

Electronic Supplementary Material to: Global Change in Agricultural Flash Drought over the 21st Century*

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Comparison with ERA5

The following plots compare the CMIP6 multi-model mean historical drought frequency for 1960-1990 against ERA5 for both shallow and root zone droughts. Consistent with the rest of the analysis, droughts lasting >3 pentads, >6 pentads and >9 pentads are considered. Unlike the ERA5 data, which is a single realisation, the CMIP6 data is a multi-model mean. The CMIP6 results are thus generally smoother, especially for the longer droughts. It can be seen that the spatial pattern in CMIP6 drought occurrence is broadly similar to ERA5 but that droughts tend to be slightly more frequent in ERA5 than in the CMIP6 data (especially over South America). It should be noted, however, that – especially for the longest and rarest droughts, it is difficult to draw robust conclusions on occurrence from a 30-year dataset.

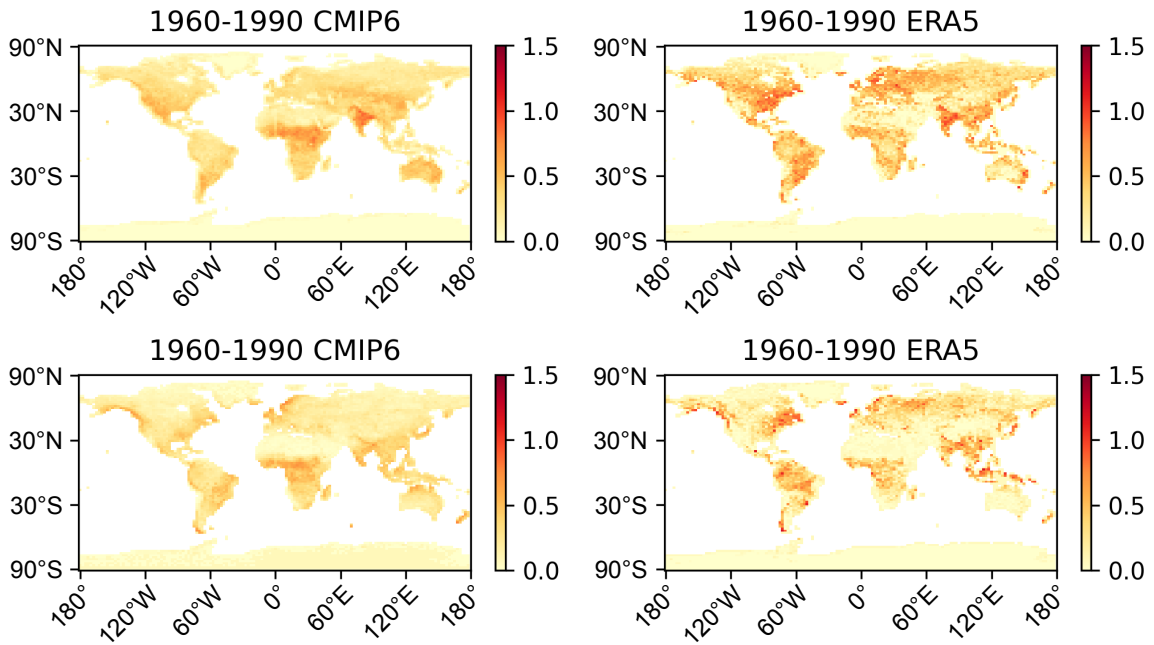


Fig. S1. Droughts lasting >3 pentads (upper panels show upper level soil droughts and lower panels show root zone droughts)

