

# **Spatially uneven impacts of stratospheric aerosol injection on compound dry-heat wave events in the GeoMIP G6sulfur experiment**

Cuini Qi<sup>1</sup>, Chloe Yuchao Gao<sup>1\*</sup>, Hyemi Kim<sup>2</sup>, Ben Kravitz<sup>3</sup>, Xiaohan Sally Li<sup>4</sup>, Lili Xia<sup>5</sup>

<sup>1</sup>Department of Atmospheric and Oceanic Sciences & Shanghai Key Laboratory of Ocean-Land-Atmosphere Boundary Dynamics and Climate Change, Fudan University, Shanghai, China

<sup>2</sup>Department of Science Education, Ewha Womans University, Seoul, Korea

<sup>3</sup>Department of Earth and Atmospheric Sciences, Indiana University, Bloomington, Indiana, USA

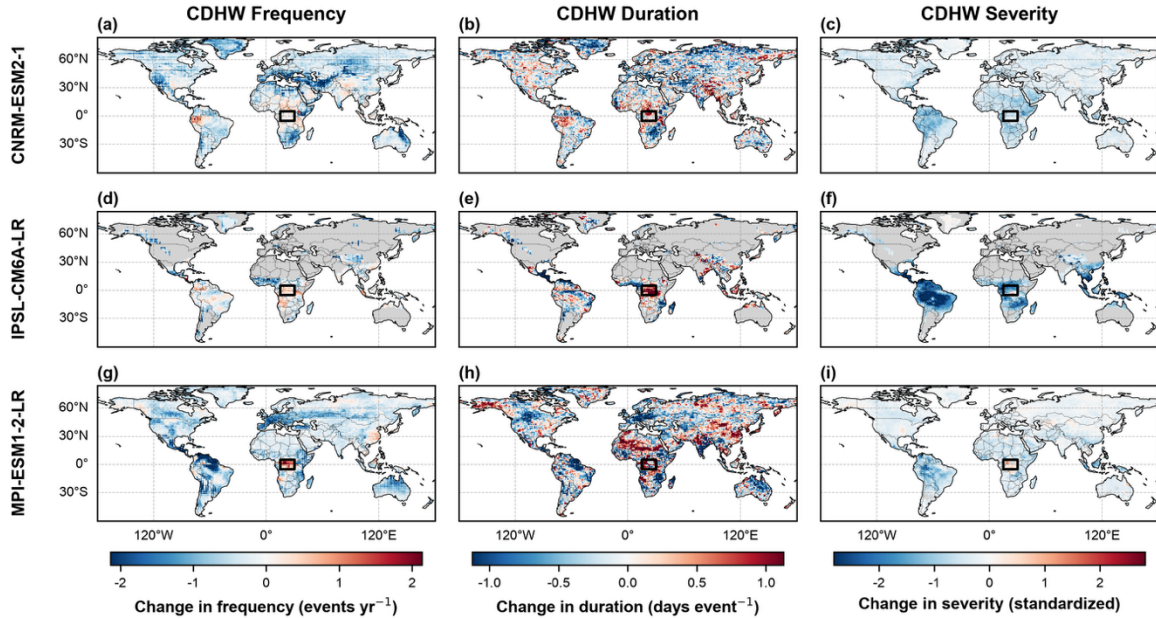
<sup>4</sup>Department of the Geophysical Sciences, The University of Chicago, Chicago, Illinois, USA

<sup>5</sup>Department of Environmental Sciences, Rutgers University, New Brunswick, New Jersey, USA

