

# HOW SIGNIFICANT ARE METHANE AND SULPHATE AEROSOLS AS ANTHROPOGENIC CLIMATE FORCING COMPONENTS?

Roger W. Bodman and David J. Karoly  
School of Earth Sciences, University of Melbourne  
VIC 3010, Australia

## 1. INTRODUCTION

A simple climate model, (MAGICC, Raper *et al.* (1996), Wigley and Raper (2001), Wigley (2008)) is used to investigate the range of future global temperatures that are likely to result from changes in selected anthropogenic forcing components. Here, we consider the concept of 'climate commitment', the role of aerosols and the significance of methane for global mean temperature change over the 21<sup>st</sup> century.

## 2. CLIMATE COMMITMENT

'Climate commitment' considers the inevitable climate changes that are likely to result from past and future changes to the atmosphere due to human activity up to the present. The aim is to convey a measure of what we have already set in train and point out that further global warming will result even if we could halt what we are doing now. Past greenhouse gas (GHG) emissions will lead to an increase in the global mean surface temperature even if it were possible to stop further emissions.

Climate commitment can be looked at in a number of different ways, with a range of authors having used various definitions. Wetherald *et al.* (2001) discuss 'warming commitment' as the difference between realised warming at a specific time and equilibrium warming for a given GHG concentration. Hare and Meinshausen (2006) discuss four forms of 'commitment':

1. Constant emissions commitment. This is the warming that would result from maintaining present emissions. At current levels, this would lead to increasing GHG concentrations and hence further warming.
2. A constant forcing commitment, or constant-composition commitment, with fixed GHG and aerosol concentrations. The warming commitment is due to the slow adjustment of the climate system to changes in radiative forcing.
3. Abrupt cessation of emissions, or 'geophysical commitment'. The resulting temperatures are a function of the biogeophysical aspects of the climate system adjusting to the GHGs and aerosols in the atmosphere and uptake of GHGs into the biosphere and the ocean.

4. Feasible emissions scenario commitment, where warming is determined from a plausible emissions profile taking into account current trends and feasible technological, economic and political change.

Wigley (2005) has examined constant-composition commitments and constant-emissions commitments. Teng *et al.* (2006) noted that there is a commitment to additional warming and sea-level rise even if atmospheric GHG and aerosol concentrations could be stabilised right now. Stabilising GHG and aerosol concentrations at 2000 levels, their results show the globally averaged temperature from an average of 16 AOGCM models increased by nearly 0.5°C ±0.2°C in the late 21<sup>st</sup> century. Meehl *et al.* (2006) included consideration of climate commitment in their study, with GHGs and aerosols fixed at year 2000 levels. A number of model experiments were run with the CCSM3 coupled climate model. Their results indicated a 0.4°C committed warming for the constant composition case, additional to a 0.6°C rise over the 20<sup>th</sup> century.

The most recent IPCC report discusses many of these related issues in Chapter 7 of WGI, including the work of Brasseur and Roeckner (2005) in Figure 7.24 (IPCC (2007)) which considers the hypothetical removal of anthropogenic sulphate aerosol particles. Their results suggest this would result in an immediate increase in the global average temperature of about 0.8°C and precipitation by 3%. This climate commitment case corresponds to constant GHG concentrations but no aerosols, related to the long atmospheric lifetimes of GHGs (decades to centuries), whereas aerosols have very short lifetimes (a few days only).

A recent paper by Ramanathan and Feng (2008) notes that the 2005 GHG concentration of about 455ppm CO<sub>2</sub>-e corresponds to an estimated equilibrium temperature of 2.4°C (1.4 - 4.3°C), which is into the range of 'dangerous anthropogenic interference with the climate system'. The planet has not yet experienced this increase because it is masked by the cooling effect of aerosols and the delay in ocean heat transfer, i.e., the equilibrium temperature will not be reached until some time in the future. Ocean expansion, and hence sea-level rise, will continue for many years to come. This concept of thermal inertia, discussed, for example, by Hansen *et al.* (2005), presents a difficult challenge, since waiting for further evidence of anthropogenic climate change is likely to result in greater climate change, compounded by continuing delays in effective mitigation and the increasing risk of 'tipping points'

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\* Corresponding author address: Roger Bodman, School of Earth Sciences, University of Melbourne, Carlton 3010; e-mail [rwodman@unimelb.edu.au](mailto:rwodman@unimelb.edu.au)

occurring, such as rapid permafrost melting and the collapse of major ice sheets. Indeed, as Matthews and Caldeira (2008) state, in order to stabilise temperatures, near zero future carbon emissions will be required.

