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UK Climate Projections: UKCP Local (2.2km) Transient Projections

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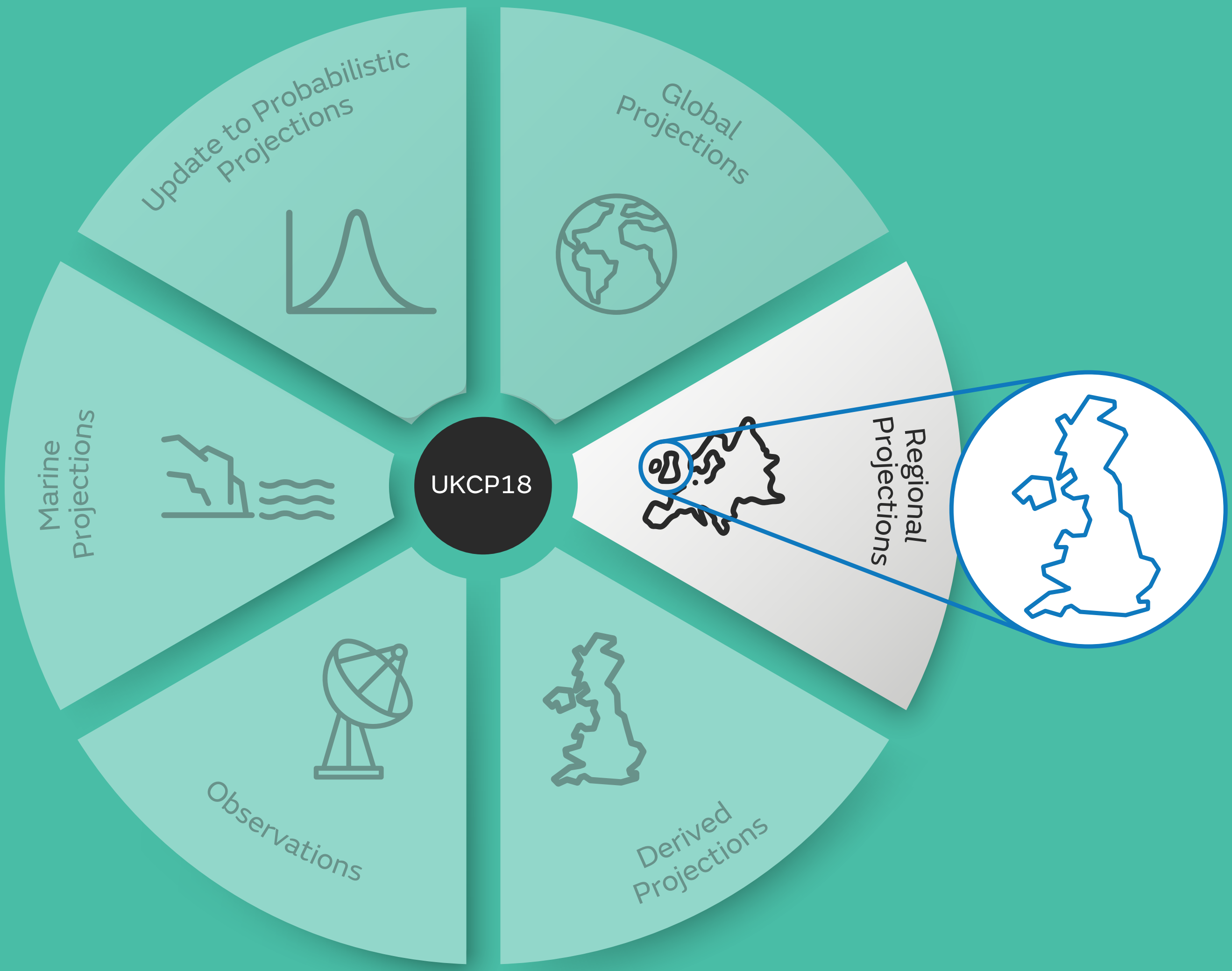

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Executive summary

- New 2.2km simulations, augmenting the UKCP Local (2.2km) Projections, have been released to provide 100 year simulations for 1981-2080 continuously spanning past, present and future times, the "UKCP Local (2.2km) Transient Projections".
- This is new capability, providing a set of plausible outcomes for each year through time, and enhances our ability to put observed events into the context of climate change.
- UKCP Local (2.2km) Transient Projections are one of a number of UKCP products. They are useful for impacts assessments that require enhanced spatial detail or information on changes in extreme weather at local and hourly timescales. However, they are based on a single model – the Met Office Hadley Centre climate model – and lack information from other international climate models. Thus, they sample a narrower uncertainty range than the UKCP Probabilistic, Global and Probabilistic Extremes products that offer additional sources of information for UK impacts and provide wider context on large-scale drivers and/or a more comprehensive sampling of uncertainty.
- Here we provide an assessment of the performance of the new UKCP Local Transient Projections in representing present-day temperature, precipitation and other key climate indicators. This establishes the credibility of the UKCP Local Transient Projections for simulating future changes in climate and its variability at local scales, including local weather extremes.
- Example applications of the use of UKCP Local (2.2km) Transient Projections include examining how changes in local weather extremes are manifest through time and exploring the uncertainty in changes for global warming levels.
- In this report we also outline caveats on use of the data, including discontinuities in the 100 year timeseries and recommendations for handling unphysical data points.

Introduction

This report accompanies the release of UKCP Local (2.2km) Projections for additional transient periods (2001-2020 and 2041-2060), leading to 100y climate simulations for 1981-2080 that continuously span past, present and future times, at 2.2km scale for the UK (Kendon et al., 2023). While it is common practice in the international community to produce ensembles of continuous transient simulations using global and regional climate models, this is (to our knowledge) the first example of such an ensemble at the kilometre scale, with the same level of spatial detail as weather forecast models. This unique set of projections therefore provides a key step forward in national climate capability allowing the examination of how changes in local weather extremes may be realised over the coming years and decades. Since twelve simulations are available, we can determine robustly their projected signals in local extremes. The transient simulations provide a set of plausible outcomes for each year through time, allowing us to put observed events into the context of climate change.

The new 2.2km simulations augment the UKCP Local (2.2km) Projections previously updated in July 2021, which provided data for three 20-year periods (1981-2000, 2021-40 and 2061-80). The new 2.2km simulations provide data for the intervening periods (2001-2020 and 2041-60) and consist of twelve ensemble members, downscaling the UKCP Regional (12km) Projections as in UKCP Local (2.2km). This results in 100y timeseries data spanning 1981-2080 and driven by a high emissions (RCP8.5) scenario (hereafter "UKCP Local Transient Projections"). Since each ensemble member timeseries is built by joining five 20y simulations, there are discontinuities at the time-slice boundaries (1st of December 2000, 2020, 2040 and 2060), which means there may be an abrupt shift in the daily weather on those four dates. The 20-year simulations were preceded by a 1-year spin-up to help ensure there was only a discontinuity in the simulated daily weather at the boundaries but not in the underlying climate characteristics. The set-up of the UKCP Local projections is as described in Kendon et al., (2021a).

The km-scale ("convection-permitting") model is able to better represent the small-scale behaviour seen in the atmosphere, in particular atmospheric convection – a key process driving many of our extreme weather events. Due to the high spatial resolution, compared to more traditional climate models, it also represents better the influence of mountains, coastlines and cities. As such the UKCP Local (2.2km) data are useful for impacts assessments that require enhanced spatial detail or information on changes in extreme weather at local and hourly timescales (Dale et al., 2018; Slater et al., 2022; Chan et al., 2022). The UKCP Local Transient Projections provide access to credible information on how climate change may impact extremes of weather for your local area over the coming years out to 2080. They provide a range of plausible outcomes for any given year, which, whilst not comprehensive, is expected to be valuable to urban planners, local authorities and flood management practitioners for adaptation planning.

