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#1
Assessing the climate impact of air transport

Towards eco-friendly operations
Acting now to reduce the climate impact of aviation

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:

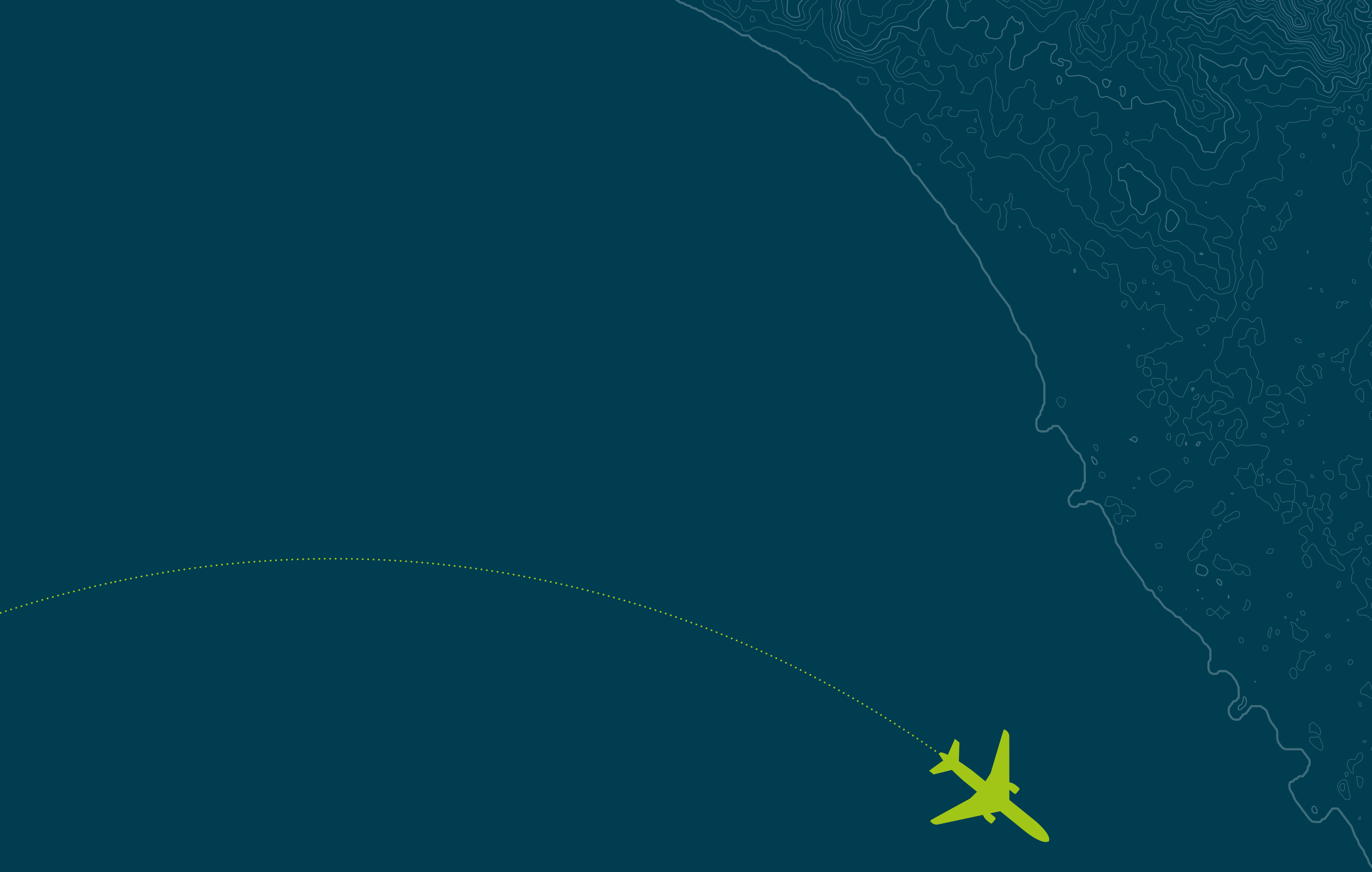
From this standpoint, climate science has made significant progress, allowing both to model and quantify the impact of carbon dioxide (CO_2) emissions, but also to better understand the effects of condensation trails their induced cirrus clouds, and to a lesser extent, those of nitrogen oxides.

