CLIMATE CHANGE IMPACT OF AIR TRAFFIC

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Abstract

The contribution of aviation to global warming represents one of the main challenges of aviation for long-term globally growing air traffic. The radiative forcing of climate by aviation has been reassessed in recent studies. There is a clear need to reduce the fuel consumption per transported passenger or freight mass. However, the largest climate change impact of air traffic may result from contrail cirrus and possibly soot induced cirrus clouds. Mitigation of contrail effects requires new air traffic management concepts which reduce the number of flights in very humid and cold regions of the atmosphere, in particular during night. Further research is required to reduce the large number of open questions related to this issue.

1 Introduction

There is growing evidence that global warming is accelerating and is driven mainly by greenhouse gases due to human activities on Earth [1]. This will be very clear from the forthcoming IPCC report which is to be published in 2007.

Aircraft engine emissions contribute to increases in greenhouse gases. They also emit gases and particles changing atmospheric ozone, methane and cloudiness.

This paper discusses the main challenges from aviation contributions to climate change for long-term and global sustainable growing air traffic.

Aviation has been growing at relatively high rates over long times, see Fig. 1. Sustained growth is to be expected in the coming decades. An increase in aviation transport in terms of passenger-km by a factor 2.6 from 2002 to 2025 has been assumed as a realistic scenario [2].

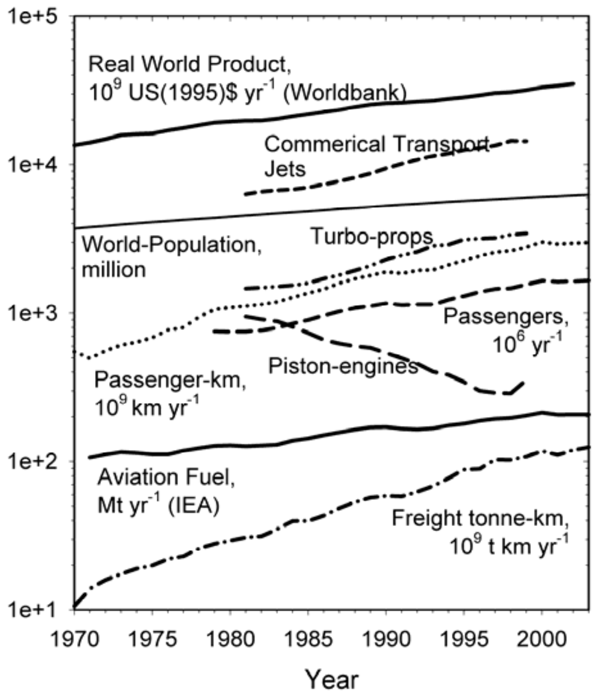

Fig. 1: World aviation in the years 1970 to 2003: Civil commercial transport aircraft (three types) registered in ICAO states, and traffic of commercial air carriers as reported by the International Civil Aviation Organisation (ICAO, Montreal), aviation fuel production as reported by the International Energy Agency (IEA, Paris, 2005), together with the real world economic product (Worldbank, Washington, DC), and the world population (US Census Bureau, 2006).

Hence, there is urgent need to address the environmental effects of air transportation including noise, air quality near airports, and climate. This paper concentrates on the climate issue but the other aspects are important as well. The need to reduce emissions from aviation that impact the global climate has been recognised both by aviation industry (ACARE), aviation organisations such as the International Civil Aviation Organisation (ICAO), the European governments, and the Commission (CEC) of the European Union. In the USA, a team under guidance of the Federal Aviation Administration has recently issued a report highlighting the environmental impact of aviation in terms of noise and local air quality and calls for research to reduce the present uncertainties in assessing the climate impact of aviation [3]. The climate statement of the G8 summit at Gleneagles signed on 8 July 2005 specifically mentions a determination to lessen the impact of aviation on climate [4].

