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#3 Challenges to overcome

Towards eco-friendly operations

Acting now to reduce the climate impact of aviation

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Towards eco-friendly operations

Acting now to reduce the climate impact of aviation

Day-to-day flight operations are perhaps the least easily understood field of air transport. Yet, it is one of the most relevant levers for short-term actions intending to reduce the climate impact of air transport, since it can affect all in-service aircraft without requiring major technological breakthroughs.

But reducing the climate impact of aviation requires understanding it:

From this standpoint, climate science has made significant progress, allowing both to model and quantify the impact of carbon dioxide (CO_2) emissions, but also to better understand the effects of condensation trails their induced cirrus clouds, and to a lesser extent, those of nitrogen oxides.

Leveraging on these results, research in the field of flight optimisation shows that implementation of eco-friendly flight operations offers the potential to **reduce the climate impact of aviation by more than 10%** when considering only CO_2 effects, and over 20% when compounding all effects.

In order to achieve tangible gains as quickly as possible and take advantage of current air traffic conditions that are favourable to experimentation, reliance on **local ecosystems** willing to commit to the ecological transition of their operations is crucial.

TO MAKE THIS TRANSITION A SUCCESS, WE MAKE THREE MAIN PROPOSALS:

- First, **set up and disseminate a single source of truth**, reliable, neutral, objective, shared and transparent, enabling each party to assess the climate impact of its operations on each segment of each flight.
- Second, develop **operational and technological frameworks that enable continuous reduction of the environmental impact of these operations** by facilitating collaboration between pilots, airlines and air navigation services, starting through digital tools. To act quickly, deployment could be limited initially in space and/or time, and later extended to increase in scope.
- Third, for each local ecosystem, put in place as quickly as possible measures making such operations economically viable for each party, for example by **facilitating communications to passengers and investors** of the ecological performance of stakeholders' operations, or promote eco-friendly behaviour through **economic**.

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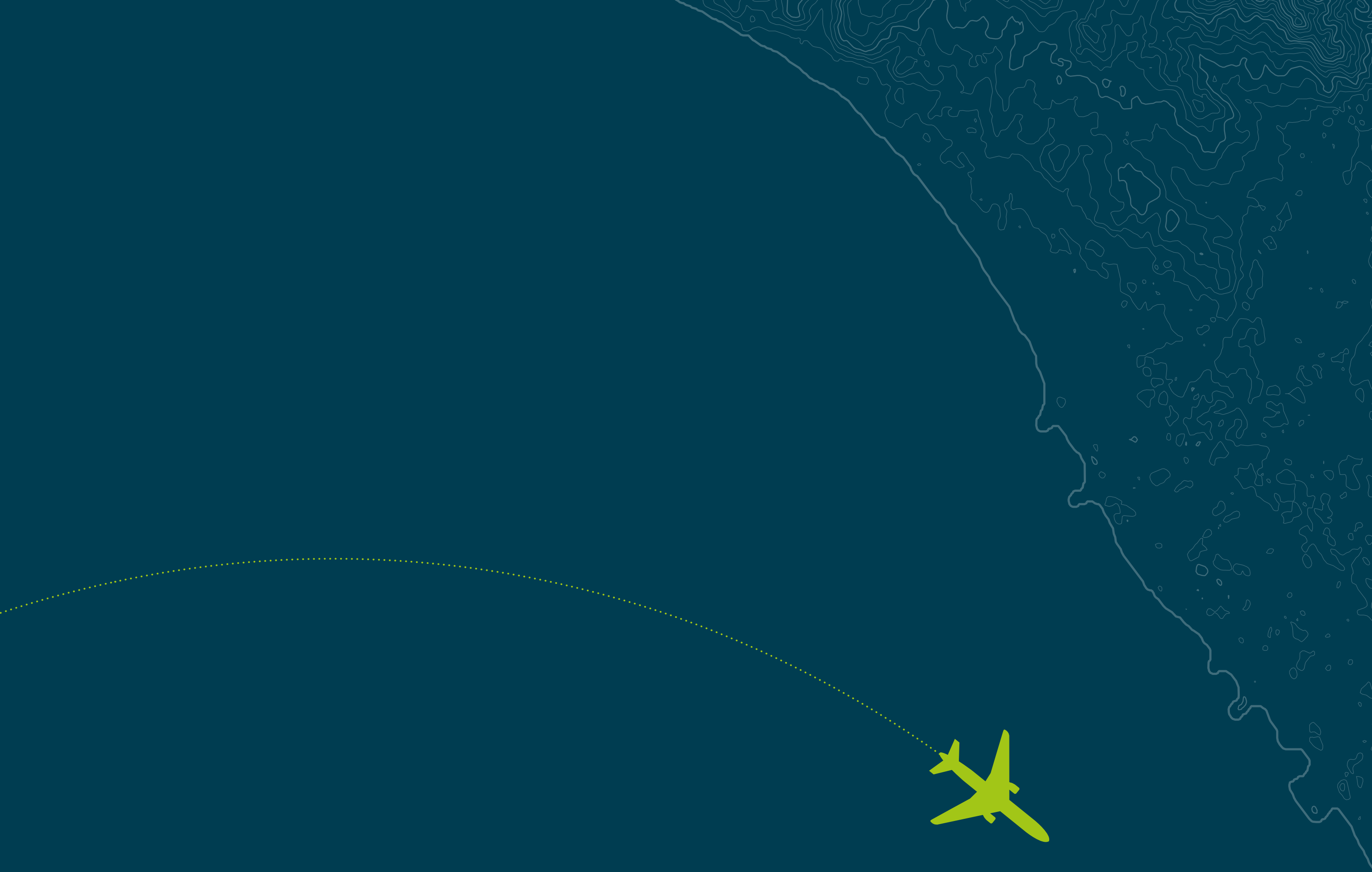

#3 Challenges to overcome

Towards eco-friendly operations

Acting now to reduce the climate impact of aviation

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Introduction

No one can deny the major role of aviation in the development of modern societies: it has brought people together and has contributed significantly to global economic growth.

