that this may have been the mechanism for contrails formed by the B-17 Flying Fortress aircraft during WW2. Recent laboratory experiments at the Michigan Technological University in the US have also demonstrated this phenomenon.

To understand total climate impact, more research is needed.

The formation of contrails from aircraft exhausts has been studied for more than a century, and we can now forecast the formation of contrails and optimise flight plans but we still don't know enough about their climate impact or how to mitigate them. The AIA aims to bring together academics and world-leading industry partners such as SATAVIA and Etihad Airways to better model the climate impact of contrails for future aviation scenarios to better inform industry bodies, policy-makers and government. By doing so, **we will ensure that future aircraft are not only carbon-neutral but also climate-neutral.**

References

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