Findings from the Reduced Complexity Model Intercomparison Project

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Motivation: Need to assess mitigation scenarios in terms consistency with temperature goals; increasing opportunities to do that in a multi-model approach like RCMIP.
Key points: A new method for probabilistic climate projections has been developed, underpinning the scenario assessment. It can emulate and constrain the diversity of complex climate models in a simple and accurate way.

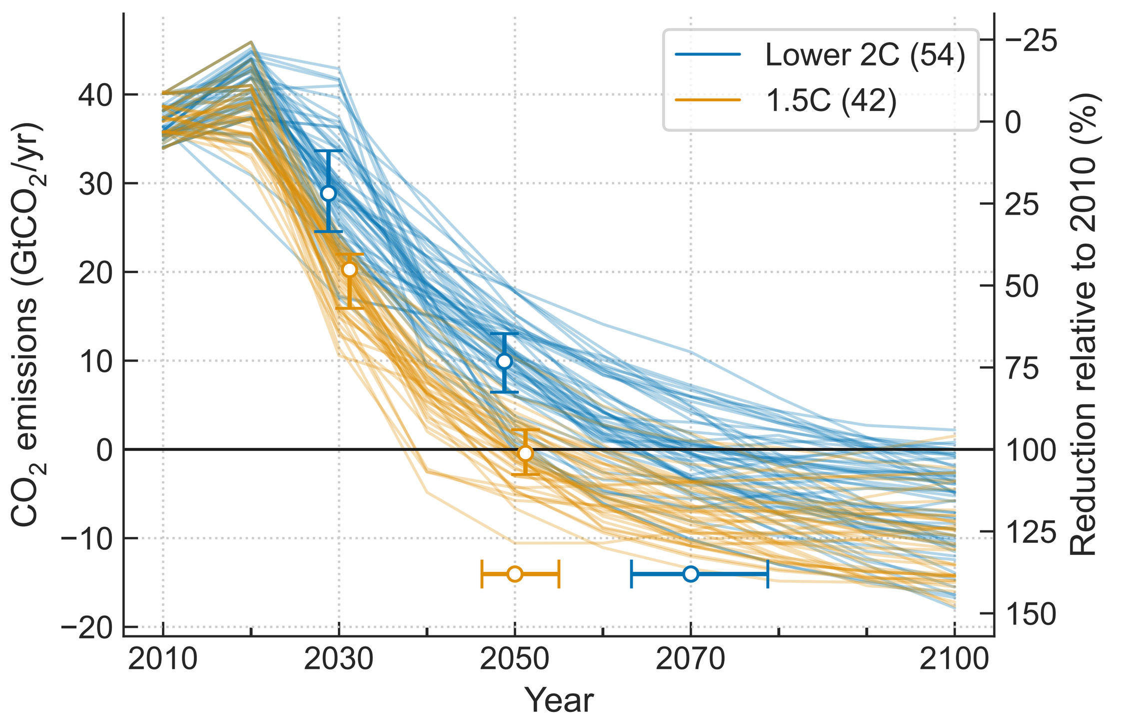
Background

A climate model emulator, or a simple climate model, plays a crucial role of categorizing many mitigation scenarios in terms of warming levels. In SR15, over 400 scenarios were categorized based on 600-member climate projections by MAGICC6, one of the representative emulators, and assessed for mitigation milestones, such as the time when emissions reach net zero (**Table 1, Fig 1**).

Table 1 SR15 scenario categories

Category	Criteria	Use in SR15
Below 1.5	$P_{1.5°C} \leq 0.5$	1.5°C-consistent
1.5 Low Overshoot	$P_{1.5°C} \leq 0.67$ & $P_{1.5°C}(2100) \leq 0.5$	1.5°C-consistent
1.5 High Overshoot	$P_{1.5°C}(2100) \leq 0.5$	
Lower 2.0	$P_{2.0°C} \leq 0.34$	2°C-consistent
Higher 2.0	$P_{2.0°C} \leq 0.5$	

Based on Huppmann et al. (2018). Criteria for each category are applied in order from to to bottom. $P_{x°C}$ expresses the probability of exceeding x°C at least at one time point until 2100 while $P_{x°C}(2100)$ expresses the probability of exceeding x°C at 2100.



Errorbars with an open circle indicate interquartile ranges and medians of 1.5°C- and 2.°C-consistent scenarios for emissions in 2030 and 2050, and for the time when emissions reach net zero. Numbers of scenarios are shown in parentheses in the legend. Scenario analysis is based on Huppmann et al. (2018).

