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G6-1.5K-SAI and G6sulfur: changes in impacts and uncertainty depending on stratospheric aerosol injection strategy in the Geoengineering Model Intercomparison Project

Walker Raymond Lee et al.

Correspondence to: Walker Raymond Lee (walkerl@ucar.edu)

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S1: Controller effectiveness

Here, we provide additional diagnostics on the performance of the feedback control algorithm used to choose injection rates in each model.

The controller error (defined as the difference between GMSAT and the temperature target, averaged over the last 20 years for each ensemble member) for each of the participating models is:

- For the three CESM ensemble members: [0.04, 0.02, 0.02] °C
- For the three E3SM ensemble members: [-0.04, -0.09, -0.12] °C
- For the ten MIROC ensemble members: [-0.05, -0.09, -0.10, -0.10, -0.09, -0.08, -0.10, -0.13, -0.09, -0.05] °C
- For the three UKESM ensemble members: [-0.07, -0.03, -0.08] °C

Considering absolute error (absolute difference between GMSAT and temperature target - meaning positive and negative error do not cancel out - averaged over the same period), these values are:

- For the three CESM ensemble members: [0.09, 0.07, 0.06] °C
- For the three E3SM ensemble members: [0.13, 0.13, and 0.13] °C
- For the ten MIROC ensemble members: [0.19, 0.18, 0.19, 0.12, 0.14, 0.16, 0.19, 0.19, 0.18, 0.19] °C
- For the three UKESM ensemble members: [0.12, 0.10, 0.11] °C

This information is visualized in Figure S1 below.

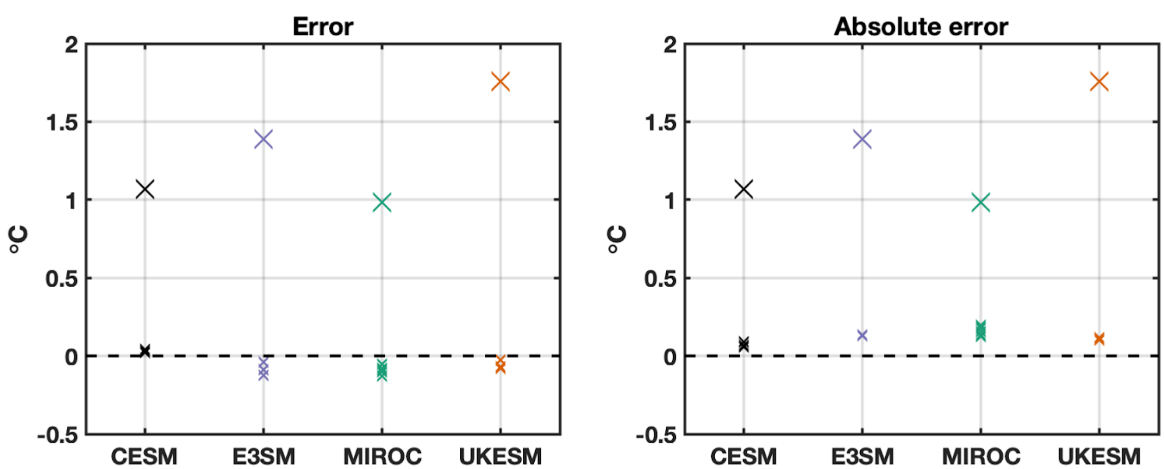

Figure S1: controller error averaged over the last 20 years of the G6-1.5K-SAI experiment, measured in distance from the temperature target in °C. Large X's denote the non-SAI (SSP2-4.5) ensemble average during the same period (i.e., the amount of warming to be offset by the intervention). The black dashed line denotes each model's respective temperature target. Small x's denote individual ensemble members of G6-1.5K-SAI. The left panel plots average error and the right panel plots average absolute error, as defined in Section S1 above.