The European vision for the year 2020 foresees the development of technology allowing for a 50 % cut in CO_2 emission per passenger-km, and 80 % cut in NO_x emissions compared to technology of the year 2000. The strong rise (near a doubling from May 2004 to May 2006) in fuel prices is a strong incentive to reduce fuel consumption. More fuel efficiency helps to reduce operational costs and saves the finite oil reserves on Earth. However reduction of NO_x is driven solely by the society's need to reduce climate impact. The issue of particle formation (which is important both for air quality and climate) and contrails has not yet been acknowledged to the degree it deserves.

In January 2005 the European Union Emission Trading Scheme (ETS) commenced operation as the largest multi-country, multi-sector ETS in the world, albeit currently limited only to CO_2 emissions. At present the scheme makes no provision for international aircraft emissions. Non-CO_2 effects have been included in some policy-orientated studies of the impact of aviation but it has been argued that the inclusion of such effects in any such ETS scheme is premature [5].

2 New Findings on the Climate Impact from Aviation

The climate impact of aviation on the global atmosphere was assessed in 1999 in the report of the Intergovernmental Panel on Climate Change: “Aviation and the Global Atmosphere” [6]. Aviation contributes to global changes by the following mechanisms: Carbon dioxide (CO_2) form aviation adds to the total CO_2 increase. Nitrogen oxides (NO_x) induce ozone increases and methane reductions [7-9]. Water vapour acts as a greenhouse gas (important mainly for supersonic transport). Water vapour also triggers contrails and contrail-cirrus in cold and humid air masses, in particular in the upper troposphere. Aerosols (mainly soot) change cirrus clouds. The largest radiative forcing and climatic impact is expected presently from spreading contrails in ice-supersaturated air masses and potentially from changes in cirrus due to soot and sulphuric acid emissions [10].

Since the IPCC report of 1999, new insight was gained, as explained below.

The radiative forcing (RF) by aviation has been reassessed in various EU-Projects, in particular TRADEOFF [11], see Fig. 2.

The most robust finding is that aviation fuel consumption increases the atmospheric CO_2 concentration and thus contributes to RF and climate change.

Past aviation contributed an order 1.5 % to the anthropogenic increase in atmospheric CO_2 and the related radiative climate forcing [12]. Because of its long mean residence time (order 80 years [12]), CO_2 emission of today will be effective for nearly one century. Therefore, reduction of seat specific fuel consumption and the related CO_2 emissions are of highest priority.