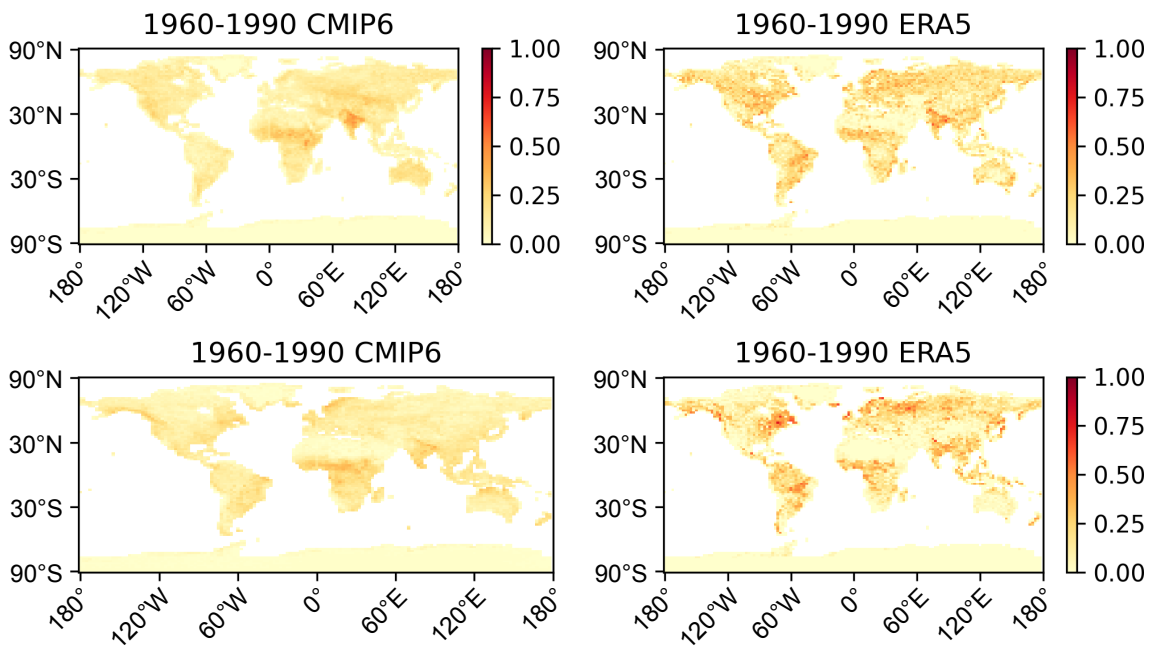


Fig. S2. As for Fig. S1 but for droughts lasting >6 pentads

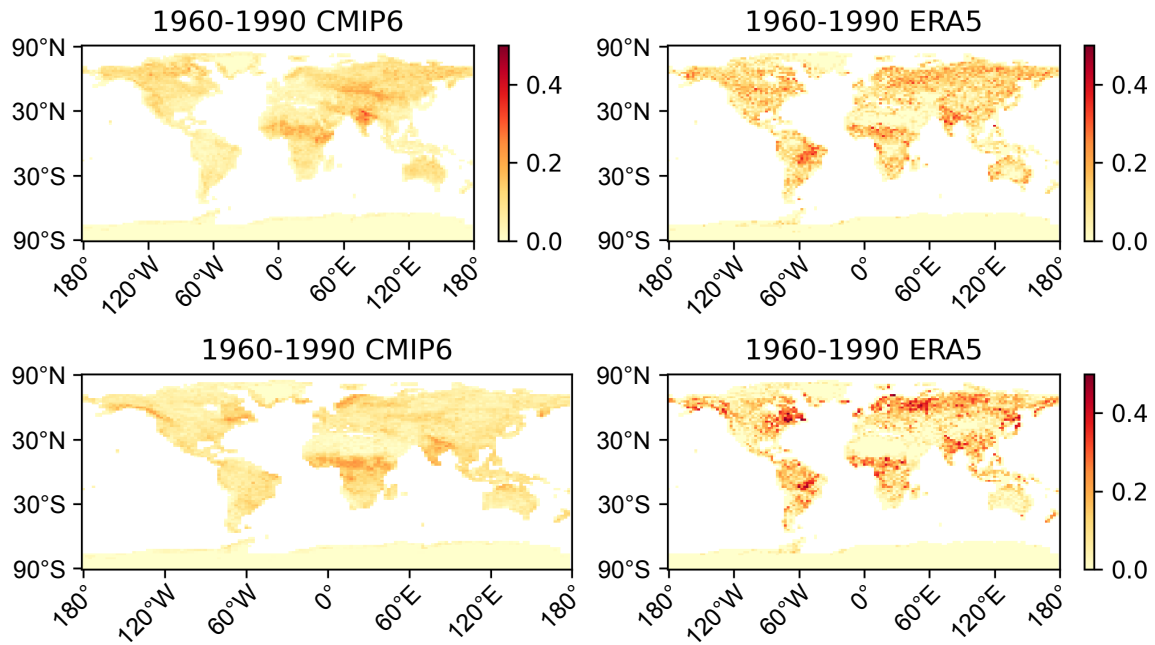


Fig. S3. As for Fig. S1 but for droughts lasting >9 pentads

Additional maps of multi-model projected changes in drought frequency

The following plots are analogous to Fig. 3 in the text for:

- Drought lengths >3 pentads, >7 pentads, >10 pentads
- 2030–2060 and 2060–2090
- SSP245 and SSP585

Scenarios, drought lengths and time slices in the figure titles. Note the changing colour scales.

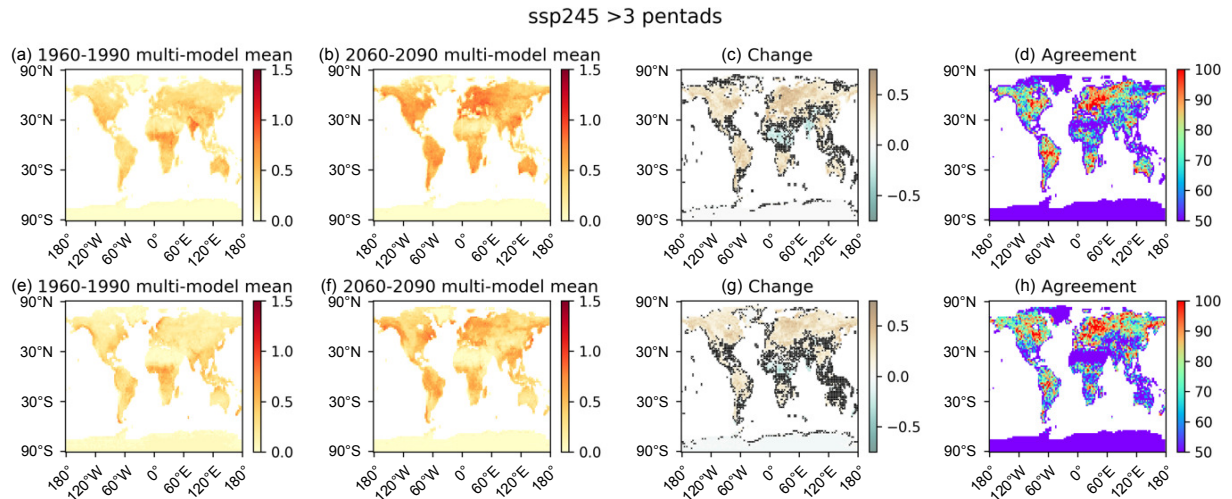


Fig. S4. Multi-model median projected change in flash drought occurrence (expressed as the mean number of droughts per year). From left to right: (a) and (e) present day (1960–1990); (b) and (f) future (2060–2090); (c) and (g) future – present; (d) and (h) the percentage of models that agree on the polarity of the multi-model mean projected change. Hashing on the future-present plots indicates that the projected change is insignificant at the 5% level (Welch t-test). The plot is for an SSP2-4.5 scenario; drought length > 3 pentads (with the pre-2015 data taken from the historical simulation). The top panels (a–d) are for surface droughts and the bottom panels (e–h) are for root-zone drought.