All projections are for the high emissions RCP8.5 scenario which, although not the most likely, remains a plausible scenario assuming unmitigated greenhouse gas emissions. This scenario was chosen as it provides a high signal-to-noise ratio, allowing us to robustly capture the climate change signal above natural variability, that is also useful in inferring changes for other scenarios (for example through characterising changes for a given degree of global warming, see section "Example applications of new UKCP Local Transient Projections"). It provides an upper estimate that supports precautionary planning in relation to future risks of extremes.

Each 2.2km projection represents a plausible realisation of the future climate assuming greenhouse gas emissions increase further, with the ensemble members differing due to natural climate variability and uncertainty in how the driving global models represent some aspects of key atmospheric processes. This is how the UKCP Local Transient ensemble provides a range of plausible outcomes in future changes on kilometre and hourly scales for use in risk assessments, providing locally relevant information to inform decision making. It is important to note that the Local (2.2km) projections only downscale versions of the Hadley Centre climate model, and so generate a narrower range than the UKCP18 global or probabilistic projections (Murphy et al., 2018). In particular, the set of 2.2km simulations lacks information from other international climate models, sampling only outcomes with a relatively high rate of global warming. In addition, the same convection-permitting model is used for all ensemble members, and thus UKCP Local does not sample uncertainties in the representation of local processes, such as land-surface feedbacks. It is important that users are aware of these limitations and of the other UKCP products, including the advantages of each for their application. Further guidance on which UKCP product(s) to choose and how to use them in combination is available from Fung et al., (2018).

Evaluation of additional time slices

We have assessed the performance of the new UKCP Local Transient Projections in representing present-day temperature, precipitation, winds, circulation patterns, cloud, humidity, soil moisture and snow. We have considered seasonal means, measures of variability and extremes, and trends compared to observations. Regional timeseries are evaluated to illustrate temporal variability in key indicators and to identify any inconsistencies between the 20y time-slices. These are named as follows TS1 = 1981-2000; TS1.5 = 2001-2020; TS2 = 2021-40; TS2.5 = 2041-60; TS3 = 2061-80 (to ensure consistency with the TS1, 2 and 3 definitions in the original UKCP Local projections, Kendon et al., 2021a). This provides the evidence base to assess the credibility of the UKCP Local Transient Projections. Here we provide a brief summary of the key results.

There is consistent behaviour across time-slices for all variables considered. For 20-year seasonal means, there is steadily increasing temperature, and increasing winter and decreasing summer precipitation across time-slices (Figs 1-2). For the ensemble-mean, there are consistent increases or decreases in seasonal mean pressure patterns, winds and cloud depending on region and season and steadily increasing specific humidity (not shown). There is also decreasing soil moisture in summer and autumn (see below). UKCP Local is also able to correctly capture the precipitation associated with key weather patterns influencing the UK (Neal et al., 2016; Fig 3). There are some biases, for example there is an insufficient rain shadow in the east under weather type 20 and too much rainfall in the south under weather type 9, but in general the key differences in the amounts and spatial pattern of rainfall between weather types is well captured.

Annual timeseries of UK-averaged values, showing the evolution of seasonal-mean temperature and precipitation through time, show no apparent jumps in the timeseries from one time-slice to the next (Figs 4-5). The general trend also shows good agreement with observations. We note that we would not expect the exact evolution of annual values to match between the UKCP Local simulations and observations, since they have no knowledge of the observed atmospheric or ocean state (being driven by a global coupled model). The standard member is shown in Figs 4 and 5 as illustrative of a single realisation, where the degree of variability is directly comparable to the observations. The standard member corresponds to the member where no perturbations have been applied to the driving model physics and is considered as plausible as any of the other ensemble member realisations. The ensemble spread gives an indication of the range of plausible outcomes each year and is useful for assessing any systematic model bias. It can be seen that the observations largely lie within this ensemble spread, except perhaps for temperature in spring where there is some suggestion that UKCP Local projections are slightly too cool.

There are also consistent trends across all five time-slices for snow (Fig 6). Again, we would not expect the exact evolution of annual values to match between the observations and model simulations, however there is some suggestion that the observations extend beyond the envelope of the simulations. In this case, comparison with observations is difficult (lying snow observations are based on the observer deciding that the ground is more than half covered in snow) and sensitive to the choice of threshold used to define a "snow day" in the model. So any model-observation discrepancies may reflect differences in what is being measured, rather than indicating a deficiency in the simulation of snow in UKCP Local.

For soil moisture, model errors can arise from biases in the land surface scheme, in rainfall or in other meteorological fields that drive surface exchanges. Direct verification of soil moisture in UKCP Local however is difficult (soil moisture measurements are available from stations, but these point observations are not representative of the UK wide picture and generally have short <20y records; whilst satellite measurements only sample the top few cm of soil). Here we use an observational proxy, WFDEI-JULES (Weedon et al., 2014), which provides estimates based on the modelled land surface but driven by reanalysis data, and thus only allows us to assess whether there are biases in the simulated circulation, temperature, rainfall and humidity that in turn impact soil moisture (see Pirret et al., 2020). We find that the UKCP Local ensemble (red shading in Fig. 7) shows good agreement with WFDEI-JULES. The standard UKCP local member (red line in Fig. 7) also shows good agreement with its UKCP Regional counterpart (blue line). The other UKCP Regional ensemble members (blue shading) have higher soil moisture due to perturbations being applied to the soil moisture parameter (psm), such that they use a different value to that in the WFDEI-JULES run. UKCP Local has consistently drier soils that the UKCP Regional standard member in summer. This is expected due to the more intense and intermittent nature of rainfall in the convection-permitting model (CPM), which is more realistic. However, it is difficult to assess whether drier soils in the CPM are closer to reality. Importantly, there are no discontinuities in soil moisture between time-slices in the new 100-year dataset, with a consistent downward trend in soil moisture seen in summer (Fig 7, and also autumn, not shown).

To assess the performance of UKCP Local in simulating local extremes, seasonal maximum values of daily maximum temperatures and hourly and daily precipitation at the local scale have been analysed. This corresponds to the most extreme values simulated in any season over any land grid box, and therefore tests the ability of the CPM to simulate rare events (subject to uncertainties arising from sampling limitations in the observed data). For temperature at the 2.2km scale, the timeseries of maximum values sampled each season anywhere in the UK shows reasonable agreement with the NCIC observations (Perry et al., 2009, recently updated in Met Office 2018). The observations lie within the ensemble spread, although the ensemble-mean is generally above the observations in summer and below in winter (Fig 8). Also, the ensemble range for summer maximum values exceeds 45°C in several years within the historical and present-day climate. The UK exceeded 40°C for the first time in July 2022, exceeding the previous record by a considerable margin (of 1.6°C). Thus, exceeding 45°C in the present-day climate appears implausible and may suggest that the CPM simulates rare summer heat waves that are too intense.

The assessment has revealed some unphysical values. These arise from numerical problems in the model, as opposed to general systematic errors in the simulated climate. For example, 53°C was simulated in one 2.2km grid box on a single summer day in 2022 (Fig 8). This occurred over a grid box on the south-east coast of England, with the rest of the UK showing less extreme values. Such a high localised temperature value is judged unphysical and further analysis has revealed that it is caused by a lack of temperature conservation in the model in convergent flows, such as sea breezes. This is a known model problem that has been reduced in later model versions through the inclusion of mixing terms. In the UKCP Local (2.2km) model such unphysical values do occur but they are rare (the fraction of grid points affected every year is very low, primarily coastal regions in summer) and there is no evidence that their occurrence is worse in the additional time-slices (compared to TS1,2 and 3 already released).

