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Climate trade-off between black carbon and carbon dioxide emissions

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Abstract

There are various difficulties involved with comparing the effects of short-lived and long-lived atmospheric species on climate. Global warming potentials (GWPs) can be computed for pulse emissions of short-lived species. However, if the focus is on the long-term effect of a pulse emission occurring today, GWPs do not factor in the fact that if a radiative forcing is applied for a short period, the climate system has time to relax back to equilibrium. The concept of global temperature change potential (GTP) at a time horizon for an emission pulse has been proposed to circumvent this problem. Here we show how GTPs can be used to compare black carbon (BC) and CO_2 emissions and the methodology is illustrated with two concrete examples. In particular we discuss a trade-off situation where a decrease in BC emissions is associated with a fuel penalty and therefore an additional CO_2 emission. A parameter—which depends on the BC radiative effects, the BC emission reduction and the additional CO_2 emission—is defined and can be compared to a critical parameter to assess whether or not the BC emission reduction wins over the fuel penalty for various time horizons. We show how this concept can be generalised to compare the climate effects of carbon dioxide against a set of short-lived species and to account for differences in climate efficacy. Finally, the need for additional research is discussed in the light of current uncertainties.

Keywords: Climate metric; GWP; GTP

1. Introduction

There is a pressing need for devising a metric that allows comparing the climate effects of short- and long-lived atmospheric chemical species. Such a metric would allow one to develop more efficient climate mitigation policies as well as to achieve better trade-offs between air quality and climate policies. For instance, Hansen et al. (2000) proposed that in order to reduce the risk of dangerous climate change the emphasis on emission reduction could be put on methane, black carbon (BC) and ozone precursors over the next 50 years, although they too argue that a reduction in CO_2 emissions is also needed. Streets and Aunan (2005) highlight the potential of BC emission reduction in the household sector in China. Although they raise the possibility of including BC emission reduction as a post-Kyoto option for China and other developing countries, they do not propose any climate metric or framework to deal with BC emission reduction in a post-Kyoto protocol. Jacobson (2002, 2005) suggested that, despite their lower fuel efficiency, gasoline cars were better for climate than BC-emitting diesel cars. However, Jacobson's analysis relied on radiative forcing (RF) and climate equilibrium calculations, which is artificial and possibly misleading because any policy or technology will only be implemented for a finite period of time.

Global warming potentials (GWPs) have been introduced to compare the cumulative radiative efficiency of different long-lived greenhouse gases over a time horizon (see Section 2.1 for a definition). GWPs are used to weigh the emissions of different long-lived greenhouse gases and a basket of them can be traded against each other under the Kyoto protocol. Although GWPs can technically be defined for short-lived species as well, their usage is not well established and there is little literature on GWPs for short-lived species. Recently Bond and Sun (2005) estimated that, despite its very short lifetime as compared with CO_2, the 100-year GWP for BC is 680. Bond and Sun

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suggested that there would be a climate benefit to cut BC emissions for a range of super-emitters even with a fuel penalty of 10%. Forster et al. (2007b) estimated a direct GWP for BC of 510 in reasonable agreement with Bond and Sun (2005). Reddy and Boucher (2007) further investigated how the direct GWP for BC depends on the region of emission. They found that the 100-year GWP for BC ranges from 374 for BC emitted in Europe to 677 for BC emitted in Africa. The regional differences in BC GWP mainly reflect differences in the BC atmospheric lifetime, which themselves are mostly due to differences in the regional efficacy of wet deposition. Reddy and Boucher (2007) also pointed out that the snow-albedo effect of BC is associated with an indirect GWP that would present even larger regional differences. In particular, it was argued that the total (direct and indirect) GWP for European BC could be as large as 1600 for a time horizon of 100 years. This argues for BC emission reduction as part of a portfolio of climate mitigation policies. However, it should be kept in mind that (i) the RF and GWP by BC are still fairly uncertain and therefore climate policies should rely on a conservative estimate if a trade-off with CO_2 is involved and (ii) GWPs do not factor in the fact that a RF concentrated at the beginning of a time period is less effective in inducing climate change at the end of the time period as compared with a RF that decays more slowly over time such as that of a CO_2 pulse (see e.g. Fig. 1 in O'Neill (2000)). Rypdal et al. (2004) also acknowledged that GWPs are not well suited for short-lived species and suggested that, because of the regional nature of the forcings, aerosol emissions could be best regulated as part of regional climate agreements linked to a global climate agreement. There are also co-benefits to further regulate aerosols and other short-lived species because of their impact on air quality, human health and ecosystems.