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**.



#1

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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.

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.

Assessing the climate impact of air transport

Much of the recent debate on aviation's ecological footprint focuses on its actual contribution to global warming. To address this question, we first introduce how the climate impact of a human activity can be assessed, then address the specifics of air transport impact[3] (and the associated uncertainties), and finally provide some elements to evaluate it.

Annex A.1
on page 14 provides further details on the different units of measurement of the ecological footprint and the climate models involved.

[3] *The environmental impact of a product generally spans over its life cycle: design, raw materials, manufacturing, operations, recycling and dismantling. However, in the case of air transport, flight operations are overwhelmingly predominant. Indeed (Tyler, 2013) shows that the share of design and production activities in the GHG emissions of a transport aircraft over its lifetime is ranging from 1.6% (long-haul) to 3.5% (short to medium-haul).*

1.
EVALUATING THE CLIMATE IMPACT OF A HUMAN ACTIVITY

One can model Earth and its atmosphere as an energy system heated by the absorbed solar irradiance and cooled by the energy radiated back to space.

Human activity increases the amount of greenhouse gases (GHG) present in the atmosphere, modifying the Earth's radiation balance and causing climate temperatures to rise.

To allow comparison between climate impact of physicochemical phenomena having different intensities and lifetimes, scientists have developed the notions of Effective Radiative Forcing (ERF) and Global Warming Potential (GWP):

- Effective Radiative Forcing (ERF) is a key metric for evaluating climate impacts of a GHG. To make it simple, the ERF of a human activity quantifies the impact of the effect on global warming in W m^{-2} – warming being positive and cooling being negative.
- The integration of this impact over time determines an energy accumulation and allows to compare effects with very different lifetimes and intensities.

  It can thus be compared to the amount of CO_2 that would have generated an equivalent warming over the same period.

  The Global Warming Potential (GWP) associated to given GHG emission corresponds thus to the amount of CO_2 which would have generated a warming effect equivalent to the GHG emission over a given period.

  GWP is a key metric of various climate agreements; it is expressed in grams of CO_2-equivalent and abbreviated gCO_2-eq. The most commonly used GWP_{100} corresponds to a time horizon of 100 years.

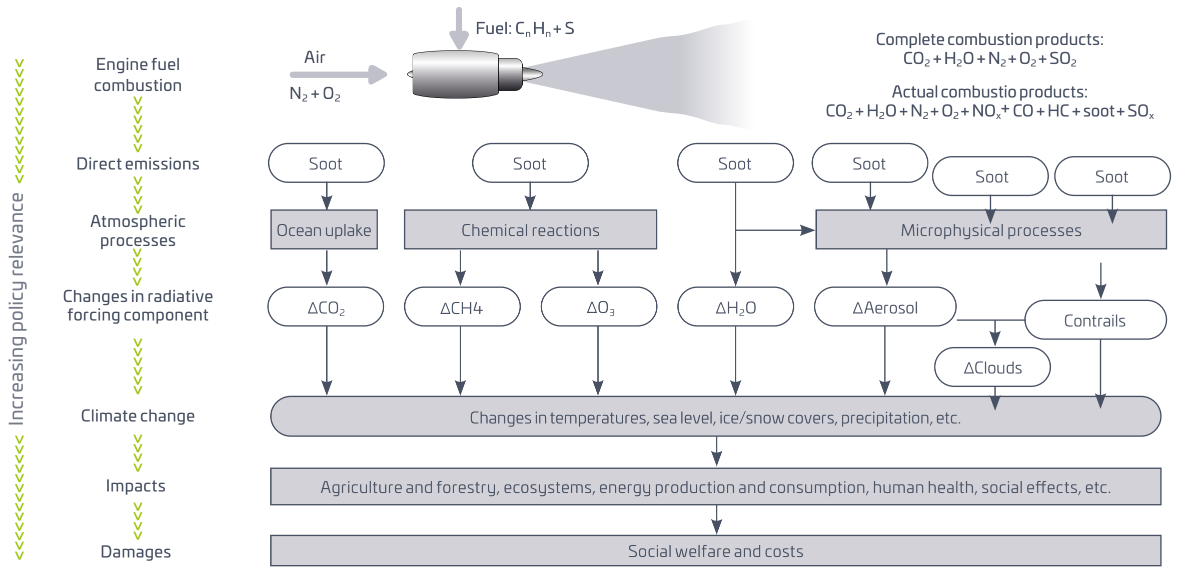
2.
UNDERSTANDING THE CLIMATE IMPACT OF AIR TRANSPORT

Science describes the climate impact of flight operations as the result from kerosene combustion by the aircraft engines. The best-known chemical byproduct of this combustion is CO_2, but other effects and byproducts directly or indirectly contribute to climate warming.