For precipitation, we assess local extremes on both daily and hourly timescales. On daily timescales, we use the NCIC observations (Perry et al., 2009, updated in Met Office 2018), which are based on up to 5000 daily rain gauges. On hourly timescales, we use the CEHGEAR-1hr observations (Lewis et al., 2018) based on fewer (up to 1900) hourly rain gauges. Where the nearest hourly gauge is >50km away, hourly values are estimated ('disaggregated') from the gridded daily data using a design storm profile. It should be noted that gauge observations are affected by systematic measurement under-catch (typically about 20%, due to snow, wind blow losses and gauge exposure; Kotlarski et al., 2014; Rajczak and Schar, 2017), they may miss localised events and also tend to be sited in valleys rather than at the tops of mountains. Therefore, we may expect the gauge observations to provide a lower estimate of the most extreme values of local rainfall, with observational biases particularly large over mountains. For the hourly dataset, the disaggregation step leads to further potential observational bias, which could either be an over or under-estimation of true values depending on the actual hourly rainfall profile (the additional error on estimating the hourly fraction of daily rainfall is about 10% or more depending on the distance to the nearest gauge; Lewis et al., 2018).

Here we firstly consider precipitation at the 5km scale to allow comparison with the 5km NCIC observations. This uses the UKCP Local 5km projections where the data has been regridded to the Ordnance Survey National Grid (OSGB), and is available to users alongside the raw 2.2km grid scale data (see below section on Accessing data). For daily precipitation at the 5km scale, the timeseries of seasonal maximum values shows good agreement between UKCP Local and the NCIC observations, given the caveats and limitations of the observed time series (Fig 9). In autumn, winter and spring, the ensemble-mean time series tracks the typical level of observed maxima quite well, and the most extreme simulated values also correspond reasonably closely to observations. However, in summer the ensemble mean tends to exceed observed values. Furthermore, the modelled maxima frequently exceed 200mm, well above the largest observed value for this season. Gauge under-catch may explain some but likely not all of this discrepancy, suggesting a tendency of the CPM to overestimate the intensity of heavy events in summer. This tendency has been reported in previous CPM studies and is a consequence of convection not being fully resolved at 2.2km resolution (Kendon et al., 2021b). We note there is a very high daily value (of >500mm) simulated in summer 2012 in a single ensemble member. This occurs over a single grid-point Scottish Island and is much higher than rainfall values over all other UK grid points. It is also apparent in the raw 2.2km daily precipitation, with a value greater than 500mm/day at a single 2.2km grid point corresponding to the island, with values lower over the sea and over all adjacent islands. This extreme localised value is judged unphysical, and we recommend that it is removed from analysis of the daily precipitation data (at both 2.2km and 5km scale).

For hourly precipitation at the 5km scale (Fig 10) we can see that UKCP Local overestimates seasonal maximum values compared to CEHGEAR observations in summer and underestimates them in winter. Observational bias is an important caveat here, although likely does not explain the large differences. As noted above, gauge observations can miss localised convective events in summer, and the use of a design storm profile for disaggregation to hourly values leads to further observational bias (of order +/-10%, Lewis et al., 2018). Over orography (where the highest values occur in winter), we may expect more persistent rainfall than the design storm profile assumed, but it is unlikely this will compensate for systematic daily gauge under-catch in these regions (which can be up to 50% in winter over high elevation, Rajczak & Schär, 2017). Thus, this analysis suggests that the CPM overestimates the most extreme hourly precipitation events in summer and underestimates them in winter. Examination of the three highest values of hourly precipitation at the 5km scale that exceed 130mm/h, also reveals the presence of some unphysical values. 137mm/h was simulated over an isolated grid box on the Isles of Scilly in autumn 2054 and 131mm/h over an isolated grid box in the Outer Hebrides in summer 2030. Due to their localised nature, both these events appear unphysical. However, 136mm/h simulated over London in summer 2070 appears plausible as it occurs alongside other very intense convective showers. Thus, it is not straightforward to identify unphysical values based on the exceedance of a high threshold alone. We also note that the unphysical value (>500mm/d) identified above in the daily data does not stand out on the hourly timescale. The extreme daily total was made up of several hours of high (but not extreme, <100mm/h) rainfall, which on their own do not appear unphysical.

Some unphysical hourly rainfall values have been identified in the UKCP Local data at the raw 2.2km scale. 178mm/h was simulated in summer 2035 for an isolated 2.2km grid point in the Outer Hebrides, with rainfall much lower in surrounding grid points and at other times of the day. This high localised value is judged unphysical and is likely due to a numerical instability in the model. Values in excess of 170mm/h have been simulated only on two other occasions in the entire dataset of 1200 years, in spring 2055 and autumn 2073, both corresponding to localised unphysical values. As demonstrated above, it is difficult however to identify a specific threshold above which events are considered unphysical. Also, it is important to emphasize that unphysical precipitation values in the UKCP Local data are very rare (both at the 2.2km and 5km scale) and are only apparent when considering such an extreme metric as the maximum seasonal value anywhere in the UK. For other analyses, the impact of these rare unphysical values will be negligible.

The above analysis was based on seasonal maximum values occurring anywhere in the UK, corresponding to very rare extremes. If we consider threshold-based metrics, corresponding to less extreme values but which are nevertheless important from an impacts perspective, we see evidence of a clear improvement in the representation of hourly precipitation events in the UKCP Local (2.2km) compared to UKCP Regional (12km). For example, Fig 11 shows the number of events exceeding of 20 mm/h at the 12km scale, indicative of flash flooding. There are consistently more extreme events in the Regional (12km) model (RCM, blue) compared to the Local (2.2km) model (CPM, red), with the CPM showing much better agreement with observations in terms of the typical numbers of events per year during the historical period. The observations lie within the spread of UKCP Local, with the single CPM realisation (standard member, thin red line) showing a similar degree of year-to-year variability. Further analysis has revealed the presence of extremely high hourly precipitation values in the RCM due to the occurrence of unphysical grid point storms. Such unphysical events are much more prevalent in the 12km RCM than the 2.2km CPM, and likely explain at least some of the overestimation in the RCM seen in Fig 11.

Overall, the above analysis gives us confidence in the plausibility of the UKCP Local Transient Projections for simulating future changes in climate and its variability at local scales, including local weather extremes. There are deficiencies, with the tendency for heavy rainfall to be too intense in summer in the CPM. There are also some unphysical values in local temperature and precipitation, although these are rare and not restricted to a single time-slice or a specific ensemble member (below we provide recommendations on how to deal with these). Nevertheless, the CPM provides a step change in our ability to represent convective processes and local storm feedbacks, to the extent that it can provide plausible projections of future changes in hourly rainfall and convective extremes.

Example applications of new UKCP Local Transient Projections

Here we present two example applications of using the new transient projections, illustrating the new capability in terms of assessing how changes in local weather extremes are manifest through time and also exploring the uncertainty in changes for global warming levels. These are just two possible applications, of many others, and should not be seen as prescriptive.