S2: Aerosol effective radius

Here, we document the process by which we derive dry effective aerosol radius from model output. From aerosol mass mixing ratio X (units kg/kg air), aerosol number concentration per unit mass of air N_{mass} (units 1/kg air), and sulfate density $\rho_{sulfate}$ (1770 kg/m^3 for CESM and E3SM; 1769 kg/m^3 for MIROC; and 1679 kg/m^3 for UKESM), we can compute mean volume v for each mode i:

$$v_i = \frac{X_i}{N_{mass,i}\rho_{sulfate}} \tag{S1}$$

For a lognormal distribution, v is related to mean radius r and the geometric standard deviation σ_g for each mode by:

$$v_i = \frac{4}{3}\pi r_i^3 \exp\left(\frac{9}{2}\left(\ln \sigma_{g,i}\right)^2\right) \tag{S2}$$

After solving for r, we can compute the moments of the lognormal distribution for each mode, which are related to r, σ_g, and the number of particles per unit volume N (note that N is distinct from N_{mass}). The n^{th} moment M_n of a lognormal distribution with multiple modes is given by the sum of the moments of each mode:

$$M_n = \sum_i N_i r_i^n \exp\left(\frac{n^2}{2}\left(\ln \sigma_{g,i}\right)^2\right) \tag{S3}$$

Finally, we compute R_{eff} as the ratio of the third and second moments of the lognormal distribution:

$$R_{eff} = \frac{M_3}{M_2} = \frac{\sum_i N_i r_i^3 \exp\left(\frac{9}{2}(\ln \sigma_{g,i})^2\right)}{\sum_i N_i r_i^2 \exp\left(\frac{4}{2}(\ln \sigma_{g,i})^2\right)} \tag{S4}$$

For this study, N, which appears in Eq. S4, is not conveniently available as climate model output, but N_{mass} is available. N_{mass} is easily converted to N by multiplying by the density of air ρ_{air}, $N = N_{mass}\rho_{air}$. In this case, $N_{mass}\rho_{air}$ can be substituted for N in Eq. S4:

$$R_{eff} = \frac{M_3}{M_2} = \frac{\sum_i N_{mass,i}\, \rho_{air}\, r_i^3 \exp\left(\frac{9}{2}(\ln \sigma_{g,i})^2\right)}{\sum_i N_{mass,i}\, \rho_{air}\, r_i^2 \exp\left(\frac{4}{2}(\ln \sigma_{g,i})^2\right)} \tag{S5}$$

In Eq. S5, ρ_{air} is common to all terms in the numerator and denominator and is independent of i, and therefore cancels out. As such, we use N_{mass} as a direct substitute for N in Eq. S4 as follows:

$$R_{eff} = \frac{M_3}{M_2} = \frac{\sum_i N_{mass,i} r_i^3 \exp\left(\frac{9}{2}(\ln \sigma_{g,i})^2\right)}{\sum_i N_{mass,i} r_i^2 \exp\left(\frac{4}{2}(\ln \sigma_{g,i})^2\right)} \tag{S6}$$

CESM and MIROC directly compute and output wet effective aerosol radius, which we plot in Figure S2 below.