However, like many human activities, air transport has an ecological footprint and more specifically a significant climate impact.

The International Council on Clean Transportation (ICCT) estimates the share of air transport at **2.4%** of 2018 global CO_2 emissions (Graver, Zhang, & Rutherford, 2018).

To reduce its environmental impact, the air transport community is thus actively working in four complementary directions:

- Develop low-carbon footprint aircraft: hydrogen, electric, hybrid…
- Introduce sustainable aviation fuels (SAF) compatible with existing aircraft: sustainable biofuels, synthetic fuels…
- Renew aging fleets with newer, more efficient in-production aircraft.
- … and finally optimize flight operations of in-service aircraft in order to reduce their environment footprint.

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ECO-FRIENDLY FLIGHT OPERATIONS: ACT NOW, EVERYWHERE, AND AT LOW COST

While the first two approaches are obviously the most promising since they enable truly low-carbon air transport, they must overcome several significant challenges:

- On one hand, development of low-carbon aircraft requires major technological and logistical breakthroughs and experts do not anticipate mass production to start before the end of the next decade.
- On the other hand, deployment of SAF will necessarily be gradual: initially limited[1] to SAF based on the sustainable exploitation/recycling of biomass, their use will grow with the development of synthetic fuel. However, large-scale deployment of low carbon synthetic fuel is not foreseen before 2035 at the earliest. The positive impact of fleet renewal on air transport environmental footprint no longer needs to be demonstrated[2]. However the cost of such renewal for airlines is very high – A320neo list price is $110M – in a time when airlines' investment capabilities are seriously hampered by the COVID crisis.

Therefore, the fourth approach seems to be the most accessible in the short term while being cumulative with the three first ones: optimizing the day-to-day flight operation of in-service aircraft to reduce their ecological impact. Throughout the following of this document, we refer to such operations as eco-friendly operations.

WHAT ARE FLIGHT OPERATIONS?

Flight operations are probably the area of air transport that is the least easily understood by the general audience.

This document focuses more specifically on the subset of these flight operations having an impact on aircraft emissions,

- Strategic and pre-tactical flight planning activities:
  - Strategic flight planning carried out by airlines (flight scheduling) and consolidated/adjusted by Air Navigation Service Providers (ANSPs), the result being a validated flight plan filed for each aircraft.
  - Flight preparation, including the determination of the quantity of fuel carried and more generally flight related operational planning (catering, supplies…).
- Tactical flight execution activities:
  - Taxiing (for departure and arrival), carried out in collaboration between air traffic control and the crew, possibly with the help of a pushback tug.
  - The actual flight and its integration into air traffic, carried out in collaboration between the crew, air traffic control and the airline, based on the filed flight plan and taking into account the conditions of the day: weather, load factor...

EVALUATE, EXPLORE, EXPERIMENT, DEPLOY...

This document thus aims at describing more precisely the challenges of the ecological transition of flight operations:

- We first summarize the methods for assessing the climate impact of aviation that has been developed by the scientific community and that are now widely recognized. We also show how the understanding of this impact itself is improving.
- Using these methods and state-of-the-art flight optimization research, we try to assess the order of magnitude of the potential for eco-friendly flight operations to reduce the climate impact of air transport.
- We then identify the challenges that air transport will have to face to deploy these eco-friendly operations.
- Finally, we introduce three proposals allowing to engage all air transport stakeholders in order to achieve these reductions as quickly as possible.

> **A few definitions**
> In the context of Air Traffic Flow Management, considering a D-day flight, the strategic phase includes dispatching and flight planning activities carried out between one year and D-7, the pre-tactical phase takes place between D-7 and D-1 and finally the tactical phase takes place on D-day.

[1] (EEA, EASA & EuroControl, 2020) estimates that, if the whole European biofuel production was dedicated to SAF, it would only account for 4% of kerosene consumption in Europe in 2019. It also states that the average use of SAF in Europe should not exceed 1% in the short term because of their high price.

[2] The latest generation A320neo is at least 15% more efficient than a classic A320 according to (Hensey & Magdalina, 2018). This number is probably underestimated as it doesn't take into account replaced aircraft's airframe and engine aging.

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Challenges to overcome

Ensuring the ecological transition of flight operations requires overcoming three major challenges:

- A structural challenge: how to implement the ecological transition in an ecosystem as complex and regulated as air transport?
- A transformational challenge: how to make environment a core tenet of flight operations?
- A conjectural challenge: what is the impact of the COVID-19 crisis on such a transition?

1. A STRUCTURAL CHALLENGE: THE COMPLEXITY OF THE AIR TRANSPORT ECOSYSTEM

The complexity of the air transport ecosystem is mainly due to its historical breakdown between airlines, ANSPs and airports on the one hand, and to a very specific regulatory framework on the other.

