Continued global warming after CO_2 emissions stoppage

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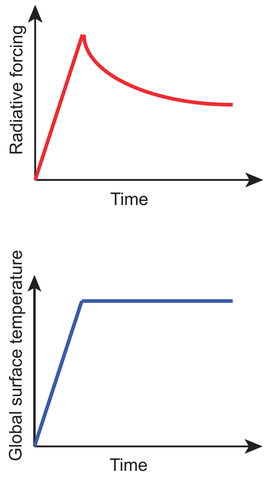
(1) Motivation

Recent studies have suggested that global mean surface temperature remains approximately constant on multi-century timescales after stopping carbon emissions. These studies suggest that the cooling effect of reduction in radiative forcing R due to the decrease in atmospheric CO_2 is roughly balanced by the warming effect of reduction in ocean heat uptake N, such that the difference R - N remains approximately constant. This effect is a consequence of the fact that: (i) the ocean heat and carbon uptake are both controlled in large part by the physical mixing of shallow oceanic waters into the deeper ocean; and (ii) under higher atmospheric CO_2, the reduction of the radiative forcing sensitivity to atmospheric CO_2 is roughly compensated by the higher airborne fraction of anthropogenic CO_2.



(2) Model & experiments

Two different Earth System Models:

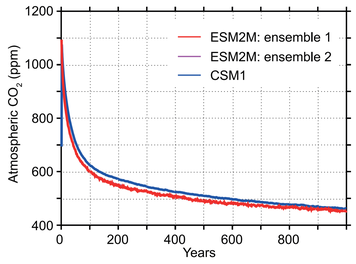
a) Geophysical Fluid Dynamics Laboratory Earth System Model (GFDL ESM2M)

b) National Centre for Atmospheric Research Climate System Model (NCAR CSM1)

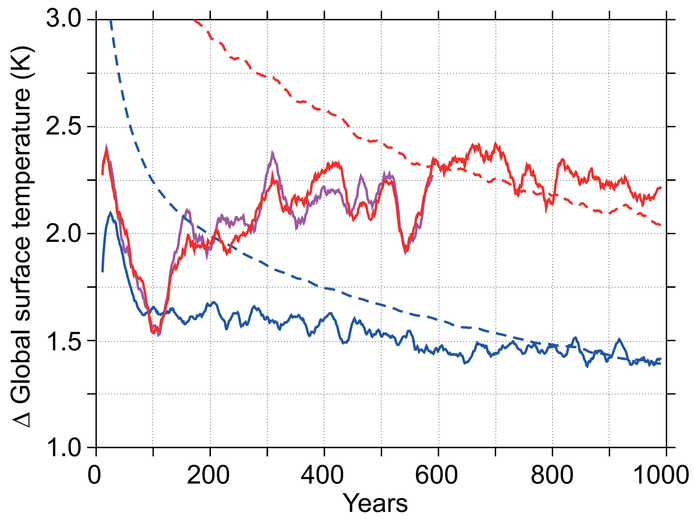
Both models include representations of the physical climate system as well as ocean and land biogeochemistry.

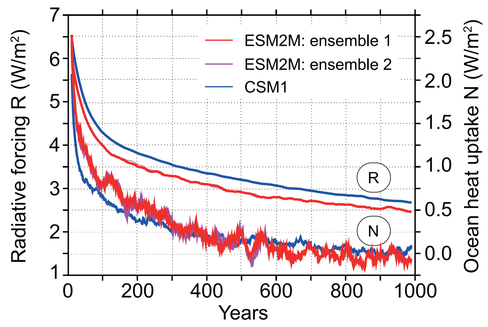
Experiments:

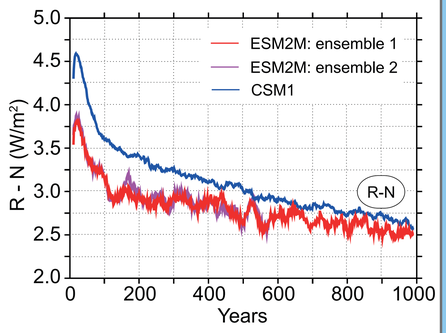
- 1800 Gt carbon pulse so that the atmospheric CO_2 concentration is instantaneously quadrupled from pre-industrial conditions. For comparison, 1000 Gt carbon is believed to lead to a global warming of 2°C.
- Non-CO_2 forcing agents are kept constant at preindustrial levels.
- 40% of initial atmospheric perturbation is removed after 20 years, 60% after 100 years, and 80% after 1000 years.



(3) Continued global warming after CO_2 emissions stoppage







$$\Delta T(t) = \frac{R(t) - \varepsilon N(t)}{\lambda}$$

ΔT: Global mean surface temperature change

R: Stratospheric-adjusted radiative forcing

λ: Equilibrium feedback factor (ESM2M = 1.19; CSM1 = 1.90)

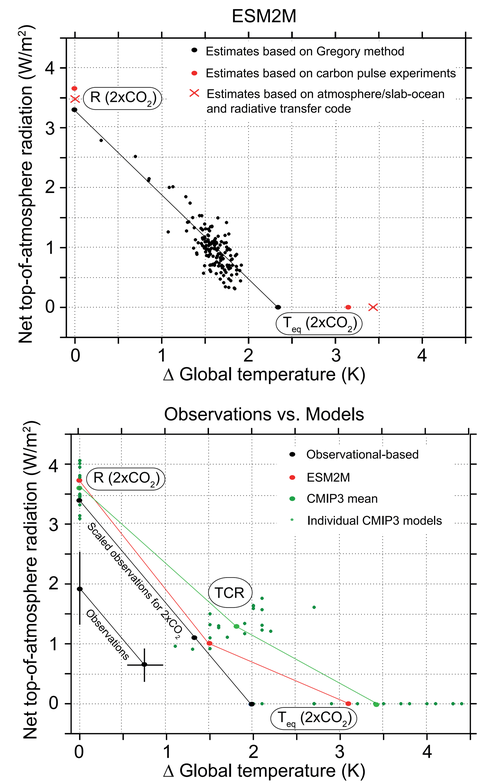
N: Net radiation flux at top-of-atmosphere (or ocean heat uptake)

ε: Ocean heat uptake efficacy (ESM2M = 1.9; CSM1 = 1.7)

Table 1 | Temperature change budget over the period of warming differences.

Model	$\Delta R/\lambda$ (radiative cooling effect)	$-\varepsilon\Delta N/\lambda$ (the ocean warming effect)	$\Delta R/\lambda - \varepsilon\Delta N/\lambda$ (estimated temp change)	ΔT (actual temp change)
ESM2M	−0.60	0.86	0.26	0.37
CSM1	−0.39	0.30	−0.09	−0.06
ESM2M–CSM1	−0.21	0.56	0.37	0.31

(4) Biased equilibrium climate sensitivity estimates



(5) Conclusions

1) Global mean surface temperature may increase on multi-century timescales after an initial century-long decrease. For example, global mean surface temperature may increase by 0.6°C after a carbon emissions stoppage at 2-degree.

2) The warming effect of decreasing ocean heat uptake together with feedback effects arising in response to the geographic structure of ocean heat uptake overcompensates the cooling effect of decreasing atmospheric CO_2.

3) The equilibrium climate sensitivity estimates based on the Gregory method are biased low, because the Gregory method does not adequately assess the approach to equilibrium along high-efficacy trajectories.

4) The total carbon emissions required to stay below 2°C global warming may be significantly lower than previously thought; about 750 GtC instead of 1000 GtC.

Ref Frölicher, TL, Winton, M, Sarmiento, JL, 2014, Continued global warming after CO_2 emissions stoppage, *Nature Climate Change*, 4, 40-44.