Supplementary Information

Carbon dioxide responses shape estimates of Amazon forest vulnerability under solar geoengineering

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Overview

This document provides additional model-resolved diagnostics and a sensitivity assessment of the CO_2-dependent forest-sustainability threshold used in the main manuscript. Threshold exceedance diagnoses environmental conditions associated with reduced equilibrium broadleaf forest cover; it is *not* a direct simulation of future forest loss.

Model-specific threshold exceedance

The model-resolved comparison in Supplementary Fig. S1 complements the scenario-mean threshold-exceedance results in the main manuscript. It shows how the near-present and late-century exceedance fractions differ among the five Earth system models when each scenario is evaluated using its corresponding CO_2-dependent threshold.

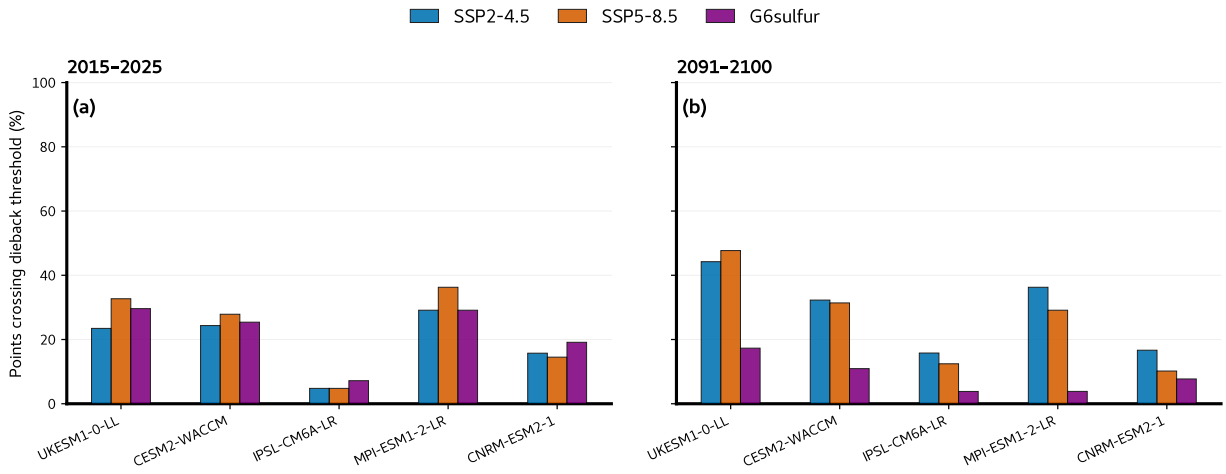

Figure S1: Threshold exceedance in individual Earth system models. Percentage of analysed Amazon grid cells exceeding the CO_2-dependent forest-sustainability threshold under SSP2-4.5, SSP5-8.5 and G6sulfur. (a) Near-present climate (2015–2025) and (b) late-century climate (2091–2100), each evaluated against the CO_2 threshold associated with its scenario and period. The metric identifies threshold-exceeding climate states, not the percentage of actual forest cover lost.

Model-resolved climate anomalies

Supplementary Fig. S2 reports model-specific anomalies underlying the multi-model climate comparisons. The heatmaps illustrate the contrast between relatively consistent temperature offsets and more heterogeneous precipitation and dry-season responses under G6sulfur.