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1.1. AIRLINES, ANSPS AND AIRPORTS

A first level of complexity in air transport is due to the historical presence of three types of parties with very different dynamics:

- Airlines, each seeking to optimize their own operations according to their specific economic criteria,
- ANSPs that must meet the demands of different airlines, adapt to the growth in air traffic, while ensuring the highest levels of safety.
- Airports that have an economic model driven by air and passenger traffic, and seek to make the best use of their available resources: the takeoff and landing slots.

Governments themselves have a role in this area as air traffic is also an indirect source of revenues for a country through international tourism: some may thus be encouraged to enable increased air traffic in order to increase these revenues.

Individual performance vs. capacity

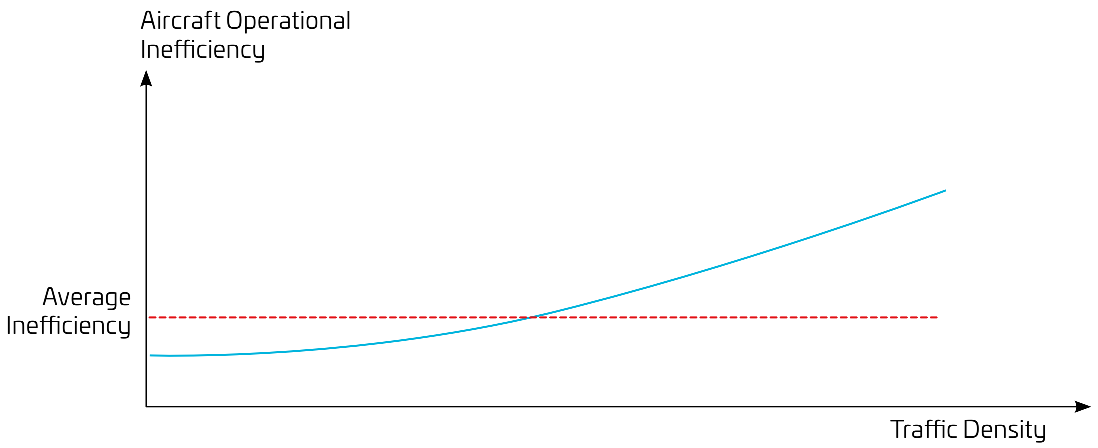
The following scenario highlights this complexity by showing how each stakeholder dynamic interferes with the others:

1. In order to increase its economic performance, each airline wants an adequate number of slots at its departure and destination airports.
2. The most attractive airports have usually the higher traffic density.
3. When traffic density is high, flights associated with these slots interfere with each other.
4. These interferences reduce aircraft operational efficiency and generate airline dissatisfaction and thus alter airline economic performance.

Figure 1 gives a notional view on how such inefficiency grows with the traffic density.

Figure 1

Aircraft operational inefficiency (blue curve) increases with traffic density. The average inefficiency (red dotted line) corresponds somehow to the ecological footprint reduction potential identified in the previous section.



1.2. A VERY SPECIFIC REGULATORY FRAMEWORK

Beyond this first level of complexity, the regulatory framework for air transport is also complex *Gonenç & Nicoletti, 2001* as they are adopted at different levels:

- Multilateral, at a global scale through ICAO:
  aircrew certificates in aviation, aircraft airworthiness certificates, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)…
- Bilateral, between countries:
  access to specific routes, right to determine capacity and set prices, authorization of charter flights, fuel tax rules…
- Regional, more specifically at the level of regional air markets (Europe, Australia/New Zealand …):
  strategy for air traffic control, local rules such as European Emission Trading System (ETS) on European domestic flights…
- National:
  operator approval, local taxes and fees, prohibited overflight zones…

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An ecosystem undergoing significant transformation

In addition to airlines, route competition affects local ecosystems including ANSPs, airports and even governments. This competition has increased with the emergence of Low-Cost Carriers (LCC), and the growth of Middle Eastern airlines, which benefit from a very favorable geography between Europe and Asia. Beyond the rise of these new players, the ecosystems are themselves stressed by the increasing role of leasers, the privatization of ANSPs, the distribution of responsibilities between national and supranational parties (particularly at the European level), to name a few.

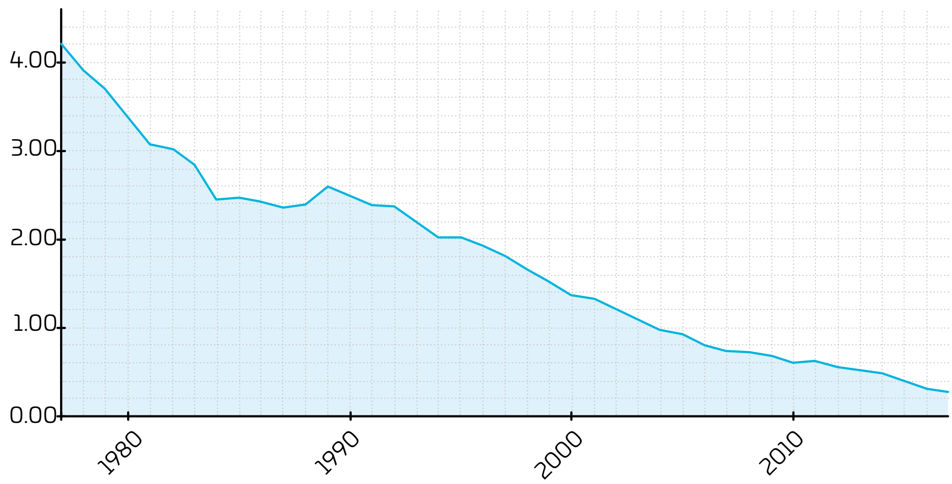
1.3. ... BUT EFFECTIVE MEANS OF ACTION

Despite this complexity, air transport has successfully come together around the improvement of shared performance indicators, either at the level of regional ecosystems or at worldwide scale: flight safety, air system capacity (in terms of passengers carried and therefore traffic) or flight operation efficiency for instance.

