Increase of uncertainty in transient climate response to cumulative carbon emissions after stabilization of atmospheric CO_2 concentration

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Abstract

- We analyzed a dataset from an experiment of a simplified earth system model (focus: on the change in TCRE* after atmospheric CO_2 concentration was stabilized in RCP 4.5. (*:transient climate response to cumulative carbon emissions)
- We estimated the TCRE in 2005 at 0.3–2.4 K/TtC for an unconstrained case and 1.1–1.7 K/TtC when constrained with historical and present-day observational data.
- The uncertainty of TCRE increased when the increase of CO_2 concentration was stabilized.
- We also found that variation of land carbon uptake is significant to the total allowable carbon emissions and subsequent change of the TCRE.
- In our experiment, we revealed that ECS** has a strong positive relationship with the TCRE at the beginning of the stabilization and its subsequent change. (**:equilibrium climate sensitivity)
- We confirmed that for CMIP5 models, ECS has a strong positive relationship with TCRE.

Table 1. Parameters perturbed in this study and the ranges considered (Tachiiri *et al.*, 2013)

Parameter	Component	Default	Perturbation range
Climate sensitivity	Atmosphere	4.7 [b]	1–6 K†
Vertical diffusivity	Ocean	0.1–3.0 cm^2/sec*	0.3–3.0 × default
Horizontal diffusivity	Ocean	1×10^7 cm^2/sec	0.5–5.0 × default
Gent-McWilliams thickness parameter [a]	Ocean	7×10^6 cm^2/sec	$1–20 \times 10^6$ $cm^2\ s^{-1}$
Magnitude of freshwater flux adjustment	Ocean	1.0 (ratio to the values by [c])	0.5–2.0
Wind speed used in marine CO_2 uptake	Marine carbon	3.3 m/s [b]	2.0–8.0 m/s
Maximum photosynthetic rate	Land carbon	8.0–13.5 $\mu molCO_2/(m^2s)$**	0.8–3.0 × default
Specific leaf area	Land carbon	110–170 cm^2/(g drymatter)**	0.5–2.5 × default
Minimum temperature for photosynthesis	Land carbon	−5.0–11.0°C**	−4.5–+3.0°C of default
Coefficient for temperature dependency of plant's respiration	Land carbon	2.0 (dimensionless)	1.5–3.0
A parameter of temperature dependency of soil respiration	Land carbon	46.02 K	35–55 K
Total aerosol forcing	Forcing	(RCPs)	0.0–3.0 × RCPs††

