An Empirical Estimate of 20th Century Climate–to–Carbon Feedback, B25A-05

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Abstract

Climatic change has the potential to cause additional fluxes of carbon dioxide to the atmosphere, thereby giving a feedback that could amplify the anthropogenic greenhouse effect. Over the glacial-interglacial cycles, climate-to-carbon feedbacks have amplified the response of climate to the radiative changes from the 'Milanković forcing'. The recent IPCC assessment has identified climate-to-carbon feedbacks as one of the major aspects of uncertainty of climate change over the 21st century. With the availability of new CO_2 data from a high-resolution ice core, an empirical quantification of the climate-to-carbon feedback is possible, using the non-CO_2 warming over the early part of the 20th century. This suggests that approximately 10 ppm of the 20th century CO_2 increase was due to temperature increase.

1. IPCC Fourth Assessment

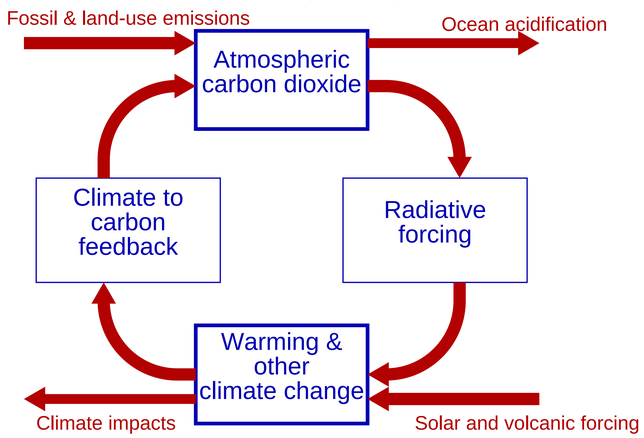
- Warming of the climate system is unequivocal.
- Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1950.
- Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.

2. IPCC caveats

- The magnitude of the positive feedback between climate change and the carbon cycle is uncertain. (AR4: TS.5.5).
- Dynamical processes not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. (AR4: TS.5.5).

3. Climate–to–carbon feedback

Increasing temperature may amplify atmospheric CO_2 (from [1]).



4. Are feedbacks implicitly included in climate models?

- Climate models are frequently calibrated with 20th Century data.
- To the extent that rising temperatures have resulted in changes in the carbon cycle, *if* a model reproduces data *without* explicitly including temperature feedbacks, then the feedbacks must be included implicitly.
- Model specific, and implicitly included through parameterisation of the carbon cycle.
- Not clear how this will extrapolate to the 21st Century (and beyond).

5. C^{4}MIP

- C^{4}MIP computer experiment: many coupled climate–carbon GCMS, forced with a standard IPCC scenario.
- Feedback amplification from 11 models range from 1.04 to 1.44, 20ppm to 200ppm.
- Estimate 1.18 ± 0.11. Uncertainty represents model spread - but how do we know which model is better?
- Large uncertainty, and possiblity that processes are missing despite ability to reconstruct 20th Century.

6. Data

- High quality global instrumental data for global mean temperature available from around 1880.
- CO_2 response to Pinatubo may tell us about feedback for timescales of years.
- 1940s dip in CO_2, temperature may give information about decadal time scale.
- Little ice age, for timescales of centuries (see Scheffer et al. [2]: negligible anthropogenic emissions, but large uncertainties due to temperature reconstructions).
- Glacial-interglacial data from Vostok ice core (difficult to quantify relevance for current climate).

Improved data from high resolution Law Dome ice cores provides an opportunity to obtain good estimates of the magnitude of climate–to–carbon feedback (see [3]).

7. Modelling

- Fit data using a statistical *black box* model, attempt to determine partitioning between effects of unperturbed carbon cycle and of temperature perturbed carbon cycle.
- Define C to be atmospheric concentration, T to be global mean temperature.
- Alternative models:

$$C = C_{\rm eqm} + \alpha \text{ Integrated emissions}$$

and

$$C = C_{\rm eqm} + \alpha \text{ Integrated emissions} + \frac{\partial C}{\partial T}\,(T - T_{\rm eqm})$$

- Assume linear feedback, with amplification factor:

$$\kappa_{\rm FB} = \frac{1}{1-\gamma}$$

where γ is the gain of the feedback loop, and

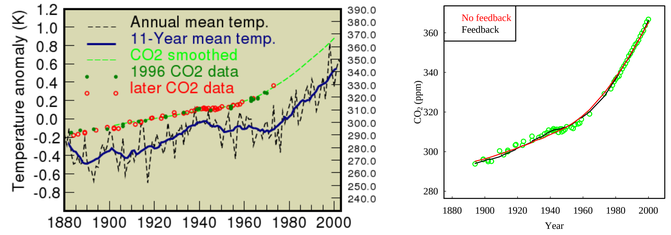
$$\gamma = \frac{\partial C}{\partial T}\frac{\partial T}{\partial C}.$$

We directly estimate $\partial C/\partial T$, while $\partial T/\partial C$ may be determined from the transient climate sensitivity.

- Couple CO_2 concentration with global mean temperature, averaged over 11 years (same as ice core data).
- Could include longer time scales with a (linear) response function formalism, but doesn't help.
- Largest uncertainty comes from land use emission time series.
- No information about the physical processes responsible.
- Validity relies on assumptions of linearity, and that changing global mean temperatures are the dominant perturbing effect on the carbon cycle.

8. 20th Century

Law Dome ice core and global temperature data (11-year smoothing of temperature matches smoothing of CO_2 in bubble trapping).



9. Results

- Including feedback allows for higher quality fits than if emissions only are used.
- Variability in estimates when different years are chosen for the start and end time, but not too much.
- $\partial C/\partial T = 13 \pm 3$ ppm/K, and thus carbon–to–climate feedback is responsible for about 10ppm of the 20th Century increase in atmospheric CO_2.
- Leads to $\gamma = 0.13$, and $\kappa_{\rm FB} = 1.15$; additional uncertainty due to transient climate sensitivity.
- These numbers measure the response of the carbon cycle to temperature perturbations on short time scales, of the order of decades.

References

[1] I.G. Enting, *Twisted: The Distorted Mathematics of Greenhouse Denial*, 2007.

[2] M. Scheffer, V. Brovkin and P.M. Cox, Positive feedback between global warming and atmospheric CO_2 concentration inferred from past climate change, *Geophys. Res. Lett.* **33**, L10702, 2006.

[3] C. MacFarling Meure et al., Law dome CO_2, CH_4 and N_2O ice core records extended to 2000 years BP, *Geophys. Res. Lett.* **33**, L14810, 2006.