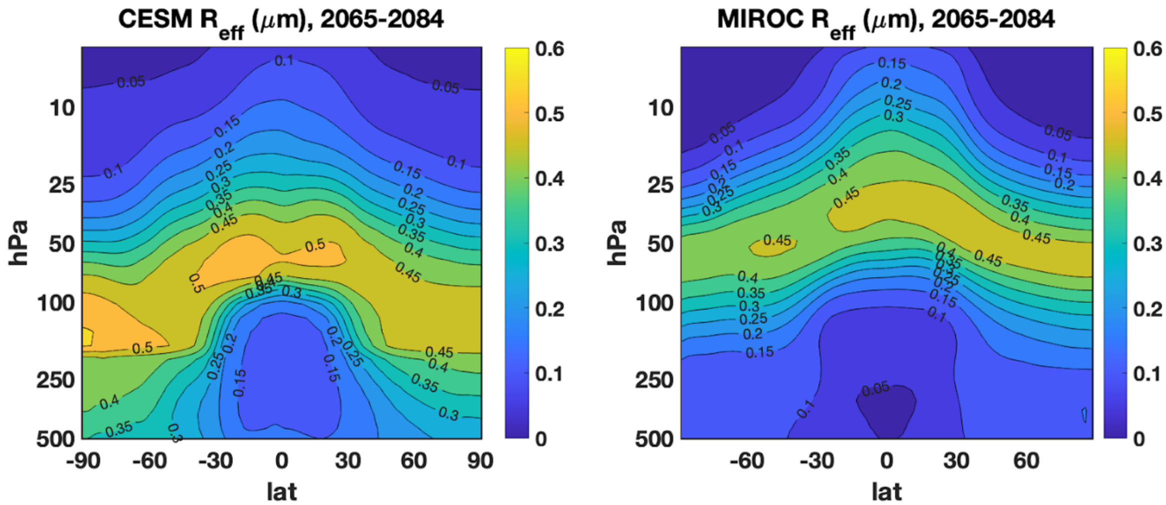

Figure S2: zonal means of wet effective aerosol radius, as output directly by the model, for CESM and MIROC. Data are averaged over the last 20 years (2065-2084) of G6-1.5K-SAI.