ssp585 > 3 pentads

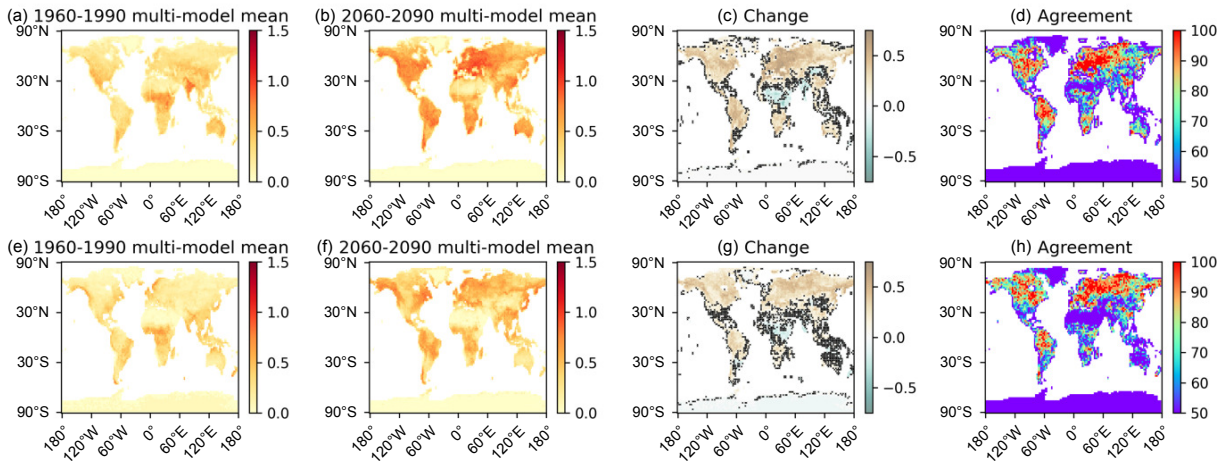


Fig. S5. As for Fig. S4 but for SSP5-8.5 and drought length > 3 pentads

ssp245 > 6 pentads

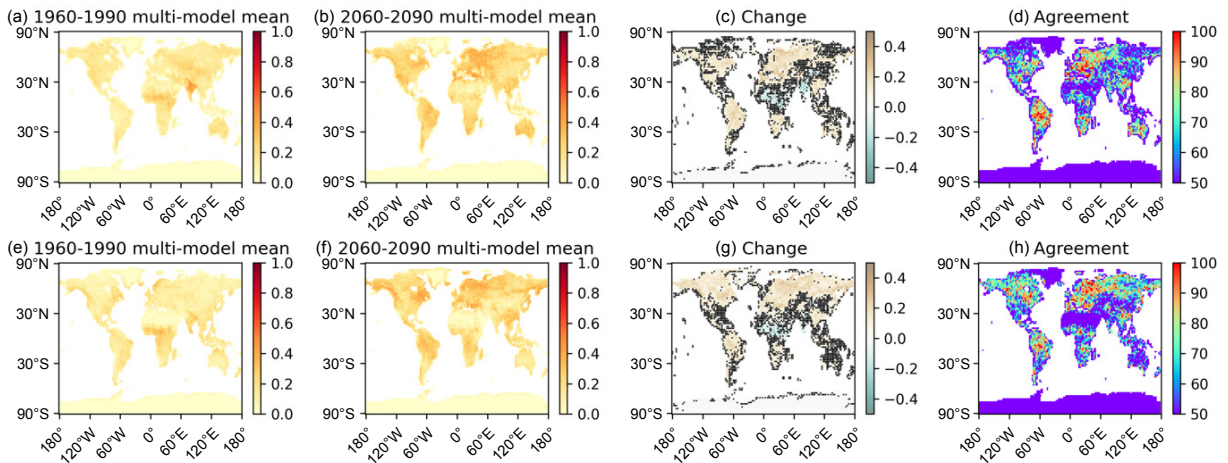


Fig. S6. As for Fig. S4 but for SSP2-4.5 and drought length > 6 pentads

ssp585 > 6 pentads

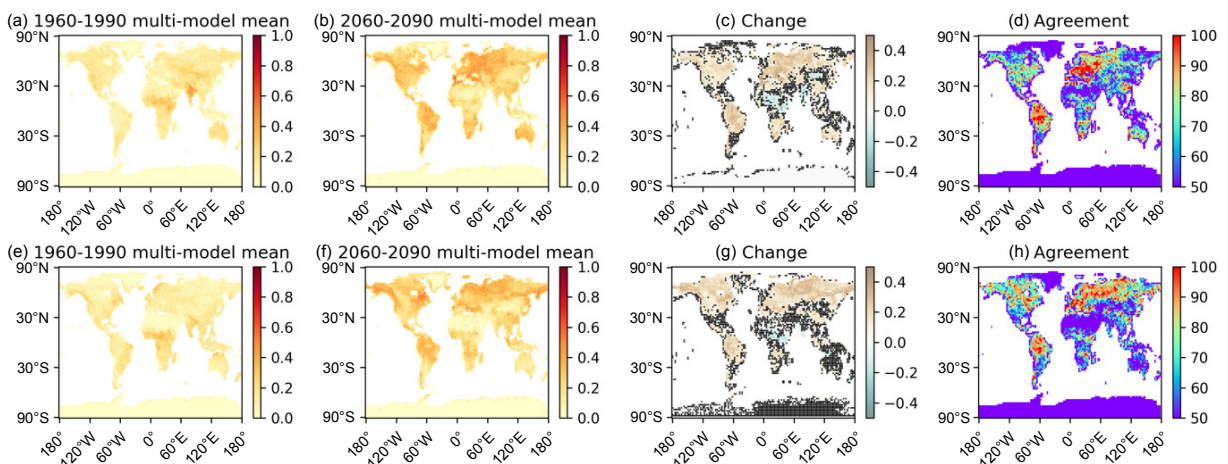


Fig. S7. As for Fig. S4 but for SSP5-8.5 and drought length > 6 pentads

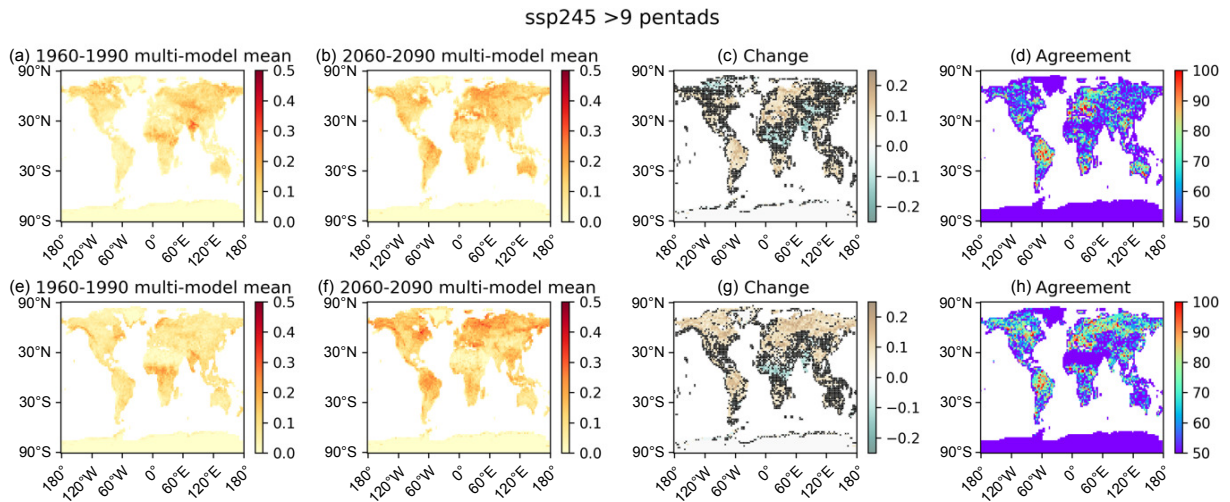


Fig. S8. As for Fig. S4 but for SSP2-4.5 and drought length > 9 pentads

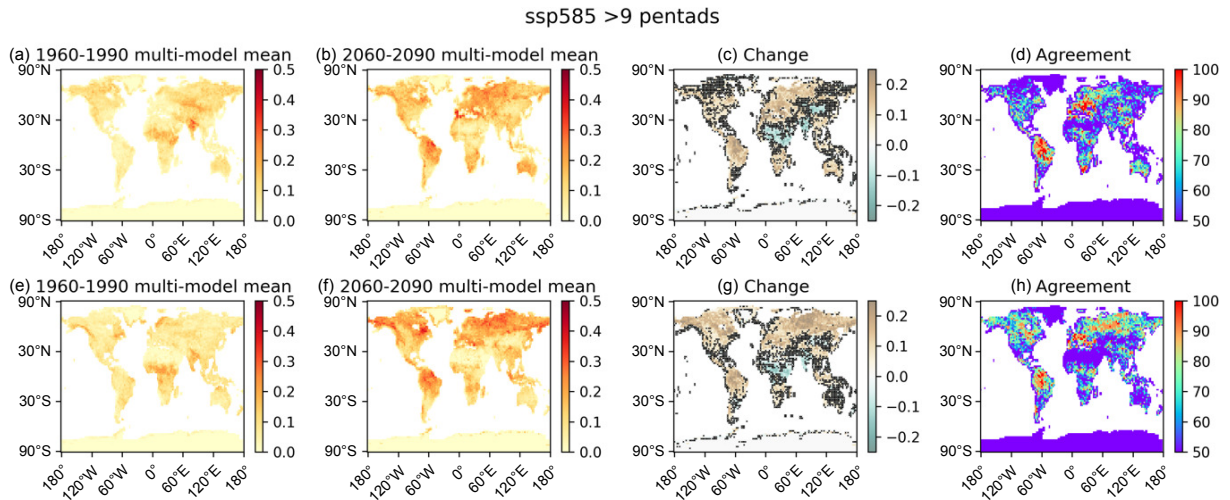


Fig. S9. As for Fig. S4 but for SSP5-8.5 and drought length > 9 pentads

Additional maps of multi-model projected changes in drought frequency, soil moisture, relative humidity, temperature and precipitation

The following plots are analogous to Fig. 4 in the text for:

- 2030–2060 and 2060–2090
- SSP245 and SSP585

Scenarios and time slices in the figure titles. Note the colour scheme change compared to Fig. 4.