These so-called non-CO_2 effects include the emissions of nitrogen oxides (NO_X), water vapor or droplets (H_2O), sulfur oxides (SO_X), and soot.

Figure 1

Environmental impact of aircraft turbofan engine emissions (Brasseur, et al., 2016)



The above figure describes the impacts of kerosene combustion by aircraft engines. It shows the three levels of this process:

- Engine fuel combustion and direct emissions (top).
- Induced atmospheric processes and byproducts (middle).
- Resulting cascading climate impacts (bottom).

2.1. CO2 IMPACT, A WELL-UNDERSTOOD LONG-LASTING PHENOMENON

Today science understands the climate effect of CO_2 quite well, and carbon life cycle models now provide accurate and reliable forecasts. While present in the atmosphere, CO_2 is a greenhouse gas causing climate temperatures to rise. Progressive absorption by natural reservoirs – so-called carbon sinks – such as oceans and forests takes many decades or even centuries. This long life cycle gives CO_2 emissions **a strongly cumulative global warming effect.**

The contribution of aviation to CO_2 emissions is also well known and is a direct result of engine fuel combustion. The mass of **CO_2 instantly produced can thus be directly derived from the instant amount of fuel burn** – a commonly accepted ratio is 3.16 kilogram of CO_2 emitted per kilogram of kerosene burned - *Graver, Zhang, & Rutherford, 2018*.

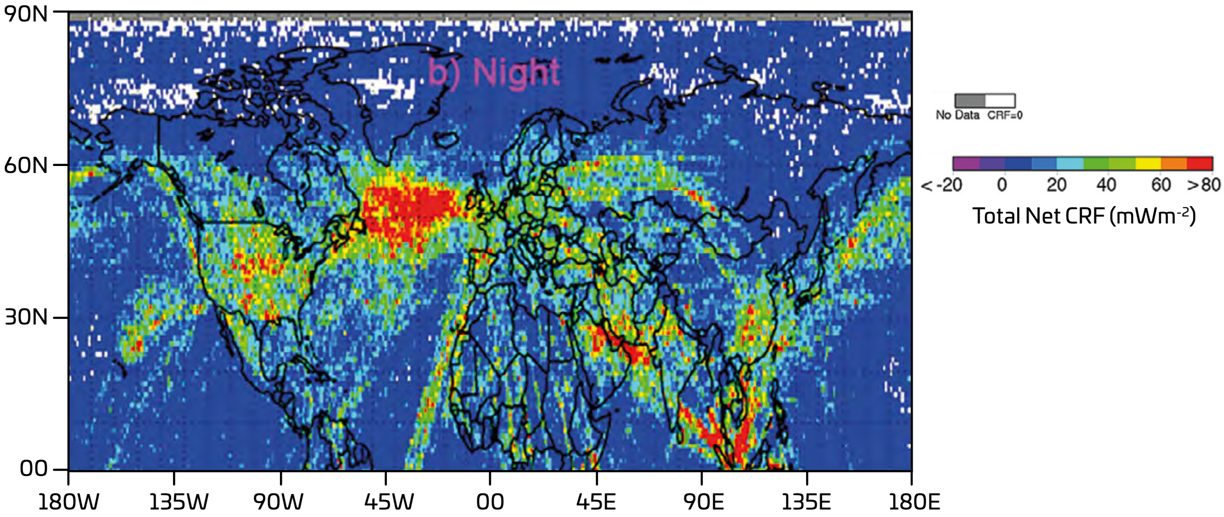
2.2. THE BRIEF BUT POWERFUL CONTRAILS

Compared to CO_2, condensation trails – contrails – and their induced artificial cirrus clouds have a far shorter lifetime – typically hours – but their impact is far more intense: their overall global warming potential is thus comparable to CO_2.