S3: Figures visualizing ITCZ position, strength, and width

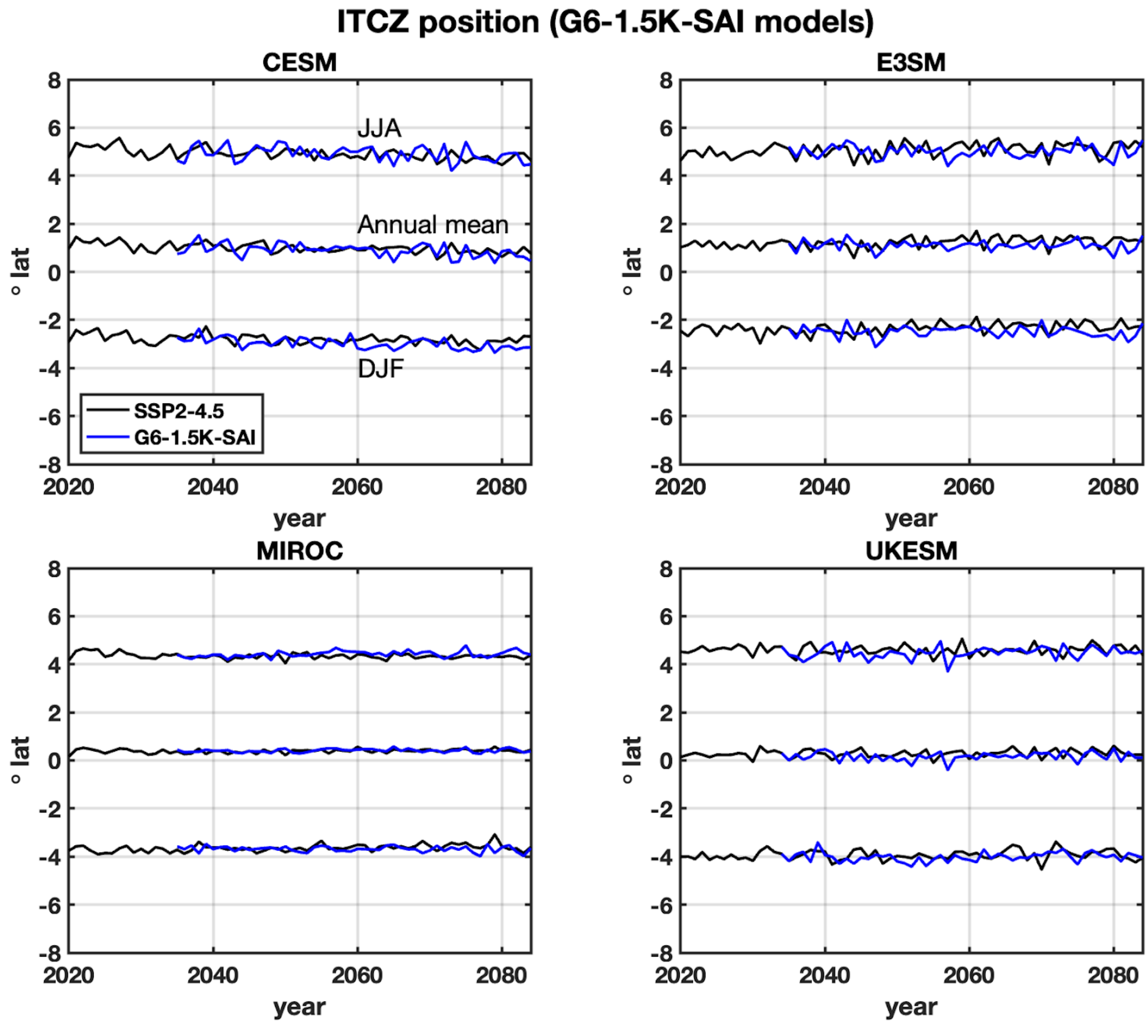

Figure S3: ITCZ position for G6-1.5K-SAI participating models. Summer (JJA, June-July- August), winter (DJF, December-January-February) and annual means are included as indicated, with JJA values in the northern hemisphere, annual mean values near the equator, and DJF values in the southern hemisphere.

