IMPACT OF CLIMATE-CARBON CYCLE FEEDBACKS ON EMISSIONS SCENARIOS TO ACHIEVE STABILISATION

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ABSTRACT

At present, approximately half of anthropogenic CO_2 emissions are absorbed by the land and oceans [*Jones and Cox*, 2005], but climate changes may act to reduce this uptake, leading to higher CO_2 levels for a given emission scenario [*Cox et al*., 2000, *Friedlingstein et al*., 2005, in prep.]. Less attention has been paid to the potential impact of carbon cycle feedbacks on the emissions reductions required to achieve stabilisation (the so called “permissible emissions”), although this is arguably more pertinent to the issue of avoiding dangerous climate change in the context of the United Nations Framework Convention on Climate change.

Here we perform experiments with prescribed profiles of CO_2, and simulate the resulting climate and the atmosphere-land and atmosphere-ocean carbon fluxes. The “permissible emissions” are diagnosed as the difference between atmospheric CO_2 changes and these fluxes. Our results for the WRE550 CO_2 profile (stabilisation at 550ppm; *Wigley et al.,* 1996) show permissible emissions calculated with HadCM3LC which are much reduced compared to the previous estimates of *Wigley et al.* [1996] (Fig. 1).

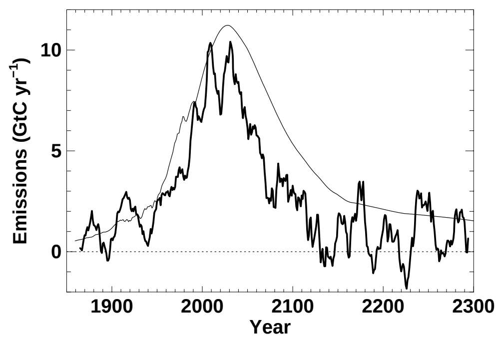

Fig. 1. Stabilisation emissions for WRE550 scenario. *Wigley et al.,* 1996 (thin line), HadCM3LC (thick line).

This reduction is driven by terrestrial carbon loss, as a result of reduced net primary productivity and increased soil respiration under climate change. Ocean carbon storage increases steadily, although at a decreasing rate as climate change also acts to reduce the rate of ocean uptake through stratification of surface waters and reduced overturning circulation.

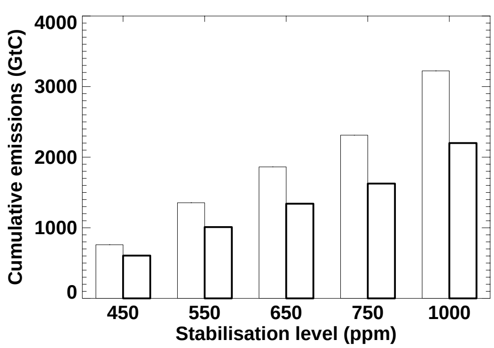

Fig. 2. Cumulative emissions totals from 2000 to 2300 for the 5 WRE stabilisation scenarios. *Wigley et al.,* 1996 (thin line), HadCM3LC (thick line).

We extend the GCM results by using a simple model, calibrated to reproduce the HadCM3LC GCM (see, e.g. Jones et al., 2003). Simple model simulations are performed for the other WRE stabilisation profiles (fig. 2). Each scenario already requires an eventual decrease in anthropogenic emissions below present day levels in order to stabilise CO_2 levels, but the impact of climate-carbon cycle feedbacks is to reduce the permissible emissions further still. For each scenario the peak emissions, the level of emissions by 2300, and the total emissions over the period are all reduced. The higher the stabilisation level, the greater the climate change and so the greater the reduction required in the total emissions compared with the case of no climate feedbacks.

We performed multiple simulations to examine the key uncertain parameters which determine the size of the carbon cycle feedback, namely: $C_{0.5}$, the half-saturation constant for the response of photosynthesis to CO_2; q_{10}, a soil respiration parameter governing the fractional increase in soil respiration rate for a 10^{o}C warming; $F_{NPP}(T)$, the response of Net Primary Productivity to climate approximated here as a quadratic function of temperature; and climate sensitivity, ΔT_{2x}, the equilibrium warming for a doubling of CO_2.