There are two important competing effects in radiative forcing components; positive radiative forcing from long-lived greenhouse gases and negative radiative forcing from aerosols, that is, aerosols have a net opposite effect to that of the long-lived greenhouse gases since they reduce the amount of warming. Their offsetting radiative forcing is comparable in magnitude to the combined positive forcing of methane, nitrous oxide and halocarbons.

This study considers the amount of committed warming these aerosols are ameliorating and some potential implications for future global temperatures if these aerosols were reduced as part of efforts to decrease air pollution and fossil fuel emissions. Most anthropogenic aerosol emissions are associated with industrial activity and carbon dioxide emissions associated with burning fossil fuels. Therefore, as we reduce CO<sub>2</sub> emissions, this balancing effect will be lost as aerosol emissions are reduced as well. Furthermore, since aerosols are short-lived (of the order of a week), their masking effect is lost very quickly when their emissions are reduced.

Although aerosols play this important role in the atmosphere, aerosol forcing is one of the larger sources of uncertainty in climate modelling. They have both negative and positive radiative forcing effects. For example, black carbon on snow reduces ice albedo and increases warming, but particles in the atmosphere cause scattering of shortwave radiation and hence reduce warming.

The IPCC categorises aerosols into direct and indirect effects (IPCC (2007) p153). The direct effect results from the scattering and absorption of shortwave and longwave radiation. The indirect effect is the result of changes in the microphysical properties of clouds that affect their radiative properties, amount and lifetime.

The indirect effect has two main aspects, referred to as the 'first indirect effect' and the 'second indirect effect', or 'cloud albedo effect' and 'cloud lifetime effect' respectively. The cloud albedo effect is the change in cloud droplet size, while the cloud lifetime effect is the change in liquid water content, cloud height and cloud lifetime. The cloud albedo effect is included in radiative forcing (RF) modelling calculations, whereas the cloud lifetime effect is not considered as an RF, and instead regarded to be part of the hydrological cycle.

The total direct aerosol RF is estimated to be -0.5 [ $\pm$ 0.4] Wm<sup>-2</sup>, which results from the reflection of incoming radiation caused by aerosol particles in

the atmosphere. The cloud albedo effect is estimated at -0.7 [-1.1, +0.4] Wm<sup>-2</sup> (IPCC (2007) p131). This combined amount, -1.2 Wm<sup>-2</sup>, is similar to the combined positive radiative forcing of CH<sub>4</sub>, N<sub>2</sub>O and halocarbons of 1.17 Wm<sup>-2</sup>, and not all that far behind CO<sub>2</sub> at 1.66 Wm<sup>-2</sup>.