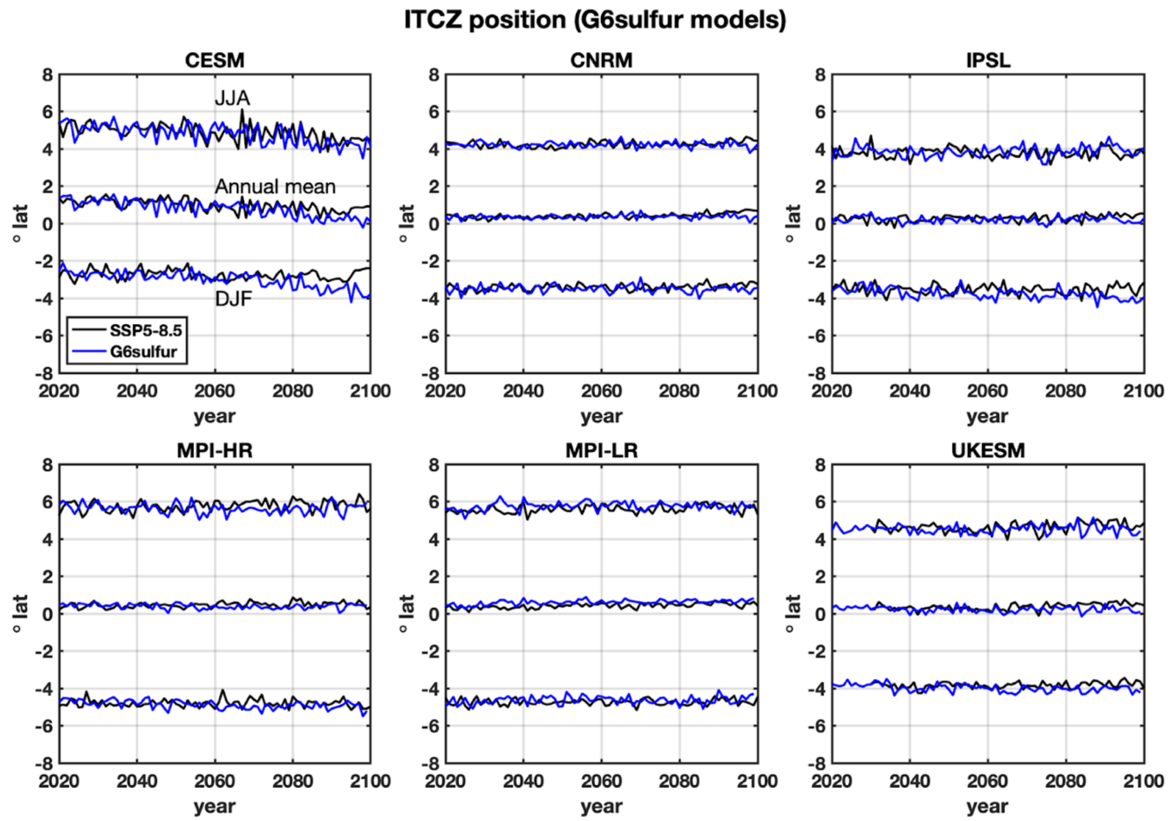

Figure S4: ITCZ position for G6sulfur participating models. Summer (JJA, June-July- August), winter (DJF, December-January-February) and annual means are included as indicated, with JJA values in the northern hemisphere, annual mean values near the equator, and DJF values in the southern hemisphere.