Contrails form at high altitude at aircraft engine exhaust or wing tips, and are composed primarily of water in the form of ice crystals. Impurities in the burnt fuel exhausts provide some of the seed particles for their formation. Contrails can dissipate in minutes through ice sublimation, or persist for dozens of hours in cold and humid areas as cirrus clouds, spreading over wide areas (see figure below).

Figure 2

Mean nocturnal radiative forcing of artificial cirrus clouds induced by contrails (results from data collected by the MODIS instrument onboard the NASA Aqua satellite)



[4] *During the day this effect is mostly offset by their reflecting of incoming sunlight.*

These account for the bulk of the climate effect of contrails *Haywood, et al., 2009, Kärcher, 2018, Lee, et al., 2020,* slowing the natural radiative cooling of the earth **mostly during the night**[4].

Their precise modeling and interactions with nearby clouds remain open research topics. Indeed, their size is small relative to the mesh size of climate simulation models. For these reasons, uncertainty as to the overall climate impact of contrails remains high.

> **The impact of synthetic fuels on contrail formation**
>
> The abundance of contrails generated inflight depends on the quantity of soot and water emissions. According to - *Beyersdorf, et al., 2014,* synthetic fuels produce 86% less soot than traditional fuels. It is thus fair to assume that SAF usage will result in a significant decrease of contrails.
>
> However, considering the expected use of SAF will probably remain low in the short term, it seems reasonable to expect a low reduction of contrails through SAF over such timeframe.

2.3. THE MIXED EFFECTS OF NITROGEN OXIDES

Nitrogen oxides (NO_x) are a byproduct of kerosene combustion. Their production depends on the fuel burn, the temperature and pressure inside the combustion chamber. Science also understands the interaction between NO_x and the atmosphere quite well.

First, NO_x are the precursors of ozone (O_3), a well-documented greenhouse gas that contributes to global warming. The production of O_3 increases:

- With altitude, given tha t NO_x has a longer lifespan at high altitude - *Fröming, et al., 2012.*
- Close to the equator, where more intense solar radiation favors the transformation of NO_x into O_3 - *Shine, Bernsten, Flugestvedt, & Sausen, 2005.*
- In anticyclonic ridges or jet streams *Fröming, et al., 2020.*

Second, NO_x interacts with methane (CH_4), a potent greenhouse gas, reducing its concentration in the atmosphere thus leading to climate cooling.

Science has a lesser understanding of this phenomenon, although it also seems to vary with altitude *Fröming, et al., 2012.*

While the climate effects of CO_2 and contrails unambiguously increase global warming, those of NO_x are mostly warming when the effect on O_3 predominates (high altitude, equator, anticyclonic ridges or jet streams) and mostly cooling when the effect on CH_4 predominates (low altitudes).

Although this makes the climate impact modeling more complex *Fröming, et al., 2020,* state-of-the-art studies *Lee, et al., 2020,* consider the overall effect as warming.

> **A warmer effect in the northern hemisphere**
>
> *Faber, et al., 2008* gives a complementary perspective: since the lifespan of the O3 effect is short (a few weeks), its warming effect is mostly local. On the contrary, its cooling effect following the reduction of methane lasts much longer (decades), and is much more global.
>
> This leads to a combined significant warming in high traffic density areas (e.g. northern hemisphere), and lower warming or even cooling in low traffic density areas (e.g. southern hemisphere).

2.4. CO_2 and non CO_2 effects: different dynamics, similar order of magnitude

Table 1 provides assessment of the GWP of **the CO_2 and non-CO_2 effects** of aviation based on the reference work performed by *Lee, et al., 2020*. These effects appear **equivalent in magnitude,** in spite of very different intensity and durations.

Indeed, several government agencies, such as ADEME in France, recommend that CO_2 and non-CO_2 effects shall be considered as approximately equivalent *ADEME, 2020*.

Table 1

Comparative impacts of CO_2 and non-CO_2 effects of aviation on GWP_{20}, GWP_{50} and GWP_{100} according to (Lee, et al., 2020), in gigatons (Gt) par year. The warming factors grouped under the "others" category correspond to lesser effects: sulphur oxides, water vapor and soot.