### 3. A STUDY WITH MAGICC

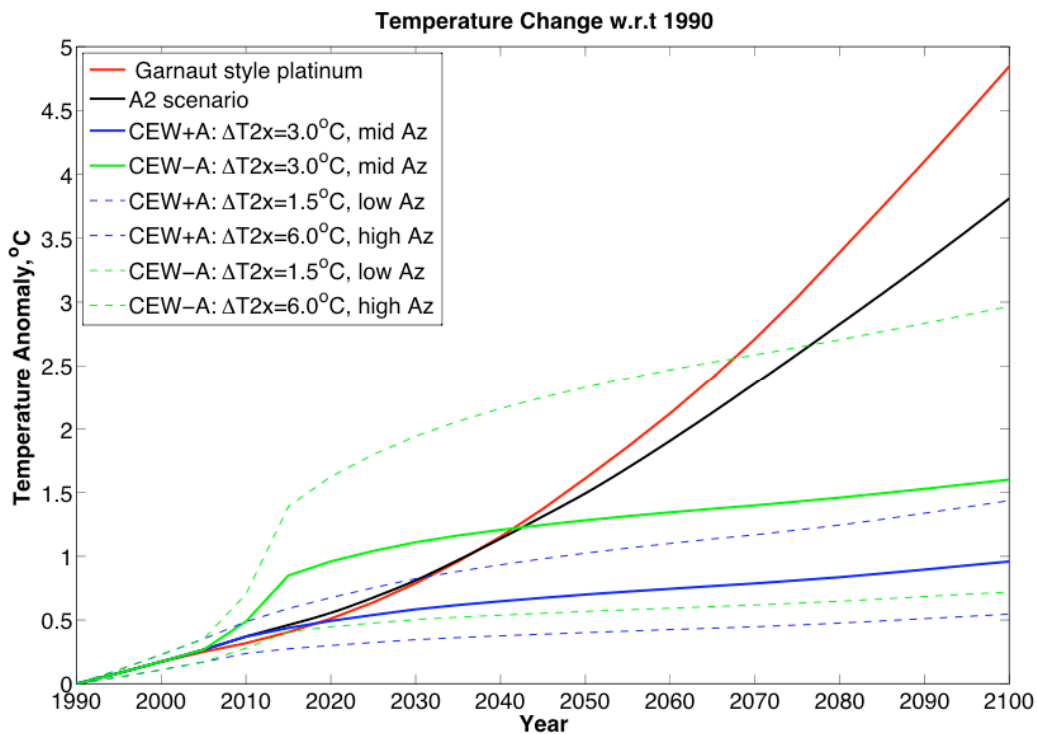
Climate commitment lends itself to investigation with a simplified climate model such as MAGICC. In this study, we investigate the effect of setting constant greenhouse concentrations in 2010 and running the model to 2100, using the SRES A2 emissions scenario to provide a realistic emissions estimate from 2000 to 2010, taking into account the model's climate sensitivity parameter and the range of sulphate aerosols as the key sources of uncertainty. In addition to using the IPCC's best estimates of climate sensitivity of 3°C and negative aerosol radiative forcing of -1.2 Wm<sup>-2</sup>, MAGICC's reproduction of the historical temperature record can be constrained by considering a lower bound with low climate sensitivity and low aerosol forcing and an upper bound with high climate sensitivity and high aerosol forcing, as discussed by Meinshausen (2006).

The results are illustrated in Figure 1. For the constant greenhouse gas concentrations case with continued aerosol forcing (blue lines, CEW+A), the temperature rise in 2100 is 1.0°C with respect to 1990, with a range of 0.5°C to 1.4°C. Then, removing the anthropogenic aerosols results in a 1.6°C temperature rise, with a range of 0.7°C to 3.0°C (green lines, CEW-A). Hence, removing the anthropogenic aerosols makes a difference of 0.6°C (0.2 to 1.6°C) for the mid-range case.

Relative to pre-industrial times, the warming commitment in 2010 for the best estimate of climate sensitivity and sulphate aerosol forcing is 2.2°C by 2100 (1.3 to 3.6°C) and almost 2.6°C by 2500 (determined from a mid-range run not shown here), based on an existing warming of 0.6°C up to 1990.

From this, the amount of committed warming in 2010 will, with greater than 50% probability, exceed the 2°C threshold for dangerous climate change identified by the European Union.

For reference, the mid-range results for the SRES A2 scenario and a 'Garnaut style platinum age' scenario, based on Garnaut *et al.* (2008), are included for comparison. These are indicative of the current warming trajectory, and point towards future warming commitments well in excess of any acceptable temperature limit.



**Figure 1:** MAGICC climate commitment and reference scenario temperature results. Solid lines are based on the best estimate for climate sensitivity and aerosol forcing.

Red line: Garnaut style platinum temperatures, based on Garnaut *et al.* (2008).