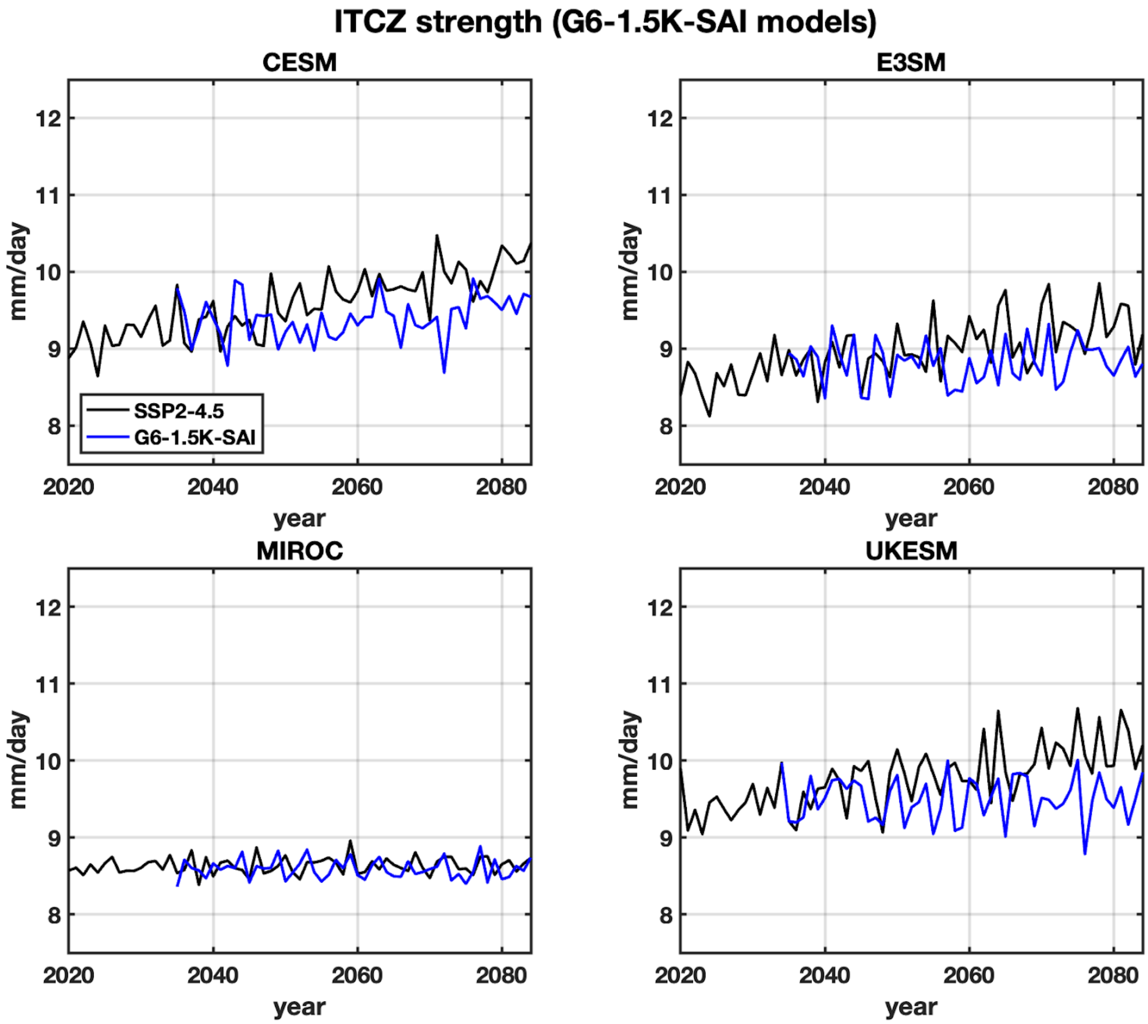

Figure S5: ITCZ strength, as measured by the maximum of zonal mean precipitation, for ensemble means of SSP2-4.5 and G6-1.5K-SAI for all participating models.

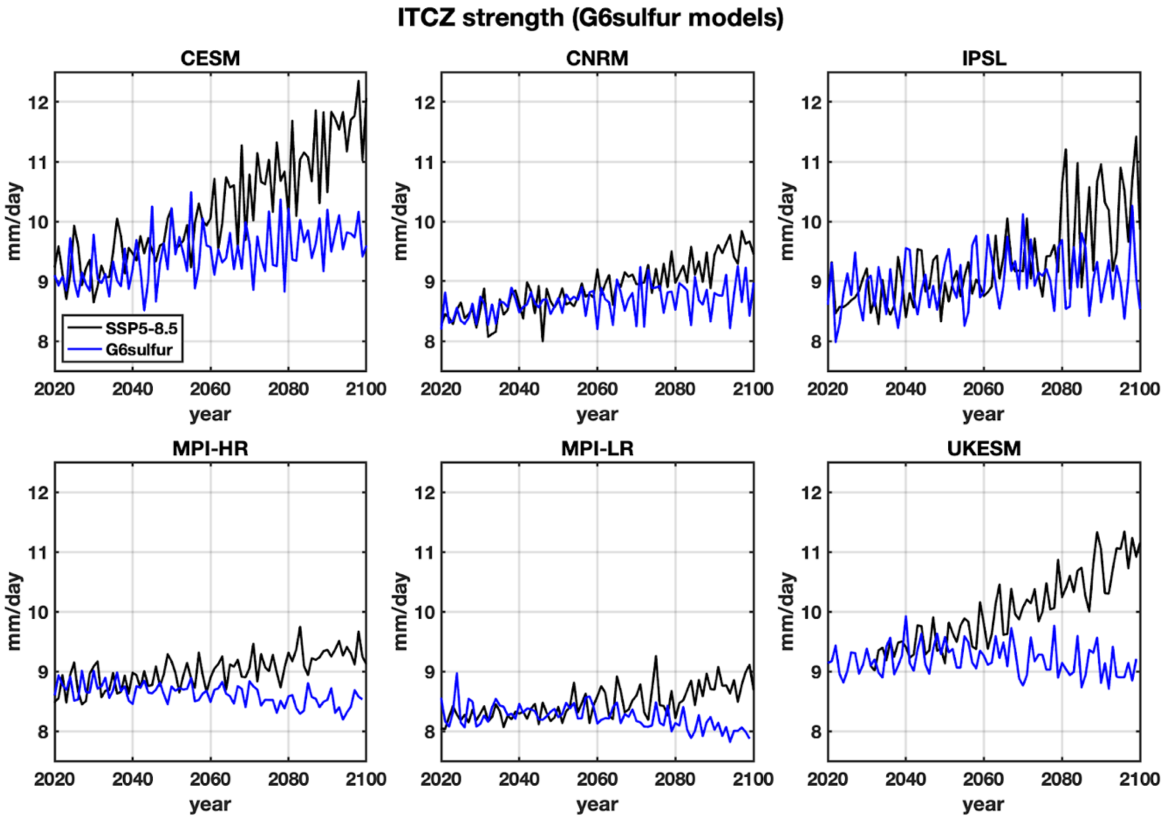

Figure S6: ITCZ strength, as measured by the maximum of zonal mean precipitation, for ensemble means of SSP5-8.5 and G6sulfur for all participating models.