Emergence of trend in hourly rainfall extremes above variability

The 100yr simulations allow us to explore how changes in rainfall extremes manifest through time. We consider the number of events exceeding 30mm/h, which is the threshold used by the Met Office/Environment Agency Flood Forecasting Centre as indicative of flash floods (Fig 12). With the benefit of multiple realisations (here 12 ensemble members), we can see a clear increasing trend through time – with on average 2-3 times more extreme events in the 2070s compared to 1990s across the UK. However, any individual realisation shows that these changes are not necessarily realised as a smooth trend. For example, the standard member (red line) shows several extreme events in the 2040s. These events could be a fluke confluence of weather events that occurred by chance, or they could be associated with larger-scale modulation by some temporary phase of decadal variability. Thus, the actual realisation of extreme rainfall events year-by-year is a manifestation of the complex interplay between the long-term underlying climate signal and natural variability on a range of timescales. This can lead to rapid intensifications of extreme rainfall, as seen in the 2040s in the standard member (red line) and seen in other decades in other ensemble members (three other example members are shown as dashed lines in Fig 12).

The UKCP Local Transient Projections show that, depending on realisation, there may be periods of rapid intensification in local hourly rainfall extremes, followed by pauses. The pauses can perhaps be viewed as 'borrowed time' and in some cases may last a decade or more. The tendency for extreme years, with lots of extreme events, to occur in close succession poses challenges for adaptation. It is also challenging for the communication of climate change. Results here highlight that climate variability on a range of time scales can exert a substantial influence on the occurrence of local precipitation extremes, large enough to temporarily enhance or counter underlying climate change trends. This contradicts a common perception of more extremes decade by decade as a steadily increasing trend (see Capstick and Pidgeon, 2014, for discussion of problematic nature of public perceptions in relation to climate change) and emphasizes the importance of carrying out a formal attribution analysis before linking individual extreme rainfall events to climate change.

Further analysis of the emerging trend in local hourly rainfall extremes in the UKCP Local Transient Projections is found in Kendon et al., (2023). This clearly demonstrates (1) the importance of resolving convection for projecting changes to local precipitation extremes; (2) the role of internal variability in record breaking behaviour and (3) that how extreme rainfall changes will be realised through time is far from a smooth trend. Previous studies at coarser resolution (e.g., Sexton & Harris, 2015) have shown the importance of including the effects of year-to-year variability in climate change projections used for adaptation. Here the new UKCP Local Transient ensemble allows us to extend this to look at local weather extremes, which display greater variability and have more of an impact for some sectors of society.

Extreme precipitation changes for global warming levels

In impacts applications, the UKCP Local Transient Projections are being exploited to provide future changes ('uplifts') to hourly rainfall extremes for specific policy relevant global warming levels (IPCC, 2018). These correspond to the changes in the climate system when global temperature is, for example, 1.5°C or 2°C (referred to in the UN Paris Agreement) or 4°C (for a higher level) warmer than a pre-industrial baseline, with the projected time for this to occur depending on the emissions scenario and the global climate model sensitivity (IPCC, 2021). The analysis of uplifts for global warming levels (GWLs) builds on work under the FUTURE-DRAINAGE project, which provided uplifts to rainfall extremes for specific epochs, using the original UKCP Local Projections for 1981-2000, 2021-2040 and 2061-2080 (Chan et al., 2022). It should be noted that these uplifts were derived using only the 12 CPM runs, and do not sample uncertainty from other international climate models. Thus, they do not capture the full uncertainty range (see Recommendations below for further discussion) and may be systematically biased (for example, the Hadley Centre models tend to sample warmer drier outcomes in summer compared to some other CMIP5 models, Kendon et al., 2021). Using the UKCP Local Transient Projections, we are able to build a narrative of changes for different global warming levels, and specifically 2°C and 4°C that directly relate to the framing of risks within the Climate Change Risk Assessment, again with the caveat that here we are not sampling the full range of model uncertainty and are using CPM projections driven by a high climate sensitivity global model.

Since we do not possess CPM simulations covering historical climate change from pre-industrial to present-day, we cannot provide GWL-based local changes simulated relative to a pre-industrial baseline. However, we can provide CPM changes expressed relative to a 1981-2010 baseline that occur at future times when the global simulation driving each CPM experiment reaches a global warming of 2°C or 4°C relative to pre-industrial conditions. This future time varies for each ensemble member. Following Arnell et al., (2021), we identify relevant time slices from each driving global simulation by calculating global temperature changes relative to the 1981-2010 baseline, and adding the observed global warming of 0.61°C that occurred during 1981-2010 relative to pre-industrial climate. Therefore, our GWL-based CPM changes for a 2°C or 4°C global warming world represent future responses for a 30-year period centred on the year at which projected global warming in each driving simulation reaches 1.39°C or 3.39°C relative to 1981-2010. These local uplifts are somewhat smaller than would be obtained if we could calculate CPM changes relative to a pre-industrial baseline that represent the full regional response to a global temperature change of 2°C or 4°C. It might be possible to estimate such changes approximately, by extrapolating future CPM changes backwards in time. However, we do not attempt this here. Indeed, expressing the future changes relative to a baseline consistent with recent experience (while identifying them with the standard definition of a warmer world adopted by the Paris Agreement) may be an advantage for applications work.

The 30-year future period corresponding to the 2°C or 4°C global warming world is selected differently for each ensemble member. Thus, by considering global warming levels, we remove, by construction, a component of the response of rainfall across the ensemble that may arise from different members warming at slightly different rates. This typically leads to a reduction in the uncertainty in uplifts compared to results for a specific epoch centred on a similar year, particularly for the higher return periods (Figs 13-14). For example, the ensemble spread in uplifts is seen to be smaller for 2°C warming world (centred around 2030 but different for each ensemble member, Fig 13 purple) compared to results for TS2 2021-40 (orange). Note that we would not expect exact correspondence in the uplifts, since the baselines are slightly different between the two approaches. In particular, the more recent baseline for the "GWLevel" (purple) results (here we are following the convention of the OpenClim project, which uses the 1981-2010 baseline, to facilitate comparison, Arnell et al., 2021) explains the lower uplifts in this case (compared to FUTURE-DRAINAGE, 1981-2000 baseline). Nevertheless, accounting for this, the uncertainty in uplifts (measured by the 25th-75th percentile range) is still proportionally smaller. This analysis gives us an indication of the extent to which the uncertainty in extreme rainfall changes may be constrained through the use of global warming levels. However, we note that more ensemble members would be needed (here there are only 12 members) to confirm that these differences in ensemble spread are robust.

This analysis is feeding into work currently underway as part of the CS-NOW project (https://www.gov.uk/government/news/government-boosts-uk-resilience-against-climate-change), which will be examining UK risks including flooding at different warming levels as part of research to step up the UK's resilience to the impacts of climate change.

Recommendations and issues regarding use

The UKCP Local Transient Projections are just one of a number of UKCP products. The UKCP Probabilistic, Global (60km), Regional (12km) and Probabilistic Extremes products offer additional sources of information for UK impacts (Fung et al., 2018, Murphy et al., 2020), useful in applications where the higher horizontal resolution of UKCP Local is not required, or to provide wider context on large-scale drivers and/or a more comprehensive sampling of uncertainty. The UKCP Local projections are driven exclusively by variants of the Met Office Hadley Centre model and currently lack information from other international climate models. They are also only for a single emissions scenario, RCP8.5. They therefore do not support a probabilistic interpretation and provide a narrower sampling of uncertainty compared to the other UKCP products. For applications focussing on local weather extremes, or requiring information on fine spatial scales or at hourly time step, UKCP Local is expected to be the primary source of information. However, there are also cases where the other UKCP products might be more relevant. For example, the Probabilistic Extremes product allows consideration of other emission scenarios and provides a wider sampling of uncertainty. Where possible we recommend that the UKCP Local Transient projections are used in combination with UKCP Global or UKCP Probabilistic, rather than in isolation, in order to give a more complete picture of potential future changes.