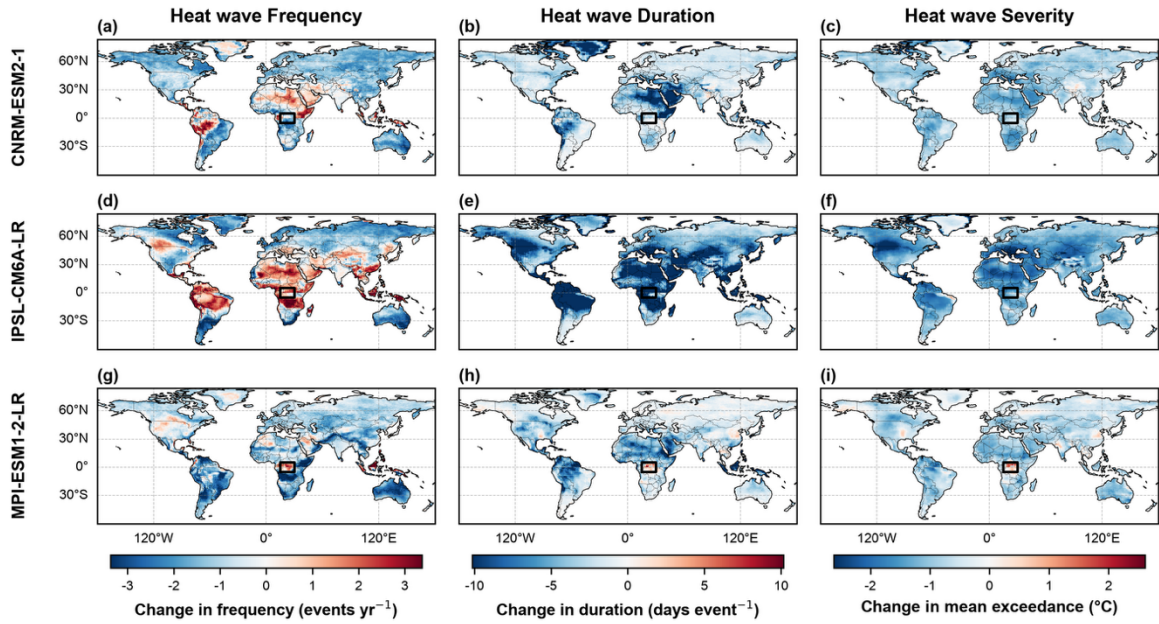
*Correspondence to:* Chloe Yuchao Gao, [gyc@fudan.edu.cn](mailto:gyc@fudan.edu.cn)

