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It is premature to include non-CO_2 effects of aviation in emission trading schemes

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Abstract

The recent G8 Gleneagles climate statement signed on 8 July 2005 specifically mentions a determination to lessen the impact of aviation on climate [Gleneagles, 2005. The Gleneagles communique: climate change, energy and sustainable development. http://www.fco.gov.uk/Files/kfile/PostG8_Gleneagles_Communique.pdf]. 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 aircraft emissions. However, the UK Government would like to see aircraft included in the ETS and plans to use its Presidencies of both the EU and G8 in 2005 to implement these schemes within the EU and perhaps internationally. Non-CO_2 effects have been included in some policy-orientated studies of the impact of aviation but we argue that the inclusion of such effects in any such ETS scheme is premature; we specifically argue that use of the Radiative Forcing Index for comparing emissions from different sources is inappropriate and that there is currently no metric for such a purpose that is likely to enable their inclusion in the near future.

Keywords: Aviation; Climate; Emission trading schemes; Contrails; Global warming potentials; Radiative forcing

1. Introduction

The UK policy on including aviation effects in the European Union Emission Trading Scheme (ETS) scheme in currently under debate. As part of this debate, there has been significant discussion as to whether the non-CO_2 effects of aviation should be included in assessing their overall climate impact. The UK Government's 2003 Aviation White Paper "The Future of Air Transport" (http://www.dft.gov.uk/stellent/groups/dft_aviation/documents/divisionhomepage/029650.hcsp) states that "the environmental impacts of aircraft… are thought to be 2–4 times greater than that from CO_2 alone". Although it is not clear within the White Paper itself whether a multiplicative factor has been used in estimating the future climate impact of aircraft, it is clear that this factor of 2–4 (specifically 2.5) has been used by the Government in such estimates. For example, in the Department for Transport's January 2004 report "Aviation and Global Warming" (http://www.dft.gov.uk/stellent/groups/dft_aviation/documents/page/dft_aviation_031850.pdf) (see especially paragraph 4.11); in addition, scrutiny of the Government's policy by the UK Parliament's

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Environmental Audit Committee (http://www.publications.parliament.uk/pa/cm200304/cmselect/cmenvaud/233/23302.htm) has used such a factor to indicate that under certain scenarios of both future aviation and other UK emissions, by 2030 aviation emissions could account for 31% of total UK greenhouse gas emissions.

The factor of 2.5, the so-called radiative forcing index (RFI), originates from the IPCC special report on aviation (IPCC, 1999) and comes from an assessment of all the quantified sources of radiative forcing due to aircraft emissions. Not only do jet engines emit CO_2 but they also lead to short-term increases in tropospheric ozone related to NO_x emissions, decreases in methane (with an associated longer term decrease in tropospheric ozone), create condensation trails (contrails) and may lead to general increases in high clouds. In the interest of equity it is clearly desirable to include as many sources of climate change as possible within an ETS. However, the application of a factor of 2.5 to aviation appears inequitable; for other sectors, the only non-CO_2 climate effects that are included are from emissions of other gases included under the Kyoto Protocol (specifically, methane, nitrous oxide, the hydrofluorocarbons, perfluorocarbons and SF_6), using a well-defined metric (the 100 year global warming potential (GWP)), whereas for aviation, the RFI impacts are from "non-Kyoto" sources of radiative forcing, for which metric design is much more difficult (Shine et al., 2005b). Worse, the use of the RFI multiplier is a mis-application of science as it fails to account for the resident timescales of emissions and thus attributes a larger fraction of climate change emissions to aircraft than is currently justifiable.

The RFI of 2.5 relates to the total *radiative forcing* (*RF*) of aircraft-climate effects. RFI is a ratio between the total radiative forcing from aviation at some given time to the radiative forcing from aviation emissions of carbon dioxide at the same time. RF is one chosen method of assessing climate impacts and in this case gives an indication of the cumulative effect of past emissions on the Earth's energy budget at a given time. The RF history is also needed for complete understanding of an emissions impact on climate. However, whenever emissions have been assessed (e.g. for the purposes of the Kyoto Protocol) it is not the RF of different climate-change agents that have been compared but the GWP (IPCC, 1990). Crucially GWPs consider the *time-integrated* RF from a pulse emission rather than just the RF alone. For example if equal masses of two different climate change agents with similar RFs were emitted on the same day and one had a lifetime of a few days and the other over 100 years, the agent with the 100 year lifetime would obviously have the far bigger impact on climate. A similar situation occurs for aircraft emissions and this is why the factor of 2.5 is so misleading if it were applied in an ETS. In the applications by the UK Government and Parliament, the factor of 2.5 has essentially been applied as if it were a GWP.