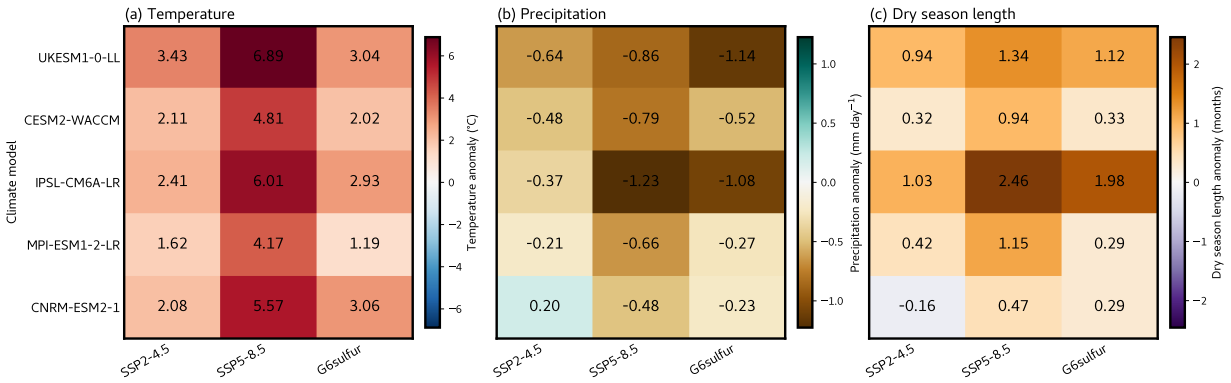

Figure S2: Model-specific Amazon climate changes. Late-century (2091–2100) minus near-present (2015–2025) anomalies in (a) near-surface air temperature (°C), (b) precipitation (mm day^{-1}) and (c) dry-season length (months). Each cell gives the mean anomaly for the indicated model and scenario. Positive temperature and dry-season-length anomalies indicate warming and lengthening, whereas negative precipitation anomalies indicate drying.

Sensitivity to the CO_2-dependent threshold response

To evaluate the dependence of diagnosed exceedance on the CO_2 term in the dry-season resilience (DSR) diagnostic, the future CO_2 increment was scaled using a dimensionless multiplier α while holding the projected temperature and dry-season length fixed:

$$\mathrm{DSR}_\alpha = \mathrm{DSL} + 0.46T - 0.0043\left[CO_{2,\mathrm{present}} + \alpha(CO_{2,\mathrm{future}} - CO_{2,\mathrm{present}})\right] - 18.7. \quad (1)$$

Here $CO_{2,\mathrm{present}}$ = 429.03 ppm; $CO_{2,\mathrm{future}}$ = 602.78 ppm for SSP2-4.5 and 1135.21 ppm for SSP5-8.5 and G6sulfur. Values of $\alpha = 0$, 0.25, 0.50, 0.75, 1.00 and 1.25 were examined. At $\alpha = 0$, the future climate is assessed against the present-day CO_2 threshold; $\alpha = 1$ recovers the original future CO_2 shift. These are illustrative sensitivity cases rather than probabilities or an estimated confidence interval.

For each model, scenario and α, exceedance was recalculated as the proportion of exported future-climate records with $\mathrm{DSR}_\alpha > 0$. The thick curves are equal-model means of the five available model fractions; thin curves are individual models and should not be interpreted as uncertainty intervals.

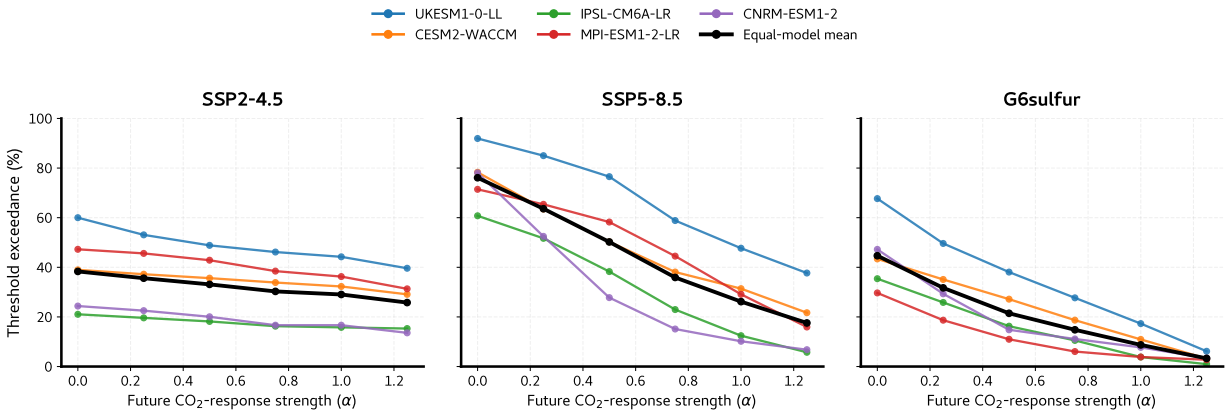

Figure S3: Sensitivity of the forest-sustainability diagnostic to the assumed future CO_2 response. Percentage of the analysed Amazon domain exceeding the forest-sustainability threshold during the late-century period (2091–2100) under (left) SSP2-4.5, (centre) SSP5-8.5 and (right) G6sulfur, as the strength of the future CO_2-dependent threshold shift is varied using the parameter α (Eq. 1). Coloured lines represent the five individual Earth system models, while the thick black lines indicate their equal-model means. Temperature and dry-season length remain fixed at their respective late-century values throughout the sensitivity experiments. Threshold exceedance is calculated as the spatially weighted fraction of the analysed Amazon domain experiencing conditions beyond the forest-sustainability threshold.