## Contents of this file

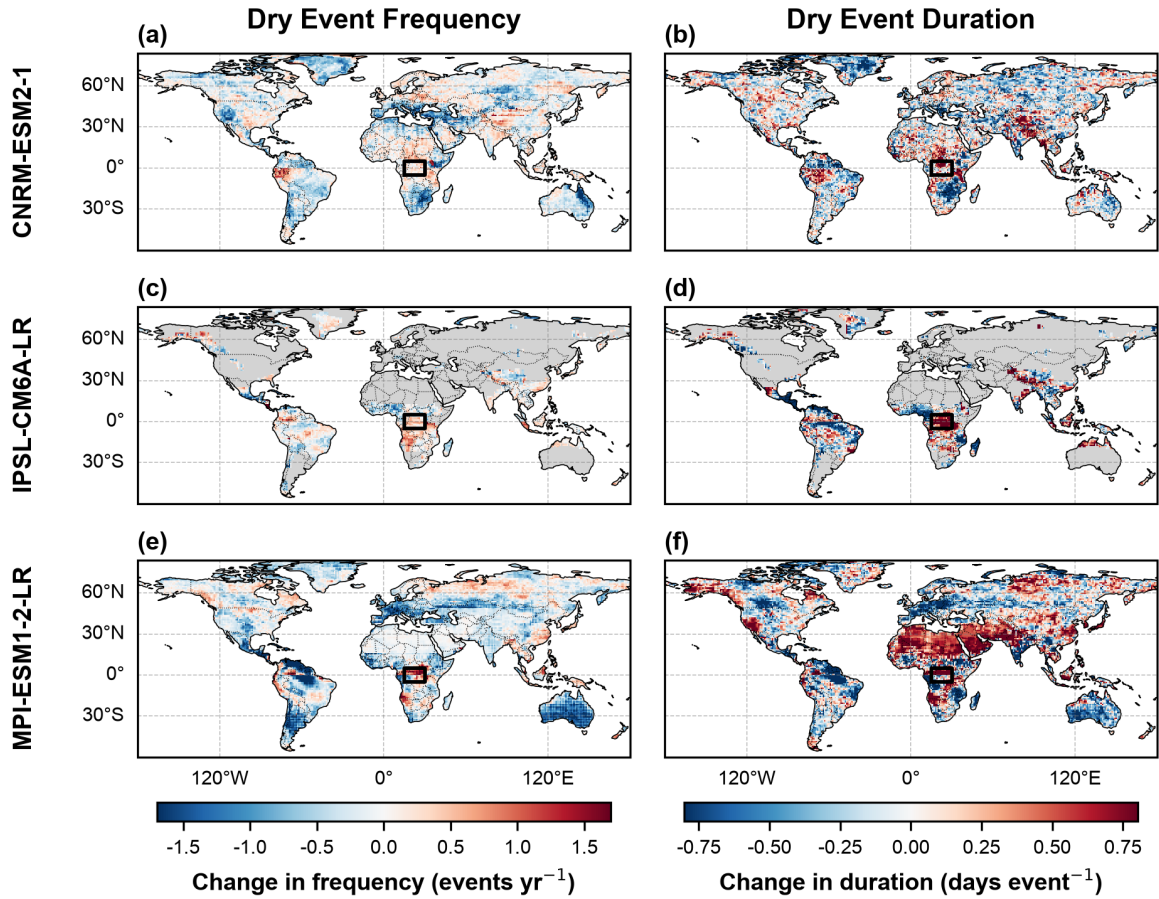
Figures S1 to S8, Table S1



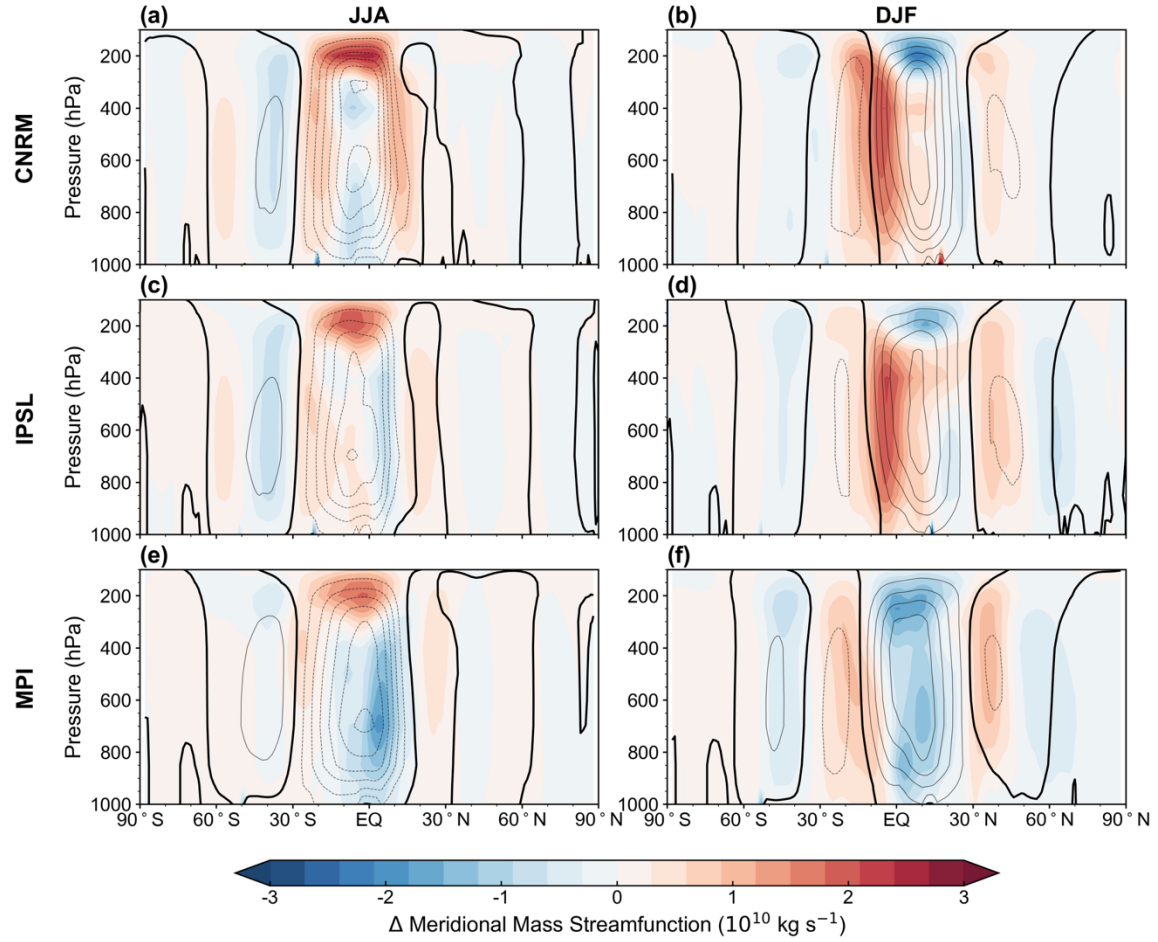
**Figure S1.** Spatial distributions of changes in CDHW characteristics under G6sulfur relative to SSP5-8.5 during 2071–2100. Results are shown for CNRM-ESM2-1 (a–c), IPSL-CM6A-LR (d–f), and MPI-ESM1-2-LR (g–i). Columns show changes in CDHW frequency (a, d, g; events yr<sup>-1</sup>), duration (b, e, h; days event<sup>-1</sup>), and severity (c, f, i; dimensionless). The analysis is restricted to the local summer season, defined as JJA in the Northern Hemisphere and DJF in the Southern Hemisphere. Grey shading in the IPSL-CM6A-LR panels indicates grid cells where precipitation during the local summer is exactly zero in the historical period. Dry events and, consequently, CDHWs cannot be identified in these grid cells (see Sect. 4 of the main text). The three models use the same colour scale within each column. The scale is based on the 1st to 99<sup>th</sup> percentiles of the pooled land values, except for the duration column, where the 90<sup>th</sup> percentile of the absolute changes is used so that the largest reductions correspond to the darkest colour. Maps cover the latitude range from 60°S–84°N.