Compared to contrails, CO_2 emitted by aircraft will have much smaller initial RF, but, crucially, it will remain in the atmosphere many times longer and continue to give a RF for the next 10–300 years, whereas the contrails and cloud RF only last for a few hours. Most other aircraft related climate effects have timescales of ~10 days. Aircraft-induced methane reduction and its associated indirect effect on ozone are the only other aircraft-related climate effect with an appreciable timescale of around 10 years. In addition there is some limited evidence that RF from both upper tropospheric ozone changes and contrails may have a smaller effect on surface temperature than an equivalent forcing from CO_2 changes, termed an efficacy (Joshi et al., 2003; Ponater et al., 2005); this would also act to reduce the emission-based weighting factor.

Extending the RFI approach to other sectors would reveal the complications in accounting for emissions beyond the Kyoto gases. For example diesel engines in ships and unscrubbed coal-fired power stations emit tiny aerosol particles or their gaseous precursors, which stay in the atmosphere for about a week. Sulphate aerosol particles are believed to cool the climate by both reflecting sunlight directly and changing the properties of low-level clouds to reflect more sunlight. If we used a RFI-based weighting to assess these sectors we might find that increasing their emissions could incorrectly be interpreted as being beneficial to climate.

When aircraft fly at a lower altitude they burn more fuel—and hence emit more CO_2 but they are also much less likely to form contrails (Williams et al., 2003). Flying at lower altitudes could therefore reduce the RFI but exacerbate climate change. If the emissions weighting factor was based on RFI, the aircraft industry might then argue for a reduced factor, when in reality this "mitigation" would be adding to climate warming.

The non-CO_2 climate effects of aviation may prove to be very important and the science behind them needs to be carefully assessed *before* they are included in any ETS. Most importantly there is a need to find a way to assess their time-integrated impact on climate. For the purpose of illustration we make a preliminary attempt at assessing this. More refined calculations would require the careful use of 3D chemical transport model calculations, especially to model the RF due to changes in ozone and methane which are similar in size but opposite in sign. In addition, as stressed by Shine et al. (2005b), there are many difficult metric design issues for emissions of NO_x (especially a strong regional dependence and whether it is appropriate to use global-mean inputs for such metrics) but again for the purposes of illustration we limit the discussion to conventional metrics such as GWP and RFI. We do this because in the applications referred to at the beginning of this paper, the RFI has been applied to emissions as if it were a GWP, and we will show that even if we were to accept the GWP as an adequate metric for aviation emissions, its value differs significantly from that of the RFI.

2. Illustration of the time dependence of radiative forcing index

To illustrate the impact of the different lifetimes of aircraft-induced RFs on the RFI, we consider a scenario of constant aviation emissions. Using constant current emissions as a basis for our scenario is logically the most appropriate way to evaluate current emissions in an emission trading scheme, without having to make value judgements about how they will change in the future. The RF as a function of time can be calculated using a suitable carbon cycle model (see Fig. 1); the model we used was based on the ocean mixed layer pulse response model (Joos et al., 1996).

We needed to make some additional assumptions to model the aviation RFs. The most important is that the non-CO_2 RFs do not change under constant emissions, i.e. we assume that they are already in equilibrium with their emissions. This assumption is weakest for the aviation-induced decrease in methane (and the associated ozone decrease), which has a response time of about 10 years (Stevenson et al., 2004). This will lead to a small (~10%) underestimate in RFI during the early part of the century but will have negligible impact beyond about 20 years, when the system is close to equilibrium.

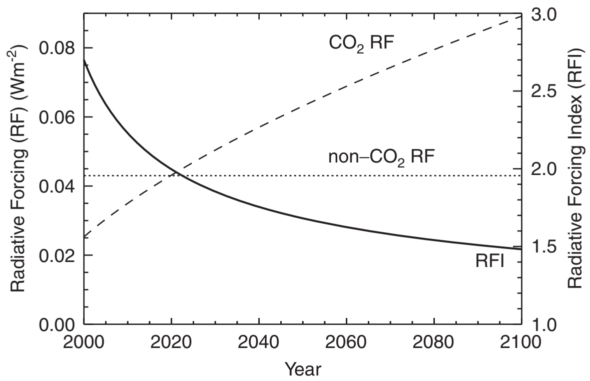

Fig. 1. The CO_2 radiative forcing (dashed line) and the non-CO_2 radiative forcing (dotted line) as a function of time from constant (year 2000) aviation emissions. The corresponding RFI is also shown (solid line). The scenario is deliberately chosen to have an RFI of 2.7 in 2000—the RFI from the IPCC (1999) report.

We also model aviation emissions by assuming an exponential increase since 1950 to its year 2000 global emissions of 150 Tg C (Eyers et al., 2004). We make such a simple assumption since the purpose of this work is to illustrate the problems of using the RFI. Different scenarios for aviation growth until 2000 were also investigated. Adopting other scenarios modified the RF in the year 2000 but had little effect on the RFI timeseries as seen in Fig. 1. We further assume that when aviation's emissions are fixed in 2000, the CO_2 emissions from other sectors continue to grow following the SRES A1B scenario (IPCC, 2000). Tests showed that none of these assumptions affected the calculated RFI by more than 0.1.