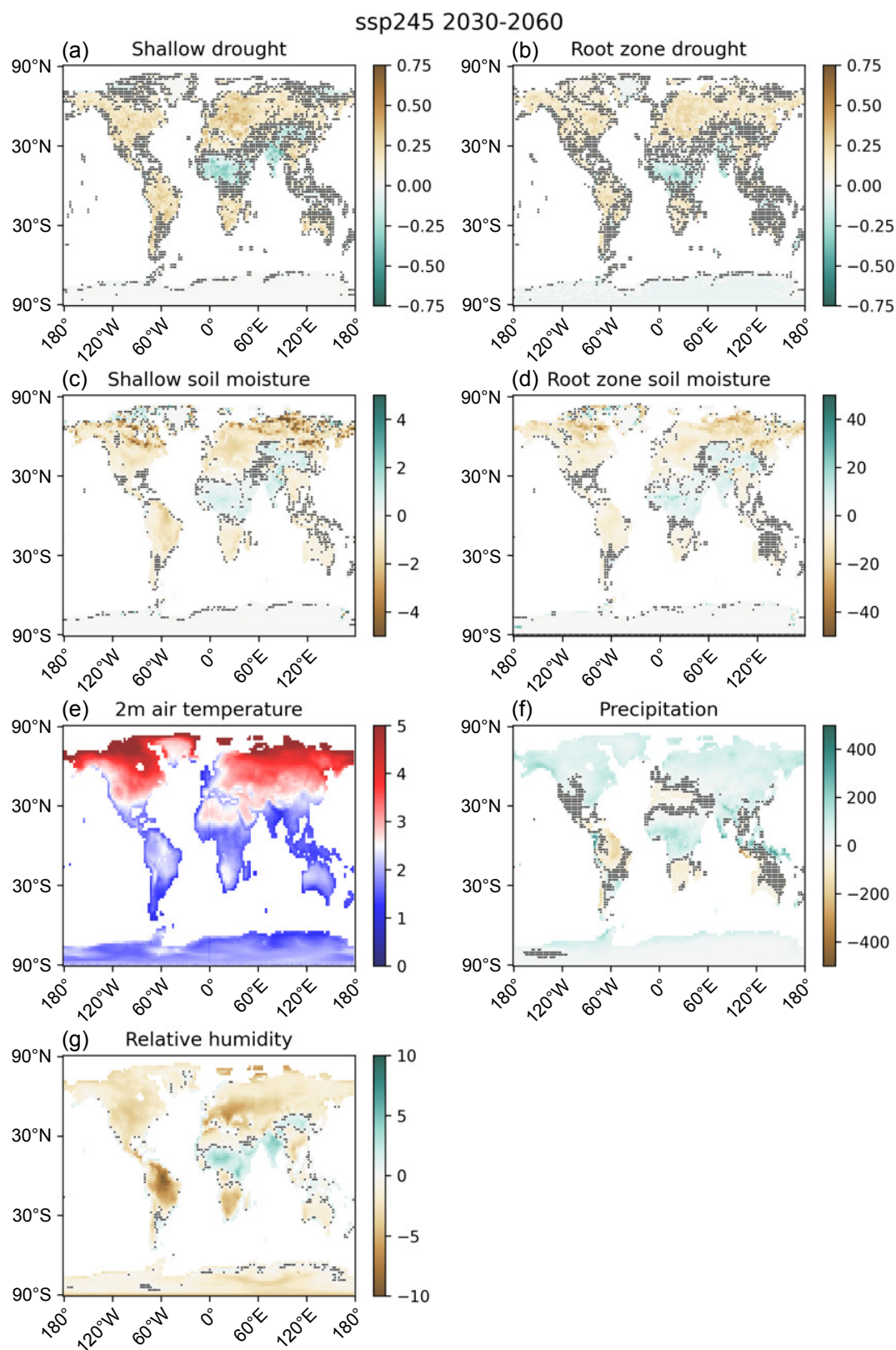


Fig. S10. Multi-model mean projected change in (a) shallow drought; (b) root-zone drought; (c) shallow-soil moisture; (d) root-zone soil moisture; (e) 2m air temperature; (f) precipitation; (g) relative humidity. Hashing indicates that the projected change is insignificant at the 5% level. The plot is for an SSP2-4.5 scenario, comparing 2030–2060 and 1960–1990 (with the pre-2015 data taken from the historical simulation).