One of the highlights of this collective strength is the progress in flight safety, as illustrated by the following figure. The number of air transport accidents has dramatically decreased despite the relentless growth in air traffic, by implementing a culture of continuous improvement shared by all parties, and supported by major international and national organizations such as ICAO, EASA, FAA, local supervisory authorities…

Figure 2

Number of accidents per million flying hours over the period 1977-2017 (Flight Safety Foundation, 2020)



The aviation industry has already proven its ability to **join forces in order to dramatically improve its performance:** safety, punctuality, capacity, efficiency...
It is the same type of **collective improvement approach** that can enable the ecological transition of its operations

2. A TRANSFORMATIONAL CHALLENGE: THE ECOLOGICAL TRANSITION

In any market economy, economic players' actions are intended to induce an economic benefit, whether it is direct – increased income, decreased expenses... – or indirect – brand image, customer satisfaction, stock market valuation... Air transport is no exception: its ecological transition may thus sometimes conflict with economic viability.

[3] This is typically one of the reasons why most airlines do not use Maximum Range Cruise, as the cost induced by the additional flight duration – labor costs and engine maintenance costs – would not be offset by the reduced fuel burn.

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Reducing CO_2 emissions also improves flight efficiency and As discussed in #1 Assessing the climate impact of air transpo, the reduction of CO_2 emissions is a direct result of reduced kerosene burn. profitability, therefore air transport has until now been mostly supportive of eco-friendly operations. However, there are **several cases where ecology and economy conflict.**

For example:

- Reducing contrails and induced cirrus can increase fuel burn.
- Banning tankering increases fuel procurement costs.
- Banning flight detour to avoid high overflight fees area results in higher cost for airlines.
- Decreasing flight speed to save fuel may reduce aircraft and crew rotations per day, and thus airline operational efficiency. This extended flight duration may itself result in increased maintenance and pilot costs, both being associated to the number of hours flown[3]. In some cases, it may even require the use of an augmented crew when flight duration exceeds crew flight time limitations.
- Delaying a flight until traffic and weather conditions allow optimal environmental efficiency likely causes passengers dissatisfaction, disrupts connecting flights, and can lead to financial penalties.

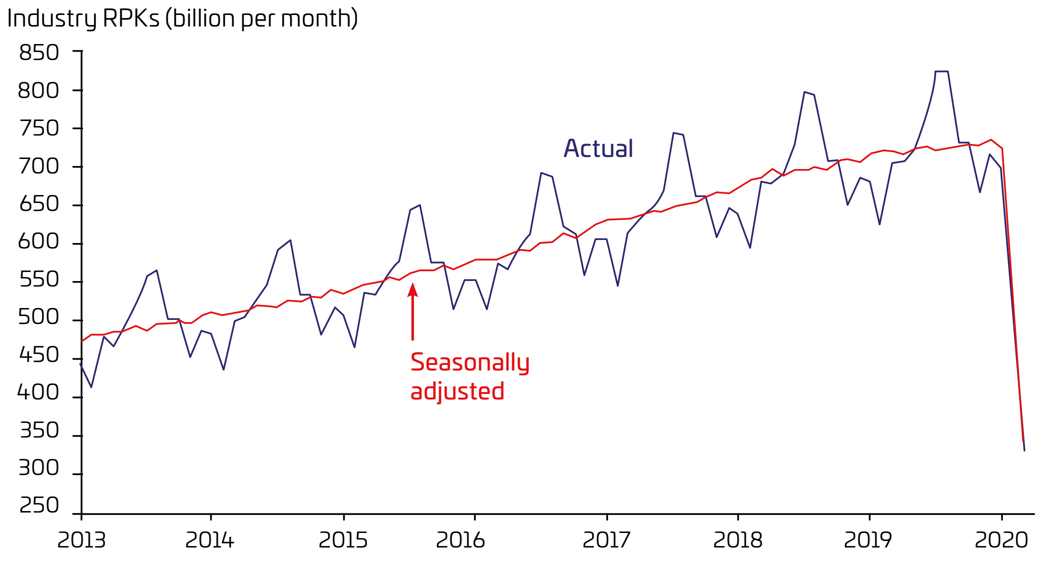
The challenge is thus to achieve ecological transition while maintaining economical viability and profitability

3. CONJECTURAL CHALLENGE: THE UNCERTAINTY GENERATED BY THE COVID 19 CRISIS

The decline in air traffic caused by the COVID-19 crisis is unprecedented in the history of commercial aviation (see figure 3). Unlike previous crises, the return to normal seems likely to take several years *ICAO Air Transport Bureau, 2020.*

Figure 3

Evolution of passenger air traffic in millions of RPK per month between 2013 and 2020, according to IATA monthly report. The purple curve shows actual data, the red one the seasonally adjusted averages.



ICAO estimates the revenue losses of commercial air transport at $256 billion over the period from January to August 2020. This primarily affects airlines, airports and ANSPs, whose revenues arise directly from traffic volume. In this financial context, as they struggle to survive, stakeholders will find it difficult to invest in fleet and equipment renewal.

