Inclusion of non-CO_2 effects of aviation in the ETS: a summary

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Including the aviation sector in the European trading scheme is certainly an improvement from the current situation, provided that it results in actual mitigation of emissions. However, there are serious concerns with a trading in which airline companies could buy rights from other sectors on the basis of "one tonne CO_2 for one tonne CO_2", i.e. without including effects of other gases and aerosols – in particular because aviation generates high clouds (cirrus) that have relatively large short term regional impacts (near the latitude of emission). Indeed, if companies buy emission quotas that only represent CO_2 (e.g. reduction of CO_2 emissions in the electricity production sector), and use these quotas as additional allowances for aviation, the impact on the climate is obviously not the same. This trading is not "climate neutral" as it should be: transactions could reduce the actual positive effect on climate as compared to a fixed target for aviation.

Measuring the aviation effects in a way that is appropriate for the emission trading and mitigation framework involves choices of definitions and objectives that imply value-judgements which should not be mistaken for scientific uncertainties. Trading requires that a common measure of impacts of different emissions types must be decided. For the Kyoto gases, it was decided that this is equivalent CO_2, an approximate measure of the global average climate effect over 100 years. Using the same metric for aviation raised concern because aviation has large short-term and regional impacts, so that this average cannot fully represent its consequences on climate, in particular at the regional scale, thus a multiplier to reflect effects of other gases defined on the basis of "equivalent CO_2" (or global warming potential, GWP) for the non-CO_2 effects of aviation does not tackle all aviation impacts. Nevertheless, it is a minimum, and it is consistent with the existing framework of the ETS. Taking all uncertainties into account, our evaluation based on the existing literature (including effects of cirrus clouds excluded from many earlier analyses) is that a multiplier defined in this way should very likely be above 1.5[1], with a best estimate of 2.4 and is likely to be below 4. Moreover, the short term warming due to aviation induced cloudiness leads to additional emissions of CO_2 from the ocean and soil, provisionally estimated here to be equivalent to about 30% of the direct emissions of CO_2 from aviation, thereby converting this short-term forcing into an additional long-term effect. Although a fixed multiplier helps to improve the counting of climate impacts in the trading system, it does not give any incentives to the reduce the non-CO_2 effects as it will always be proportional to fuel use. An improvement that calls for further research would be to count equivalent emissions based on flown kilometers per flight or per route and engine type.

[1] It is sometimes believed that the IPCC (1999) reported a bottom range value of 2, but this was the lowest value given for the "radiative forcing index", which is defined in a way that does not make it appropriate as a multiplier. In addition, our estimate is conservative as there are non-included effects – in particular the carbon cycle feedback that is mentioned below.

The following pages provide an overview of the requirements for the inclusion of non-CO_2 effects of aviation in the ETS and mitigation objectives through a "multiplier", the available scientific information to define its value, and remaining uncertainties.

1. What are desirable properties of a "multiplier" in the ETS context ?

The "multiplier" of emitted carbon dioxide is a way to count the climate impact of non-CO_2 emissions. These impacts are due to the "forcing" (net warming) of the climate system by nitrogen oxides (NOx, resulting in an initial short-lived warming by ozone and cooling by destruction of methane), the production of condensation trails (contrails) and their evolution into cirrus clouds, and smaller direct effects of sulfate aerosols, soot, and water vapor.

A requirement that appears critical is to maintain the consistency of the emission trading system:

1. Keep the trading as "neutral" as possible : a unit of gas traded by the aviation sector should have the same climate impact as a unit of gas originating in other ETS participating sectors

It is also desirable to define the multiplier so that there are no practical difficulties in its application:

2. Define the multiplier without ambiguity, in particular if it has a variable or revisable value

A specific difficulty of the aviation impact on climate is that it is not a constant proportion of the amount of consumed fuel or emitted CO_2. Other factors, such as the altitude of flight or engine type, may significantly change the consequences on the climate. This is particularly true at the regional scale, but it is possible that the fraction of climate change that is specifically regional could be better tackled by regulations outside the ETS. Indeed, the objectives of ETS relates to global changes, notably because the objectives are set in equivalent CO_2[2]. However, aviation has a global impact from non-CO_2 emissions, and for these emissions the specific characteristics of flights play a role in the climate impact. Therefore,

3. While a fixed multiplier is better than no multiplier, full accounting for the aviation consequences on climate requires a measure of non-CO_2 impacts that depends on actual flight characteristics