Relative G6sulfur benefit across CO_2 assumptions

SSP5-8.5 and G6sulfur share the same future atmospheric CO_2 concentration. Consequently, for each value of α, both scenarios are evaluated against the same CO_2-dependent forest-sustainability threshold, allowing the effects of their differing climatic conditions to be compared consistently.

For each Earth system model m, the difference in threshold exceedance is calculated as

$$\Delta F_m(\alpha) = F_{m,\mathrm{SSP5-8.5}}(\alpha) - F_{m,\mathrm{G6sulfur}}(\alpha), \tag{2}$$

where $F_{m,s}(\alpha)$ represents the spatially weighted percentage of the analysed Amazon domain exceeding the forest-sustainability threshold for model m, scenario s, and CO_2-response strength α.

Positive values of $\Delta F_m(\alpha)$ indicate lower threshold exceedance under G6sulfur relative to SSP5-8.5, whereas negative values indicate greater exceedance under G6sulfur. This comparison captures the combined effects of temperature and dry-season-length differences between the scenarios without separately attributing their individual contributions.

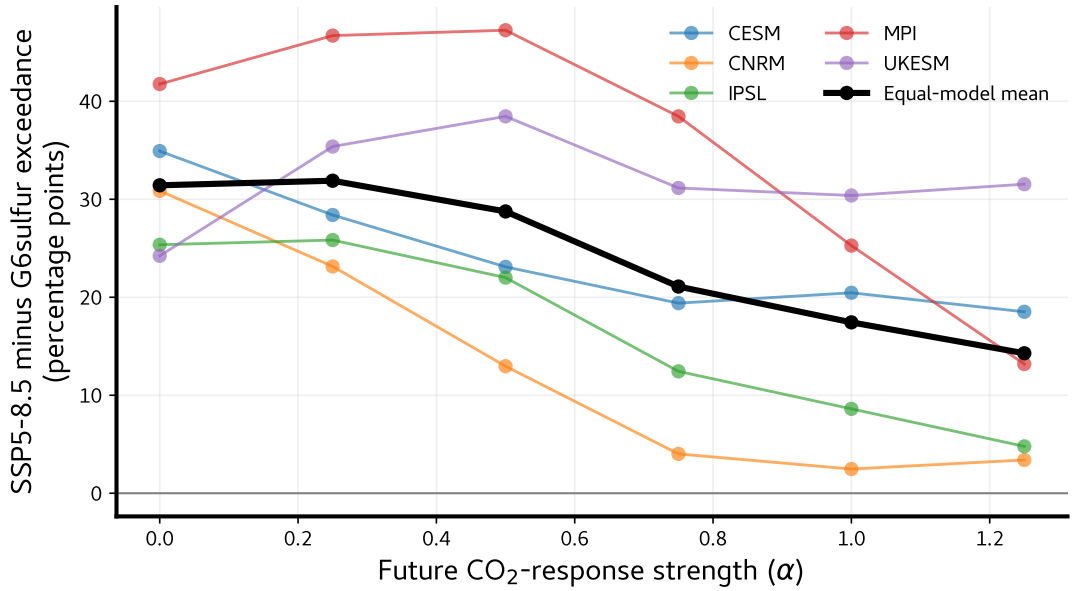

Figure S4: Difference in forest-sustainability threshold exceedance between SSP5-8.5 and G6sulfur across assumed CO_2 responses. For each Earth system model and value of α, the spatially weighted threshold-exceedance percentage under G6sulfur is subtracted from that under SSP5-8.5 (Eq. 2). Coloured lines represent individual Earth system models, while the thick black line shows the equal-model mean. Both scenarios share the same atmospheric CO_2 concentration and corresponding forest-sustainability threshold at each α value. Positive values indicate a reduction in threshold exceedance under G6sulfur relative to SSP5-8.5. These differences represent changes in exposure to conditions associated with reduced equilibrium forest cover, rather than directly simulated forest loss.