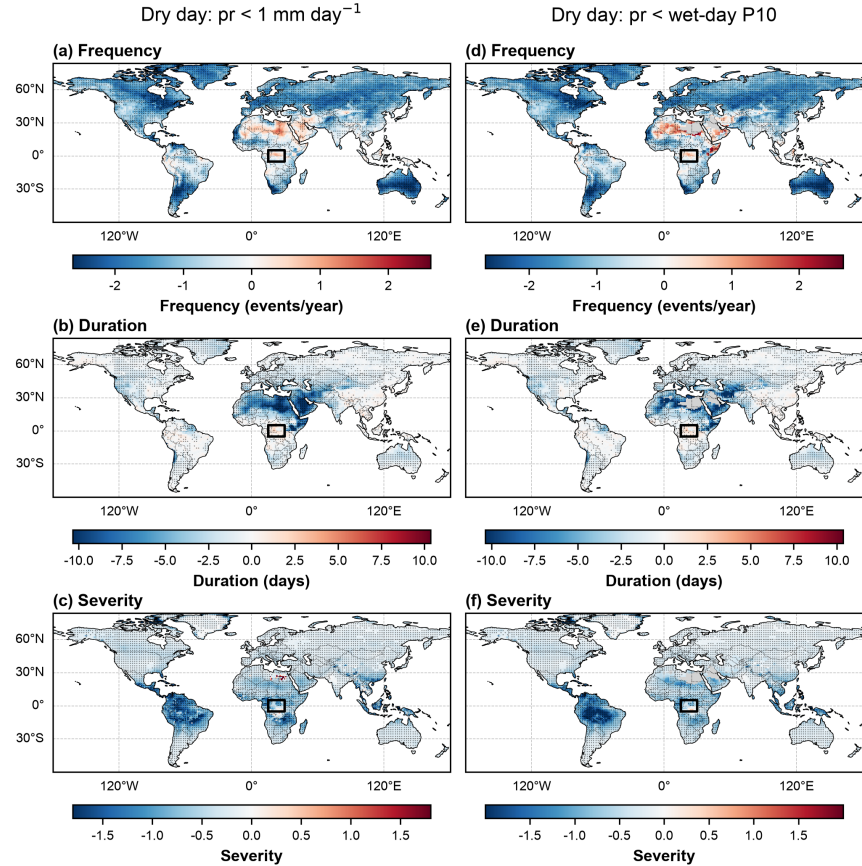
**Figure S2.** Spatial distributions of changes in HW characteristics under G6sulfur relative to SSP5-8.5 during 2071–2100. Results are shown for CNRM-ESM2-1 (a–c), IPSL-CM6A-LR (d–f), and MPI-ESM1-2-LR (g–i). Columns show changes in HW frequency (a, d, g; events yr<sup>-1</sup>), duration (b, e, h; days event<sup>-1</sup>), and severity (c, f, i; °C). HW characteristics are evaluated during the local summer season, defined as JJA in the Northern Hemisphere and DJF in the Southern Hemisphere. Within each column the three models share a common colour scale (the 1st–99<sup>th</sup> percentile range of the pooled land values; for the duration column the 90<sup>th</sup> percentile of the absolute change, so that the largest reductions are shown by the end colour of the scale). Maps are displayed for 60°S–84°N.