Indeed, condensation trails can evolve into cirrus clouds only if the air in which they are formed is supersaturated. The parcels of supersaturated air are generally very thin, and a small change in flight altitude may reduce or avoid cirrus formation, depending on the meteorological conditions. These altitude changes can however increase the fuel use and thus the emissions of CO_2, therefore a tradeoff between these two effects needs to be made. A variable multiplier taking the actual flight impacts from both CO_2 and cirrus would provide an incentive to approach such optimal flight characteristics. This is evidently more complicated and requires more research, with a view to

[2] If more weight is put on impacts that relates to certain regions (eg populated ones), changing the distribution of emissions will change the global effects on climate. It would not be possible to set a target in terms of global change in this case.

define a way to count emissions that involves an acceptable amount of computation (a compromise could be to calculate per route/operator rather than per flight) and is clearly defined.

2. Which “metrics” are available to define such multiplier?

Much of the debate around the value of the multiplier has apparently focused on the "Radiative Forcing Index" (RFI), introduced by the IPCC (1999). It is defined as the ratio of total radiative forcing to that from CO_2 emissions alone. However, it was not supposed to be used as way to "aggregate" effects, as a "metric" to count all kind of emissions. In its last report (AR4, 2007, WG1, chap 2, page 215), the IPCC notes that the RFI "should not be used as an emission metric since it does not account for the different residence times of different forcing agents". A complete discussion of the properties of the RFI is longer, because this concept may take some account of residence times[3], but not in a consistent way. At the end, RFI is not a good candidate to be used as "a metric", that is, a measure of the effect of non-CO_2 gases, and thus it can't be used to build a multiplier.

The reference unit in this context of the emissions trading system is “equivalent carbon dioxide”. Based on IPCC-AR4, in the context of emissions, equivalent CO_2 is defined as the amount of carbon dioxide emission that would cause the same total radiative forcing, over a given time horizon, as an emitted amount of well mixed greenhouse gas(es). In simple words, it is an amount of CO_2 that would have roughly the same impact on climate as that of the considered gas. The equivalent CO_2 is obtained by multiplying the amount of emitted gas by its Global Warming Potential (GWP). The mathematical definition of GWP is given in annex I.

Equivalent CO_2 and GWPs are focusing on long term, global average effects: they are indicators of the effects on the climate over a given period, which is 100 years in the Kyoto Protocol[4]. The IPCC definition also reminds that it is made to measure global average effects, as it says that it is to be applied on “well mixed gases”, that is, gases that stay in the atmosphere long enough to reach an homogenous repartition over the planet. It is clear that equivalent CO_2 cannot take full account of all aviation effects, since most of the non-CO_2 effects are very short term – e.g. cirrus clouds produced by planes can only last days, with primary effects concentrated near the latitude of emission. As it is a long term global average, equivalent CO_2 cannot describe such regional differences. Stronger changes in some regions, or a tendency to cause faster climate change compared to CO_2 could cause more damage if it is caused by the short-lived processes due to planes than with the “equivalent” amount of real CO_2. The GWP based CO_2 equivalent is thus not a complete measure of impacts on climate. However, we are not looking for the perfect scientific measure of the aviation impacts: the aim of our measure of aviation impacts is to integrate in an emission trading system. This is a different question, since the need is to have a common measure for impacts of different types.

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[3] Although it is not explicitly written in the above IPCC definition, practical uses of the RFI assume that the radiative forgings are computed for a given year taking into account *the accumulation* of emissions from a given sector *prior to the reference year*

[4] Decision 2 / CP.3, related to methodological issues

In the context of trading, and in spite of the fact that it cannot measure all effects of short-lived emissions, equivalent CO_2 remains a valuable measure. It is not only "by lack of something much better" that 100 year average GWP is currently used in international regulations. Agreements on targets are easier if there is a common measure of the need to mitigate the various emissions, and if trading is allowed then some kind of measure, a "price" of emissions is eventually needed. Using 100 years average GWP is a choice on a logical ground: some greenhouse gases stay in the atmosphere for longer (CO_2 has effects over many hundreds years), and others have shorter effects (such as methane, almost fully removed from the atmosphere in a few decades). Contrails produced by planes are an extreme case. But if their consequences (warming) must be traded together with the consequences of CO_2 warming, it is coherent to count all gases in the same way, with an approximate measure of their long-term average impacts on climate. An alternative would be to put more weight on the short-term effects (i.e. aviation), as these may indeed be worse for the climate (faster changes reduce adaptation potential and is amplified by feedbacks in the carbon cycle). However, counting greenhouse gases with such "extra weight" on short-term effects raises more questions (e.g. CO_2 staying in the atmosphere for centuries may have a larger contribution to sea-level rise), and may reduce the consistency of the system if a common measure of "mitigation" remains desired (its definition would likely be ambiguous).