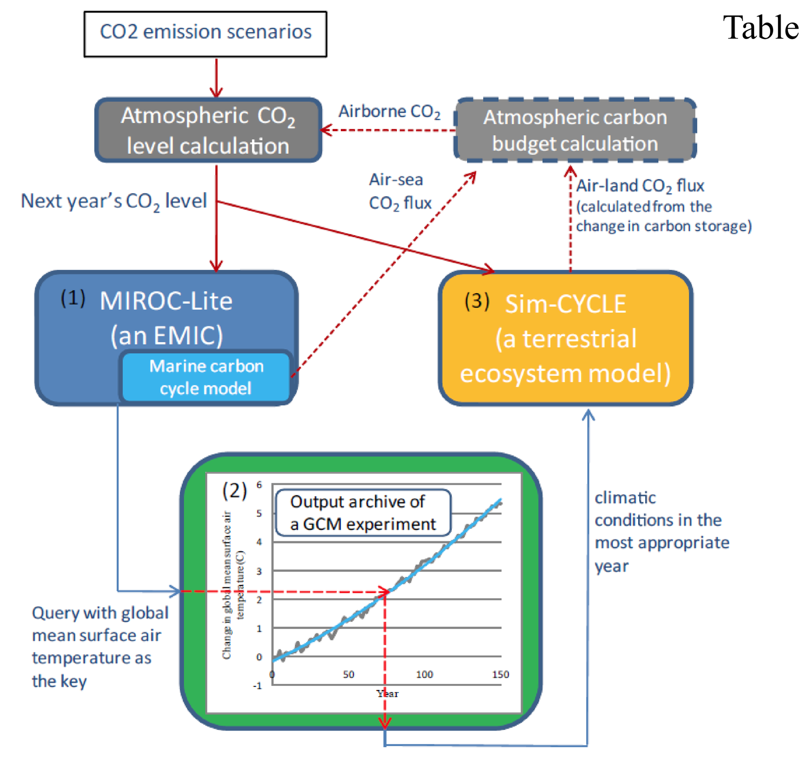

Figure 1. Structure of the loosely coupled model
The dashed box and lines indicate processes that are switched on for emission scenario experiments. (Tachiiri *et al.*, 2010)

Table 2. Observation data used for constraint of simulations (Tachiiri *et al.*, 2013)

No.	Variables	Assumed distribution
1	Trend of global mean air surface temperature (1906–2005)	T
2	Trend of ocean heat content for 0–700 m depth (1969–2003)	T
3	Historical fossil fuel emission*** (1980–2008)	geometric mean of Gaussian weights for 3 periods
4	Net Primary Production (1961–90, spatial 2D)	Gaussian
5	Atlantic meridional overturning circulation (after spinup for 1850)	Gaussian
6	Present air surface temperature (mean for 1968–96, spatial 2D)	Gaussian
7	Present sea temperature (mean for 1990–97, spatial 3D)	geometric mean of Gaussian weights for 4 layers
8	Present sea salinity (mean for 1990–97, spatial 3D)	geometric mean of Gaussian weights for 4 layers
9	All variables	Product of 1–8

Methods

- The experiment (Tachiiri *et al.*, 2013) was performed using an EMIC called the Japan Uncertainty Modelling Project—Loosely Coupled Model (JUMP-LCM; Tachiiri *et al.*, 2010).
- The model has a two-dimensional energy–moisture balance atmosphere, coupled with an ocean general circulation model. In addition, a process-based land ecosystem model is 'loosely coupled' .
- We took the global mean temperature from the EMIC and found a year with a corresponding temperature, from a run of a general circulation model (GCM, MIROC3.2) with a 1% per year (1 ppa) increase in CO_2 concentration, and used that to drive the land component (Fig. 1).
- In the experiment using an ensemble of 512 members, in which 12 parameters, both physical and biogeochemical, were perturbed.
- The ranges of parameters are tuned as close as possible to those of the C4MIP models (Friedlingstein *et al.*, 2006).
- Each ensemble simulation is then weighted using a set of eight key observations (Table 2) related to global thermal properties of the Earth system and the carbon cycle.
- In caluclating TCRE, as temperature change we use CO_2-induced warming $\Delta T_{CO_2} = \Delta T \times \frac{RF_{CO_2}}{RF_{all}}$, where ΔT is the temperature anomaly, and RF_{all} and RF_{CO2} are total and CO_2-induced radiative forcing in the RCP scenario.

Results (Tachiiri *et al.*, 2015)

TCRE range (unconstrained and constrained)

In 2005; 0.3–2.4 K/TtC (unconstrained case) and 1.1–1.7 K/TtC (constrained case)