Effect	GWP_{20}	GWP_{50}	GWP_{100}
CO_2 (GT CO_2)	1034	1034	1034
Contrails and cirrus (Gt CO_2-eq)	2399	1129	652
Net effect of NO_x (Gt CO_2-eq)	887	293	163
Others (Gt CO_2-eq)	-188	-88	-51
Total Gt CO_2-eq	4128	2366	1797
CO_2-eq toCO_2 ratio	4.0	2.3	1.7

These results illustrate the **complexity** of climate impact assessment and **associated policies:** short-lived contrails and their induced cirrus clouds have a much stronger effect on GWP_{20} than on GWP_{100}, while CO_2 effects are much longer lasting: when CO_2 emission and contrail avoidance require contradictory measures, shall regulators privilege short term climate impact (and thus contrail) or long term CO_2 impact?

Table 2 summarizes the confidence level associated with the understanding of these three phenomena: it shows that, even if the **confidence level** on the effects of contrails/ induced cirrus on the one hand and NO_x on the other hand are of different natures, they remain low.

Table 2

Level of confidence in the climate effect models of the main contributors of aviation, according to (Lee, et al., 2020)

	Contributor	Confidence level 5
CO_2 effects	CO_2	High
non-CO_2 effects	NO_x	Low
	Contrails and induced cirrus	Low

3.
ASSESSING THE CLIMATE IMPACT OF AIR TRANSPORT

While it would be very difficult to estimate the ERF and GWP_{100} of each car trip or building on a global scale, such an assessment is technically feasible in the short term for each commercial flight, based on data emitted by the aircraft or collected onboard and on models from climate research.

Table 3 describes the data required to compute such impact on any trajectory segment – that is to say over any given area – based on the reference models of the three main effects we have just described.

Table 3

State of the art of the data needed to calculate the ERF or GWP_{100} of an individual flight over

Effect	Required data
CO_2	Fuel consumption for the considered flight segment: CO_2 results from a commonly accepted ratio of 3.16 kg of CO_2 emitted per kilogram of kerosene burned, *Graver, Zhang, & Rutherford, 2018.*
Contrails and induced cirrus	Weather conditions in the area of the flight segment (humidity, temperature and pressure). Knowledge of engine thrust level along the flight segment can improve this assessment (the reference models assume the same default thrust level for all aircraft types).
Net effects of NO_X	Engine thrust level, weather conditions and composition of the atmosphere in the flight segment area (solar radiation, winds and pressure).

Obviously, far from constituting immutable references, these models are constantly evolving as research progresses. These evolutions mainly concern:

- Emission measurement/emission models: increasing accuracy of emission models and measurements, increasingly direct emission measurements.
- Measure of the atmospheric conditions around the plane: increasing accuracy of atmosphere models, increasingly direct atmospheric condition measurements.
- Physicochemical models of the atmosphere: increasing accuracy of the models associated with emissions' lifecycle and their interactions with their environment.
- Modeling of climatic events: increasing accuracy of climate models associated to the physicochemical interactions in the atmosphere.

It is therefore **possible to evaluate the climate impact of any flight segment** with a reasonable accuracy using existing operational data and models. This **accuracy will increase** as research on models progresses and collected data accuracy increases.

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.