In summary, GWP does not count short-term effects of aviation in a complete manner, but it does count all gases in a consistent way (average effect, over 100 years). It is not "wrong" from a scientific viewpoint, it is merely incomplete. However, it seems logical that any aggregated measure of the very different effects of short-lived and long-lived emissions would be unable to measure their possible consequences in a complete manner, in particular because the difference between short and long term effects will depend on the future path of global emissions for all sectors. The details of the "value" of contrails vs carbon dioxide warming potentials is not defined a priori without knowing these future emissions. A frequent misunderstanding is that the key issue is a lack of scientific data or understanding: in fact there are fundamental limitations to the use of an aggregated measure of climate warming (or damages) potential. Research may help in making sound choices, but there is already enough understanding of aviation impacts to conclude without ambiguity that aviation is having more global scale effects on climate than those from CO_2 alone.

The use of equivalent CO_2, while not fully measuring aviation effects, can provide a measure of these long term ones. Their inclusion in a cap-and-trade system in which each factor is counted using is GWP may possibly be supplemented by regulations concerning short-term effects. This would be particularly justified in Europe, as short-term effects are also local effects that are larger around the latitude of emission.

Other aggregate measures of non-CO_2 effects have been proposed. An example is the global temperature potential (GTP), which is defined as the ratio between the global mean surface temperature change at a given future time horizon following an emission of the considered compound relative to the reference gas (e.g., CO_2) (IPCC AR4, 2.10.4). The considered emission can be a "pulse" at the beginning of the period or an emission sustained throughout the period. While the GWP is an integral quantity over the time horizon (i.e., the contribution of the RF at the beginning and end of the time horizon is exactly equal), the GTP uses the temperature change at the end of the selected period: radiative forcing closer to the end contributes relatively more. As noted by Shine et al. (2005), there is a near equivalence between the GTP for sustained emission changes and the GWP (defined for a pulse emission). The GTP metric has the potential advantage over GWP that it is more directly related to surface temperature change (it may include "efficacies" that relates radiative forcing to temperature changes). In the context of trading, the requirement is to count the effects of present emissions, so that the focus is on the "pulse" variant of the GTP metric. As only temperature changes at the end of the period are counted, effects at the beginning of the period will only be seen through feedbacks and inertia in the climate system, so that gases that have short lifetimes will be weighted less with GTP than with GWP. It is possible that the GWP offers a more balanced measure of the impacts of short and long lived emissions.

As there are different types of agents that have an impact on climate, involving very different time scales (from days to centuries), no single metric can measure all aspects of impacts; in addition, impacts of a given gas are dependent upon the future emissions of other gases. Thus any single metric is a compromise. In conclusion, while there is scope for more research regarding measures of impacts of climate altering atmospheric emissions, the GWP metric currently used in international agreements is valuable. Its replacement would require careful assessment of potential new measures or improvements.

3. What do we know about multiplier values and uncertainties ?

Following the discussion in section 2, we focus on GWP as a measure of non-CO_2 impacts compared to those from CO_2. It is a consistent metric that reasonably satisfy the first two criteria set out in section 1 (criteria 3 is discussed in the last section), and in addition it is the one used in the ETS. The detailed definition of the GWP-based multiplier[5] is given in Annex I. As explained above, it approximately represents the total average climate impact over a given period compared to that of CO_2 alone. While climate policy focuses on the 100 years time average, we also computed the multiplier for a 20 years average to illustrate the fact that focusing on shorter term impacts results in larger impacts of non-CO_2 (mostly short term) agents compared to CO_2, which means higher multiplier values. It is important to note that all these results are derived from existing studies (see appendix) that we combine to provide a GWP-based multiplier including all significant impacts: NOx (ozone and methane effects), contrails, induced cirrus (excluded from many earlier analyses) :

	Components of non CO_2 impacts (as fraction of the total non CO_2 impacts)			multiplier (all impacts)		
	NOx	contrails	cirrus	low	best estimate	high
20 years	2 – 4%	14 – 37 %	60 – 83%	2,7	6	12
100 years	-0,2 – -0,5 %	14 – 38%	63 – 86%	**1,5**	**2,4**	**4,1**

The scientific uncertainty related to each effect as it has been evaluated in the existing literature was taken into account to provide a range for the multiplier values.

