Supplementary Data – The characteristics of summer sub-hourly rainfall over the southern UK in a high-resolution convective permitting model
1. Additional discussions for 10-min precipitation profiles and return levels

The spatial variations of the total accumulation and peak intensity are shown in Supplementary Fig. 1. While there appears to be a NW-SE gradient for the peak 10-min intensities in the present-climate simulation, it is not clear if this extends to the future simulation. There is also no clear spatial pattern for total accumulation. Spatial variations in peak 10-min intensity appears to follow the Tees-Exe Line: a line which delineates rainfall tending to be large-scale (orographic) in Wales and south-west England from more convective and shower-like rainfall in south-east England [1]. The changes (panels e and f of Fig. 1) for both are positive nearly everywhere. While there are substantial local variations in the change, including values below 1.0 (intensity and accumulation reductions) and above 2.0 (doubling), there are no clear spatial patterns. The high degree of “noisy” spatial inhomogeneities in the changes suggest that taking a spatial median profile is more meaningful than trying to diagnose spatially-variable local changes. The high spatial variability is perhaps related to the short time series at each grid point where signals may only be detected through spatial smoothing and aggregation.

The variation of the return levels as a function of return period and its change are shown in Supplementary Fig. 2. The 10-min and 1-hr rainfall return levels increase by \( \approx 20\% \) across a range of return periods above 5 years, and are similar to the increase in \( z(10) \) in Fig. 3. Similar to the 12-km re-gridded estimates, the return level increases are generally independent of return period [2]. The return level changes in 1-hr rainfall here are higher than estimates using data re-gridded to 12-km grid boxes (\( \approx 10\% \)) [2]. Indeed, the differences in changes between different accumulation periods are smaller than or comparable to the differences in changes between different levels of spatial averaging. Thus, return level changes here for the sub-daily timescale are sensitive to changes in spatial aggregation.

2. Peaks-over-threshold with simple regional pooling

For Peaks-over-threshold, we first define a threshold value (t) for an extreme event – this is defined to be the 99th and 95th percentile for 10-min and 1-hr “wet” values respectively. The “wet” value thresholds are 0.05 mm/10 min and 0.1 mm/1 hr accumulations respectively. The 1-hr wet and extreme thresholds follow previous work [3]. The exceedances above the percentile threshold are then declustered using an automatic declustering algorithm [4], and declustering addresses the difficultly in determining consistent thresholds for 10- and 1-hr data by isolating intensity maxima. We compute the frequency of exceedance (\( \lambda \)) by simply dividing the number of declustered exceedances by the number of years of data. The declustered values are then fitted with the generalised Pareto distribution (GPD) using maximum likelihood estimation. The fitting yields 2 additional parameters – the scale (\( \sigma \)) and the
dimensionless shape ($\xi$) parameter. The n-year return level $z(n)$ is:

$$z(n|t, \sigma, \xi) = t + \frac{\sigma}{\xi} \left[(\lambda n)^\xi - 1\right]$$  \hspace{1cm} (1)

A detailed description of the methodology can be found in previous papers [5; 6]. Depending on the literature, $\xi$ may be defined with an opposite sign.

Regional frequency analysis [7] is a method used to pool return level estimates over multiple points. Specific metrics can be used to check if the points share similar characteristics [7]. Here we assume that adjacent grid points are likely to be similar, and can be pooled. We follow the procedure described previously in which we have already obtained local parameter estimates [7], and take an average of the estimated parameters over our “region” of interest after proper normalisation. We use a $21 \times 21 = 441$ moving grid-point window for the native 1.5-km grid box resolution. Non-land points are excluded from the moving window. We compute the 2-year return level ($Z(2)$) at each grid point using the non-pooled estimates. Following previous work in which we assume the normalised scale parameter and shape parameter to be uniform over the pooled area [8; 9], we normalise $\sigma$ at each grid point with the 2-year return level “index flood” ($\gamma = Z(2)^{-1}\sigma$). Equal-weighted moving-window averages are computed for $\gamma$ and $\xi$:

$$\langle \hat{\gamma}, \hat{\xi} \rangle = J^{-1}(\sum_{J \leq 441} \gamma, \sum_{J \leq 441} \xi) \quad (2)$$

New local return levels are estimated with a combination of the spatially-smoothed ($\hat{\gamma}, \hat{\xi}$) and local ($t, z(2), \lambda$) parameters:

$$z(n|t, \hat{\gamma}, \hat{\xi}) = t + z(2)\frac{\hat{\gamma}}{\xi} \left[(\lambda n)^\xi - 1\right]$$  \hspace{1cm} (3)

The threshold is unchanged during the averaging [11]. We do note that the above “regions” are moving and overlapping windows. The above procedure is more akin to spatial smoothing instead of producing a more common regional “growth curve” for non-overlapping regions [7].

References


‡ This choice of “index flood” follows previous work [10], but other physically reasonable values can be used as well [7].
REFERENCES


Supplementary Figure 1. The peak 10-min rainfall intensity ($P(t=5)$; left column) and total profile accumulation ($\int_{-300}^{300} P(t^*)dt^*$; right column) for the present- (upper row) and future-climate (middle row) simulation at each land grid point across the SUK. The change (future divide by present) is given in the bottom row. The spatial median values are already provided in Fig. 2. Accumulations here (left panel) have a different spatial median as in Fig. 2b as the cumulative totals in Fig. 2 are computed by integrating panel a of that figure.
Supplementary Figure 2. The spatial median and inter-quartile range of the (a) return level and (b) its change as function of return period. For panel a, red and blue for present- and future-climate simulation respectively; for panel b, the change (future divide by present) for 10-min and 1-hr rainfall return levels are presented.
Supplementary Figure 3. Histograms of peak intensity of individual profiles at different daily-averaged surface air temperatures. Left, middle and right columns are for profiles with daily-averaged surface air temperature in the lower-quartile, middle-50, and upper-quartile. Red and blue are for present- and future-climate simulations respectively. The mean peak intensity is given at the title of each panel. The fractional increase between the future and present simulations for the lower-quartile, middle-50, and upper-quartile temperatures are $5.89/4.01 \approx 1.47$, $6.66/4.57 \approx 1.46$, and $7.22/5.31 \approx 1.36$ respectively.