# EMISSIONS TARGETS FOR $CO_2$ STABILIZATION AS MODIFIED BY CARBON CYCLE FEEDBACKS

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## ABSTRACT

This study examines the potential for feedbacks between the carbon cycle, atmospheric carbon dioxide ($CO_2$) increases and climate change to affect the anthropogenic emissions that are required to stabilize future levels of $CO_2$ in the atmosphere. Using a coupled climate-carbon cycle model, I found that positive carbon cycle-climate feedbacks reduced allowable emissions by an amount that varied with the model's climate sensitivity. Emissions were further reduced if $CO_2$ fertilization was assumed to be inactive in the model, as this removed an otherwise important negative feedback on atmospheric $CO_2$.

## INTRODUCTION

The global carbon cycle has a direct effect on levels of atmospheric carbon dioxide. Under current climate changes due to increasing $CO_2$, changes in the carbon cycle can either increase (positive feedback) or decrease (negative feedback) the rate of $CO_2$ accumulation in the atmosphere. Positive carbon cycle-climate feedbacks result from decreased terrestrial and oceanic carbon uptake due to the negative impact of climate change on carbon sinks. With respect to the terrestrial carbon cycle, the stimulation of vegetation productivity by increased $CO_2$ ($CO_2$ fertilization) creates the potential for a negative feedback between terrestrial carbon uptake and atmospheric $CO_2$. Several recent modeling studies have demonstrated the potential for carbon cycle feedbacks to affect levels of atmospheric $CO_2$ substantially over the next century [e.g. *Cox et al.*, 2000; *Thompson et al.*, 2004; *Matthews et al.*, 2005].

Stabilization of atmospheric $CO_2$ is a key target set out in the United Nations Framework Convention on Climate Change [*United Nations*, 1992]. A number of future $CO_2$ concentration profiles have been developed that lead to stabilization at various levels over the next several centuries [e.g. *Wigley et al.*, 1996]. It is known that changes in the carbon cycle will have a direct impact on the emissions required to meet a given stabilisation target [*Prentice et al.*, 2001]. In this study, I used a coupled climate-carbon cycle model to quantify the potential influence of carbon cycle feedbacks on anthropogenic emissions that are consistent with $CO_2$ stabilization.

## MODELS AND METHODS

The model used is the University of Victoria Earth System Climate Model version 2.7, comprised of an intermediate complexity physical climate model [*Weaver et al.*, 2001] coupled to models of the terrestrial and oceanic carbon cycle [*Matthews et al.*, 2005]. The model was forced by a $CO_2$ increase from pre-industrial levels to stabilization at 550 ppmv at the year 2150; changes in terrestrial and oceanic carbon uptake were simulated in response to changing atmospheric $CO_2$ and climate. Emissions were calculated as the sum of prescribed $CO_2$ increases and modeled changes in terrestrial and oceanic carbon sinks.

## RESULTS

I found that positive carbon cycle-climate feedbacks reduced peak emissions by 2.3 GtC/yr (gigatonnes of carbon per year) using the standard model configuration, compared to a run where climate changes did not affect the carbon cycle (Figure 1). Climate sensitivity (the amount that a model warms in response to $CO_2$ increases) has been shown to affect the strength of positive carbon cycle-climate feedbacks [*Friedlingstein et al.*, 2003], and as such would be expected to have an important influence on emissions consistent with $CO_2$ stabilization. In two additional runs with climate sensitivities corresponding to 2.6 and 5.4 °C (where the standard model's climate sensitivity was 4.2 °C), peak emissions were reduced by