Additional effect of carbon feedback

The above figures takes into account all the major effects that have been discussed in the literature. However, they are still conservative estimates at least one important effect that was not taken into account: the short term warming due to non-CO_2 effects leads to an additional positive feedback

[5] Also called emissions weighting factor (EWF)

(= an amplification of the change) in the carbon cycle that converts this short-term forcing into a long-term effect.

The soil respiration and the atmosphere-ocean chemistry are both dependent on the temperature. An augmentation of this temperature will lead to an increased concentration of CO_2 in the atmosphere, thus leading to more warming and giving a positive feedback on the increase of temperature.

An investigation of this effect with the *Java Climate Model" (appendix II), using a scenario consistent with the calculations of the AGWP showed that this feedback effect adds an additional 21% to the cirrus+contrail forcing. Comparing to the uncertainty of the forcing this number seems relatively small but it also converts this short-term pulse forcing into a long-term effect (this "indirect" aviation CO_2 is an extra 30% on top of "direct" aviation CO_2 emissions). Therefore, even when considering only long term effects, this (non-CO_2) effect should be taken into consideration. This additional forcing is also much less sensitive to the time-horizon considered than the total aviation forcing, since it only involves CO_2 (rather than a mix of other agents with short and long term impacts that needs to be converted to a common unit), so its relative importance is less dependent on a methodological choice involving a value judgment.

4. Conclusion and discussion

To limit the global warming under about 2°C above pre-industrial temperatures (following EU policy objective, and advocated by many scientists to avoid most severe impacts), it is necessary to take the emissions from all sectors into account and strongly reduce the total. If global aviation does not contribute to mitigation efforts, the burden on other sectors would be very significantly increased. For example, a recent calculation with the "Java Climate Model" (JCM, see ABCI, 2008) showed that:

- In a scenario limiting global temperature rise to 2°C (EU policy), but with unmitigated aviation (Fa1), aviation (including CO_2, ozone, cirrus etc.) adds about 15-20ppm CO_2 equivalent in 2050
- To compensate for this unmitigated aviation forcing, CO_2 emissions from all other sectors must be about 30% lower in 2050 in order to reach the 2°C target.

While the details of the numbers in this example are highly dependent on many hypotheses or uncertain factors[6], it clearly shows that with unmitigated aviation emissions, the extra effort required in other sectors would be large.

Therefore, including CO_2 from aviation in the EU-ETS is a much welcome progress. However, other impacts of aviation on climate will also need to be tackled. These include in particular a contribution to the formation of cirrus clouds, which is very likely to represent a major fraction of aviation impacts, and the effects of nitrogen oxides (NOx, contributing to short term warming by ozone but with little long term average impact, following destruction of methane). Counting all

[6] Regarding aviation emissions and the resulting climate forcing, but also the time-profile of the emissions pathway, the carbon cycle, the climate sensitivity, etc. JCM can be used to explore these factors both in an interactive mode, and also to make a more systematic probabilistic analysis covering thousands of combinations. The model is available on www.climate.be/jcm/jcm5

these impacts may seem difficult, but it is important to note that it is not primarily due to scientific uncertainties : a key issue is that trading requires that a common measure is constructed for the different types of emissions. However, no single metric can provide a complete view on all aspects of impacts of which some are very important in the short term and others in the long term, and with climate impacts from one gas influenced by future emissions of others : value judgments and compromises are needed.

As we noted frequent confusion on the possible ways to include these non-CO2 impacts (in particular in the form of a "multiplier"), we summarized the main indexes that have been mentioned in that context. It is first important to remember that the “radiative forcing index” from IPCC (1999) was not defined to provide such a multiplier, and was recognized as inappropriate. By contrast, the more common GWP, used to compute CO_2 equivalent in the framework of the Kyoto protocol, appears to remain a valuable concept in spite of its limitations. Because it is an average impact over 100 years, it does not provide a complete accounting of the short term impacts of aviation, and so it is a minimum estimate of aviation impacts.