The UKCP Local Transient Projections have been generated by joining five 20-year simulations, for each ensemble member. As a result, there is a break in the timeseries at 00:00 on the 1st December of the following years 2000, 2020, 2040 and 2060. For almost all analyses, this should not cause a problem – for example, it is fine to look at trends in seasonal metrics through time. However, where users are interested in measures of persistence or correlations between different times, it is important in this case to exclude values that span the break points.

As outlined above, there are some unphysical values in local temperature and precipitation. These may arise from numerical instabilities or more general model issues, and where the values are considerably outside observed experience, they are more likely to be unbelievable rather than just unseen. Such unphysical values are rare in UKCP Local, and only expected to impact results for applications focusing on extreme events at local (5km or less) scales. For such analyses, we would recommend that users visualise any outlying high values in their data sample. For hourly rainfall, we would suggest an approximate threshold of 100mm/h as indicative of a high value, and for temperature a threshold of 45°C in the present-day climate (based on the maximum values that have been observed). If the outlying values correspond to very localised events (with much lower values across all of the surrounding grid boxes) then we suggest that they are likely unphysical and should be removed from further analysis. Supporting evidence for unphysical daily maximum temperature values is if they occur during summer (or between May and September) near the coast (as they tend to occur in association with sea breezes); whilst for precipitation, additional supporting evidence is if there is little rainfall at the given grid point on adjacent hours. Outlying values identified as unphysical values should be successively removed until the highest few events appear realistic. It is not possible to identify a generic threshold that can be uniformly applied to distinguish unphysical events and instead the assessment needs to be done on a case-by-case basis, based on visual inspection and judgement of the user. It is likely to vary regionally, seasonally and through time. For example, an implausibly high temperature in the present-day may be commonplace in later time periods. For applications that do not consider local extreme events – for example, analyses of seasonal means or spatially averaged metrics – contamination by rare unphysical local values is expected to be negligible and no action is required. Similarly for temporally aggregated metrics, such multi-day heatwaves, we would expect little impact.

Bias adjustment of UKCP18 outputs may be needed for some applications. This is especially likely when interested in the exceedance of specific absolute thresholds, e.g. temperature thresholds relevant to infrastructure design or rainfall thresholds indicative of flash flooding, as well as intensity metrics. Bias adjustment methods adjust the modelled mean, variance, and/or higher moments of the distribution of climate variables, so that they more closely match the observations. They require sufficient observational data to characterize the reference climatology. In practice this is at least 30 years of data. The observational data must also be of sufficient quality and high enough (spatial and temporal) resolution to provide reliable adjustments for a given variable. There are a number of different approaches to bias adjustment (see Table 1) and the appropriate choice will depend on the application. It is important to emphasize, however, there are caveats associated with bias adjustment. For example, it can lead to unphysical changes, including potentially distorting the relationship between different variables, and also most methods assume biases do not vary with time, which may not be valid as we move to a future warmer climate and especially where the bias is due to compensating errors. For more information on bias adjustment methods and when to use them see Fung (2018) and Doblas-Reyes et al., (2021).

Bias adjustment method	Approach	Advantages	Disadvantages
Linear shift	Adjusts model projections accounting for any bias in the mean	Simple	Does not account for biases in model variance that can impact extremes; assumes adjustments do not vary with time
Scaling of variance (Hawkins et al 2013)	Scales model variance, in combination with adjusting the mean bias	Simple	Does not account for biases in other moments of the model distribution that can impact extremes; assumes adjustments do not vary with time
Delta change	Average future change from model projections is added (or applied as a multiplicative factor) to the observational timeseries	Simple	Loses all modelled changes to variability and extremes
Quantile mapping	Adjusts model values by different amounts depending on their position in the modelled distribution	Accounts for present-day biases in model variance and extremes	Assumes that error adjustment values between the modelled and observed distributions do not vary with time (i.e. assumes stationarity), resulting in the distortion of trends
Scaled distribution mapping (Switanek et al 2017)	Scales the observed distribution by raw model projected changes in magnitude, rain-day frequency (for precipitation), and likelihood of events. The scaling changes as a function of the bias adjustment period.	Accounts for biases in mean and variability. Makes no assumption of stationarity	The correlation between neighbouring grid cells does not enter the method and so it is not suitable in a multi-site context (e.g., modelling hydrological extremes).

Table 1. Summary of bias adjustment methods and their advantages and disadvantages.

Accessing data

Data are available from the UKCP User Interface (https://ukclimateprojections-ui.metoffice.gov.uk/ui/home) or from the CEDA archive (https://catalogue.ceda.ac.uk/?q=ukcp18). The User Interface (UI) allows users to download datasets, including UKCP Local projections regridded to the 5km Ordnance Survey National grid, and to plot graphs and maps for the UK. Some datasets are not available via the UI, such as the raw 2.2km UKCP Local projections. These instead are available for download from CEDA. The CEDA archive contains the following UKCP Local (Convection-permitting) datasets:

1. UKCP Local Projections at 2.2km resolution for 1980-2080
2. UKCP Local Projections by Administrative Regions over the UK for 1980-2080
3. UKCP Local Projections for UK Countries for 1980-2080
4. UKCP Local Projections by UK River Basins for 1980-2080
5. UKCP Local Projections on a 5km grid over the UK for 1980-2080

Data from the new UKCP additional time-slices will be added to the existing CEDA entries, but with an update to the dataset description, making it clear that the entries now relate to the full UKCP Local Transient Projections. The following peer-reviewed paper, which provides a description of the model experiments, can be used when referring to the UKCP Local Transient Projections:

> Kendon, E.J., E.M. Fischer and C.J. Short (2023) Variability conceals emerging trend in 100yr projections of UK local hourly rainfall extremes, Nature Comms, doi:10.1038/s41467-023-36499-9 https://www.nature.com/articles/s41467-023-36499-9

The 2.2km raw data are on a rotated pole grid, whilst the 5km regridded data are on the Ordnance Survey National grid (OSGB). The data are also available for three types of aggregated areas: country regions, administrative regions and river basin regions. We note that UKCP Local (2.2km) data over the Shetland Isles are not reliable due to its proximity to the northern boundary of the model domain and should not be used. We do not include these grid cells in calculating the regional average.

For more information on accessing UKCP data, including other UKCP18 products, please see the UKCP Guidance document on Data availability, access and formats (https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18_data_availability_jul-2021.pdf). All data is provided under the Open Government Licence.

Future planned updates and additional data sources

Additional UKCP Local simulations downscaling other CMIP5 models have recently been completed. Four CMIP5 models have been selected for downscaling (MRI-CGCM3, MPI-ESM-LR, IPSL-CM5A-MR and ACCESS1-3). These correspond to four of the 13 CMIP5 models in UKCP18 that have a sufficiently high model top and were also selected to span a diversity of future changes. We note that MPI-ESM-LR was used instead of MPI-ESM-MR (which was the original selection from the CMIP5-13 set) due to difficulties getting lateral boundary forcing for the latter. Each of these simulations has been downscaled by the UKCP Regional standard member, which in turn has been downscaled by UKCP Local. Post-processing and evaluation of the model outputs is currently underway, before release of the data in time for feeding into the Fourth Climate Change Risk Assessment (CCRA4). These additional CMIP5 downscaled simulations will augment the existing UKCP Local projections and likely broaden the range of downscaled projections available for detailed UK impact studies. Release of these simulations is currently planned for late 2023 or early 2024.