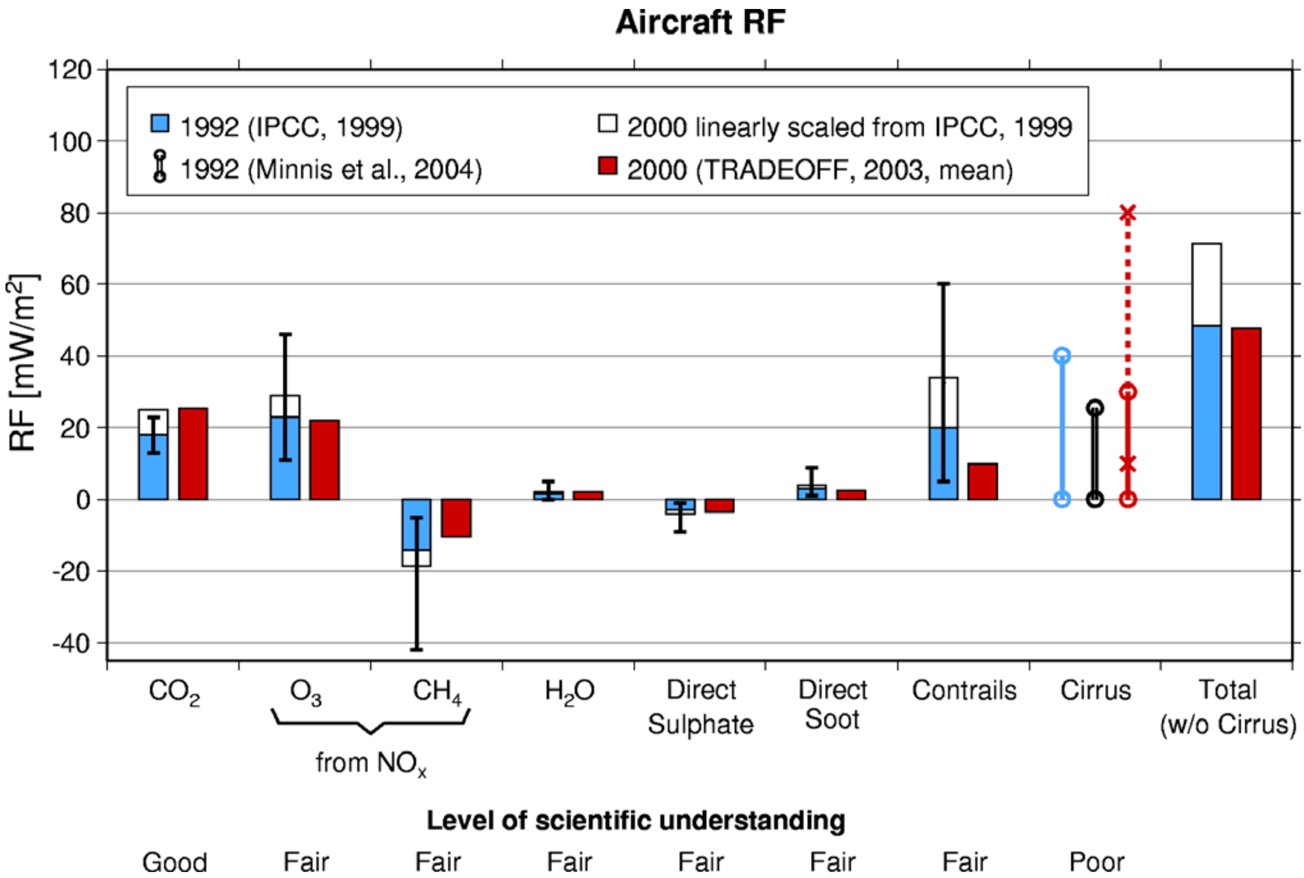

Fig. 2. Radiative forcing (RF, [mW/m²]) from aviation for 1992 and 2000, based on IPCC (1999) and TRADEOFF results [11]. The whiskers denote the 2/3 confidence intervals of the IPCC (1999) value. The lines with the circles at the end display different estimates for the possible range of RF from aviation induced cirrus clouds. In addition the dashed line with the crosses at the end denotes an estimate of the range for RF from aviation induced cirrus. The total does not include the contribution from aviation induced cirrus clouds.

Aviation also emits nitrogen oxides which contribute a few percent to upper tropospheric ozone. Since ozone is also a greenhouse gas, which is very effective in particular in the cold regions near the tropopause where most long-range aviation occurs, the RF from ozone is comparable to that of CO_2. On the other hand, NO_x emission enhances the oxidation capacity of the atmosphere and reduces the life time of methane, which reduces the global effect of aviation NO_x on climate to a still not well known degree. Recent and still to be published findings on the importance of lightning induced NO_x (e.g. within the EU project TROCCINOX) call for reassessment of the aviation NO_x contribution. Also recent findings on the distribution of halogens in the lowermost stratosphere, uptake of nitric acid into ice particles and their potential interactions with ice particles and aerosols [13, 14] may cause revisions in quantification of aviation NO_x impact on ozone and methane.

A further important finding of recent years is that line shaped contrails cause less climate impact than estimated before mainly because of smaller optical depth [15, 16]. The climatic impact of such line-shaped contrails has been assessed with global climate model studies. The results of a global circulation model [17] shows an equilibrium response of less than 0.003 K due to present line-shaped contrail cover of about 0.1 %, more than 100 times less than earlier studies, mainly because of different contrail cover and optical thickness, see Table 1.

On the hand, further confirmation for trends in cirrus cover were found which indicate that the change in cirrus cover exceeds that by line-shaped contrails [18-21].