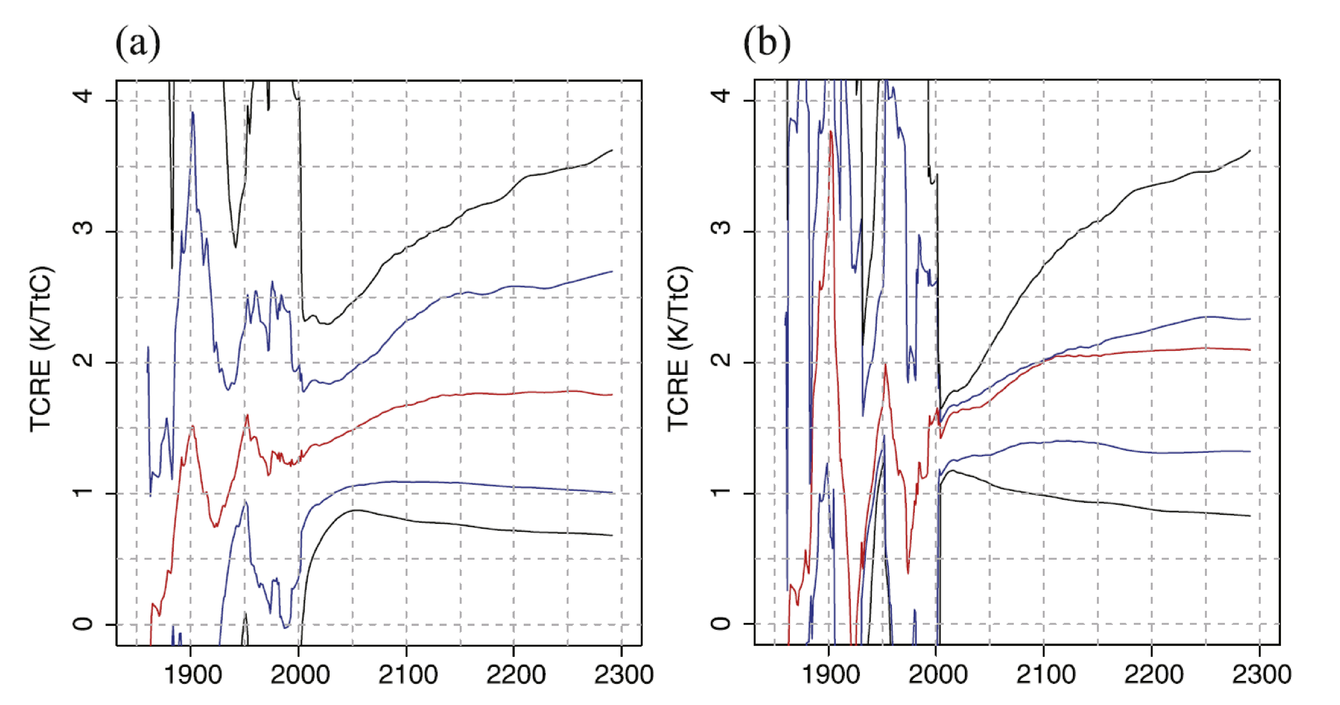

Figure 2. Temporal change in range of uncertainty of TCRE for RCP4.5: (a) unconstrained and (b) constrained cases. Red: median, blue: 16th and 84th percentiles, black: 5th and 95th percentiles. Twenty-year averages are presented.