Black line: SRES A2 temperatures.

Blue lines: CEW+A: Constant concentrations, fixed aerosols with upper and lower bounds determined from high climate sensitivity and high aerosol forcing to low climate sensitivity and low aerosol forcing.

Green lines: CEW-A: Constant concentrations, zero anthropogenic aerosols with upper and lower bounds.

#### 4. METHANE

Methane is one of the anthropogenic greenhouse gases of current interest since some people, such as Brooks and Russell (2007), have argued that, due to its higher Global Warming Potential (GWP), more emphasis should be placed on reducing methane emissions as this would be more effective in avoiding climate change in the short term compared to reductions in carbon dioxide emissions.

The GWP is used to convert different greenhouse gas emissions into a single measure, carbon dioxide equivalent (CO<sub>2</sub>-e) emissions. It is a measure of the radiative forcing over a 100-year period due to the emission of a specific mass of a long-lived greenhouse gas, relative to that due to the emission of the same mass of CO<sub>2</sub>. It is a way of taking into account the different atmospheric lifetimes and the different radiative absorption properties of the different gases. This is the standard practice used for national greenhouse gas inventories under the auspices of the UNFCCC.

Methane is a significant contributor to warming, with a radiative forcing value 0.48 Wm<sup>-2</sup> compared to CO<sub>2</sub> at 1.66 Wm<sup>-2</sup> (IPCC (2007) p141).

Methane's concentration is 1,774 (±1.8) ppb or about 1.8 ppm compared to 379 (±0.7) ppm for CO<sub>2</sub>, that is, CH<sub>4</sub> concentration is approximately 0.5% that of CO<sub>2</sub>. Although this is a small amount, it has a substantial warming effect. This is reflected in methane's 100-year GWP of 25 (IPCC, 2007) although the 20-year GWP is 72. It could be argued that it is this latter number that is more relevant in considering the benefit arising from short-term methane reductions. In looking at reducing CO<sub>2</sub> equivalent emissions, can a significant reduction of global mean warming be gained by making more effort to reduce CH<sub>4</sub> emissions in the short term than in reducing CO<sub>2</sub> emissions?

There are limitations in using GWPs for this type of analysis. These measures have a place when used for accounting purposes in national GHG inventories, but are less useful for projecting future warming.

- GWPs are used as a measure of CO<sub>2</sub>-equivalent *emissions*, not CO<sub>2</sub>-equivalent *concentrations*. It is the atmospheric greenhouse gas concentrations that determine the amount of radiative forcing

and the resulting global mean temperature change.

- Using the 100- or 20-year GWP, or any other time frame, is a matter of choice. Since methane is emitted continually, what basis is there for choosing the higher GWP? Shouldn't the 20-year GWPs be used for all the gases to consider transient warming influences?

Instead, a simple climate model such as MAGICC provides a means of testing the effect of changing methane emissions within an emissions scenario.

Two approaches have been investigated here:

1) Modelling the SRES A1FI emissions scenario with 50% and 100% methane emission reduction to determine what difference this makes to the temperature projections.

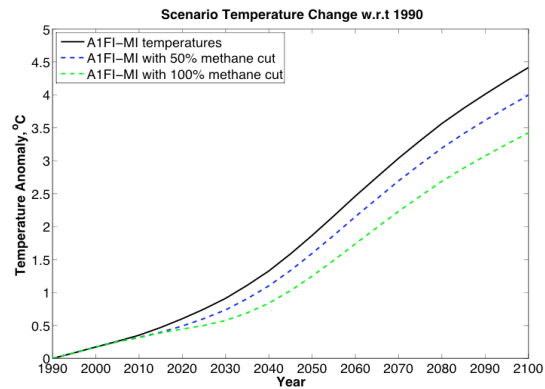
2) For a CO<sub>2</sub> equivalent stabilisation scenario such as a 450ppm or 550ppm CO<sub>2</sub>-e scenario, what is the temperature difference for a given CH<sub>4</sub> reduction while maintaining the overall CO<sub>2</sub> equivalent amount? That is, if we could change the mix of gases within a given 'stabilisation budget', is there an appreciable benefit to be gained from reducing methane in the short term? This allows some room for CO<sub>2</sub> to increase, but, with methane's higher GWP, a reduction in temperature would be expected.