Taking all uncertainties into account, our evaluation based on the existing literature (combined to include the effects of cirrus clouds) is that a multiplier defined in this way should very likely be above 1.5, , with a best estimate of 2.4 and is likely to be below 4. Moreover, the short term warming due to aviation induced cloudiness leads to additional emissions of CO_2 from the ocean and soil, provisionally estimated here to be equivalent to about 30% of the direct emissions of CO_2 from aviation.

Including the non-CO_2 effects as a fixed multiplier of CO_2 emissions would thus further improve on the currently planed scheme. The scientific knowledge is sufficient to provide an estimation of this multiplier on a sound basis (GWP), and our calculations show that its value should significantly change the value of impacts attributed to one tonne of CO_2 from aviation (including all impacts) compared to other sectors.

As noted at the end of section 1, such fixed multiplier does not provide an incentive to reduce the non-CO_2 impacts of aviation. A variable multiplier, depending on the actual flight conditions can partly solve this problem, but has also limitations as the climate impacts of contrails and cirrus cloud is not necessary proportional to fuel use. Thus options to count this aviation induced cloudiness separately from fuel use should be considered, also keeping in mind that there are often tradeoffs with the direct CO_2 effects, so that incentives to mitigate each effects should remain balanced.

The implementation of technological options to inhibit the production of contrails are not effective, or not practical (see Gierens, 2008), thus air traffic management regulations have to be envisioned in order to reduce the impacts of cirrus clouds formed by air traffic. A strict restriction of flight altitudes, would need to be quite large (all airplanes would need to fly below roughly 7 km of altitude) in order to avoid the formation of an important part of persistent contrails. This restriction would also limit the impact of NOx emissions, but it would imply an important increase in fuel use and also imply contribute to congestion of the airspace. However, on a case by case basis, smaller changes in flight altitude would be sufficient to reduce or inhibit aviation induced cloudiness because it occurs in specific meteorological conditions - supersaturated air - that occurs in thin layers of atmosphere (on the order of 200-500 m). Such changes in altitudes can lead to a small increase in fuel consumption an present an additional workload for air traffic controllers. This measure would not have a strong influence on the impact of NOx emissions, so that separated counting and/or regulations might be needed to tackle these specific short term effects. Such a regulation would have difficulties to take into account that for a given engine technology, there exists a tradeoff between NO_x and CO_2 emissions.

As separate measures may cause difficulties to take into account the tradeoffs between the emission of carbon dioxide and the non-CO_2 gases, it seems logical that a total cap on emissions, and a trading system, should take each impact into account, expressed in a common unit (e.g. equivalent CO_2 as in the Kyoto Protocol). Expressing the effects of contrails and cirrus clouds in such a unit is not easy, as their creation cannot be expressed in terms of mass (it is not possible to trade "tons of contrails"). This problem cloud be solved by expressing their climate impact per km flown, because the formation of these clouds does mainly depend on the distance flown (not on the burned fuel). It could thus be possible to calculate an equivalent CO_2 amount per km. However, different types of planes and engines may be be more or less prone to induce cloudiness (see Sussmann, 2001), so that further research is needed before such a measure could be used.

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Appendix 1 : definition and computation of the GWP-based multiplier

The GWP of a component i, is the time integrated radiative forcing following a pulse emission of 1kg of i, also called absolute GWP (AGWP), divided by the corresponding value for the reference gas (here CO_2). For a time horizon of 100 years (IPCC AR4):

$$GWP_i = \frac{AGWP_i}{AGWP_{CO_2}} = \frac{\int_0^{100} RF_i(t)\,dt}{\int_0^{100} RF_{CO_2}(t)\,dt}$$

The role of the emissions weighting factor (EWF, or multiplier) is to obtain the amount of CO_2 equivalent (Q_{CO_2eq}) corresponding to all emissions from air traffic that generated a given quantity of actual CO_2 (Q_{CO_2}). This total equivalent CO_2 is given by the sum over all types of radiative forcing caused by aviation of its GWP times its amount:

$$Q_{CO_2eq} = EWF\ Q_{CO_2} = \sum_i Q_i GWP_i$$

The multiplier (also called emission weighting factor), is thus the weighted sum of the GWPs (CO_2, O_3, CH_4. linear contrails and induced cirrus clouds):

$$EWF = \sum_i \frac{Q_i}{Q_{CO_2}} GWP_i = \sum_i \frac{Q_i}{Q_{CO_2}} \frac{AGWP_i}{AGWP_{CO_2}}$$

As we are dealing with long term (100 years) effects, we may compute the multiplier on the basis of emissions over one year rather than instantaneous emissions. This allows us to compare the average impact of contrails, which cannot be measured in units of mass to the emissions of other gases emitted by aircraft.

