Parametric uncertainty in allowable carbon emission for RCP4.5 concentration scenario

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Introduction

With societal requirement for energy and related economic activity at present so tightly linked to the burning of fossil fuels, it is a requirement that the feasibility of any particular future pathway is evaluated. This is especially true for those pathways that imply major decarbonisation and so an evaluation is needed as to whether alternative non-fossil fuel energy sources will be available.

The IPCC Expert Meeting made "benchmark emission scenario" called Representative Concentration Pathways (RCPs) which is used to initiate the climate models to develop more practical scenarios. There are four RCPs named after radiative forcing in 2100; RCP3-PD, 4.5, 6.0, and 8.5 and they are used in CMIP5 and then IPCC AR5. Here we consider the RCP4.5 scenario (and its extension to 2300), which is perhaps considered a moderate pathway, relatively ecofriendly but, perhaps, not unattainably extreme.

There are presently just a small number of results published estimating allowable emission for the various RCPs. As expected, these estimates differ from the "harmonized" allowable emission values (Meinshausen et al., 2011, Clim. Change). Different models have a different estimate of climate sensitivity, and also alternative depictions of components of the global carbon cycle, and thus, as in previous multi-model experiments, are expected to produce a wide range of results. Here we preempt the new multi-model results by considering a range of uncertainty in the inputs to our uncertainty framework consistent with the scientific consensus as presented by the last IPCC report.

Table 1 Perturbed parameters and their ranges

Parameter	Component	Default	Perturbation range
Vertical diffusivity	Ocean	0.1-3.0cm2/sec	0.3-3.0*default
Horizontal diffusivity	Ocean	1x10^7 cm2/sec	0.5-5.0*default
Climate sensitivity	Atmosphere	4.7 (Tachiiri et al. 2010)	1-6K
Gent-McWilliams thickness parameter	Ocean	7x10^6cm2/sec	1-20*10^6 cm2/sec
Magnitude of freshwater flux adjustment	Ocean	1.0 (ratio to the Oort (1983) values	0.5-2.0
Wind speed used in marine CO2 uptake	Marine carbon	3.3m/s (Tachiiri et al. 2010)	2.0-8.0m/s
Maximum photosynthetic rate	Land carbon	8.0-13.5 μ molCO2/(m2s)	0.8-3.0*default
Specific leaf area	Land carbon	110-170 cm2/(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 direct aerosol forcing	Forcing	(RCP4.5)	0.0-2.0*RCP4.5

Table 2 Comparision with C4MIP
α: linearised transient climate response
β: carbon sensitivities to atmospheric CO_2 concentration
γ: carbon sensitivities to atmospheric temperature change

	Unit	This study	C4MIP
α	K/ppm	0.0054±0.0013	0.0061±0.0012
β_L	PgC/ppm	1.1±0.3	1.3±0.6
β_O	PgC/ppm	1.2±0.3	1.1±0.2
γ_L	PgC/K	-97±75	-79±44
γ_O	PgC/K	-33±11	-31±16

No.	Parameter	Average±Standard deviation	Assumed distribution
1	Trend of global mean air surface temperature (1906-2005)	0.74±0.18 (K/100y)	T
2	Trend of ocean heat content (1969-2003)	0.32±0.05 (1022J/y)	T
3	Historical emission (1959-2005)	2.00 (PgC/y)**	Gaussian
4	Net Primary Production (1961-90, spatial (2D))	1.08**	Gaussian
5	Atlantic meridional overturning circulation (after spinup for 1850)	10 Sv	Threshold
6	Present air surface temperature (mean for 1968-96, spatial (2D))	474 (K)**	Gaussian
7	Present sea temperature (mean for 1990-97, spatial (3D))	124/35/3.6/1.1***(K)	Product of Gaussianbased weights for 4 layers
8	Present sea salinity (mean for 1990-97, spatial (3D))	2.13/0.34/0.08/0.03***(psu)	Product of Gaussianbased weights for 4 layers
9	All variables	--	Product of 1-8

Table 3 Data used for constraint

Method

Model

We use JUMP-LCM system loosely coupling MIROC-lite (a simplified atmosphere-ocean coupled model including a marine ecosystem component, Oka et al., 2001. Clim. Dyn.) with the land surface model Sim-CYCLE (Ito and Oikawa, 2002, Ecol. Model.) which is driven by an archive of meteorological outputs from a full GCM: MIROC3.2 medium resolution version.