ssp585 2030-2060

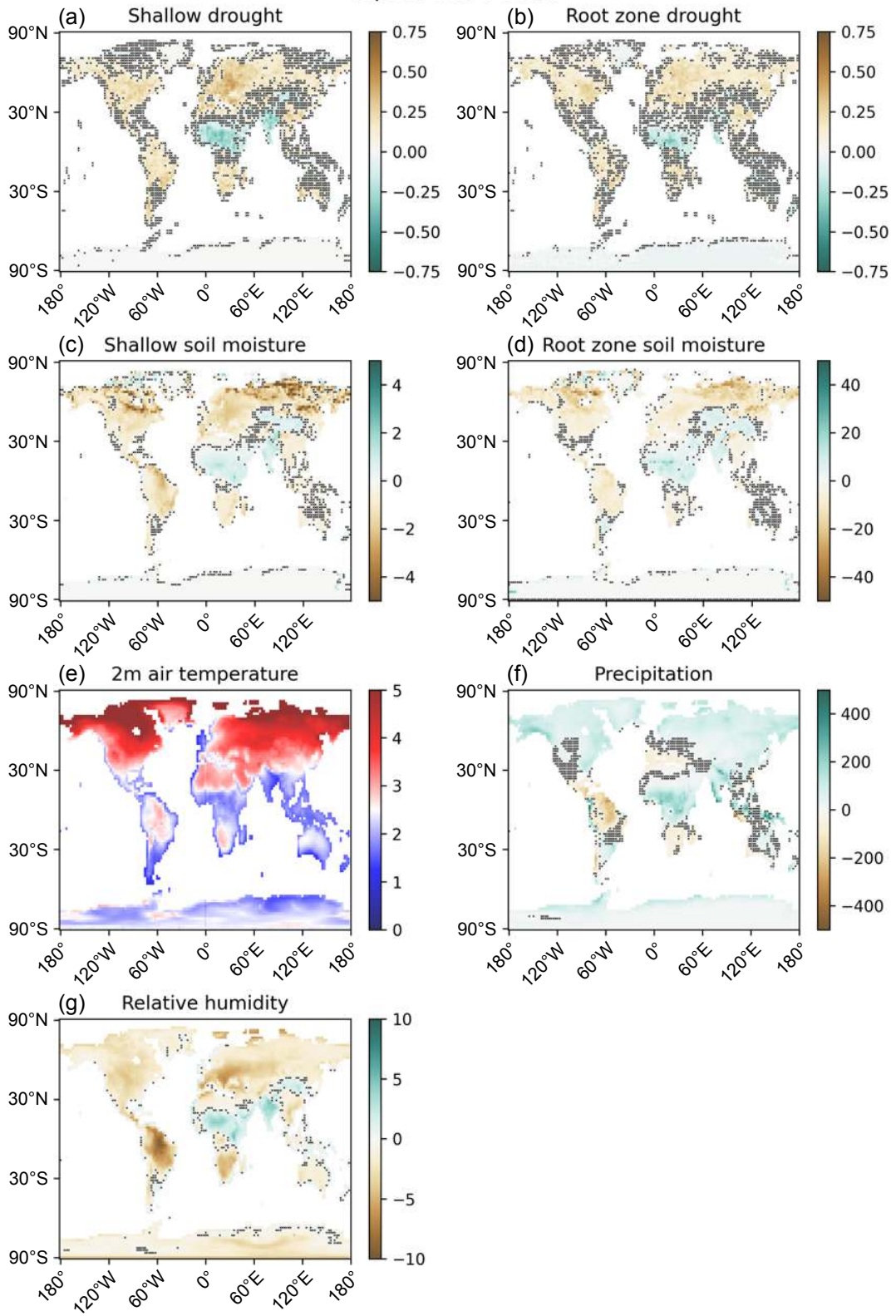


Fig. S11. As for Fig. S10 but for SSP 5-8.5

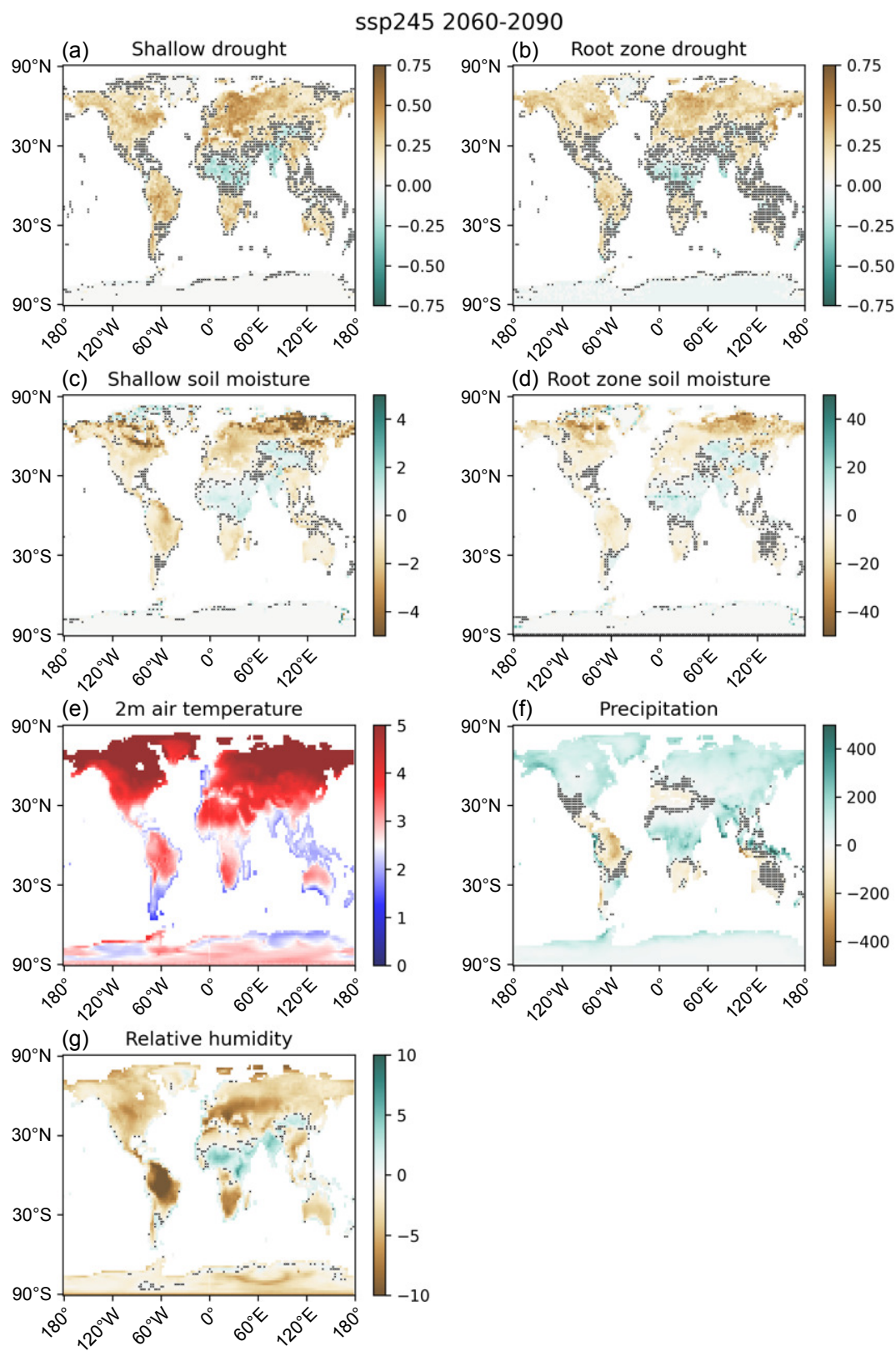


Fig. S12. As for Fig. S10 but for SSP 2-4.5 2060–2090

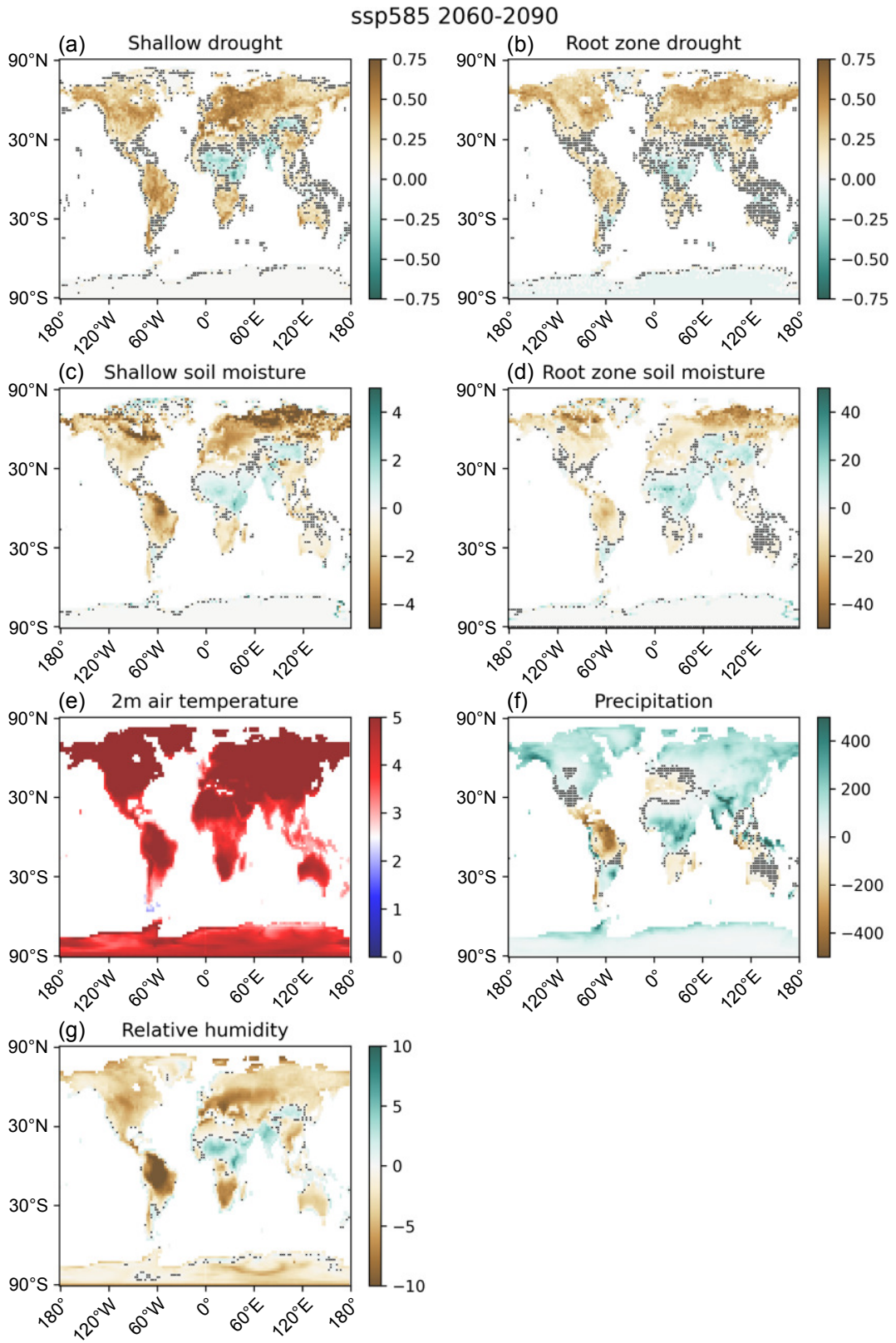


Fig. S13. As for Fig. S10 but for SSP 5-8.5

Drought pre-cursors for individual models

As for Fig. 5 in the main text, but for individual models

ACCESS-ESM1-5

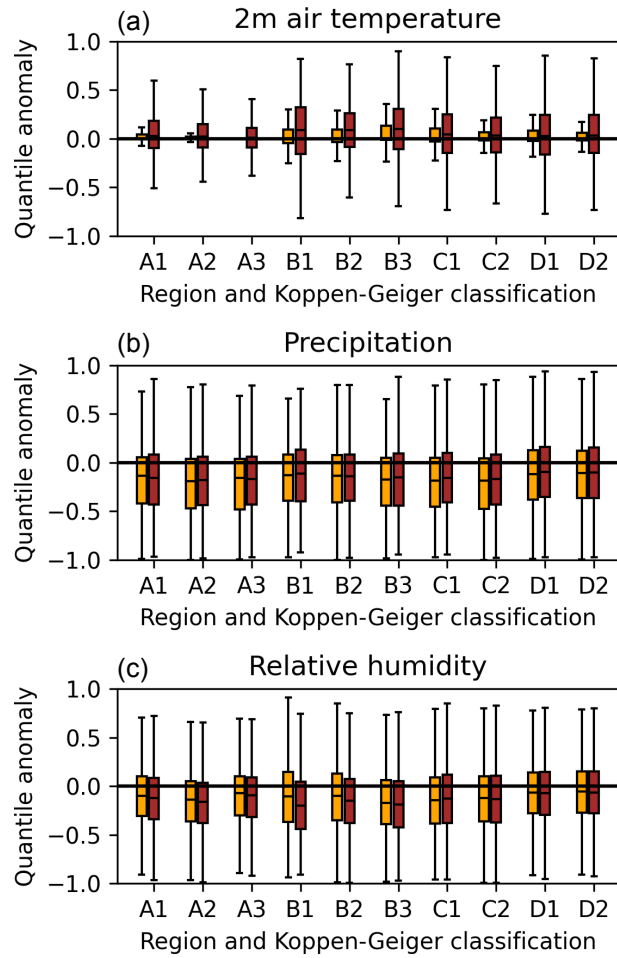


Fig. S14. Box and whisker plots of the anomalies for (a) 2m air temperature (top), (b) precipitation (middle), and (c) relative humidity (bottom) in the three pentads preceding deep soil and shallow-soil flash droughts. The box and whisker plots are displayed for the regions shown in Fig. 1 [ACCESS-ESM1-5]