Given the recent progress in modelling the climate effects of BC and other short-lived species and the growing political interest to regulate these species, it is timely to assess how to compare emissions of CO_2 and BC. It is the purpose of this paper to do so using the framework of the global temperature change potential (GTP) climate metric

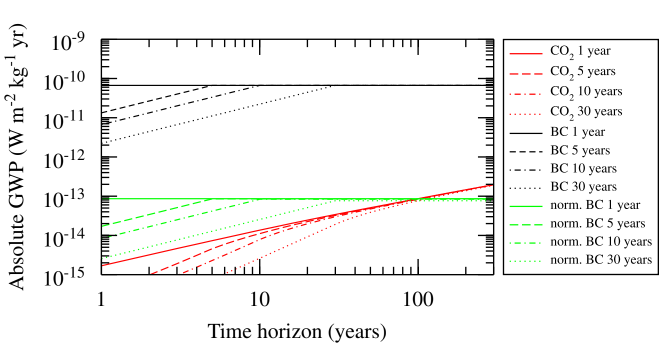

Fig. 1. Absolute generalised GWP (in $W\,m^{-2}\,kg^{-1}$ year) for CO_2, BC and normalised BC as a function of the time horizon. By definition, the normalised BC absolute GWP is equal to that of CO_2 for a time horizon of 100 years.

introduced by Shine et al. (2005, 2007). Section 2 summarises and discusses the concepts of GWP and GTP. We then illustrate in Section 3 how the concept can be applied to concrete policy-relevant issues. Section 4 shows how the methodology developed in Section 3 can be generalised to account for several short-lives species and different climate efficacies.

2. Climate metrics

2.1. Global warming potentials

The absolute GWP is defined as the integral of the radiative forcing caused by the pulse emission of 1 kg of a chemical species over a time horizon *T*, which results in a unit of $W\,m^{-2}\,kg^{-1}$ year. It depends both on the atmospheric decay time and on the radiative efficiency of the chemical species. Instead of a pulse emission, we define our GWPs for emission sustained during a period of 1, 5, 10 or 30 years. In any case, the total emission is kept the same and equals 1 kg as for the usual definition of GWP. Different policy questions involve different emission periods. For instance, a sustained emission period of a year should be used to assess the benefit of subsidising the phasing out of old cars that would have been withdrawn from the fleet in a short time anyway. A sustained emission period of 5 years would correspond to the lifetime of a diesel trap that would be retrofitted on an old vehicle. A sustained emission period of 10 years corresponds to the lifetime of a new vehicle and would be used to assess the relative benefits of different engine technologies. Finally, a sustained emission period of 30 years would be used for infrastructure with a longer lifetime, such as an aeroplane. We briefly discuss below the impact of considering variable emission periods instead of a pulse emission.

Rather than focusing on a particular time horizon, we first estimate and show in Fig. 1 the absolute GWP for both CO_2 and BC as a function of the time horizon *T*. The calculation of the absolute GWP for CO_2 is described in Appendix A. The absolute GWP for CO_2 shows a steep increase over the first 50 years followed by a less steep increase. The effects of lengthening the emission period are limited to the first 20–50 years and become negligible after 100 years. The absolute GWP for BC increases linearly during the emission period and is then constant as the residence time of BC in the atmosphere is very short. The absolute GWP for a 1-year sustained emission of CO_2 and for a 100-year time horizon comes out at $8.6\times10^{-14}\,W\,m^{-2}\,kg^{-1}$ year, in close agreement with more detailed studies for a pulse emission. The absolute GWP for BC has been somewhat arbitrarily set at $6.6\times10^{-11}\,W\,m^{-2}\,kg^{-1}$ year—which corresponds to a present-day RF of $+0.4\,W\,m^{-2}$ for a global emission rate of $6\times10^{9}\,kg\,year^{-1}$ or a 100-year GWP of about 770. Fig. 1 also shows the absolute GWP of a hypothetical very short-lived species that has the 100-year absolute GWP of CO_2. This clearly shows that different species with the same