Fig. 1 shows that the RFI has a strong time dependence and assuming a single value is inappropriate. The reason for this is that unlike the non-CO_2 forcings which remain constant when aviation emissions are held constant, CO_2 continues to rise throughout the century because of its long lifetime.

3. Approximate GWPs for aircraft emissions

We give estimates of year 2000 GWPs from aviation emissions in the Table 1, but recognize the *severe* difficulties in calculating and using GWP for emissions of short-lived species (Fuglestvedt et al., 2003; Shine et al., 2005b). Our purpose in using them here is to illustrate the flaws in using the RFI as an emissions index.

Table 1
CO_2 and approximate non-CO_2 aviation AGWPs at different time horizons

Timehorizon (2000 start) (year)	CO_2 AGWP	CH_4 and O_3 NET AGWP	Contrail AGWP	CO_2 EWF
1	0.25	2.0	6.7	36
20	2.65	0.37	6.7	3.7
100	9.15	0.012	6.7	1.7
500	29.9	−0.009	6.7	1.2

Units of AGWPs are $10^{-14}\,W\,m^{-2}\,kg\,CO_2^{-1}$ year. The appropriate CO_2 Emission-Weighting Factor (EWF) for the total aviation effect at the given time horizon is given in the last column. This is the sum of the middle three columns divided by the CO_2 AGWP.

Our calculation assumes that the contrails produced during a year cause their RF in the same year and we use a recent assessment of the contrail RF for the year 2000 ($0.01\,W\,m^{-2}$) (Sausen et al., 2005). We associate a 1 year integrated RF from these contrails with the mass of CO_2 emitted within the same year to calculate an Absolute GWP (AGWP): the time-integrated radiative forcing from contrails for a 1 kg pulse of CO_2 emitted by aviation. As contrails are assumed to last only for the duration of the emitted pulse, their AGWP does not vary with time horizon.

For ozone and methane the calculation of an AGWP is much more complicated. A pulse emission of aviation NO_x leads to a short-lived increase in ozone followed by a longer-term decrease in methane, which is itself accompanied by a decrease in ozone (e.g. Stevenson et al., 2004). The GWP is therefore made up of a relatively large short-lived positive component followed by a smaller, but longer lived negative component. Most of the ozone forcing occurs in the year of emission whilst the methane forcing is slower to develop; we use data available in Table 4 of Stevenson et al. (2004) to calculate the AGWPs.

The CO_2 AGWPs are calculated with the carbon cycle model. The CO_2 AGWPs are very similar to those found from previous calculations (Shine et al., 2005a). The constant emission scenario discussed in the previous paragraph has also been used to calculate a global temperature change potential (GTP) for sustained emissions (Shine et al. 2005a), an alternative way of assessing the climate impact of emissions. GTP uses a simple analytical global-mean climate model to evaluate a temperature change after a number of years from the radiative forcing resulting from either a pulse or constant emission scenario. We found that the GTP values for constant aviation emissions were very similar to their GWP values (see also Shine et al., 2005a).

Table 1 clearly illustrates that before a weighting factor can be applied for emissions, a time horizon needs to be chosen. If one's concern was climate change over 100 years (the time horizon adopted for the GWPs used by the Kyoto Protocol) then an emission weighting factor (EWF) smaller than 2.5 is appropriate. However, if we are concerned by climate change over shorter time horizon a much higher factor than 2.5 might be more appropriate.

The uncertainties associated with these EWFs are difficult to evaluate, but would be appreciable. There are approximately factor of two uncertainties associated with both the non-CO_2 RFs from aviation and the climate efficacies of these effects. These would directly scale the non-CO_2 AGWPs. These uncertainties could lead to $>50\%$ uncertainties in the EWFs. Further, as discussed by Shine et al. (2005b), intermodel differences in the effect of NO_x emissions are likely to impact severely on the methane–ozone GWPs derived here. Nevertheless, the main point of this illustration is to show that it is inappropriate to use a single value of RFI as an emissions index without giving serious consideration to the timescales of the climate effects.

4. Conclusions

To conclude, we believe that a number of issues need to be addressed before an emission weighting factor for aviation could be adopted in any emissions trading scheme.

(1) For fairness, any emission-based weighting of non-CO_2 climate effects (beyond emissions of gases included within the Kyoto Protocol) should be applied to all sectors—not solely aviation.

(2) The use of a single value of the RFI as an emissions index is clearly inappropriate and misleading, as it tends to exaggerate the climate impact of aviation emissions. It is important to choose an index which is emissions based (e.g. related to the GWP or GTP), but a robust emissions based index is not yet available. When choosing this metric, model uncertainties, the fact that the metric values may be dependent on the location of the emissions, varying climate efficacies and the role of negative forcings will require many decisions to be made by policy-makers (Shine et al., 2005b).
(3) A suitable time horizon (e.g. 100 years) needs to be chosen.

Adopting any weighting for the non-CO_2 effects of aviation before assessing these considerations is, we believe, premature.

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