Assessing the role of internal variability in the carbon budgets framework

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BACKGROUND:

Global mean warming is proportional to the total amount of CO_2 emitted. This ratio of warming to cumulative CO_2 emissions is known as the Transient Climate Response to cumulative CO_2 Emissions (TCRE), and provides the basis for the concept of carbon budgets.

Carbon budgets are a policy tool that specifies the cap on global cumulative CO_2 emissions that would be in line with limiting global mean warming to a desired level, for example 1.5 °C above pre-industrial specified in the Paris Agreement.

The Paris Agreement refers to the anthropogenic component of the warming only, excluding the unforced natural fluctuations of the climate system (i.e. internal variability) emerging from the coupled interactions between Earth system components. However, observation-based estimates of anthropogenic warming are subject to uncertainty arising from the effects of internal variability.

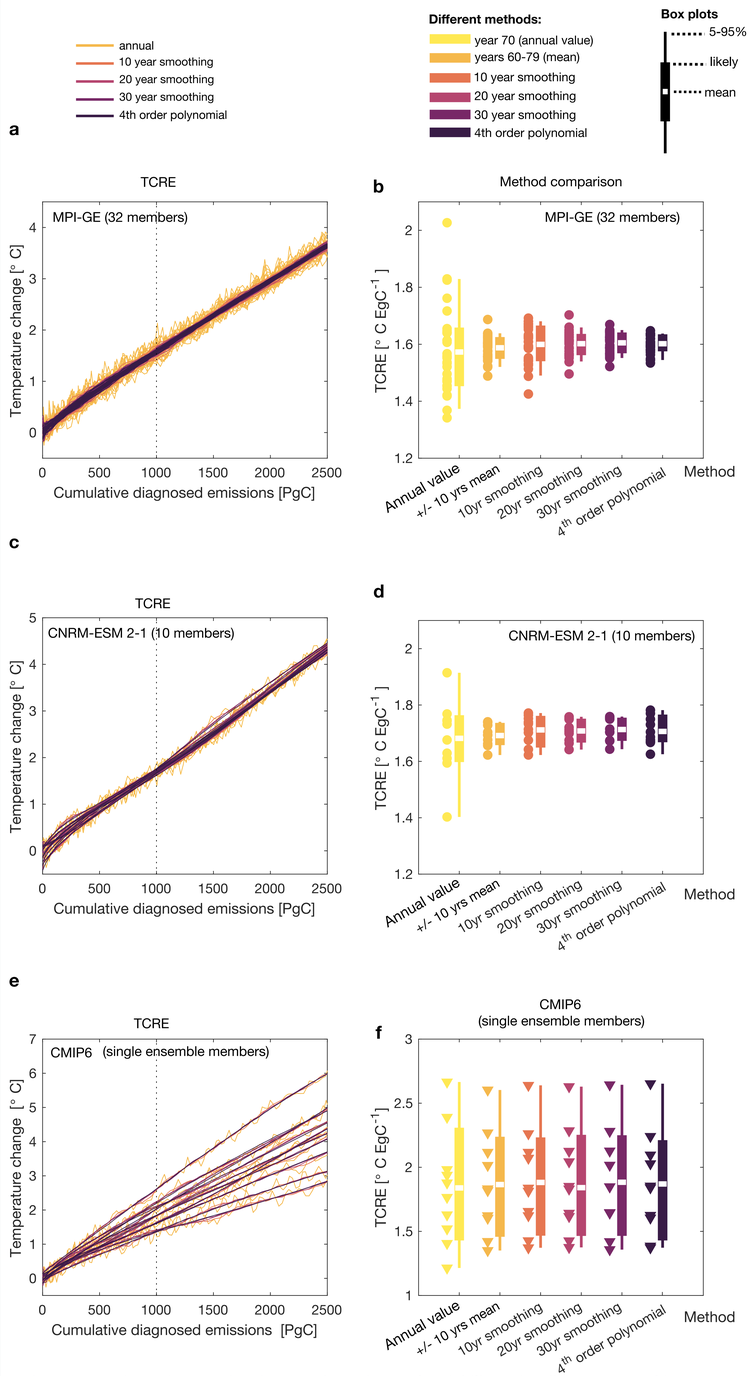

Fig. 1. Comparison of uncertainty in TCRE due to internal variability, using different smoothing methods. (**a**,**c**) Temperature as a function of diagnosed cumulative CO_2 emissions in MPI grand ensemble (32 members) and CNRM-ESM2-1 (10 members) in 1pctCO_2 simulation; (**b**,**d**) TCRE range in each model using different smoothing methods, as labelled (5-95%, likely 17-83%, and mean value); (**e**) as in (**a**,**b**) but for CMIP6 models (one ensemble member per model) in 1pctCO_2 simulation. (**f**) Resulting multi-model TCRE distribution calculated using different smoothing methods, as labelled. *Note: In all panels, potential drift in temperature response was removed by a linear fit to corresponding pre-industrial control simulations.*

THE PROBLEM:

It is unclear how internal variability of the climate system can be removed entirely to allow for estimation of Paris Agreement compatible carbon budgets. Uncertainties arising from internal variability have not been quantified in TCR, TCRE, and related carbon budget estimates.