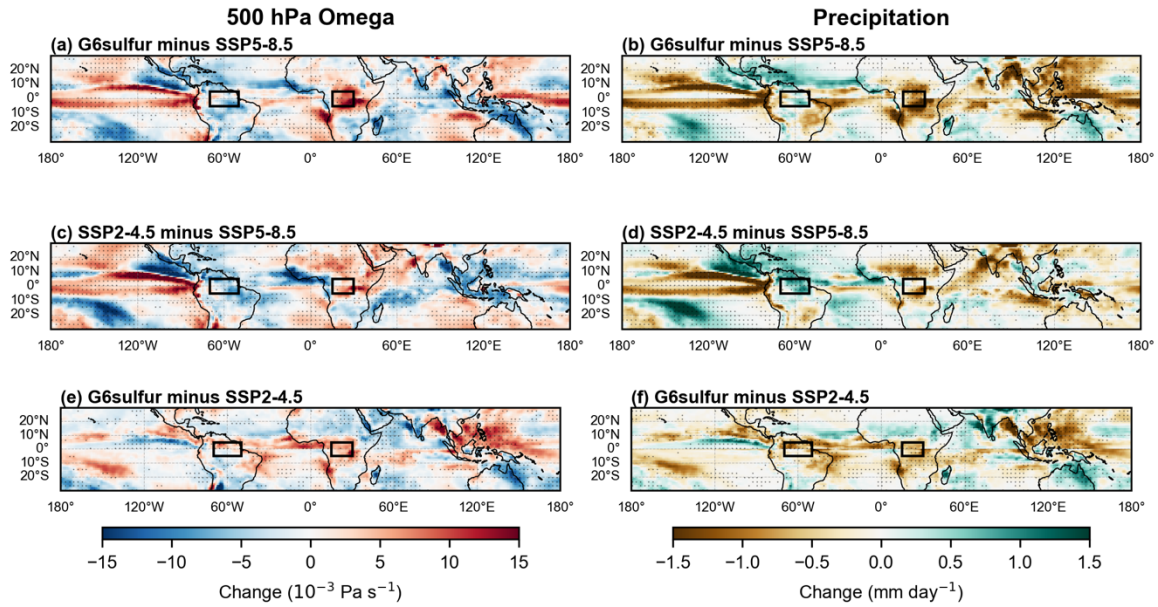
**Figure S3.** Spatial distributions of changes in dry event characteristics under G6sulfur relative to SSP5-8.5 during 2071–2100. Results are shown for CNRM-ESM2-1 (a, b), IPSL-CM6A-LR (c, d), and MPI-ESM1-2-LR (e, f). The left and right columns show changes in dry event frequency (a, c, e; events yr<sup>-1</sup>) and duration (b, d, f; days event<sup>-1</sup>), respectively. The analysis is restricted to the local summer season, defined as JJA in the Northern Hemisphere and DJF in the Southern Hemisphere. Grey shading in the IPSL-CM6A-LR panels marks grid cells where the historical local summer *P*10 is exactly zero, so that dry events cannot be identified there (see Sect. 4 of the main text). Within each column the three models share a common colour scale (the 1st–99<sup>th</sup> percentile range of the pooled land values; for the duration column the 90<sup>th</sup> percentile of the absolute change, so that the largest reductions are shown by the end colour of the scale). Maps are displayed for 60°S–84°N.