The CORDEX-Flagship Pilot Study on Convective Phenomena (Coppola et al. 2020) and European Climate Prediction System (EUCP) project (Hewitt and Lowe, 2018) have recently produced a coordinated set of multi-model CPM simulations over Europe. Simulations have been carried out by multiple climate modelling centres for a common Alpine domain (15 different CPMs), with some groups also providing additional simulations for other regions of Europe. For NW-Europe including the UK, there are 4 different CPM simulations available. This is an additional dataset, complementary to the UKCP Local Transient Projections, which will be made publicly available in the future through the Earth System Grid Federation nodes with other CORDEX-style simulations. It will allow an assessment of the extent to which future changes are robust across different CPMs (Ban et al 2021, Pichelli et al 2021).

The NERC FUTURE-FLOOD project (starting April 2023) will exploit the UKCP Local Transient Projections to look at emerging flood risk through time. In this, the LISFLOOD-FP (Neal et al., 2021) hydrodynamic and DECIPHER (Coxon et al., 2019) hydrological models will be directly driven by UKCP Local to estimate pluvial and fluvial flooding across the UK. It will include changes in the full spatial and temporal variability of rainfall and their interactions with the landscape. A pilot study for Bristol demonstrated that this can lead to radically different flood estimates compared to standard uplift approaches, where observational data input into flood models is uplifted by a given factor to estimate a given return-period flood.

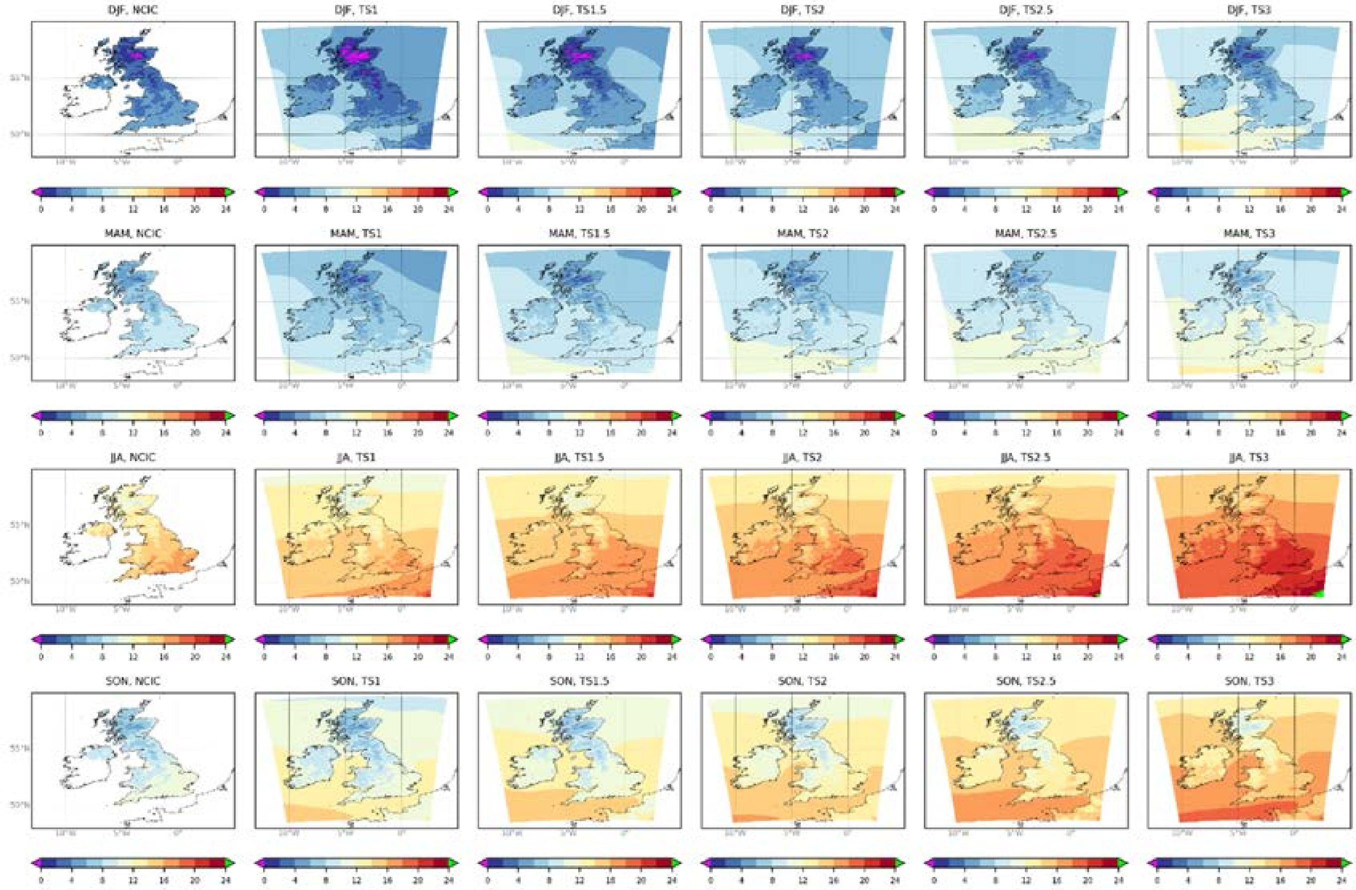


Figure 1. Seasonal mean temperature (°C) for each 20-year time-slice. Results are shown for the NCIC observations (1981-2000) and for the UKCP Local ensemble mean for the 5 time-slices (TS1 = 1981-2000, TS1.5 = 2001-2020, TS2 = 2021-2040, TS2.5 = 2041-2060 and TS3 = 2061-2080). Results are shown for the 4 seasons (December-January-February DJF, March-April-May MAM, June-July-August JJA and September-October-November SON).