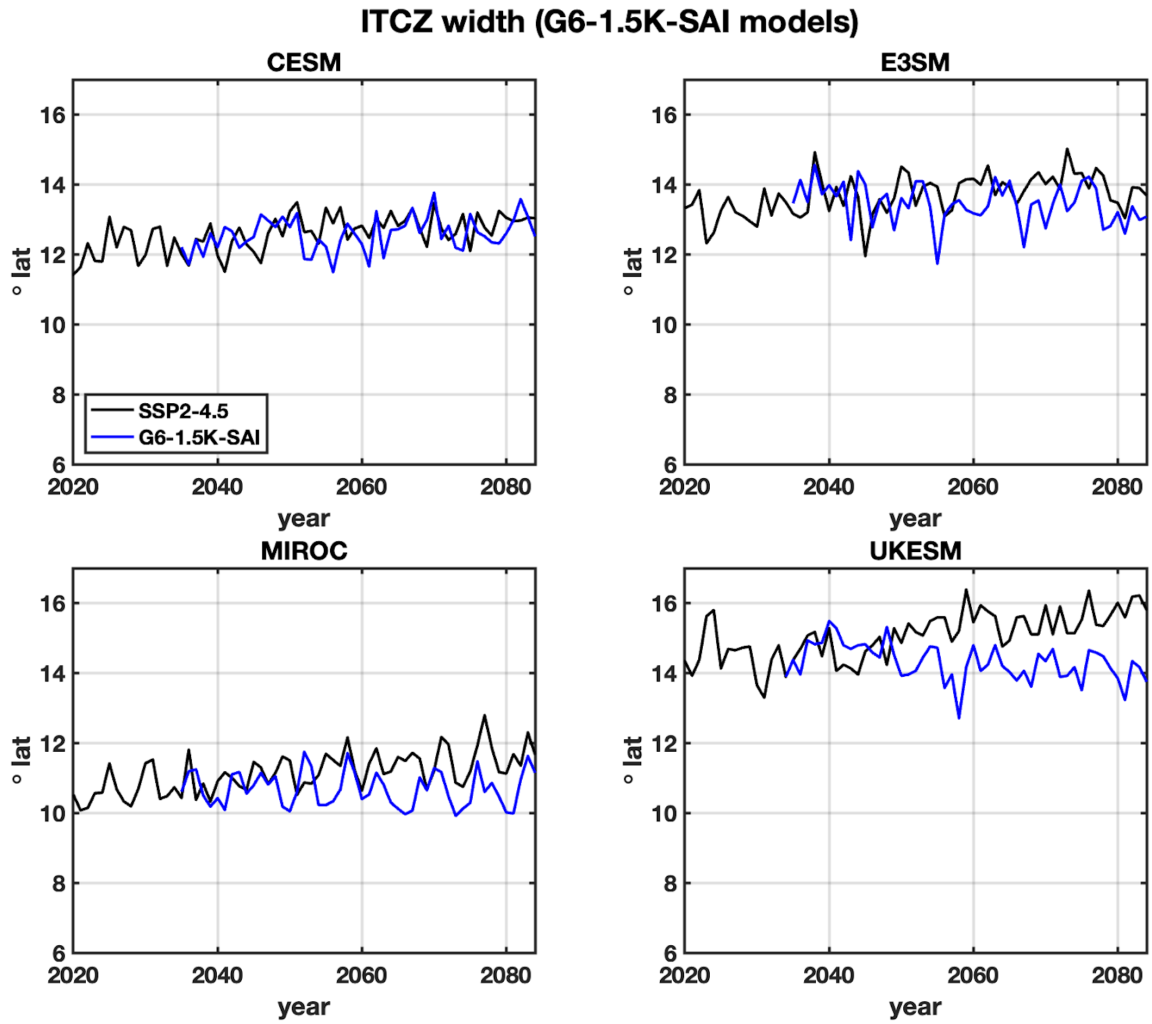

Figure S7: ITCZ width, as measured by the size of the latitude band which contains the zonal mean maximum where the precipitation rate is greater than 5 mm/day, for ensemble means of SSP2-4.5 and G6-1.5K-SAI for all participating models.