The AGWP for CO_2 is taken from AR4, the radiative forcing for contrails and cirrus clouds for the year 2000 is taken from (Sausen, 2005) and the fuel use for the same year is taken from "Java Climate Model" (based in particular on UNFCCC greenhouse gas inventory data). Finally the AGWP for NO_x emissions of aviation in 2000 is taken from (Forster, 2006).

Combining these sources, which give the most up-to-date information, we can derive the EWF given in table in section 3 (page 5), as well as the importance of the non-CO_2 effects as a fraction of the EWF.

Appendix 2 : Additional impacts due to Climate-Carbon feedbacks

Regarding the additional forcing from CO_2 caused by aviation contrails and cirrus, via climate-carbon feedbacks, some preliminary calculations were made in UCL/ASTR using the "Java Climate Model" (see www.climate.be/jcm/jcm5).

Results are given for the default setup of the model (version July08), whose carbon cycle includes the feedback of global warming on soil respiration and on surface-ocean chemistry, with parameters tuned to fit the average from AR4 WG1 Table 7.4. In this case the 100-year AGWP for CO_2 gave a value 3% lower than that from AR4 WG1 Section 2.10.2, whose uncertainty range is given as ±15%. The baseline scenario used was set as close as possible to that used for GWPs as in AR4, i.e. constant concentration fixed at 380ppm, (except for an initial peak at 393 consistent with recent emissions).

The corresponding 100-year AGWP for additional CO_2 (integral over the following 100 years) due to the same pulse of cirrus and contrails adds 21% to the cirrus and contrail forcing (integral over one year). This could apply to any short-lived gas (not only those from aviation). Or saying it differently the additional forcing from "indirect" CO_2 due to aviation cirrus+contrails, via climate-carbon feedbacks, is 30% of that from the direct aviation CO_2 emissions. These numbers are also much less sensitive than the GWP to the time-horizon considered, and so are less dependent on a methodological choice involving a value judgement.

Some caveats should be noted :

- This effect is scenario dependent, as is the AGWP for CO_2. Both figures will be lower for higher scenarios, as each additional ppm of CO_2 has less effect on the radiative forcing due to saturation of the absorption band (which outweighs the other effect of increased CO_2 lifetime due to higher temperature and sink saturation in higher scenarios). For comparison the 100-year AGWP for CO_2 calculated with JCM for the A1B scenario is 18% lower, and the equivalent figure for the aviation cirrus and contrails is 15% lower.
- This extra effect should only be included in a GWP calculation if similar climate-carbon feedbacks are also taken account in the AGWP for CO_2. We presume that this was the case for the AR4 AWGP for CO_2 calculated using the Bern2.5CC(2001) model which incorporates the LPJ dynamic vegetation model.
- These calculations are calculated using a simple global upwelling-diffusion energy-balance model, in which the climate-carbon feedbacks (both land and ocean) are based only on the global average temperature. In reality these feedback effects apply regionally, and so it might be expected that the effect of the aviation forcing would be even greater because aviation is concentrated over land at northern mid-latitudes, the same zonal band as the majority of global soil carbon stock, and also because the direct effect of aviation cirrus on sunlight and hence photosynthesis might also reduce the carbon uptake of plants. On the other hand, this calculation does not include any "efficacy" factor (which would reduce the effective global forcing of aviation cirrus).
- The magnitude of climate-carbon feedbacks is highly uncertain, as indicated by the range of C4MIP results in AR4 WG1 Table 7.4. Later work will explore the effect of using the full range of results from C4MIP to tune the carbon cycle parameters - (this is anticipated to affect the result for C-C feedback AGWP by >100%).
- Climate-carbon feedbacks in JCM are calculated using the global average temperature from the previous year, consequently the effect of the short-term time-profile of the temperature peak due to the pulse of forcing is not properly taken into account. Later work may explore the effect of reducing the timestep of this part of the model.

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