
Supplementary information

Precipitation trends determine future occurrences of compound hot–dry events

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Supplementary Material to “Precipitation trends determine future occurrences of compound hot-dry events”

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Supplementary Discussion

For the sake of clarity, in the following, we provide a detailed explanation of some of the statements of the main manuscript that are based on Extended Data Figure 3 and 5.

Interpretation of Extended Data Figure 3

- As described in the caption of Figure 2, stippling in Figure 2a indicates areas where future f_{HD} values are above 10%. Warming in isolation would increase future f_{HD} to about 10% worldwide, which is the historical frequency of dry events, therefore deviations from 10% result from precipitation changes (see sketch in Figure 3d). As a result, areas where the future f_{HD} is larger than 10% (stippling in Figure 2a) coincide with regions where dry event occurrences increase (Extended Data Figure 7a,b).

Extended Data Figure 3a confirms that the effect of the projected warming in isolation is constraining future f_{HD} at about 10% (see magenta isolines converging to 10% for increasing expected ΔT_{mean} and expected $\Delta P_{mean}=0$). Hence, for the multimodel mean projected combination of expected temperature and precipitation changes (standardized changes at different locations are indicated by the closed contour), positive and negative deviations from 10% (from about 1% to 30%) result from negative and positive precipitation changes (see the values of the magenta isolines within the closed contour).

A comparison of Extended Data Figure 3a,c,e shows that the behaviour described above is similar also if the underlying correlation between temperature and precipitation, $cor(T,P)$, was null or positive, though it is more pronounced for $cor(T,P) < 0$.

- The uncertainty range in the future f_{HD} is controlled by the uncertainty in precipitation and is not affected by uncertainty in the local warming. Extended Data Figure 3a,b shows that this is the result of a particular combination of expected

changes in temperature and precipitation. That is, changes in precipitation are small relative to changes in temperature; see closed contour in the Extended Data Figure 3a-b with respect to the second axes, which show the distribution of the changes (relative to present-day standard deviations) of the the two variables at different locations. For example, both temperature and precipitation would control the uncertainty range in the future f_{HD} if expected changes in temperature and precipitation were comparable (see shading along the green sloping line in Extended Data Figure 3a-b).

Note that the similarity of the paired panels in the three rows (a-b, c-d, and e-f) indicates that the underlying negative correlation between temperature and precipitation has little effect on favouring the emergence of the mechanism above already in a moderately warmer climate. Hence, in other seasons, when correlations between temperature and precipitation may be positive¹ (and when a similar ratio as in the hottest season is expected between normalised trends in temperature and precipitation), the mechanism above is expected to emerge as well at sufficiently high warming trends (as confirmed by Extended Data Figure 4c-d for the wettest season).

- In addition to the statements made in the main manuscript, here we note that the areas where the uncertainty range in f_{HD} due to uncertainties in precipitation trends is relatively small (Figure 3e) are associated with increasing mean precipitation (Extended Data Figure 7b). This is in line with Extended Data Figure 3b (see the variation of the shading along the y-axis within the closed contour), which shows that – at the given projected warming level (expected ΔT_{mean}) – the uncertainty range in f_{HD} is smaller for positive than for negative expected changes in precipitation. Such behaviour is in line with the fact that positive expected changes in precipitation lead to lower f_{HD} (see the magenta isolines within the closed contour) and therefore to lower uncertainty in absolute terms.

Interpretation of Extended Data Figure 5

- Our results show that simulations, i.e. models or ensemble members, that project a stronger increase in mean precipitation are associated with lower future f_{HD} values, and vice versa. Extended Data Figure 5 shows that the exclusive control of future f_{HD} from precipitation trends is mainly the result of mean temperature changes being strong relative to precipitation changes (see closed contour in the Extended Data Figure 5c,d relative to the second axes).

However, the figure also shows that if the underlying correlation between temperature and precipitation $cor(T, P)$ was zero, and especially if $cor(T, P) > 0$, at some locations f_{HD} would be slightly correlated with temperature variability (panels e,g) and less correlated with precipitation variability (panels f,h), compared to the case $cor(T, P) < 0$ (panel c and panel d). This finding is in line with the fact that, at a very few locations, the intermodel correlation between future f_{HD} and precipitation changes are slightly weaker when assuming $cor(T, P)=0$ (Extended Data Figure 6c) than when considering the observed $cor(T, P) < 0$ (Figure 3f).

Nevertheless, we note that although changes in temperature may be slightly correlated with future f_{HD} if $cor(T, P) \geq 0$, the explained variance of future f_{HD} from changes in temperature would be much smaller than that from changes in precipitation (see green shading within closed contour in Extended Data Figure 3e and 3f, respectively). This is in line with Extended Data Figure 6a,b.

Hence, overall, for a given projected combination of expected moderate increase in mean temperature and weak change in precipitation, the actually realised precipitation trend controls future f_{HD} largely independently of $cor(T, P)$.

References

1. Singh, H., Najafi, M. R. & Cannon, A. J. Characterizing non-stationary compound extreme events in a changing climate based on large-ensemble climate simulations. *Clim. Dyn.* **56**, 1389–1405 (2021).