CMCC-CM2-SR5

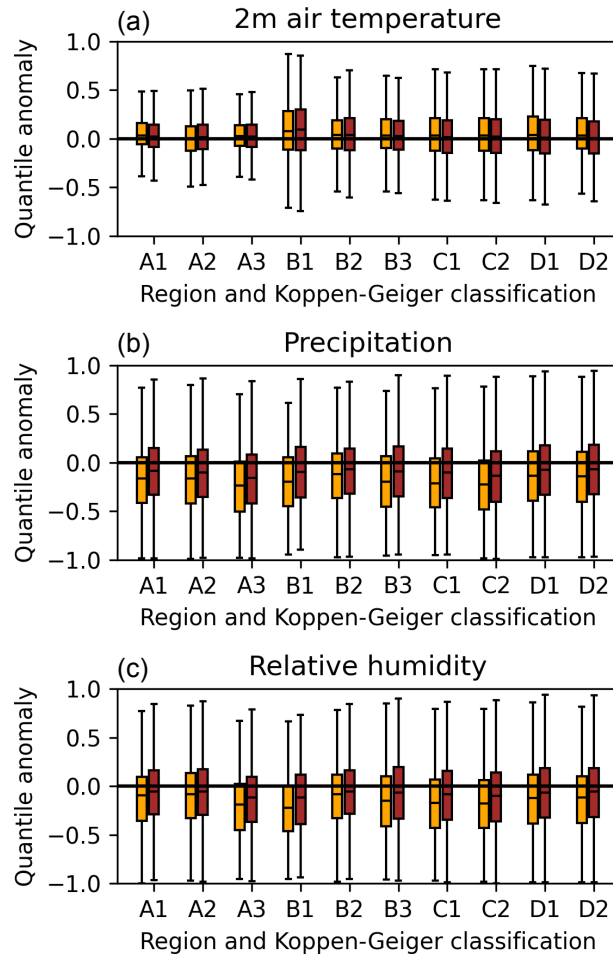


Fig. S15. Box and whisker plots of the anomalies for (a) 2m air temperature (top), (b) precipitation (middle), and (c) relative humidity (bottom) in the three pentads preceding deep soil and shallow-soil flash droughts. The box and whisker plots are displayed for the regions shown in Fig. 1 [CMCC-CM2-SR5]

CNRM-CM6.1

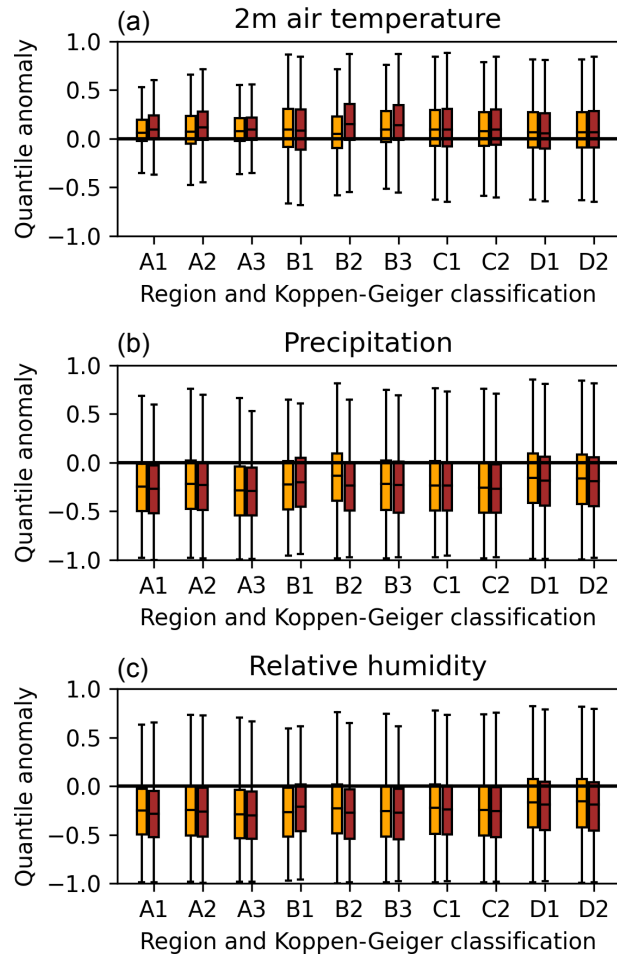


Fig. S16. Box and whisker plots of the anomalies for (a) 2m air temperature (top), (b) precipitation (middle), and (c) relative humidity (bottom) in the three pentads preceding deep soil and shallow-soil flash droughts. The box and whisker plots are displayed for the regions shown in Fig. 1 [CNRM-CM6.1]