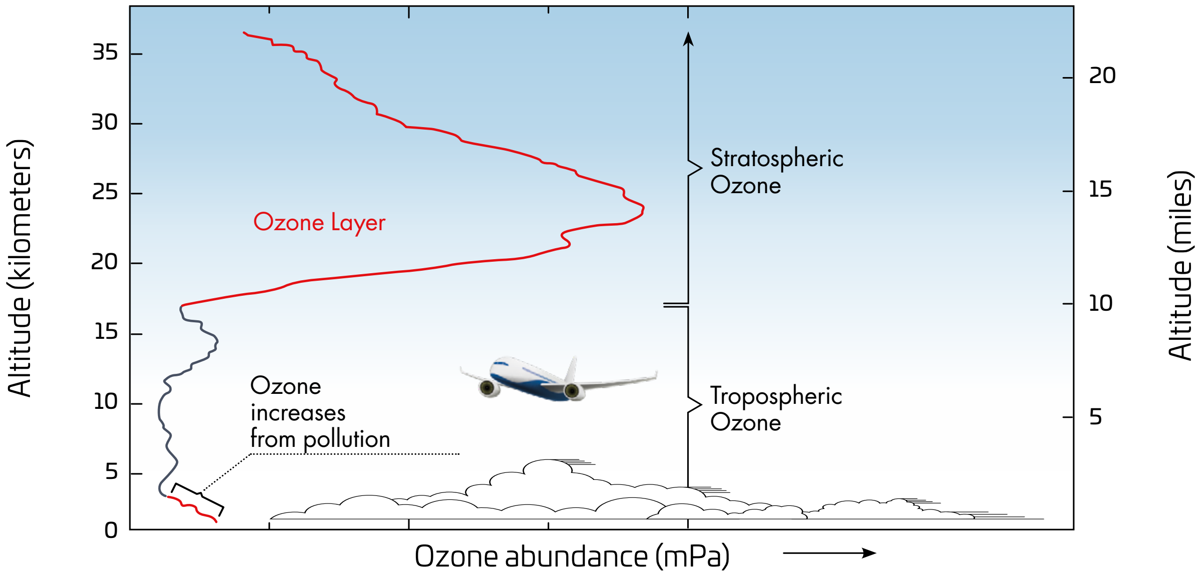
A.1. RADIATIVE FORCING

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)

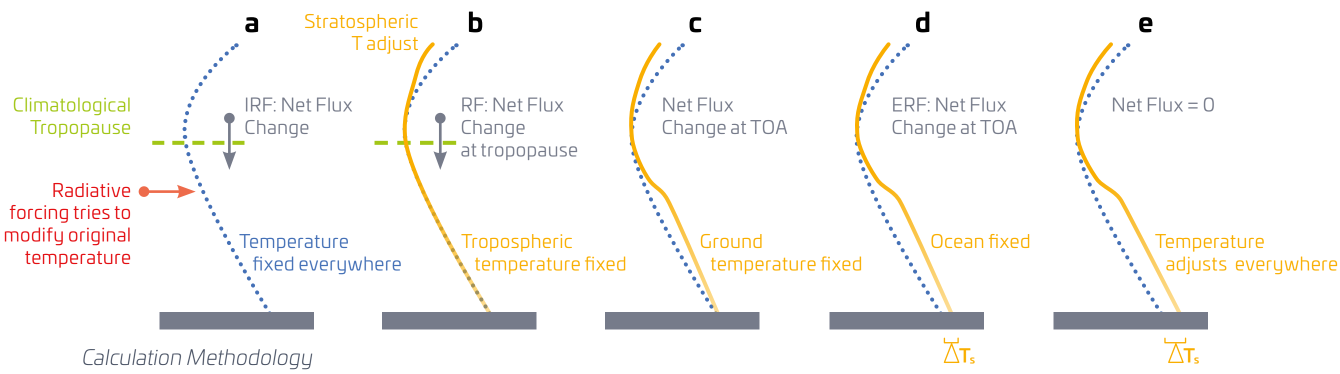


The energy state of the Earth's climate system results from the difference between the radiative power flux incoming from the sun and that reflected or emitted by the earth. Disturbances cause the system to shift towards a new equilibrium, with measurable changes in temperature at different altitudes.

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.

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.