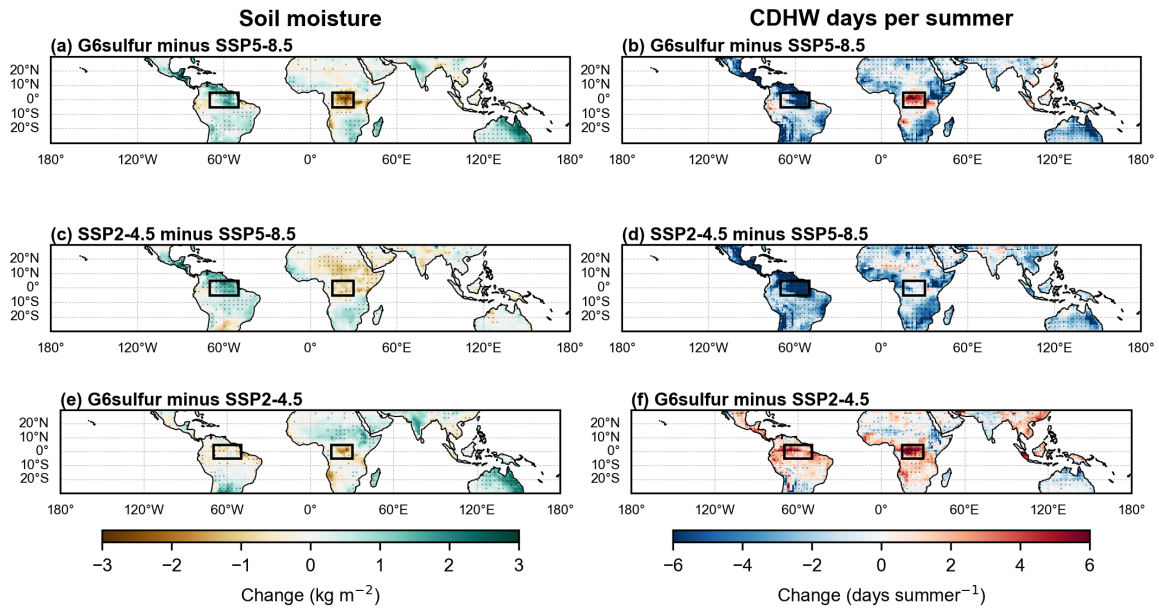
**Figure S4.** Changes in the zonal-mean meridional mass streamfunction under G6sulfur relative to SSP5-8.5 during JJA and DJF. Results are shown for CNRM-ESM2-1 (a, b), IPSL-CM6A-LR (c, d), and MPI-ESM1-2-LR (e, f). The left column (a, c, e) shows the response during JJA, while the right column (b, d, f) shows the response during DJF. Positive and negative values indicate changes in the direction and strength of the zonal-mean meridional overturning circulation.