OUR APPORACH:

Large Ensemble simulations

1. We make use of CMIP5 and CMIP6 simulations that had large or medium size ensembles available under high emission scenarios (RCP 8.5 and SSP 5-8.5) scenarios, SSP 2-4.5 scenario, and idealized 1pctCO_2 scenarios, in concentration-driven simulations.
2. Each models' ensemble spread represents uncertainty due to internal variability.
3. We test how different approaches in estimating TCR, TCRE, and remaining carbon budgets, differ, depending on the smoothing applied, and how the spread due to internal variability affects the estimates of the remaining carbon budgets.

KEY RESULTS

- Differences in diagnosed TCRE due to internal variability in individual models can be as large as ±0.1 °C/1000 PgC (5-95% range).
- Remaining carbon budgets for 1.5 and 2.0 °C temperature targets differ by about ± 30 PgC (or ±110 $GtCO_2$; 5-95% range), in concentration-driven simulations of large ensembles of CMIP6 and CMIP5 models.

TAKE AWAY POINTS

- Our results do not question the validity of a carbon budget approach in determining mitigation requirements, but urge caution when interpreting small remaining budgets in the light of internal climate variability, and particularly when applying framings like 'years-left' until a given temperature level.
- Due to intrinsic uncertainty arising from internal variability, it may only be possible to determine the exact year when a budget is exceeded in hindsight.

Material undergoing peer-review. Please do not distribute.

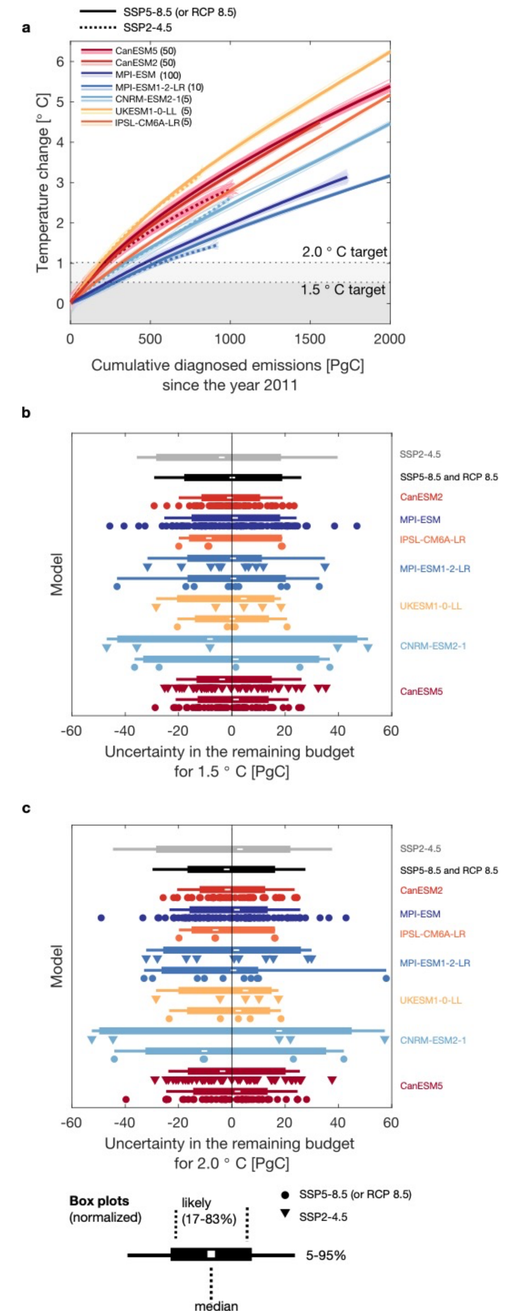

Fig. 2. Effective TCRE and normalized uncertainty due to internal variability in remaining carbon budgets until 1.5 °C and 2.0 °C warming is reached. (a) Temperature as a function of cumulative CO_2 emissions based on SSP 5-8.5 scenario and SSP 2-4.5 scenarios (and RCP 8.5 scenario for CanESM2 and MPI-GE), based on forced response estimates by fitting fourth-order polynomials to individual ensemble members); (**b**) uncertainty in the remaining carbon budgets for 1.5 °C; (**c**) uncertainty in the remaining carbon budgets for 2.0 °C. Note: The uncertainty is based on carbon budgets for 1.5 °C and 2.0 °C (with respect to the 2006-2015 baseline), calculated directly from the effective TCRE (panel a), and is normalized by the mean distribution for each model. Top black and grey boxes in panels (b) and (c) indicate a multi-model average budget estimate for each scenario, where each simulation was weighted according to the ensemble size of each model to avoid a bias towards models with large amount of ensemble members.

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