EC-Earth3-CC

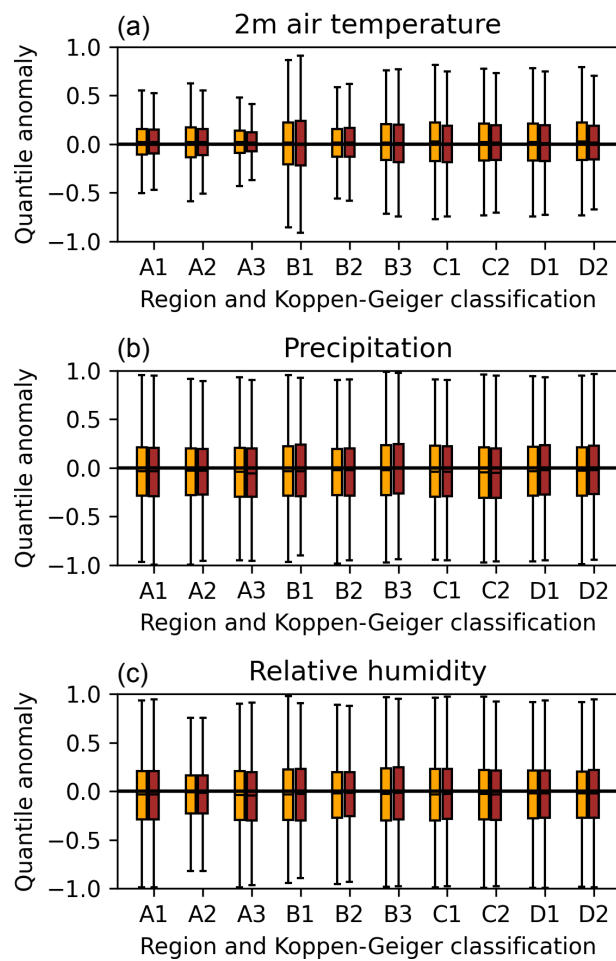


Fig. S17. Box and whisker plots of the anomalies for (a) 2m air temperature (top), (b) precipitation (middle), and (c) relative humidity (bottom) in the three pentads preceding deep soil and shallow-soil flash droughts. The box and whisker plots are displayed for the regions shown in Fig. 1 [EC-Earth3-CC]

HadGEM3-GC31-LL

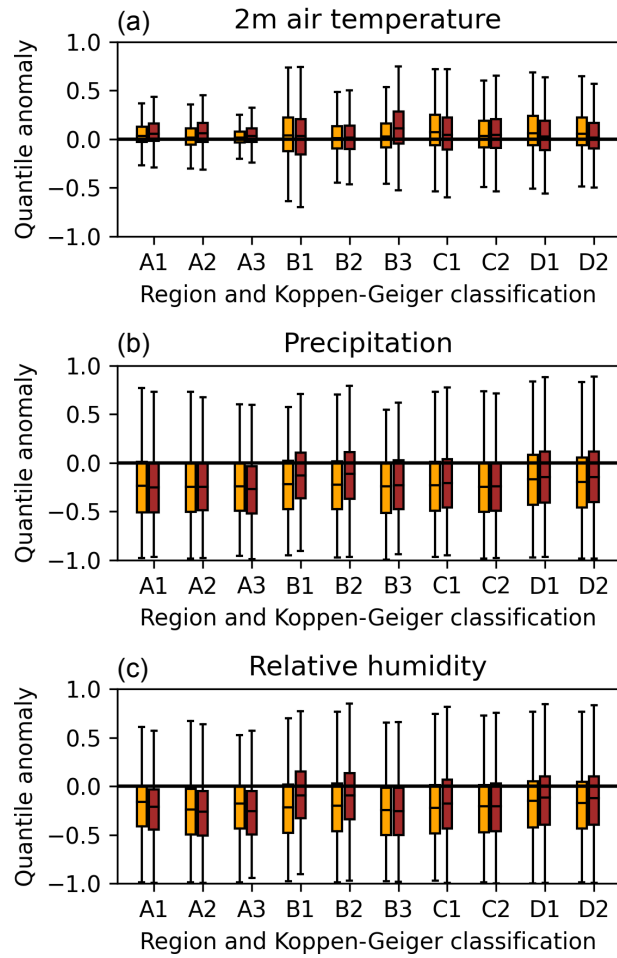


Fig. S18. Box and whisker plots of the anomalies for (a) 2m air temperature (top), (b) precipitation (middle), and (c) relative humidity (bottom) in the three pentads preceding deep soil and shallow-soil flash droughts. The box and whisker plots are displayed for the regions shown in Fig. 1 [EC-Earth3-CC]

IPSL-CM6A-LR

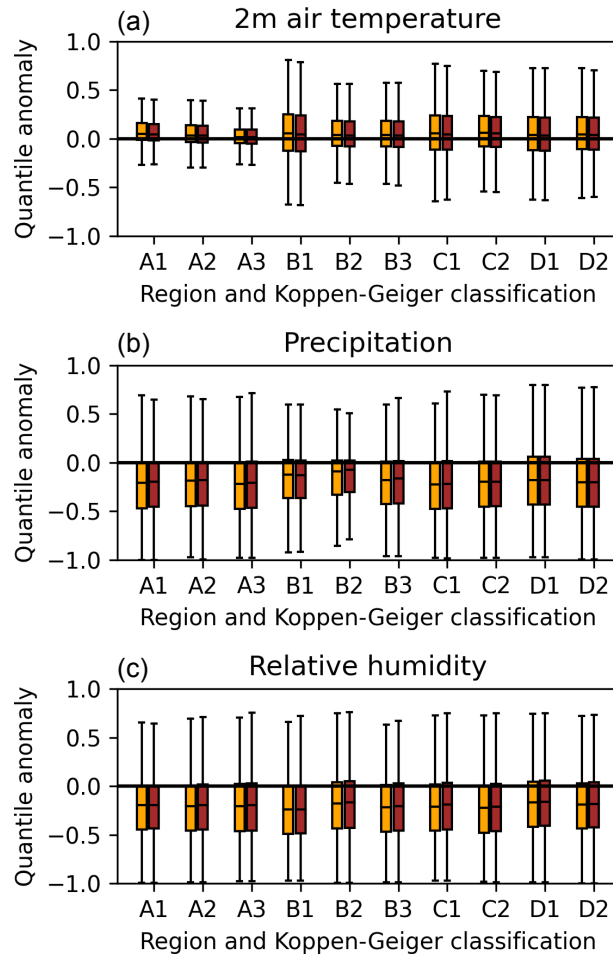


Fig. S19. Box and whisker plots of the anomalies for (a) 2m air temperature (top), (b) precipitation (middle), and (c) relative humidity (bottom) in the three pentads preceding deep soil and shallow-soil flash droughts. The box and whisker plots are displayed for the regions shown in Fig. 1 [IPSL-CM6A-LR]