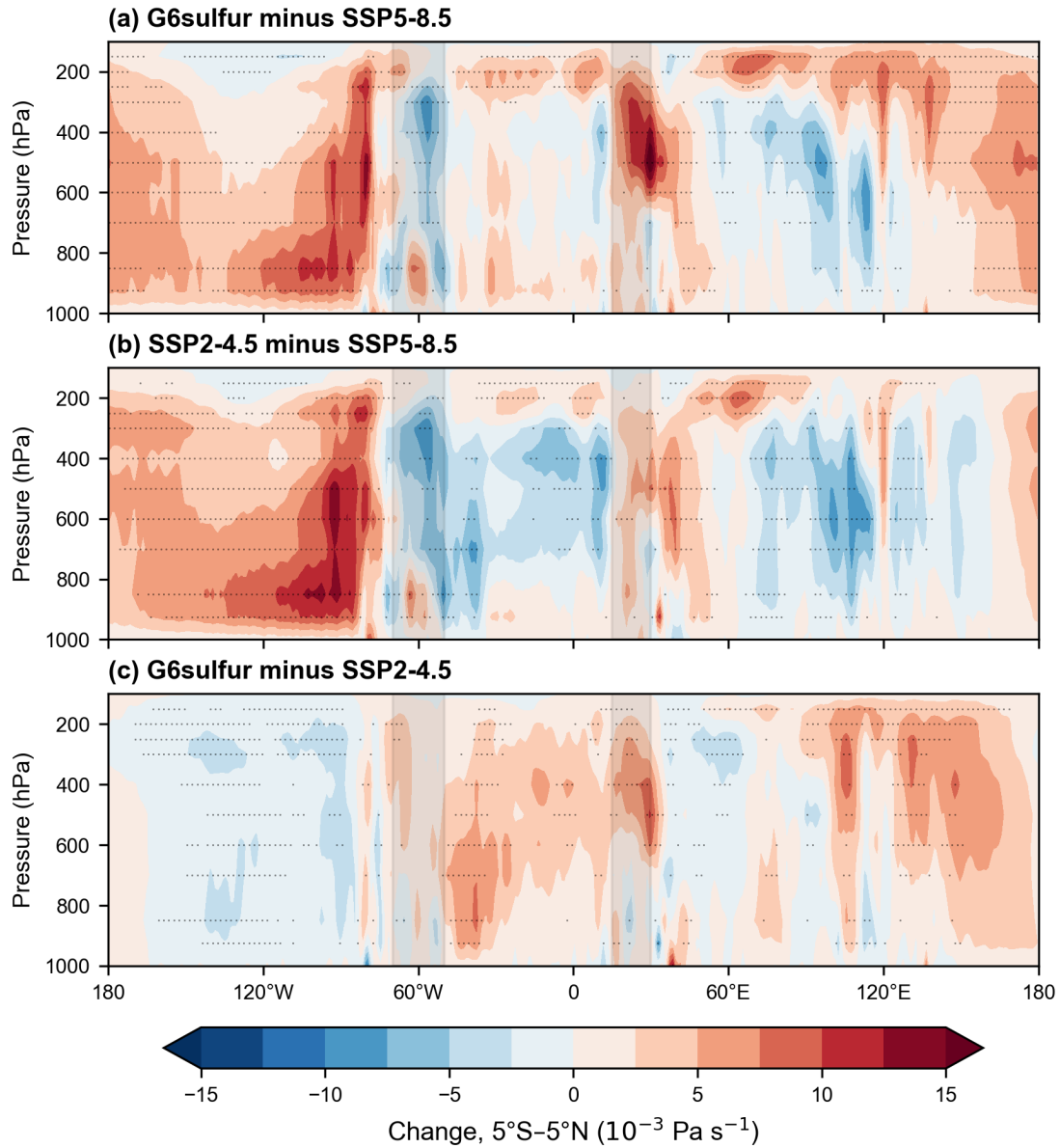
**Figure S5.** Sensitivity of the CDHW response to the dry-day criterion. As in Fig. 2, but with dry days defined by (a–c, left column) a fixed threshold (daily precipitation  $< 1 \text{ mm day}^{-1}$ ) and (d–f, right column) the 10<sup>th</sup> percentile of wet days ( $\geq 1 \text{ mm day}^{-1}$ ) during the local summer of the 1985–2014 reference period; the heat wave criterion, the three-day event definition and the severity formulation are unchanged, with the hydrological component evaluated relative to the corresponding threshold. Columns show MME differences between G6sulfur and SSP5-8.5 during 2071–2100 in CDHW frequency (events  $\text{yr}^{-1}$ ), duration (days  $\text{event}^{-1}$ ) and severity (dimensionless). Stippling indicates grid cells where all models agree on the sign of the change; grey shading in the right column marks grid cells where the wet day threshold is undefined (fewer than 30 wet days in the reference period). Note that over arid regions nearly every summer day satisfies these criteria, so that CDHWs there reduce to heat waves. The Central African region is outlined with black boxes; maps are displayed for 60°S–84°N.



**Figure S6.** As Fig. 9, but for the full tropics (30°S–30°N): (a, c, e) 500 hPa vertical velocity (positive downward) and (b, d, f) precipitation for G6sulfur minus SSP5-8.5, SSP2-4.5 minus SSP5-8.5 and G6sulfur minus SSP2-4.5, 2071–2100 local summer, MME. Stippling marks grid cells where all models with a defined value agree on the sign. Boxes mark Central Africa (15°–30°E, 5°S–5°N) and the Amazon box (70°–50°W, 5°S–5°N).