	Strauss et al., 1997 [22]	Rind et al., 2000 [23]	Hansen et al., 2005 [24]	Ponater et al., 2005 [17]
Model	Regional	GCM	GCM	GCM
Prescribed cloud cover change, CC, %	0.5	1	0.8 (1.09)	3.2
Optical Thickness, τ	0.28	0.33	0.25	≈ 0.1
Radiative Forcing, (W/m2)	0.15	0.1	Fs= 0.029	0.19 (0.29)
RF/(τ CC), (W/m2)/%	1.1	0.3	0.15	0.6 (0.9)
Temperature Change ΔT, K	0.05	0.43	0.031 ± 0.028	0.008
ΔT/(τ CC) (K/%)	0.36	1.3	0.15 ± 0.15	0.26

Table 1: Computed surface temperature equilibrium change from various contrail climate studies using either a region model or global circulation models (GCM). Note that the various studies predict strongly different temperature responses ΔT, but the scatter in the results gets considerably reduced when ΔT is normalized with optical thickness τ and contrail cover CC.

Recent studies on the correlation between cirrus cover and regional aviation traffic density at the same time show that aviation induces contrails which turns into additional cirrus clouds and cover a rather large fraction of the sky [25], see Fig. 3.

Over mid Europe, the additional cover by contrail cirrus is ten times larger than the cover by line-shaped contrails. Air traffic induces an additional cirrus cover of 3 % over central Europe. The observed cirrus change is caused by contrails spreading in ice supersaturated air masses. The potential additional cirrus cover given by the area fraction of ice-supersaturated air regions outside thick cirrus is larger than 10 %. It is not possible to calculate their radiative impact without further information [17]. The radiative effect of the aviation induced cirrus clouds may be more than 10 times the effect of the linear contrails. The lifetime of contrail cirrus has to be measured in hours rather than in minutes. Therefore part of the impact of air traffic over Europe is shifted to the night hours, where only the warming effect of cirrus clouds is remaining.

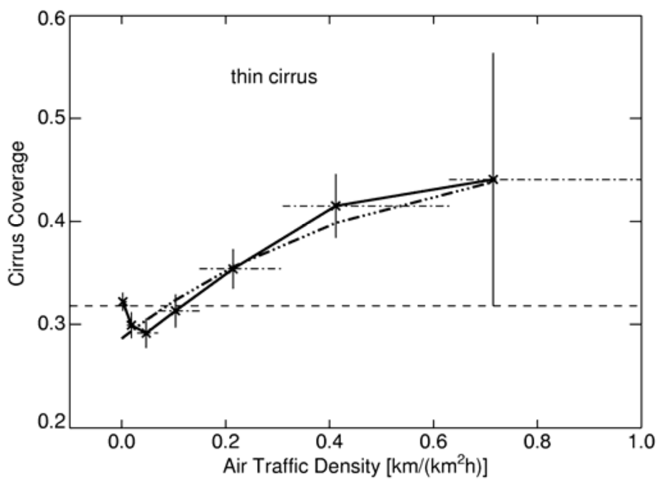

Fig. 3. Cirrus coverage derived from METEOSAT data as a function of air traffic density [25]. The figure shows the mean cirrus coverage within seven air traffic density classes indicated by the dash-dotted horizontal bars. The vertical bars indicate the range of statistical confidence at a 95 % level derived from variance and number of independent observations for the single air traffic density classes, the horizontal dashed line the mean value of cloud coverage as defined by the algorithm. The cirrus coverage according to a theoretical conceptual model is indicated by the thick dash-dot-dotted curve.

This kind of study has been renewed in an ESA-EUROCONTROL project "contrails" by H. Mannstein et al. [26] with further data (METEOSAT-second-generation for the year 2004 and EUROCONTROL traffic data for the same period). The study shows the same increase in contrail cover with air traffic density, and hence confirms the findings of the previous study. Moreover, for the first time, the radiative fluxes induced by contrail cirrus clouds both in the solar and the infrared range has been evaluated from METEOSAT data [27]. The sum of the outgoing solar and infrared fluxes is approximately equivalent to the radiative forcing (RF). The results show that the RF increases with increasing aviation density. However, this increase is not monotonic. It reaches a maximum for a certain aviation density and then decreases slightly. Moreover, this RF is a very strong function of daytime, surface albedo, and temperature of the underlying ground (including the otherwise existing cloud cover). The RF is far larger than the daily average during night and can be negative during day time. The mean value is not very representative, because it is the difference between two large numbers (day and night values) with large uncertainties.