UKESM1-0-LL

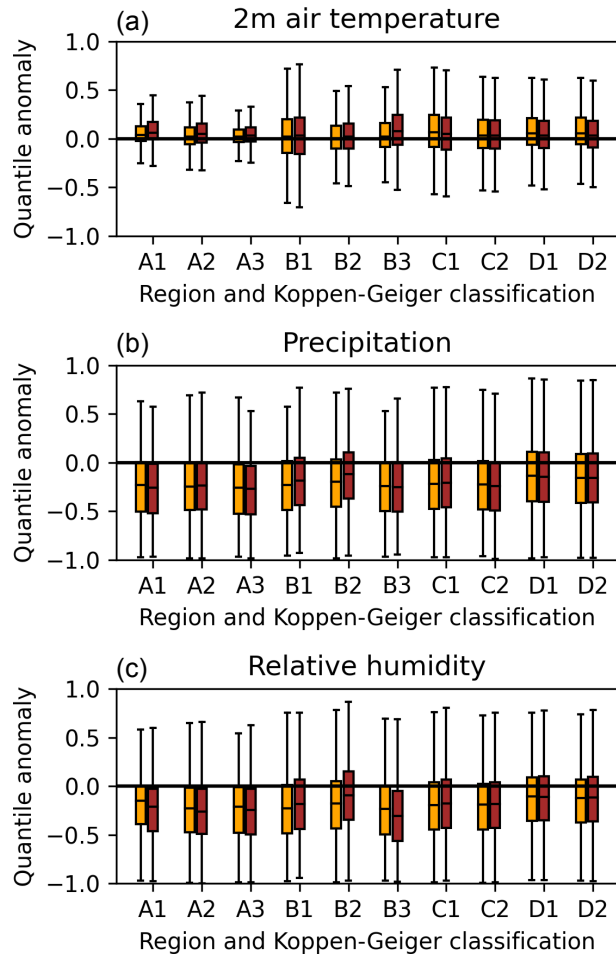


Fig. S20. Box and whisker plots of the anomalies for (a) 2m air temperature (top), (b) precipitation (middle), and (c) relative humidity (bottom) in the three pentads preceding deep soil and shallow-soil flash droughts. The box and whisker plots are displayed for the regions shown in Fig. 1 [UKESM-0-LL]

Time series for the Koppen-Geiger regions
Figures 6, 7, 8 and 9 but for the SSP245 scenario

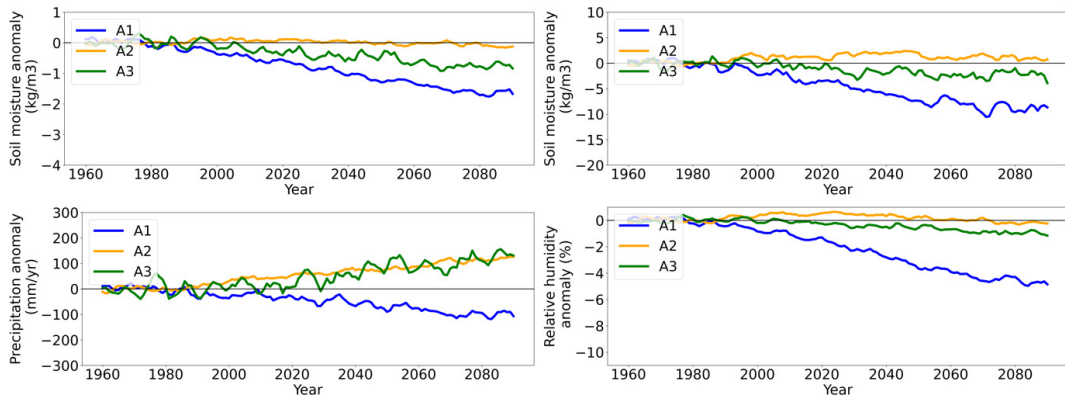


Fig. S21. As in Fig. 6, but for the SSP2-4.5 scenario

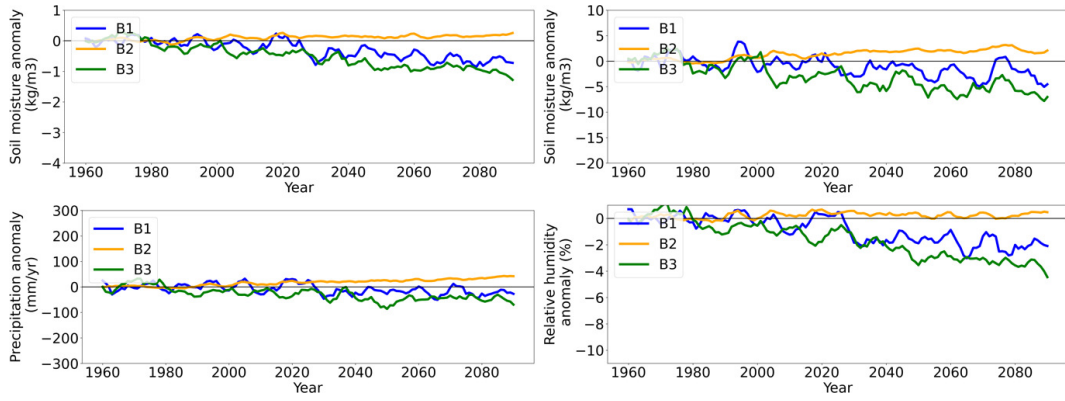


Fig. S22. As in Fig. 7, but for the SSP2-4.5 scenario

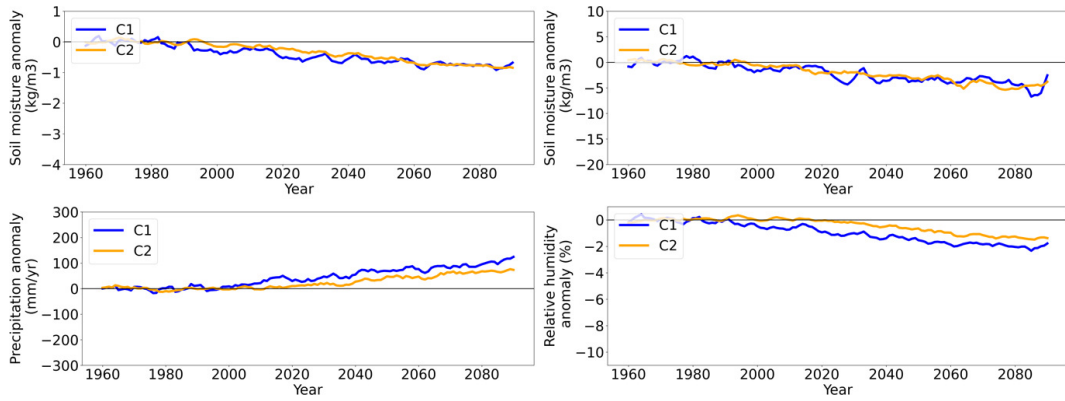


Fig. S23. As in Fig. 8, but for the SSP2-4.5 scenario

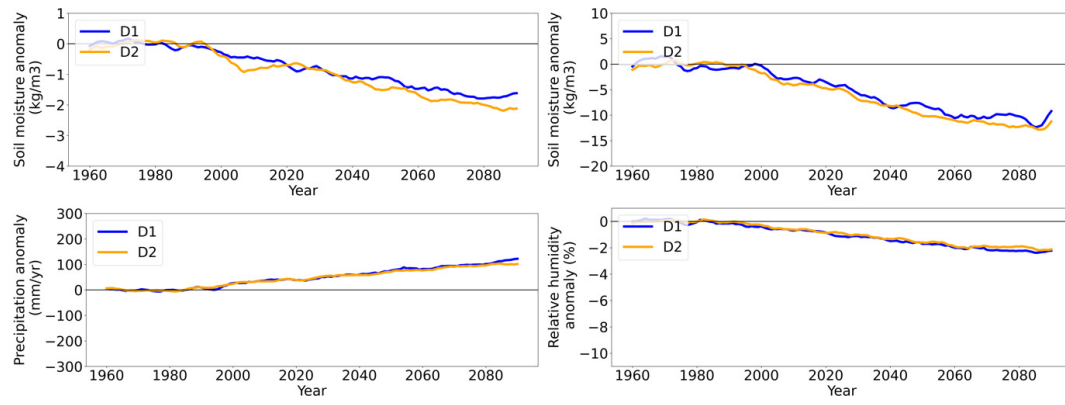


Fig. S24. As in Fig. 9, but for the SSP2-4.5 scenario