Varying each parameter individually gives a large spread of uncertainty in permissible emissions (Fig. 3), with $F_{NPP}(T)$ being the most important carbon cycle response. Varying climate sensitivity within the IPCC-TAR range of

1.5-4.5K, gives a spread of permissible emissions greater than that due to individual ecosystem parameters. The uncertainty is even larger and permissible emissions reduced still further, when values of climate sensitivity up to 10K are considered.

Such large sensitivities are unlikely but cannot be ruled out from observations [*Andreae et al*., 2005]. For high climate sensitivities, cumulative emissions over the next three centuries are negative, implying a requirement for net capture of CO_2 from the atmosphere. For all ecosystem parameters and climate sensitivities considered, the feedbacks result in much lower emissions than when carbon cycle feedbacks are neglected.

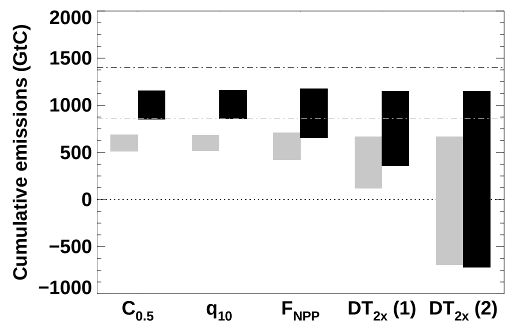

Fig. 3. Bounds on permissible emissions from 2000-2300 due to single parameter uncertainty. WRE450 (pale bars), WRE550 (black bars). ΔT_{2x} varied from 1.5-4.5K (1) and 1.5-10K (2). Dash-dot horizontal lines show the original estimates of *Wigley et al*. [1996].

The simulations exhibit significant spread of emissions *prior* to present day. Hence, observed emissions may be used to eliminate unrealistic parameter combinations. Varying multiple parameters, and using historical emissions to select the best combinations, we are able to reduce uncertainty bounds on estimates of future stabilisation emissions.

Permissible emissions consistent with this historical constraint show good agreement up to the present day, but significant spread in the future (Fig. 4). For climate sensitivity of 3.0K (black shading), the historical constraint has reduced the spread of permissible emissions. However, the historical record is not able to constrain climate sensitivity [*Andreae et al.,* 2005] and a large spread of permissible emissions remains for climate sensitivities from 1.5-4.5K (medium shading) and 1.5-10K (pale shading). Only climate sensitivities below 3.0K allow any emissions above the WRE level, and even then only for a short period. By 2050 all climate sensitivity values imply emissions substantially below those of WRE.

CONCLUSIONS

All realistic carbon cycle feedbacks consistent with the historical record imply permissible emissions for stabilisation which are much less than previously assumed. Nevertheless, large uncertainties in permissible emissions remain, with the largest contribution arising from the ongoing uncertainty in the climate sensitivity to CO_2. Refining our estimate of climate sensitivity is therefore more crucial than ever, as it not only determines the climate change for a given CO_2 level, but also, through carbon cycle feedbacks, determines the CO_2 emissions consistent with stabilisation at this level.

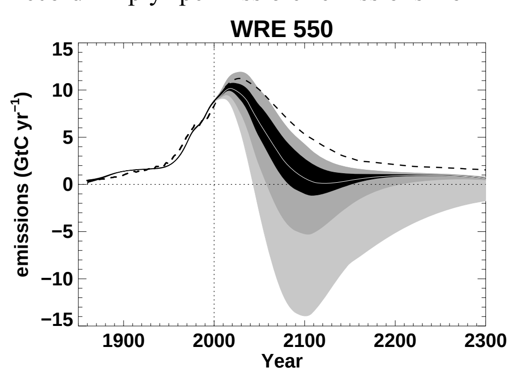

Fig. 4. Observationally constrained permissible emissions for WRE550. Simple model initial parameters (white line). Uncertainty for climate sensitivity=3K (black shading), from 1.5-4.5K (medium grey shading), from 1.5-10K (pale grey shading). The dashed lines show the emissions profiles from *Wigley et al* [1996].

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