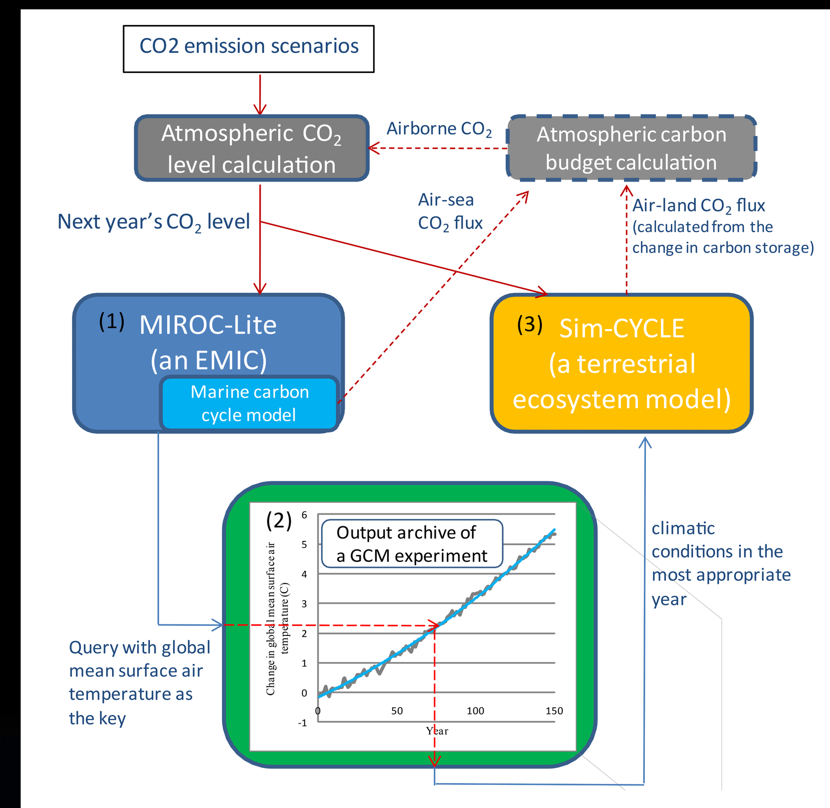


Fig. 1 JUMP-LCM (Tachiiri et al, 2010, GMD)
Physical feedback (e.g., albedo and evapotranspiration is not considered)

Parameter ranges

To achieve comparability between parameter ranges for JUMP-LCM and the C4MIP ensemble (Fliedlingstein et al., 2006, J. Clim.), except for climate sensitivity and aerosol forcing fixed as presented in Table 1, the tuning was carried out heuristically using a small ensemble with 20 members as follows. (1) Based on the results of the previous experiments ranges were defined. (2) Considering the resulting relationship between the input parameter values and the modelled values for α, β and γ we shifted and/or expanded the perturbation ranges. (3) Iterate the process (2) to get acceptable result and close mapping between the effective parameter bounds.

Experiment

RCP4.5 concentration sceanrio is used to the model with 512 paremete sets flatly cover the parameter space in Table 1. The non-CO_2 forcing is considered as radiative forcing.

Constraint

To consider a realstic PDF in climate sensitivity, we selected 358 members by using B(1.8, 2.2). Then we use the data presented in Table3. The data sources are: Physics: HadCRUT3 data (http://www.cru.uea.ac.uk/cru/data/temperature/), Levitus et al. (2009), NCEP/NCAR reanalysis, and World Ocean Atlas, http://www.esrl.noaa.gov/psd/data/gridded/data.nodc.woa98.html. Carbon cycle: CO_2 emission in 1959-2005 (CO2Now.org, http://co2now.org/) and present day NPP(http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds id=614). Weight: **A CPI** (Murphy et al 2004, Nature)-like score.