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3.1. HIGHER DIFFICULTY TO IMPLEMENT NEW ECOLOGICAL TAXES ON AVIATION

Among the measures aimed at promoting the ecological transition of air transport parties, a widely studied means is to increase taxation, particularly to take non-CO_2 effects into account, as proposed in a recent EASA study *EASA, 2020*. For instance, among the measures envisaged is the extension of the ETS to non-CO_2 effects, and more specifically to NO_X.

The purpose of this paper is not to discuss the actual relevance of these measures. However, the necessary consensus they require in the complex aviation ecosystem seems difficult to achieve due to the COVID crisis, as these taxes may be a fatal blow to many airlines. The timeframe envisaged by EASA for such measures – more than five years – reflects this state of affairs.

3.2. A UNIQUE OPPORTUNITY FOR EXPERIMENTS

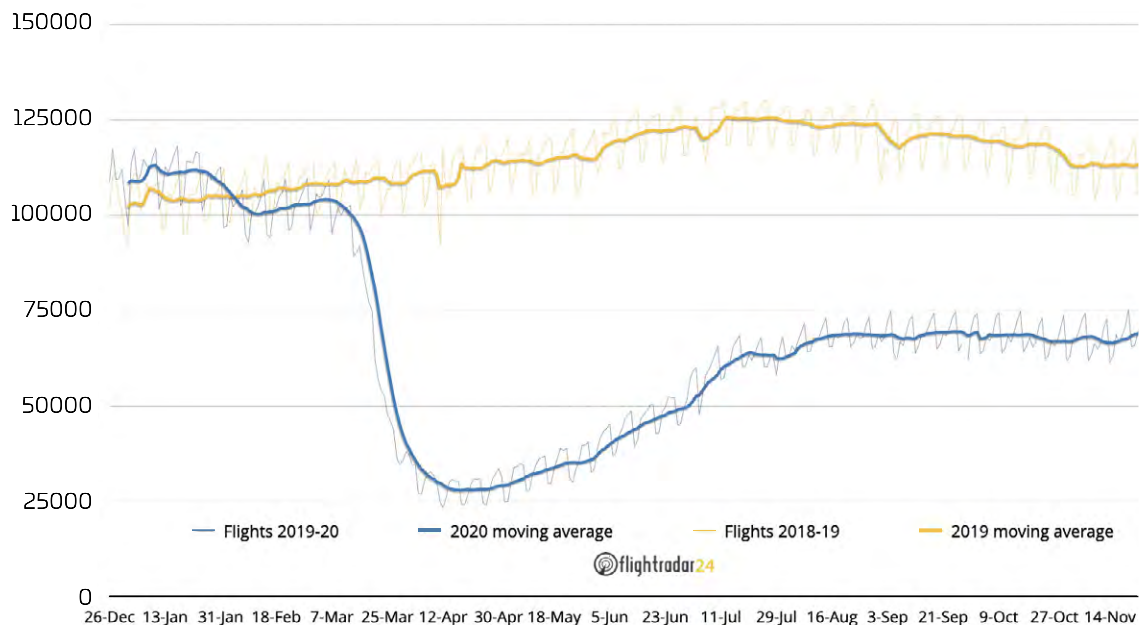
Yet the COVID-19 crisis creates a unique opportunity: it is common to say that "air traffic never stops", making every transformation long and hard to implement.

With a commercial traffic decrease of more than 50% over a period of several months (figure 4), air traffic system assets (airports, ANSP) are significantly underused: for the first time, large-scale experiments and changes are feasible.

The COVID 19 crisis, drastically reducing concerns over congestion and capacity, offers a **unique framework for experimentation and transformation.**

Figure 4

Moving average of the number of commercial flights over the December 2019 – October 2020 period (blue curve) relative to the previous December 2018 – October 2019 period (yellow curve), according to Flight Radar 24.



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Appendices

BETTER UNDERSTANDING THE CLIMATE IMPACT OF AVIATION

This appendix describes in detail the different elements used to measure the climate impact of an emission and their mutual relationships: radiative forcing, effective radiative forcing, concentration trajectories, global warming and temperature change potential. It then introduces the reference climate models used to calculate the impact of CO_2, NO_X and contrails.

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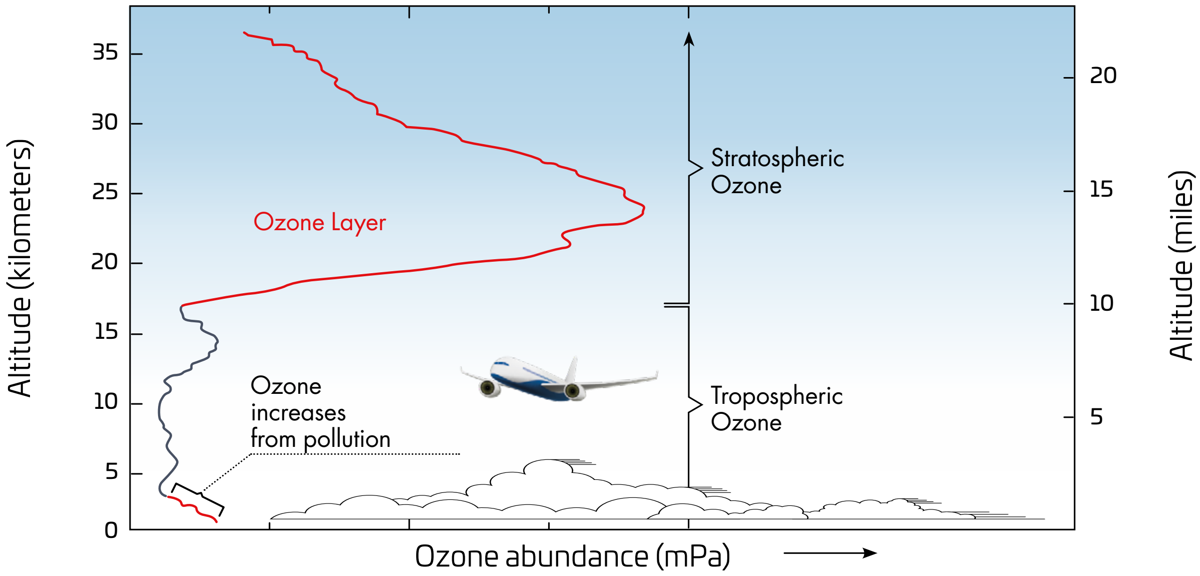
A.1. RADIATIVE FORCING