Fig 1 Global CO_2 emissions in mitigation scenarios assessed in SR15

The author has been developing one such tool, called MCE (Tsutsui, 2021), with the aim of synthesizing new insights into Earth system behavior and improving scenario assessment. The MCE enables successful emulation of full-scale complex climate models in a minimal way with sufficient accuracy and low computational cost. It is suitable for building parameter ensembles reflecting complex models' diversity and several constraints of key climate indicators.

RCMIP exercise

Reduced Complexity Model Intercomparison Project (RCMIP) is the first comprehensive model intercomparison of emulators. During Phase 1, a new framework was established to systematically evaluate multiple emulators from scenario experiments as conducted in Coupled Model Intercomparison Project (CMIP) for complex climate models. Phase 2 then focused on probabilistic climate projections underpinning the scenario categorization, and nine models were compared under the same set of constraints, i.e., the ranges of specific Earth system quantities, e.g., CO_2 and other agents' forcing levels, land and ocean carbon uptake, climate sensitivity, and observed warming trends (Nicholls et al., 2021).
The temperature response (**Fig 2**) is generally lower in the emulators than in the CMIP models due to the constraints given to the emulators only. The emulators themselves show significant differences associated with model structures and the implementation of the constraints.
The MCE is one of the RCMIP participants, and was found to have good performance in terms of consistency with the given constraints, except for climate sensitivity that is relatively lower biased.