Change in uncertainty in TCRE for RCP4.5

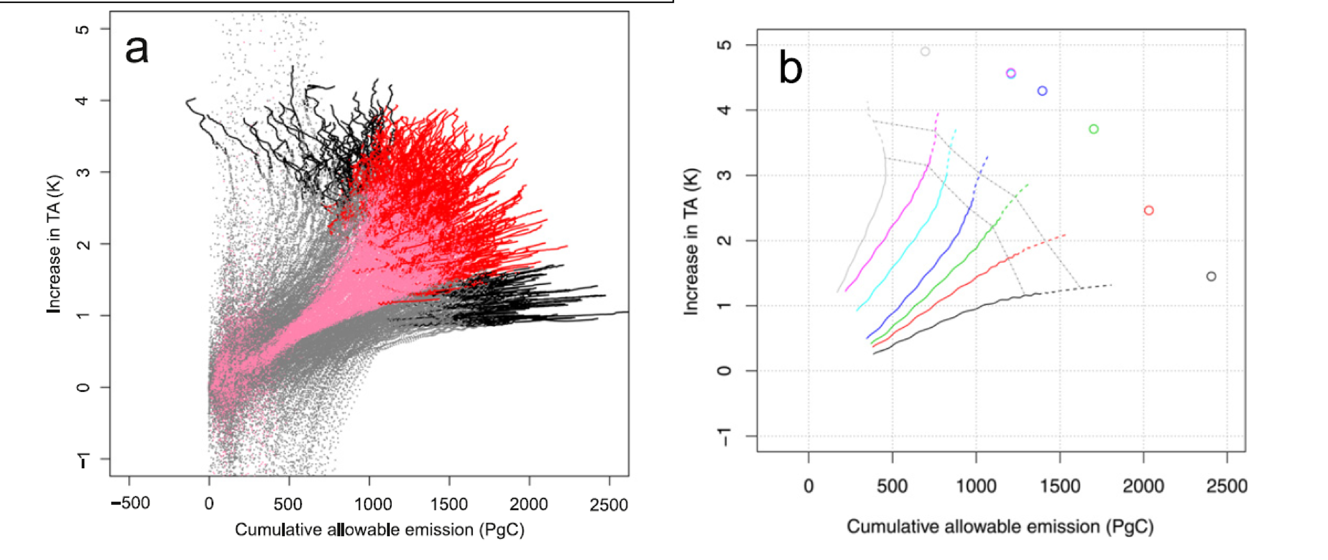

Figure 3 (a) All 512 members. Pink (1850–2115, i.e., before CO_2 concentration is nearly stabilized) and red (2115–2300) curvesrepresent the ensemble members within the 5–95% TCRE range for each year (after the constraint). Grey and black curves are the same but for those beyond the 5–95% TCRE range for each year. (b) After grouping based on average TCRE in 2111–2120:<1.0 (black), 1.0–1.5 (red), 1.5–2.0 (green), 2.0–2.5 (blue), 2.5–3.0 (cyan), 3.0–3.5 (magenta), and>3.5 (grey)K/TtC (years before 2010 are not presented because they demonstrated too much fluctuation). The solid and dotted lines present 1850–2115 and 2115–2300, respectively. Points at years 2100 and 2200 in curves are connected by dashed black lines to clarify their relative positions in those years. Open circles depict equilibrium states (after 3000-year run for atmosphere and ocean and 2000-year run for land).

