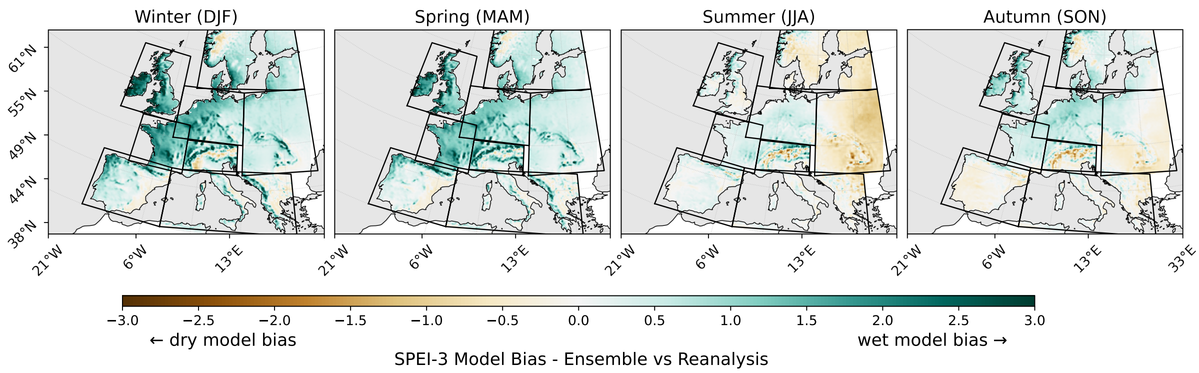
Supplementary Information for:

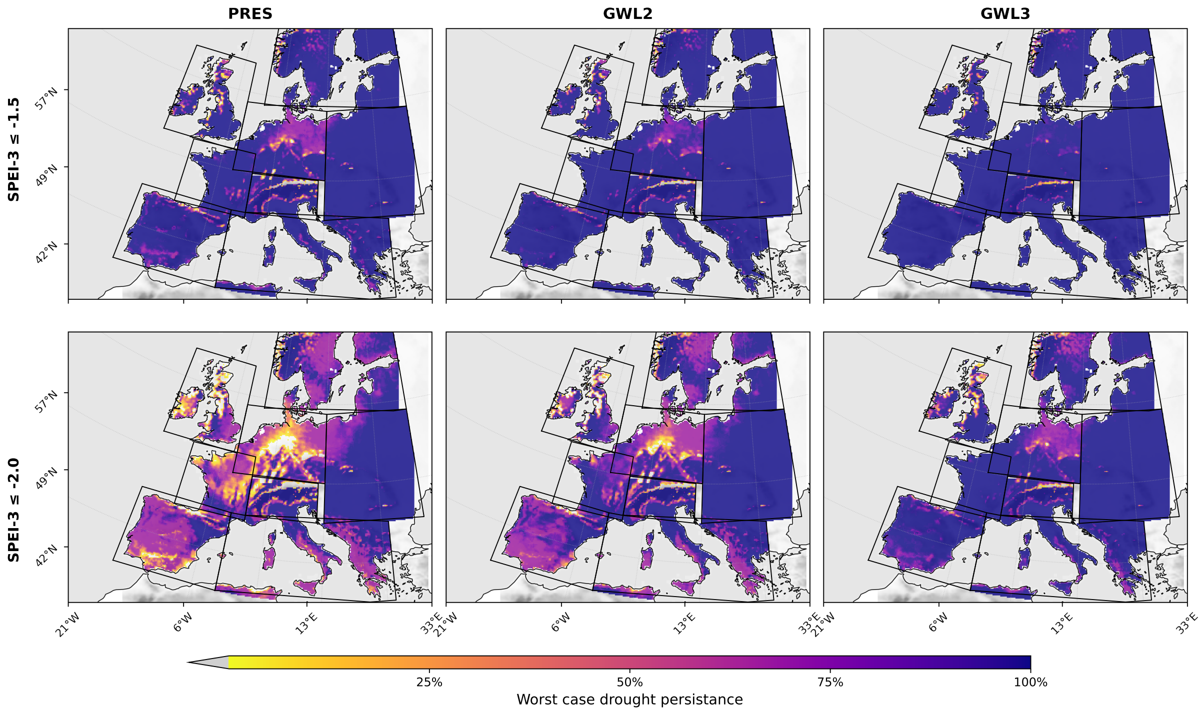
A near-certain late-summer drought hotspot across southern and eastern Europe under global warming

Supplementary Figures



Supplementary Figure 1. Seasonal SPEI-3 bias of the CRCM5-LE ensemble relative to ERA5-Land. The bias is the difference between the ensemble-mean SPEI-3 and the ERA5-Land reanalysis SPEI-3, shown for winter (DJF), spring (MAM), summer (JJA), and autumn (SON) on the EUR-11 rotated-pole grid. Positive values (teal) indicate a wet model bias and negative values (brown) a dry model bias. PRUDENCE region boundaries are overlaid.

Supplementary Figure 1 shows a wet bias across most of Europe in winter and spring, with a pronounced effect in BI, FR, and ME. In summer, the bias over eastern Europe transitions to a dry bias. In autumn, the bias is weaker in most of Europe. Because the variability decomposition is recovered from within-family-member differences, where any shared bias cancels, this level offset does not propagate into the two-sided variability bounds (see Methods).



Supplementary Figure 2. Worst-case drought persistence in late summer (JAS) under global warming. This is the lower-bound counterpart to the near-certain persistence maps in the main text (Fig. 5). Persistence is the fraction of late summers within each warming window in which the dry-side variability bound SPEI-3^L falls below the threshold, so it represents the maximal plausible drought frequency if internal variability acts to deepen drought. Columns facet across the three warming windows (PRES, GWL2, GWL3, left to right). The top row shows severe drought (SPEI-3 ≤ -1.5) and the bottom row extreme drought (SPEI-3 ≤ -2.0).

In Supplementary Figure 2, a value of 50% indicates that, in the worst case, a drought can occur in at least one of every two late summers at that location. The thresholds shown expand a plausible worst-case drought hotspot across the entire European domain, with an annual recurrence.

Supplementary Note

The variability model is fitted on the climatic water balance ($P - \mathrm{PET}$) rather than on the SPEI, although the SPEI is retained as the impact-relevant reporting index. The SPEI is, by construction, a local and time-specific standardisation: at each grid cell, the accumulated water balance is fitted to a parametric distribution over a reference period and mapped to a standard normal variable. This makes it unsuitable for estimating variability. Within the reference period, the SPEI has unit variance everywhere by definition, so a scale parameter estimated in SPEI space carries no physical units. The field is also not spatially comparable, since an anomaly of a given magnitude corresponds to very different absolute water deficits across Europe.

This matters for the central result: the probabilistic variability bound, whose wet end defines the minimum drought exposure Europe can expect under global warming, is only interpretable in a physical field. In millimetres of water balance, the wet end is a genuine lower bound on exposure; in SPEI units, it is defined relative to the local norm and could not be translated into a physical minimum. We therefore estimate the forced response and the variability in the water balance, both of which have units and a clear interpretation, and transform them to the SPEI for communication.