**Figure S7.** As Fig. S6, but for (a, c, e) surface soil moisture and (b, d, f) CDHW days per summer (land only).



**Figure S8.** Longitude-pressure sections of the change in pressure velocity averaged over 5°S–5°N (positive downward), 2071–2100 local summer, MME, for (a) G6sulfur minus SSP5-8.5, (b) SSP2-4.5 minus SSP5-8.5 and (c) G6sulfur minus SSP2-4.5. Grey shading marks the longitudes of the Central African (15°–30°E) and Amazon (70°–50°W) boxes; dots mark sign agreement of all three models.

**Table S1.** Regional mean changes over Central Africa (15°–30°E, 5°S–5°N) and the Amazon box (70°–50°W, 5°S–5°N), 2071–2100 local summer, MME, for the three differences of Fig. 9. An asterisk marks values whose sign is shared by all three models.  $\omega$  is positive downward; net surface radiation is positive downward and the turbulent fluxes positive upward, as in Fig. 8. The first column equals the sum of the other two.

| Variable                                       | Central Africa                |                               |                               | Amazon                        |                               |                               |
|------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
|                                                | G6sulfur<br>minus<br>SSP5-8.5 | SSP2-4.5<br>minus<br>SSP5-8.5 | G6sulfur<br>minus<br>SSP2-4.5 | G6sulfur<br>minus<br>SSP5-8.5 | SSP2-4.5<br>minus<br>SSP5-8.5 | G6sulfur<br>minus<br>SSP2-4.5 |
| 500 hPa $\omega$<br>( $10^{-3}$ Pa s $^{-1}$ ) | +9.3*                         | +3.9                          | +5.4                          | -2.1                          | -4.1                          | +2.0                          |
| Precipitation<br>(mm day $^{-1}$ )             | -0.96*                        | -0.35*                        | -0.61*                        | +0.09                         | +0.58*                        | -0.50                         |
| 500 hPa<br>relative<br>humidity<br>(%)         | -4.7*                         | -3.8*                         | -0.9                          | -1.6*                         | -1.7*                         | +0.1                          |
| Total cloud<br>cover (%)                       | -3.9*                         | +0.5                          | -4.5*                         | +0.1                          | +2.6*                         | -2.6                          |
| Net surface<br>radiation (W<br>m $^{-2}$ )     | +3.8                          | +12.1*                        | -8.3*                         | -11.3*                        | -4.3*                         | -7.0*                         |
| Latent heat<br>flux (W<br>m $^{-2}$ )          | -1.1                          | +10.6*                        | -11.7*                        | -4.6*                         | +4.9*                         | -9.5*                         |
| Sensible<br>heat flux (W<br>m $^{-2}$ )        | +4.7*                         | +1.6                          | +3.1                          | -6.5*                         | -9.2*                         | +2.6                          |
| Surface soil<br>moisture (kg<br>m $^{-2}$ )    | -1.41*                        | -0.69                         | -0.72                         | +0.84*                        | +1.10*                        | -0.26                         |

|                                                    |        |        |        |        |        |       |
|----------------------------------------------------|--------|--------|--------|--------|--------|-------|
| Summer<br>mean Tmax<br>(°C)                        | -0.79  | -1.58* | +0.79* | -2.19* | -2.67* | +0.48 |
| Dry days<br>per summer                             | +2.5*  | -1.5   | +4.0*  | -4.2*  | -6.8*  | +2.6  |
| CDHW<br>days per<br>summer                         | +2.9*  | -1.0*  | +3.9*  | -5.3*  | -7.8*  | +2.4  |
| CDHW<br>duration<br>(days<br>event <sup>-1</sup> ) | +0.74* | +0.13  | +0.66* | -0.49* | -0.69* | +0.20 |
| CDHW<br>frequency<br>(events yr <sup>-1</sup> )    | +0.40* | -0.22* | +0.62* | -0.72* | -1.14* | +0.42 |