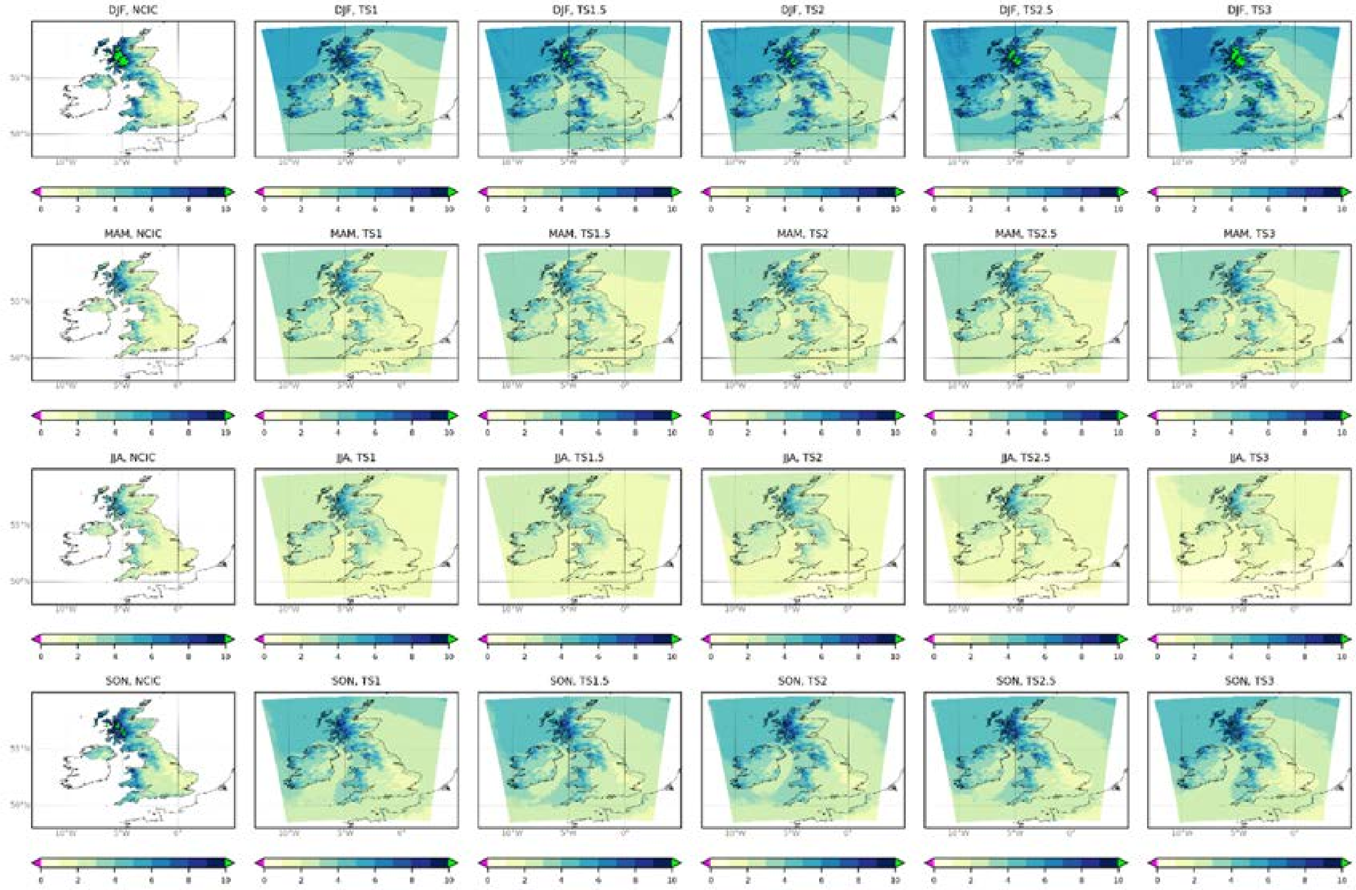


Figure 2. Seasonal mean precipitation (mm/day) for each 20-year time-slice. Results are shown for the NCIC observations (1981-2000) and for the UKCP Local ensemble mean for the 5 time-slices (TS1 = 1981-2000, TS1.5 = 2001-2020, TS2 = 2021-2040, TS2.5 = 2041-2060 and TS3 = 2061-2080). Results are shown for the 4 seasons (December-January-February DJF, March-April-May MAM, June-July-August JJA and September-October-November SON).

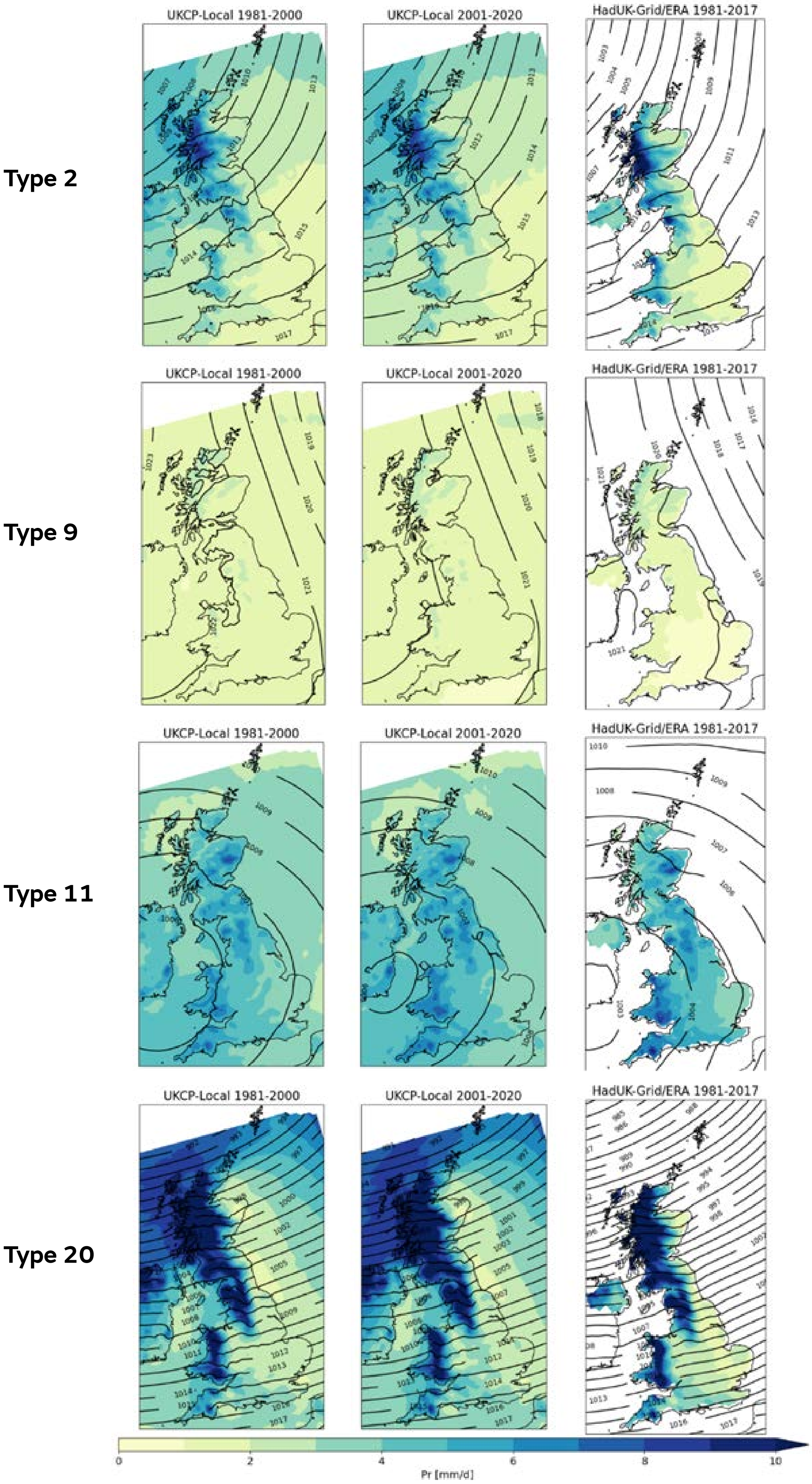


Figure 3. Mean precipitation and mean sea level pressure (MSLP) associated with selected weather patterns. Shown is average precipitation (filled contours, mm/day) and MSLP (line contours, hPa) on days annually with (top) weather pattern 2, corresponding to a cyclonic southwesterly with a returning polar maritime airmass, (2nd row) weather pattern 9, corresponding to anticyclonic north-northeasterly with a high centred near Iceland, (3rd row) weather pattern 11, corresponding to cyclonic with a low centred over southern UK and (bottom) weather pattern 20, corresponding to cyclonic westerly with an intense low near Iceland. Results are shown for (left) UKCP Local TS1 (1981-2000), (centre) UKCP Local TS1.5 (2001-2020) and (right) NCIC observations for precipitation and ERA5 reanalysis for MSLP (1981-2017).