Radiative forcing (RF) can be conceptually defined as a change in the energy equilibrium of earth system, caused by a perturbation – gas or aerosol emission. It is a flux expressed in $W.m^{-2}$.

In a quantitative way, RF is therefore an incident flux difference caused by a perturbation on Top of Atmosphere (TOA) or at the tropopause.

Figure 5

Ozone abundance in the atmosphere as a function of altitude (Atmosphere Monitoring Service, 2020)

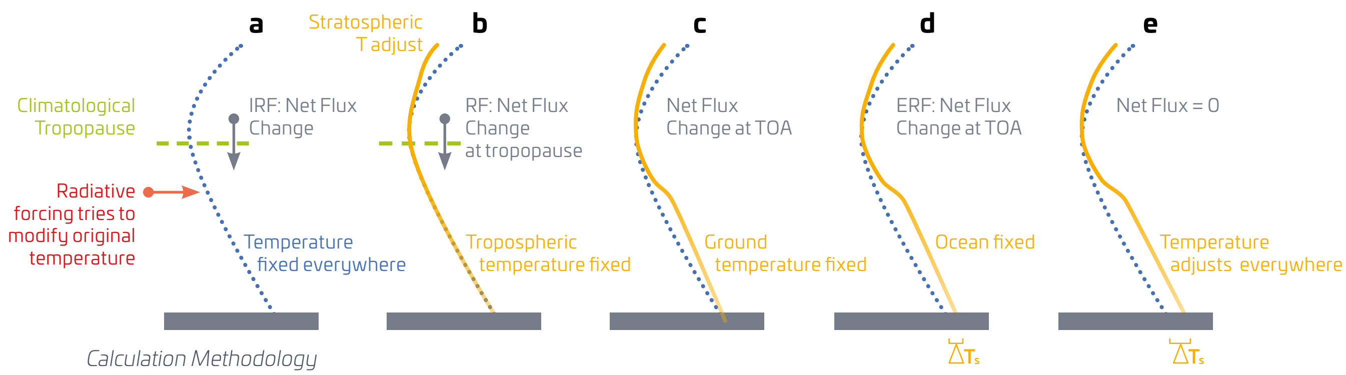


The energy state of the Earth's climate system results from the difference between the radiative power flux incoming from the sun and that reflected or emitted by the earth. Disturbances cause the system to shift towards a new equilibrium, with measurable changes in temperature at different altitudes.

The following figure shows different boundary conditions for the return to equilibrium.

Figure 6

Altitude vs. temperature graphs showing different boundary conditions for the return to equilibrium



Radiative Forcing (RF) and Effective Radiative Forcing (ERF) correspond to two types of boundary conditions, described in the table below.

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Table 1

Boundary conditions corresponding to radiative forcing and effective radiative forcing.

	RF	ERF
Altitude	Tropopause	TOA
Free variables	Stratosphere temperature - Water vapor - Cloud cover - Surface temperature	- Atmosphere temperature
Fixed variables	- Surface temperature - Troposphere temperature - Water vapor - Cloud cover	- Surface temperature (partially)

The ERF/RF ratio is sometimes used to characterize which element is most disturbed, such as surface temperature.