Significance of land carbon uptake

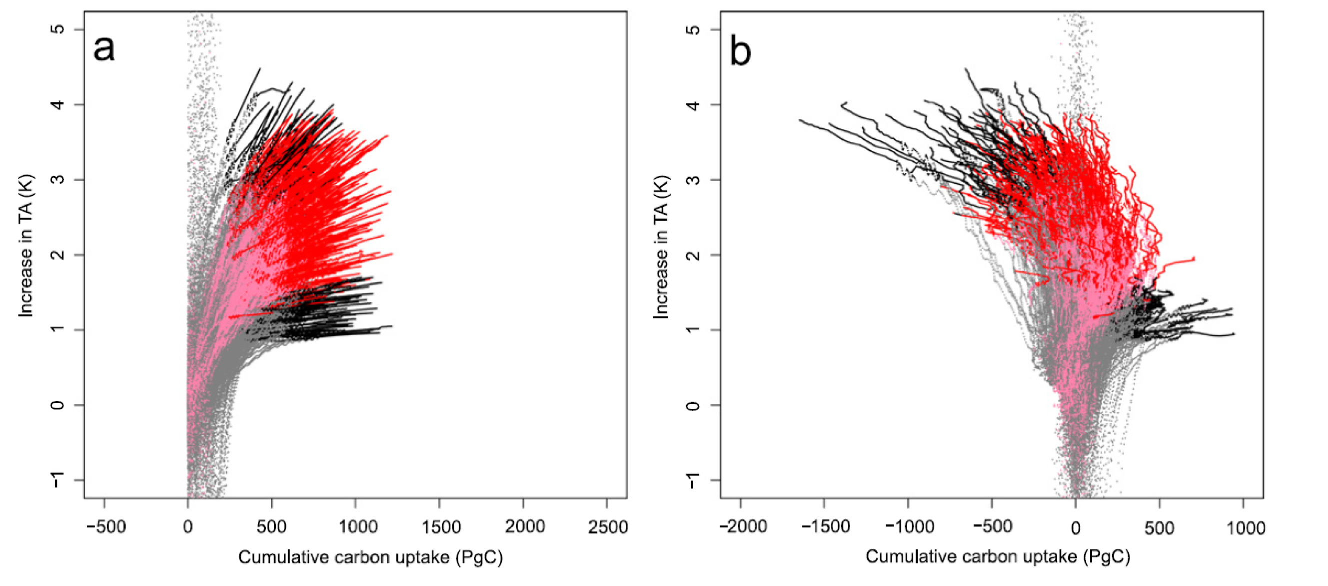

Figure 4. Modelled time-evolving relationships between air temperature change (CO_2-induced) and cumulative land/ocean carbon uptakes for each ensemble member and RCP4.5: (a) ocean and (b) land. Pink (1850–2115, before CO_2 concentration is nearly stabilized) and red (after that) curves represent the ensemble members within the 5–95% TCRE range for each year after constraints. Grey and black curves are the same but for those beyond the 5–95% TCRE range for each year.

Validation for CMIP5 models

Lower half of Fig. 3b is observed in CMIP5 models.

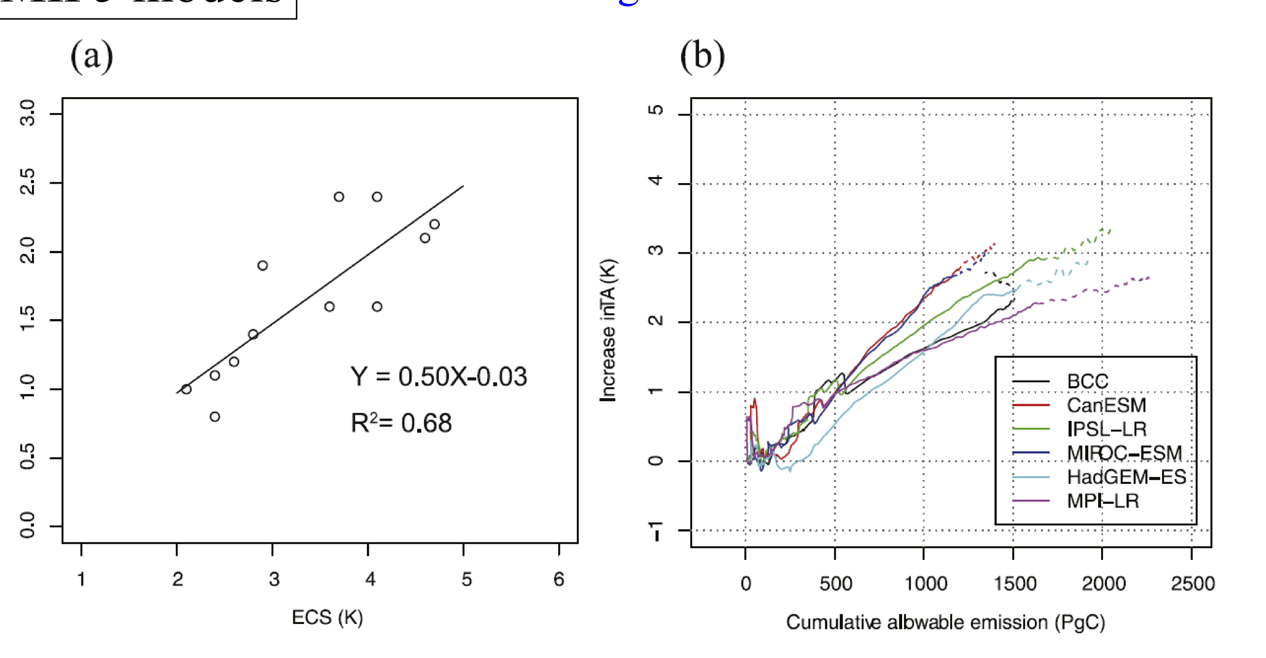

Figure 5. Behaviours of earth system models
(a) Relationship between ECS and TCRE for ESMs. (b) Temperature anomaly and cumulative carbon emissions (20 year averages). The CO_2-induced warming is calculated from ΔT for each model, multiplied by the ratio of CO_2-induced and total radiative forcing in the RCP4.5 radiative forcing scenario.

References

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