Result

1. The ensemble mean of the experiment allows slightly smaller emissions than the standard RCP4.5 emission scenario.
2. Despite our extensive use of contemporary measurements to further constrain the results, the range of temperatures corresponding to RCP4.5 is large.
3. By year 2300, the predicted global temperature increase has 2.7±1.5 (K) (2SD), while without using present-day measurements, so each model simulation has equal weighting, gives a slightly smaller mean of 2.5 (K).
4. In the peak emission period, the projected emission is 10.6 ± 2.5 (PgC), while RCP4.5 emission scenario and MIROC-ESM are (11.4 and 9.8 PgC).
5. Our ensemble predicts that with a probability of 3%, then there will need to be an extended period of time with global negative emissions for 2151-2200.

Fig. 2
Temperature change (relative to the average of 1961-1990)
(a)(b): uncontrained,
(c)(d): constrained

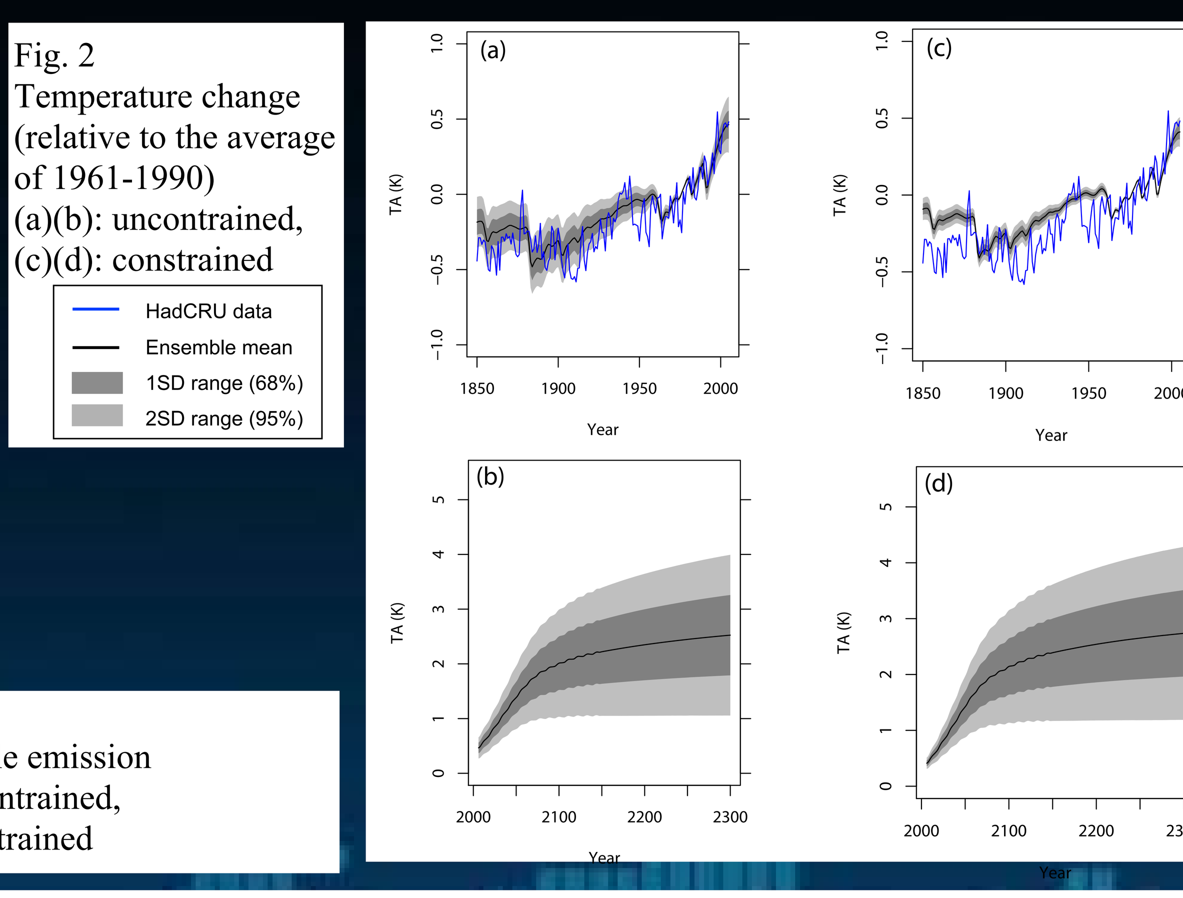
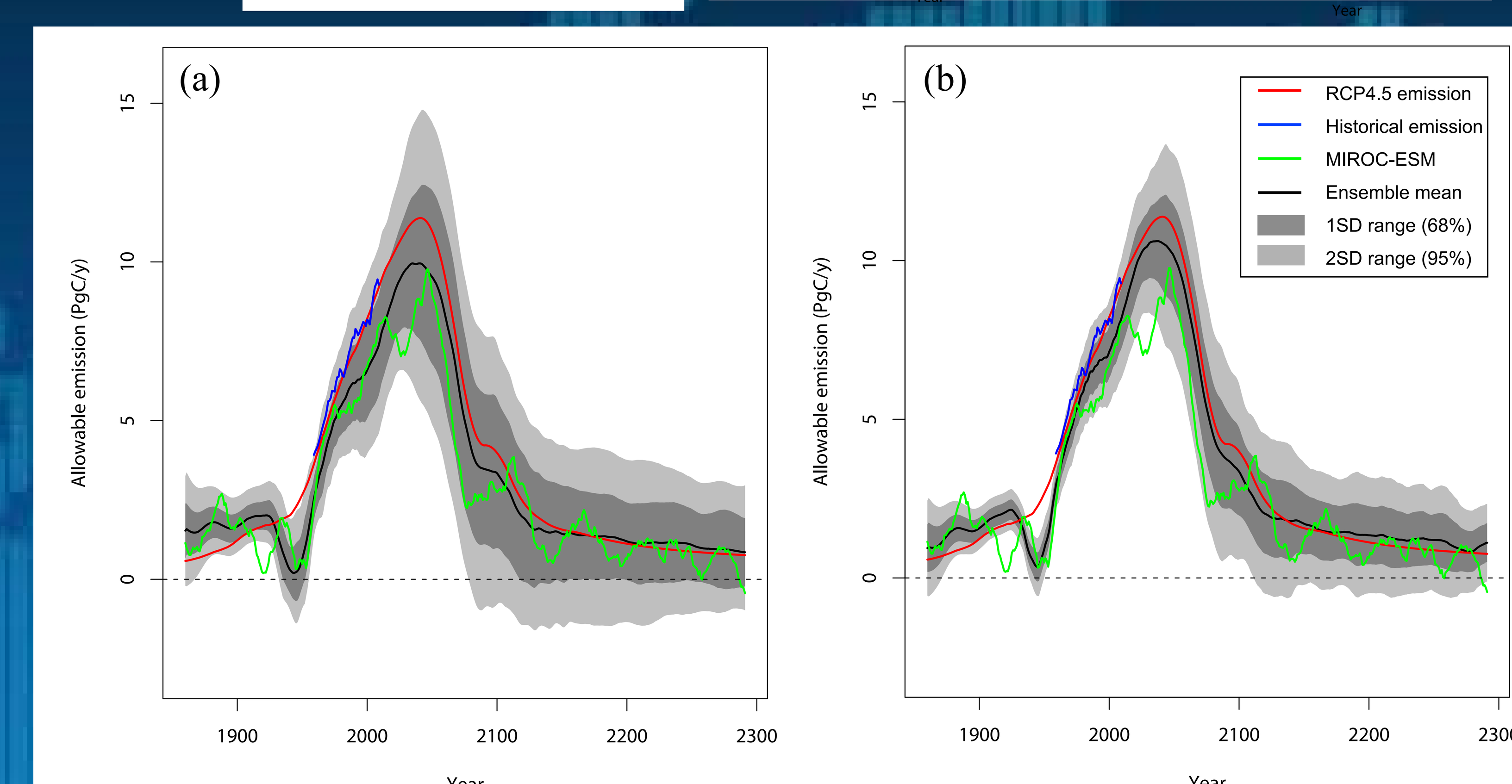


Fig. 3
Allowable emission
(a): uncontrained,
(b): constrained



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