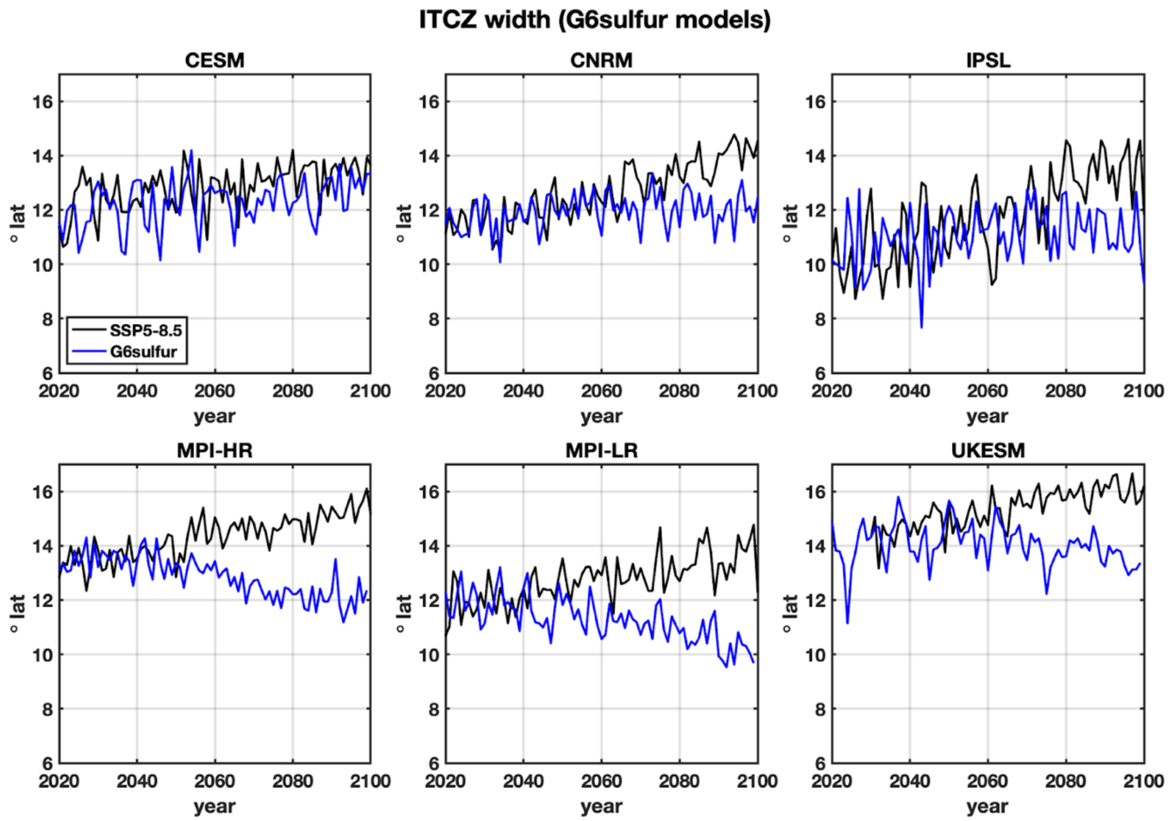

Figure S8: ITCZ width, as measured by the size of the latitude band which contains the zonal mean maximum where the precipitation rate is greater than 5 mm/day, for ensemble means of SSP5-8.5 and G6sulfur for all participating models.