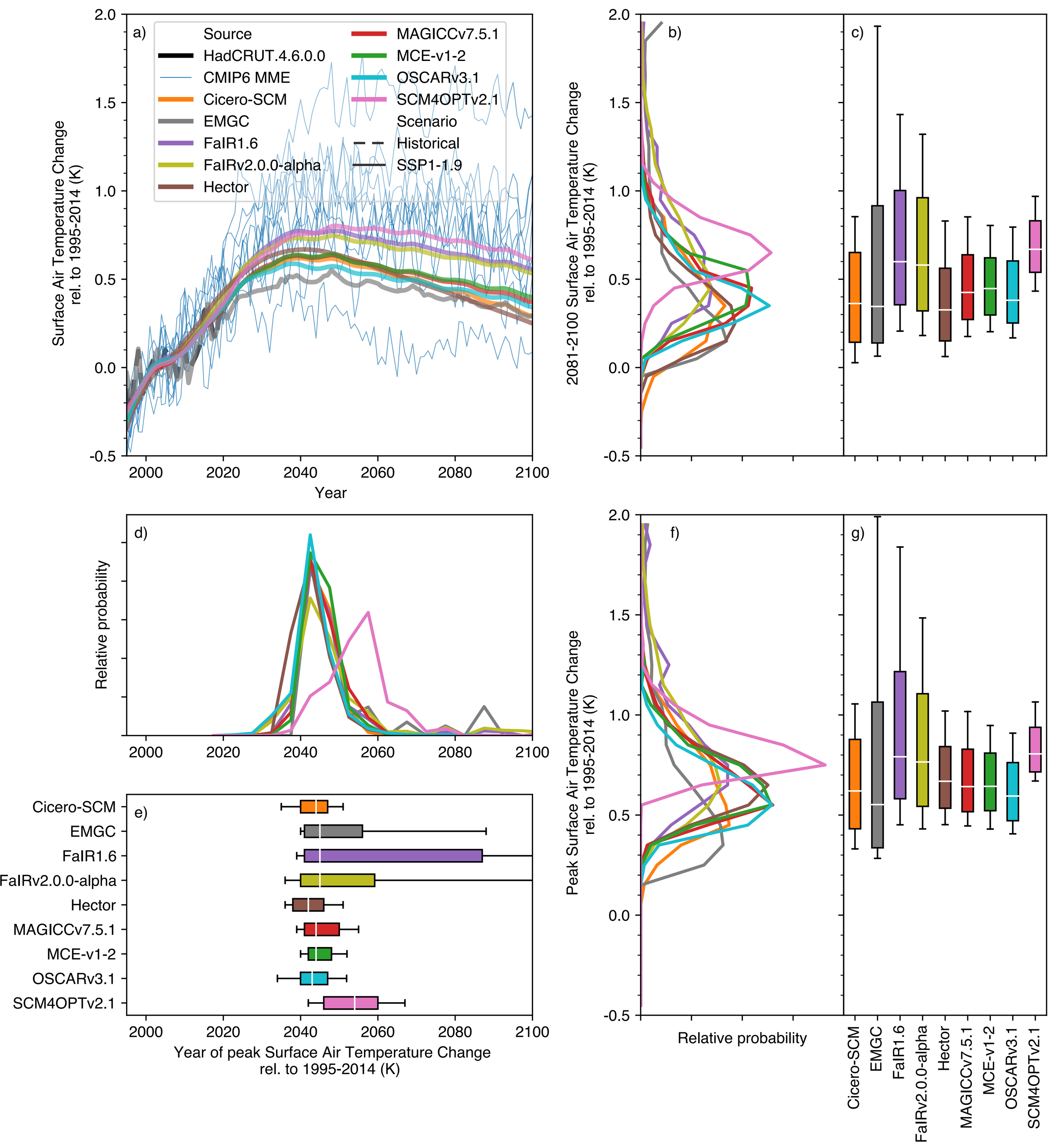


Fig 2 Highlight of RCMIP phase 2

Adopted from Fig 2 of Nicholls et al. (2021). Surface air temperatures relative to 1995–2014 under SSP1-1.9 scenario; a) median timeseries including those from observations (HadCRUT4.6.0.0) and CMIP6 models; b) distribution of 2081–2100 mean; c) very likely (whiskers), likely (box), and central (white line) 2081–2100 mean; d, e) same as in b, c) except for the year in which the temperature peaks; f, g) same as in b, c) except for the peak temperature.

Present study

To further investigate the effect of the RCMIP constraints, the followings compare the MCE's probabilistic climate projections between CMIP-consistent and RCMIP-constrained ensemble runs.
The RCMIP-constrained agrees well with recent warming trends while the CMIP-consistent is overestimated (**Fig 3**). However, uncertainties remain regarding longer trends and unforced climate variability.

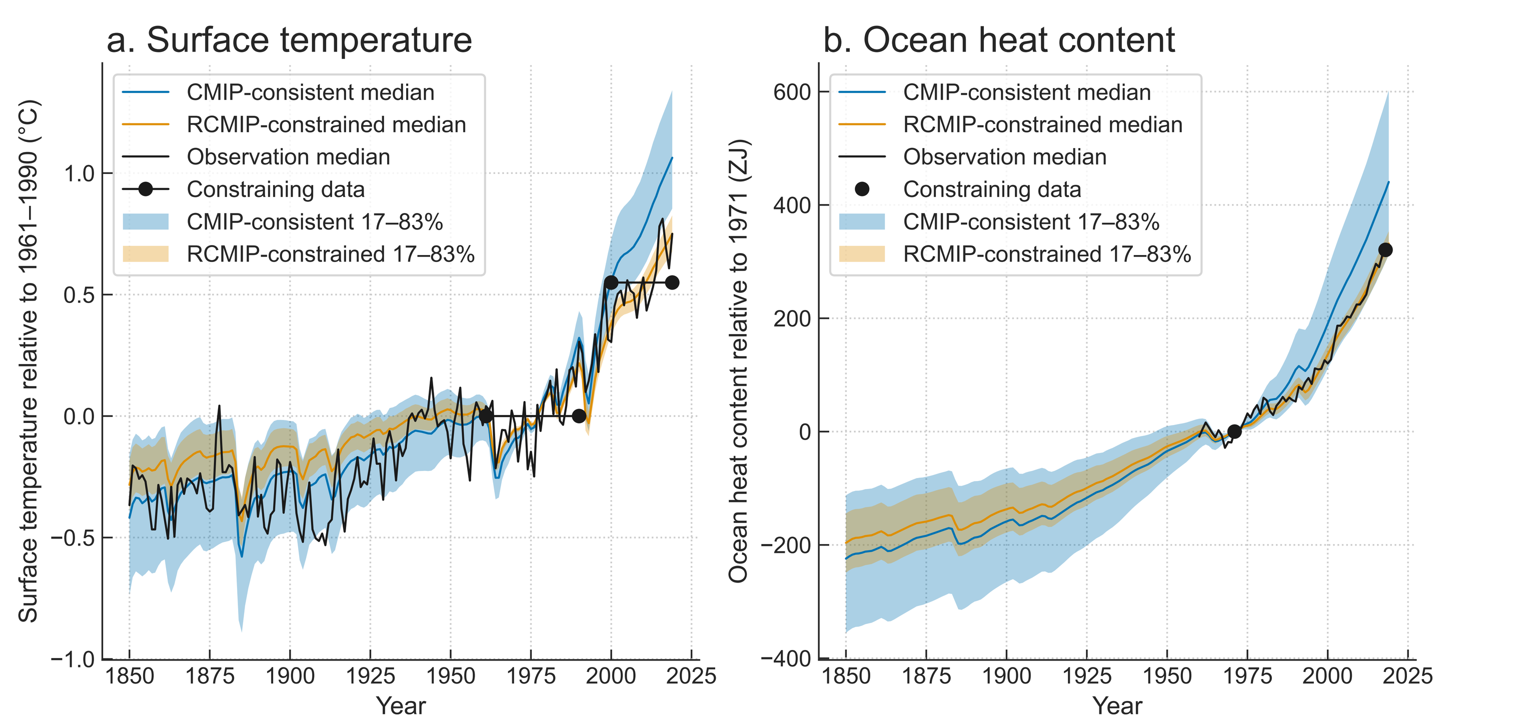


Fig 3 Historical changes in the surface temperature and ocean heat content

Black dots indicate the levels at two different periods or years used for the warming trend constraints. The observed heat content data is limited to the period after 1960.