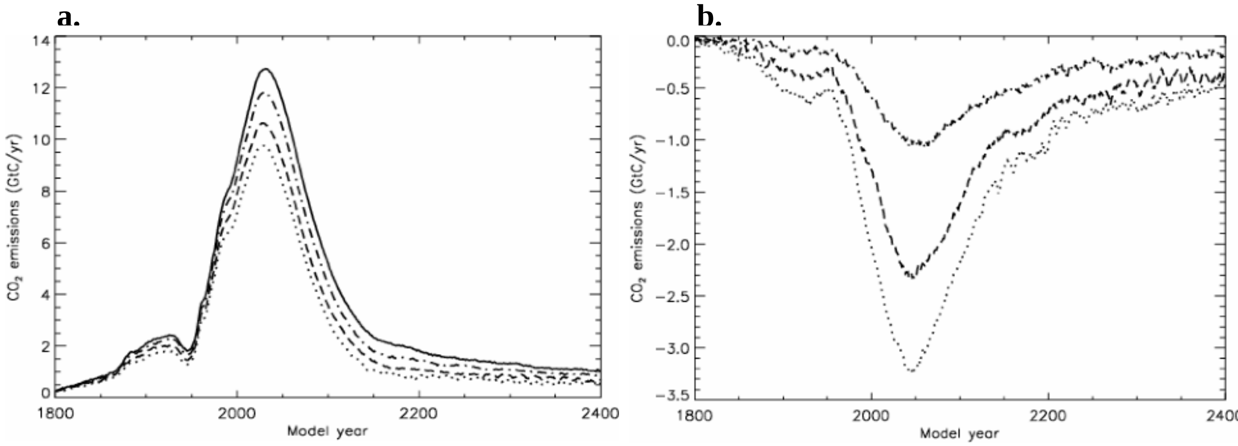


Fig. 1. a. *Calculated emissions consistent with $CO_2$ stabilization at 550 ppmv for the standard model (dashed line, climate sensitivity = 4.2 °C), and two additional model runs with climate sensitivities corresponding to 2.6 °C (dot-dashed line) and 5.4 °C (dotted line). The solid line represents the case where climate changes did not affect the carbon cycle.* **b.** *The effect of positive carbon cycle-climate feedbacks on emissions, shown as differences between model runs with climate sensitivities of 2.6 (dot-dashed), 4.2 (dashed) and 5.4 (dotted) °C, and the run with no climate changes (solid line in a.).*

1.0 and 3.2 GtC/yr respectively. Peak emissions were further reduced in all cases (by more than 4 GtC/yr – not shown) if $CO_2$ fertilization was assumed to not affect the strength of the terrestrial carbon sink throughout the model simulation.

## CONCLUSIONS

This research represents a preliminary assessment of the effect of some key uncertainties in the carbon cycle on emissions targets for $CO_2$ stabilization. Both climate sensitivity and $CO_2$ fertilization were found to have a substantial effect on calculated emissions. This conclusion highlights the critical role of the carbon cycle in affecting emissions targets for the stabilization of future levels of atmospheric $CO_2$, and emphasizes the importance of improving our knowledge of the interactions between climate and the global carbon cycle in the context of present and future anthropogenic climate change.

## REFERENCES:

Cox, P. M., R. A. Betts, C. D. Jones, S. A. Spall, and I. J. Totterdell (2000), Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model, *Nature*, *408*, 184–187.

Friedlingstein, P., J.-L. Dufresne, P. M. Cox, and P. Rayner (2003), How positive is the feedback between future climate change and the carbon cycle?, *Tellus, 55*B, 692–700.

Matthews, H. D., A. J. Weaver, and K. J. Meissner (2005), Terrestrial carbon cycle dynamics under recent and future climate change, *J. Climate*, *18*, 1609–1628.

Prentice, C., et al. (2001), The carbon cycle and atmospheric carbon dioxide, in Climate Change 2001: *The Scientific Basis*, edited by J. Houghton et al., pp. 183–237, Camb. Univ. Press.

Thompson, S. L., B. Govindasamy, A. Mirin, K. Caldeira, C. Delire, J. Milovich, M. Wickett, and D. Erickson (2004), Quantifying the effects of $CO_2$-fertilized vegetation on future global climate and carbon dynamics, *Geophys. Res. Lett.*, *31*, L23,211.

United Nations, Earth Summit Convention on Climate Change, United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 1992.

Weaver, A. J., et al. (2001), The UVic Earth System Climate Model: Model description, climatology and applications to past, present and future climates, *Atmos.-Ocean*, *39*, 361–428.

Wigley, T. M. L., R. Richels, and J. A. Edmonds (1996), Economic and environmental choices in the stabilization of atmospheric $CO_2$ concentrations, *Nature, 379*, 240–243.