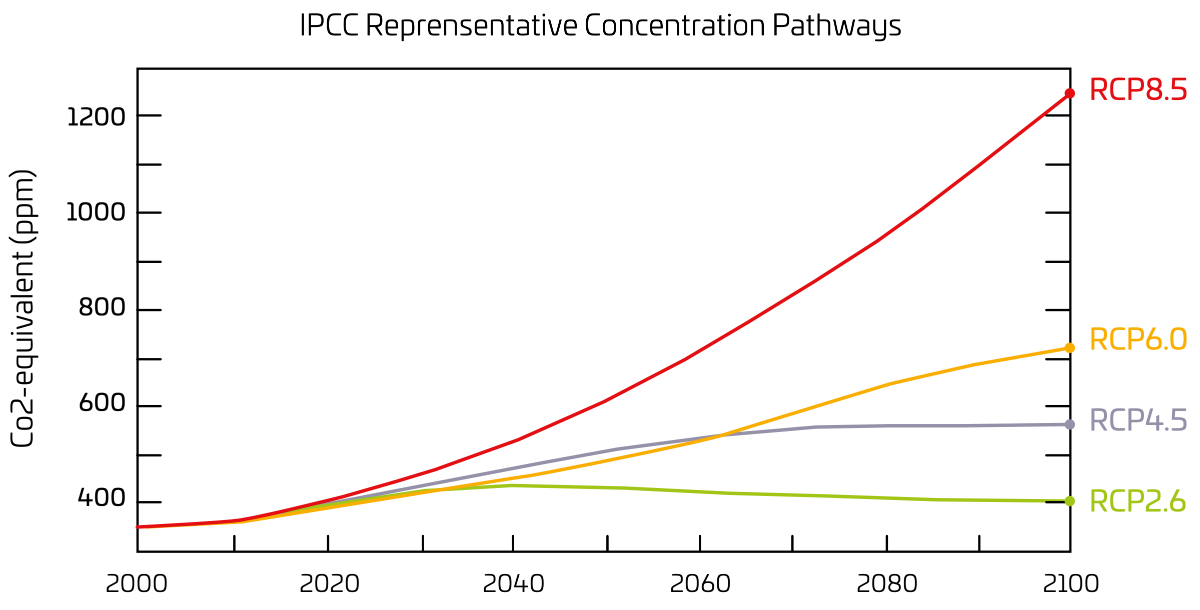
A.2. REPRESENTATIVE CONCENTRATION PATHWAY

In its fifth report, IPCC established four RCP (Representative Concentration Pathway) trajectory scenarios of radiative forcing to the 2100 horizon *Intergovernmental Panel on Climate Change, 2014.*

Each RCP scenario forecast climate changes likely to result from different assumptions regarding greenhouse gas emission over this century. Their names correspond to the predicted radiative forcing reached in 2100: the RCP2.6 scenario corresponds to a radiative forcing of +2.6 $W.m^{-2}$, the RCP4.5 scenario to +4.5 $W.m^{-2}$, and so on for RCP6 and RCP8.5 scenarios.spreading over wide areas (see figure below).

Figure 7

The four RCP scenarios considered by the IPCC (Intergovernmental Panel on Climate Change, 2014)



Each RCP scenario has different effects, as shown in the following table. The climate community widely deems the RCP8.5 scenario (also called "business as usual") as unlikely, because of climate actions already undertaken. RCP4.5 roughly matches current global warming trends, while climate agreements aim for RCP2.6 or better.

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Table 2

Changes in temperature and sea level for each RCP scenario, according to IPCC (Intergovernmental Panel on Climate Change, 2014).

Scenario	Temperature change (°C)	Sea level rise (m)
RCP 2.6	+0,3°C to +1,7°C	+0,26m to +0,55m
RCP 4.5	+1,1°C to +2,6°C	+0,32m to +0,63m
RCP 6.0	+1,4°C to +3,1°C	+0,33m to +0,63m
RCP 8.5	+2,6°C to +4,8°C	+0,45m to +0,82m

A.3. CALCULATIONS

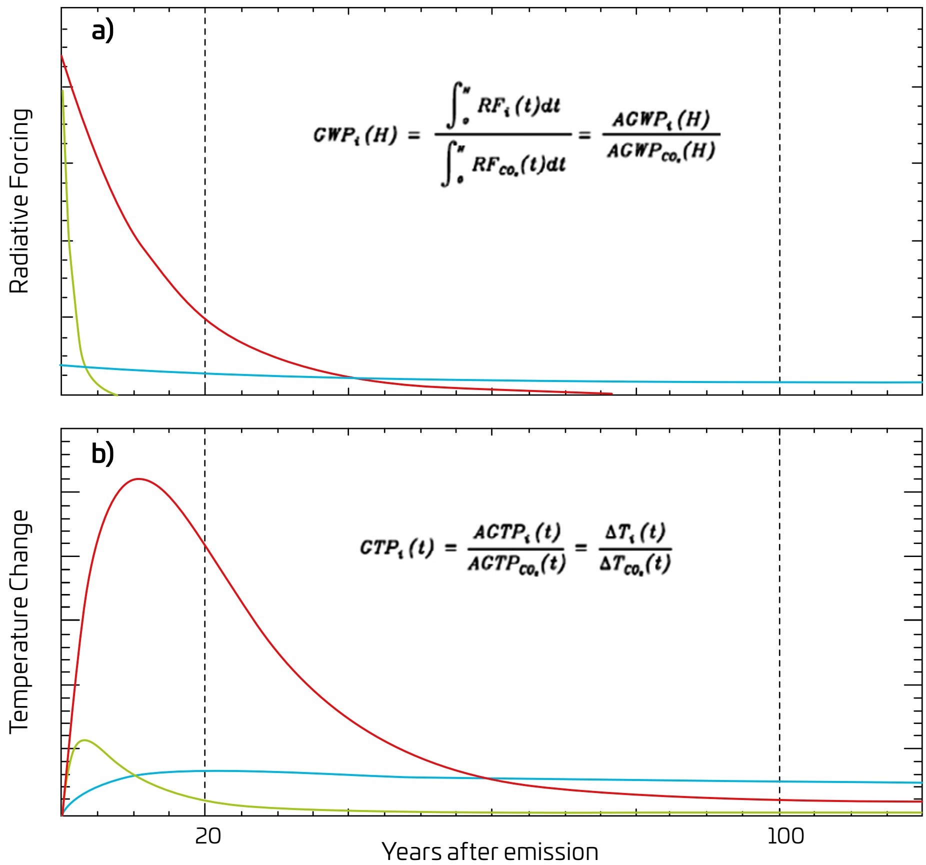
Climate change estimate can range over different time horizons, typically 20 to 100 years.

The Global Warming Potential (GWP) represents the overall energy added to the climate system because of pollution, compared to reference CO_2 emissions. In figure 6, the blue curve represents the radiative forcing of CO_2 in time, the green and red curves that of other pollution with shorter but more intense effects. GWP is the integration of radiative forcing over the considered period, and gives the equivalent CO_2 (CO_2-eq) emissions to various pollutions over a given period.