Recent studies show that also aviation soot may change cirrus properties [28, 29]. Hence, besides "contrail cirrus" also "soot cirrus" needs to be considered.

3 Emission Trends

Global civil aviation consumed about 6.1 Litre per 100 km and per passenger kilometres (including freight equivalents) in 2002 (derived from Eyers et al. [2]). The engines on average emitted 0.64 g(NO_2) per passenger-kilometre or about 13.2 g(NO_2) /kg(fuel) (derived from [2]).

In the past, more fuel efficient engines caused NO_x emissions to increase at a rate faster than fuel consumption. Soot mass and soot number emissions have been reduced in the past considerably [30], but may still have a significant impact on atmospheric aerosols and clouds [28, 29]. Fuel sulphur may impact the number of ice particles for sulphur contents larger about 10 µg/g. The amount of sulphuric acid (H_2SO_4) emitted depends not only on the fuel sulphur content but also on combustion chemistry inside the engine combustor [31].

For long term climatically sustainable growth of aviation, specific fuel consumption might eventually need to be reduced faster than the growth rate of air traffic. New emission data bases and scenarios assume the air traffic (in terms of passenger kilometre) to increase by a factor of about 2.6 from 2002 to 2025. The expected reduction in NO_x and CO_2 emissions in the real aviation fleet until 2020 is likely far less than what may be feasible with newly developed technology. Instead of a 50 % reduction in CO_2 emissions per passenger-kilometre, the reduction in the operational fleet of 2020 may be of order 20 % compared to 2000. For NO_x, the reductions in the operational fleet of aviation is expected to range from zero (or even slightly negative values; [32]) to reductions of an order 40 % in terms of NO_2 mass emission per passenger-kilometre [2].

For sustainability of global aviation in terms of climatic impact, global fuel consumption and global emissions of CO_2, NO_x, soot, and sulphuric oxides should stay constant or decrease. This requires even quicker development of low CO_2-NO_x-soot-H_2SO_4 technologies than planned so far.

4 Mitigation Options

Contrail formation can be avoided only by flying outside cold and humid regions, at ambient temperatures above the Schmidt-Appleman threshold [33]. However, contrails remain short in dry air (such as in the lower stratosphere). Larger climatic effects are to be expected from the formation of contrail induced cirrus clouds. Contrail induced cirrus can be avoided only by flying outside ice-supersaturated regions, i.e. at relative humidities below 100 % with respect to ice (order 60 % with respect to liquid water).

If contrail cirrus turns out to be indeed responsible for the largest aviation induced climate impact, then new air traffic management procedures are required to reduce or avoid traffic in cold and humid atmospheric regions, for example by flying higher or lower or circumventing cold atmospheric regions with high humidity [34]. This might best be implemented by a weather prediction dependent air traffic management (ATM).

In order to allow for slightly higher flight levels, with cruise flights at midlatitudes in the dry lowermost stratosphere, where contrail cirrus occur less frequently, more research is needed to exclude that such flight level increases have negative impact on fuel consumption and the ozone layer [35].

In addition, since contrail cirrus is long-living, and has strongest climatic effect during night, one should consider to reduce evening and night-time traffic and to shift traffic further into morning hours.

Moreover, new ATM procedures should be developed to reduce fuel consumption by better taking into account the meteorological conditions along flight routes and to avoid contrail and cirrus formation by proper selection of traffic routes. Implementation of such ideas requires airborne humidity observations and the development and verification of better weather predictions for relative humidity in the upper troposphere and of contrail-cirrus formation prediction methods for installation into ATM.

Hence, a sustainable air traffic system requires intensified research and improvements in all aviation components, including the aircraft, the engines, the fuel, and the air traffic management, in addition to research on the atmosphere and climate change.

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