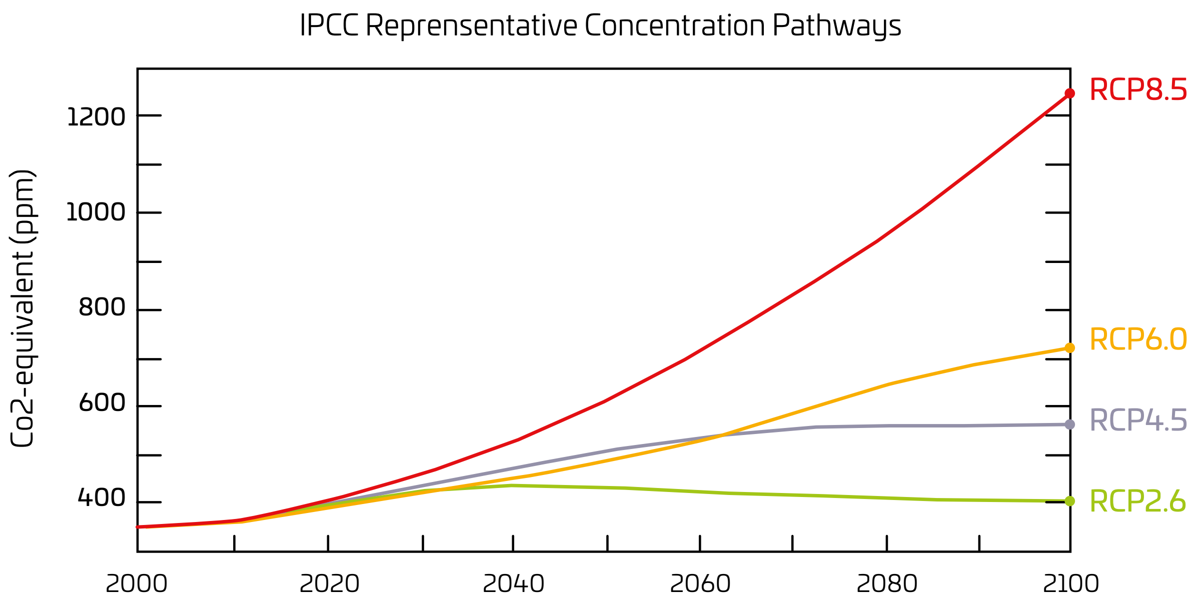
A.2. REPRESENTATIVE CONCENTRATION PATHWAY

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.

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

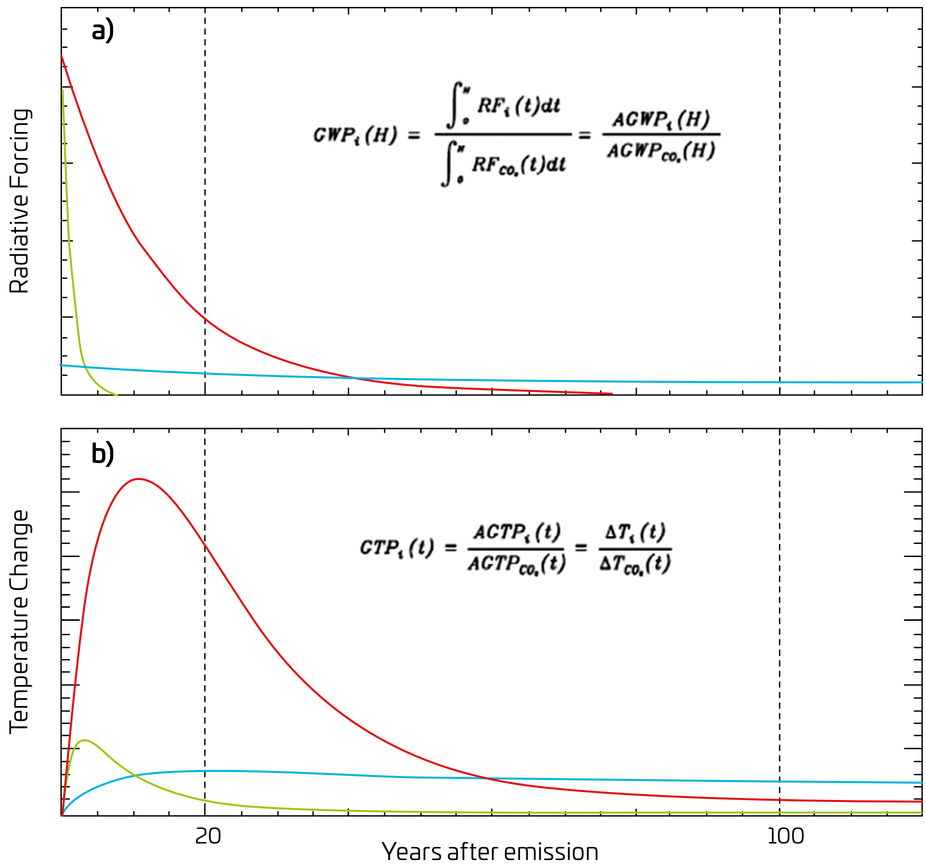
Climate change estimate can range over different time horizons, typically 20 to 100 years.

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)



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.*

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

A.3. REFERENCES

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