The Global Temperature change Potential (GTP) represents the global average change in surface temperature at a given time in response to a pulse of given type of emissions compared to CO_2.

Figure 8

Global Warming Potential (GWP) and Global Temperature change Potential (GTP) according to (Intergovernmental Panel on Climate Change, 2014)



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A.4. APPLICATION TO AIR TRANSPORT

Air traffic emissions include emissions of CO_2, NO_X, water vapor, contrails cirrus, aerosols and soot. The RF can be calculated from changes in emission concentration in the atmosphere, or attenuation of solar radiation, especially when complex phenomena are involved (interactions, exchanges...).

> RF calculation for CO_2 and associated uncertainty

The RF of CO_2 is a function of fuel burn, according to the stoichiometric coefficients of the combustion reaction[4]. The CO_2 dilutes in the atmosphere and results in a concentration measured in parts per million (ppm).

Natural sinks capture the CO_2 according to kinetics approximated by Impulse Response Function (IRF) models. The Beer-Lambert formula thus computes the RF:

$$RF = \alpha . ln \left(\frac{C_o + \Delta C}{C_o} \right)$$

Where C_0 is the reference concentration in 1940 and α is a constant equal to 5.35 W.m^{-2} *Myrhe, Highwood, Shine, & Stordal, 1998.*

For each year, given the quantity of fuel burn, we can deduce CO_2 emissions, the resulting CO_2 concentration in the atmosphere, and the IRF, which can predict CO_2 concentration over time. We can finally integrate the latter over the chosen duration.

When *Lee, et al., 2020* identify an average RF of 34 mW.m^{-2}, it corresponds to the RF of CO_2 accumulated between 1940 et 2018 in the atmosphere, deduction made of the CO_2 captured by natural sinks.

In addition to fuel burn uncertainties, calculation uncertainties arise in the atmosphere carbon cycle and carbon capture impulse response models.

> RF calculation for NO_X and associated uncertainty

In atmospheric chemistry, NO_X refers to the sum of NO and NO_2. In the presence of light, two cycles of coupled chemical reactions between NO_X and HO_X produce ozone (O_3) and consume methane (CH_4) and carbon monoxide (CO) *Isaksen, et al., 2014.* These well-known phenomena lead to positive forcing for ozone and negative forcing for methane.

Models with different biases exist, to account for both short-term and long-term effects. They lead to a high degree of uncertainty in the estimates and the when combining the two effects.

> RF calculation for contrails, and associated uncertainty

Aviation creates artificial clouds induced by the formation of contrails in an atmosphere supersaturated with ice[5] through nucleation, mainly on combustion soot particles. There are two disturbances: linear contrails and artificial cirrus resulting from their fusion.

Calculating the RF of contrails and the artificial cirrus clouds they induce relies on a global climate model. Required inputs include cloud cover, volume and length of the trail, the ice/water ratio and the concentration of ice crystals. A reference model is the ECHAM5-CCMod *Bickel, Ponater, Bock, Burkhardt, & Reineke, 2020.* There are two types of uncertainties:

- The response of artificial cirrus clouds to solar illumination (flux transfer model in particular in the presence of ice crystals, cloud homogeneity, impact of the presence of soot),
- Mechanisms of formation of artificial cirrus from contrails (supersaturation rate, lifetime, interactions with natural clouds).

[4] *The commonly used ratio is 3.16kg of CO^2 emissions per kilogram of kerosene burned (Graver, Zhang, & Rutherford, 2018).*
[5] *Quenching a saturated solution results in a supersaturated solution.*

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A.2. ABBREVIATIONS

- **AIC**
  Aircraft Induced Cloudiness (cloud formation induced by combustion soot)
- **ANSP**
  Air Navigation Service Providers
- **APU**
  Auxiliary Power Unit
- **ATAG**
  Air Transport Action Group
- **ATM**
  Air Traffic Management
- **ATSU**
  Air Traffic Service Unit
- **CDM**
  Collaborative Decision Making
- **CORSIA**
  Carbon Offsetting and Reduction Scheme for International Aviation
- **DLR**
  German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.)
- **EASA**
  European Aviation Safety Agency
- **EFB**
  Electronic Flight Bag
- **EMAS**
  Eco-Management and Audit Scheme
- **ERF**
  Effective Radiative Forcing
- **ETS**
  European Emission Trading System
- **FABEC**
  Functional Airspace Block – Europe Central
- **FMS**
  Flight Management System
- **GHG**
  Green House Gases
- **Gt**
  Gigatons (106 metric tons)
- **GTP**
  Global Temperature change Potential
- **GWP**
  Global Warming Potential
- **ICAO**
  International Civil Aviation Organization
- **ICCT**
  International Council for Clean Transportation
- **IPCC**
  Intergovernmental Panel on Climate Change
- **IRF**
  Impulse Response Function
- **KPI**
  Key Performance Indicator
- **LCC**
  Low-Cost Carrier
- **MODIS**
  Moderate Resolution Imaging Spectroradiometer
- **NM**
  Nautical Mile
- **RCP**
  Representative Concentration Pathway
- **RF**
  Radiative Forcing
- **RPK**
  Revenue Passenger Kilometers
- **RTK**
  Revenue Ton Kilometers
- **SAF**
  Sustainable Aviation Fuel
- **SESAR**
  Single European Sky ATM Research
- **SMS**
  Safety Management System
- **SSOT**
  Single Source of Truth
- **TOA**
  Top Of Atmosphere

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