The two ensembles are most distinctively different for the recent trends mainly due to different climate sensitivity distributions (**Fig 4**). The climate sensitivity constraints used in the RCMIP have narrower ranges than those assessed in AR5. For those narrowed ranges, the two ensembles are biased toward different directions, resulting in completely separate climate projections (**Fig 5**). Although the present method effectively emulates and constrains CMIP models' diversity, it needs further improvement in overall consistency using the upcoming AR6 assessed ranges.

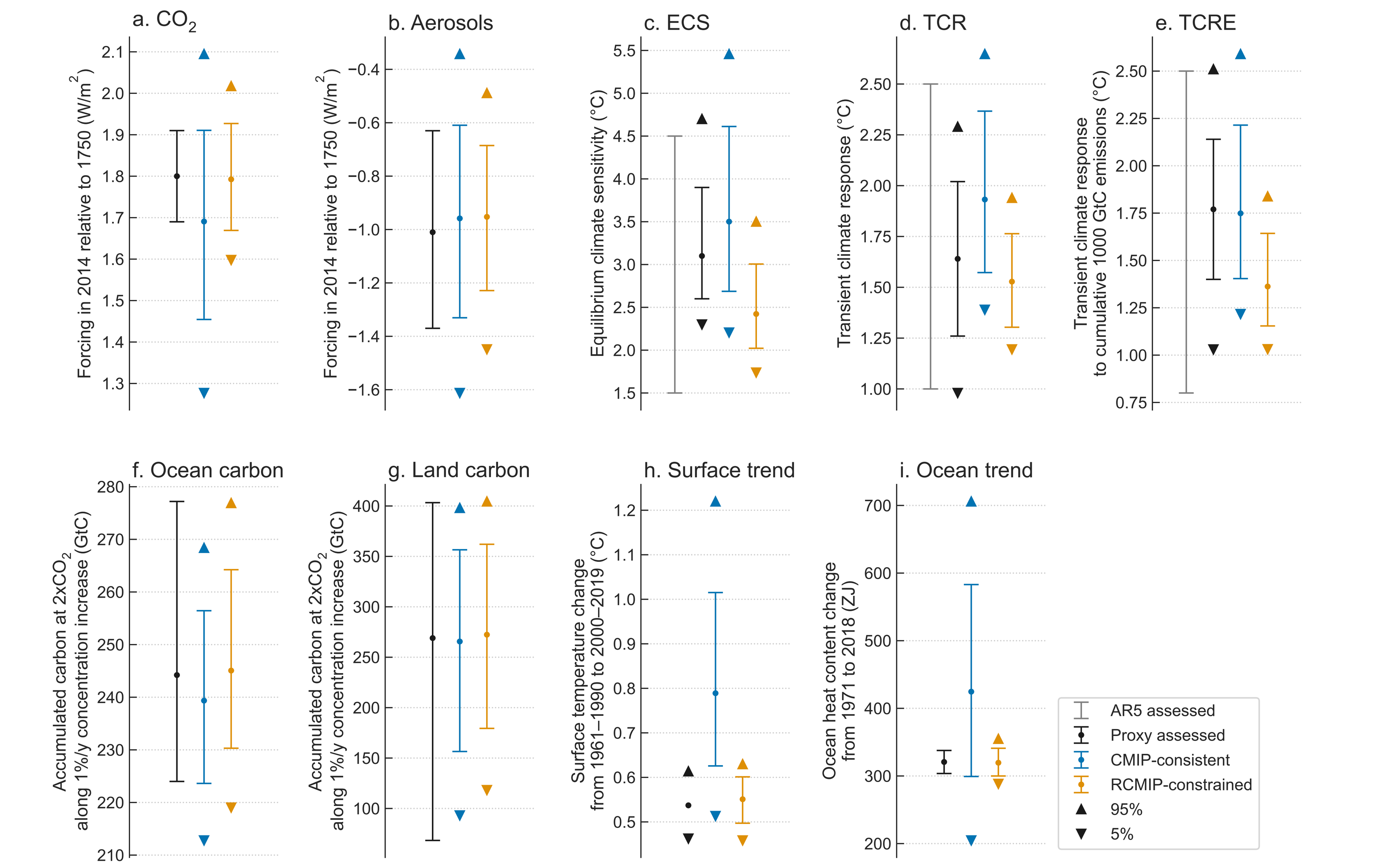


Fig 4 Distributions of key climate indicators

The ranges of the two ensembles are compared with the 'proxy' assessed ranges used in the RCMIP as well as the AR5 assessed ranges for the three climate sensitivity metrics in panels c–e. Here, the 'proxy' means that they are based on recent literature, leading to the AR6 (not yet available) assessed ranges.