#### 4.1. Reduce Methane in A1FI

The results for significant reductions in methane emissions from 2010 for the A1FI scenario, keeping the other components unchanged, are shown in Figure 2. This is with MAGICC's default parameter settings including climate sensitivity at 3°C (the IPCC AR4 best estimate).

By 2100, the (mid-range) temperature projection is 4.4°C, which drops to 4.0°C if anthropogenic methane emissions were cut by 50% after 2010, or to 3.4°C with a 100% cut. The mid-century figure of 1.9°C drops to 1.6°C and 1.3°C respectively. Note that these numbers are relative to 1990.

Significant cuts in methane would make an important contribution to reducing the projected increase in average global temperatures. Whether cuts of such magnitude are feasible is another question, and clearly methane cuts alone are not sufficient to avoid a rise above 2°C.

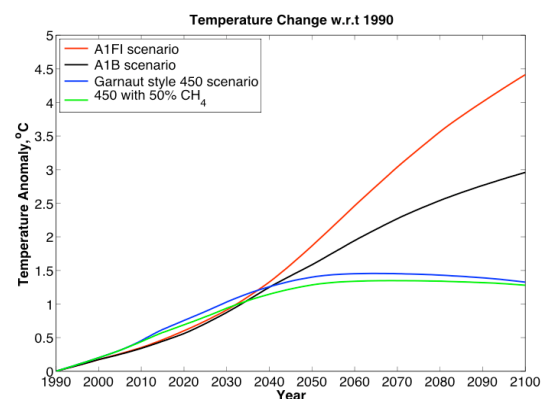


**Figure 2:** The effect on global average temperatures from significant methane cuts.

#### 4.2. Reduce Methane within a stabilisation budget

Here we consider a Garnaut style 450ppm CO<sub>2</sub>-e scenario (a scenario close to one used in the Garnaut Climate Change Review (2008)) and investigate the temperature difference for a 50% CH<sub>4</sub> reduction while maintaining the overall CO<sub>2</sub> equivalent concentration profile. That is, for a given 'stabilisation budget', if we could change the mix of gases, is there an appreciable benefit in reducing methane? This allows for a CO<sub>2</sub> increase, but, with methane's higher GWP, a near-term reduction in temperature would be expected. The results are shown in Figure 3.

The maximum warming reduction is 0.1°C during mid-century, before tapering back to the 2100 stabilisation temperature (not the equilibrium temperature). The 450ppm case reaches its maximum temperature of 1.5°C in 2064, at which time the 50% methane cut saves 0.1°C, only 7%.



**Figure 3:** Temperatures for a Garnaut style 450ppm CO<sub>2</sub>-e stabilisation scenario (blue line) compared to a 50% reduced CH<sub>4</sub> scenario (green line). Two SRES scenarios are included for reference (red line A1FI, black line A1B).

## 5. CONCLUSIONS

Our investigation of committed warming finds that if atmospheric GHG concentrations could be fixed in 2010, the rapid removal of anthropogenic aerosols would lead to a global mean temperature rise of 2.2°C (1.3 to 3.6°C) above pre-industrial by the end of this century. Hence, due to greenhouse gases in the atmosphere in 2010, there is greater than 50% probability of exceeding the 2°C warming threshold for dangerous climate change.

This investigation proposes that, while decreasing methane emissions could contribute to avoiding further warming, significant reductions would be required to make a noticeable difference. A combined approach to all the long-lived greenhouse gases is going to be required to reduce future warming.

Within a 'stabilisation budget', such as a 450 ppm CO<sub>2</sub>-e stabilisation scenario, prioritising methane emissions reductions over carbon dioxide results in only a small reduction in global warming, perhaps disproportionate to the effort that would be required to achieve a 50% or greater cut in methane emissions.

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