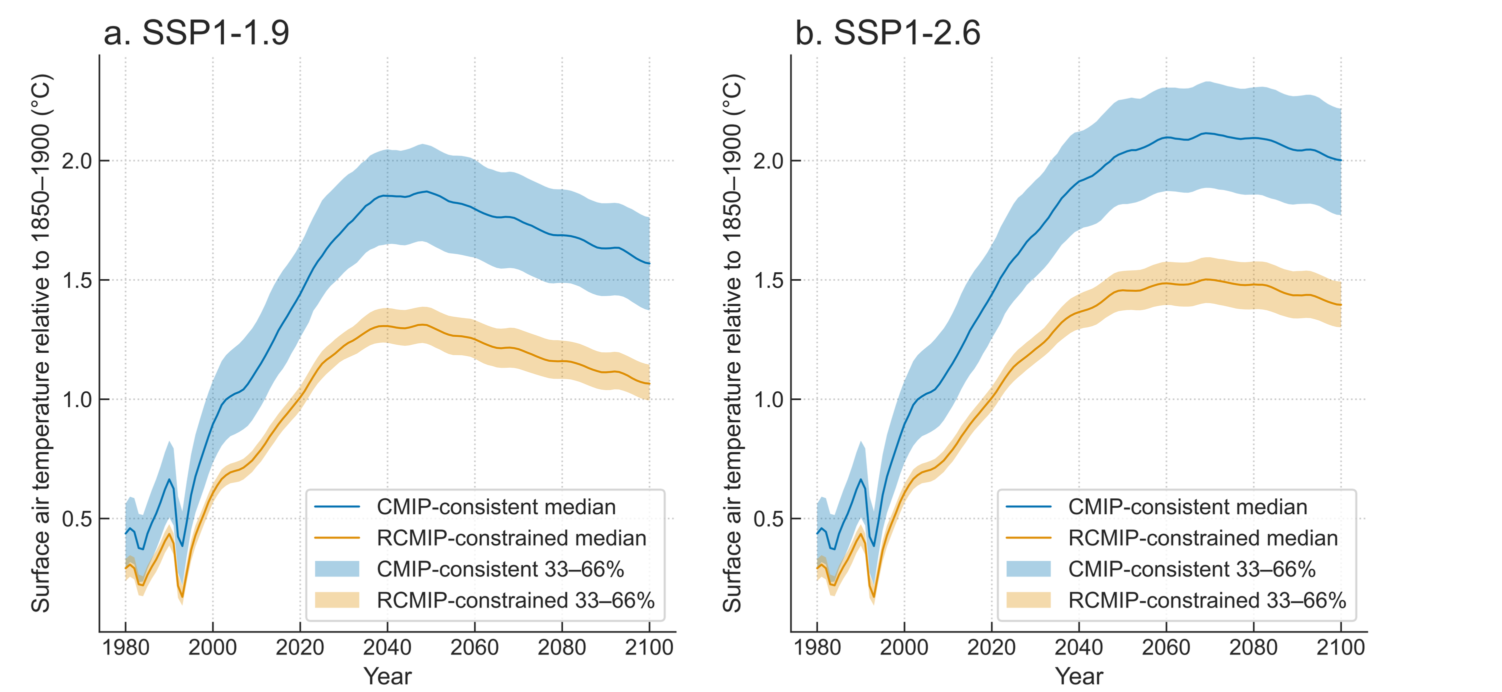


Fig 5 Changes in the surface temperature under strong mitigation scenarios

The upper bound of 33-67% range corresponds to the level to which warming is likely (66–100%) to be limited at the time, while the lower bound corresponds to the level which warming is likely to exceed.

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References

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Nicholls, Z. et al. (2021), 'Reduced Complexity Model Intercomparison Project Phase 2: Synthesising Earth system knowledge for probabilistic climate projections', *Earth's Future* e2020EF001900, `https://doi.org/10.1029/2020EF001900`

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