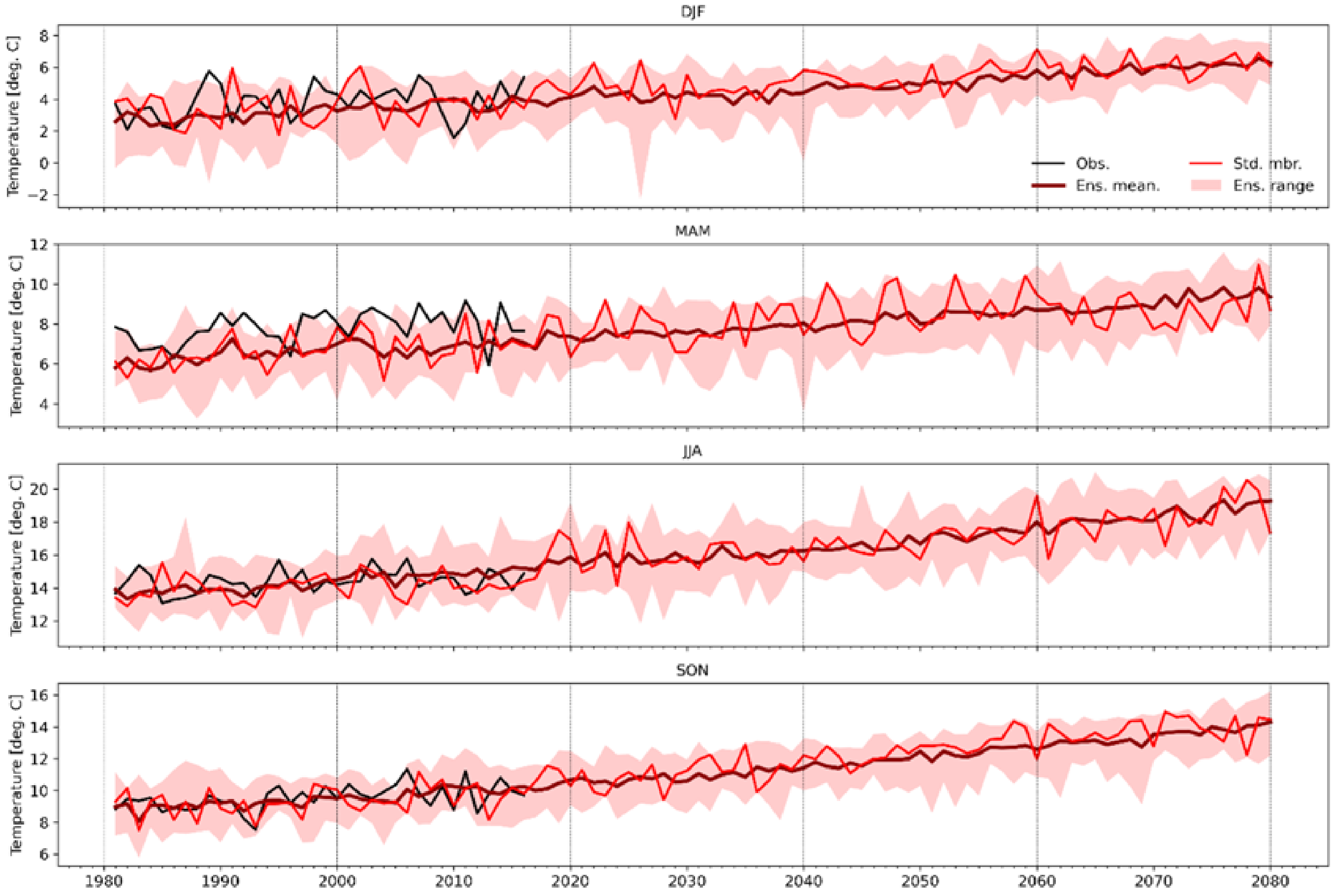


Figure 4. Annual timeseries of UK-average seasonal mean temperature from 1981-2080, for each of the 4 seasons. Results are shown for the standard ensemble member (red), ensemble mean (dark red), ensemble spread (min to max, shaded) of the UKCP Local (2.2km) projections. Also shown are the NCIC observations from 1981-2016 (black).

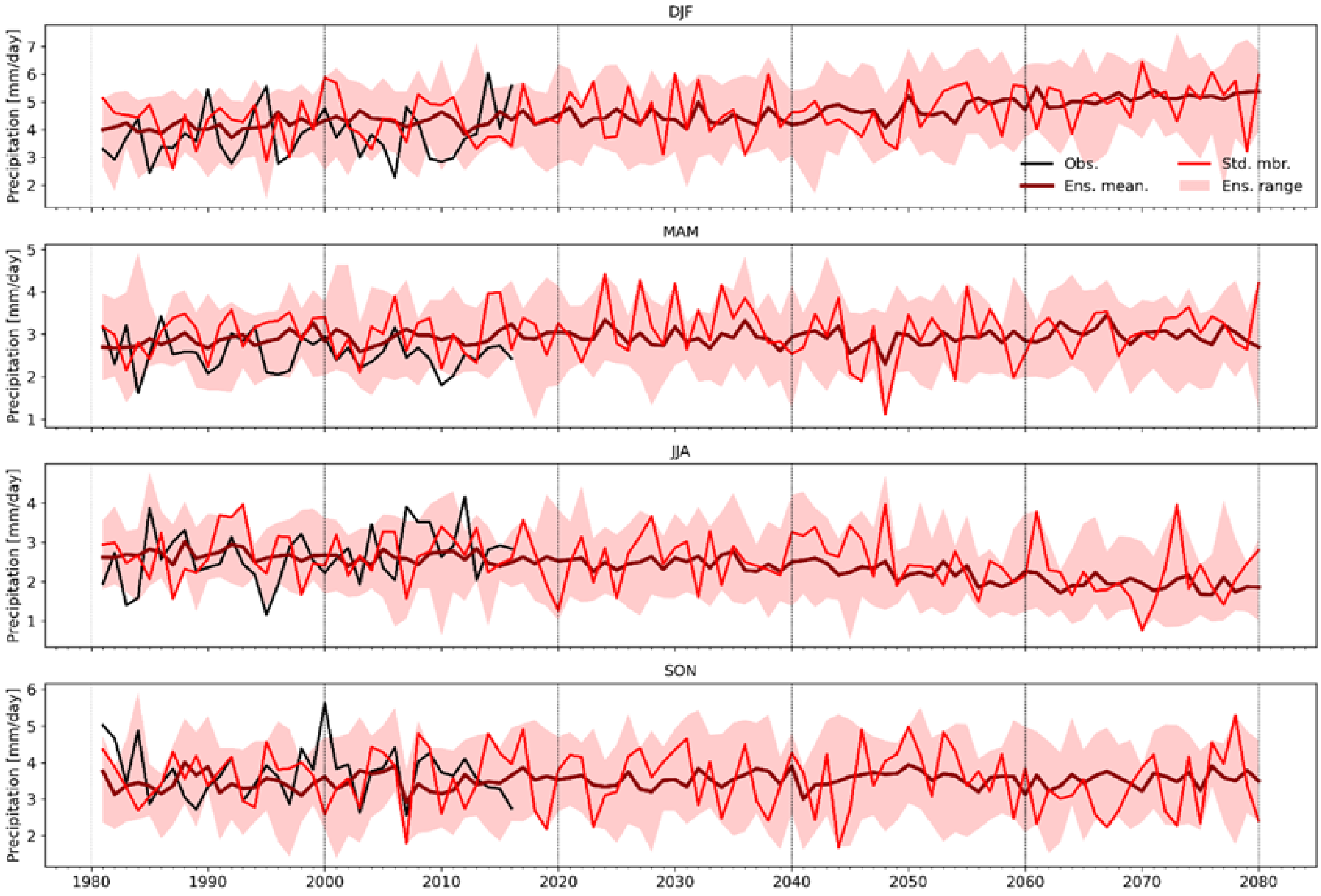


Figure 5. Annual timeseries of UK-average seasonal mean precipitation from 1981-2080, for each of the 4 seasons. Results are shown for the standard ensemble member (red), ensemble mean (dark red), ensemble spread (min to max, shaded) of the UKCP Local (2.2km) projections. Also shown are the NCIC observations from 1981-2016 (black).

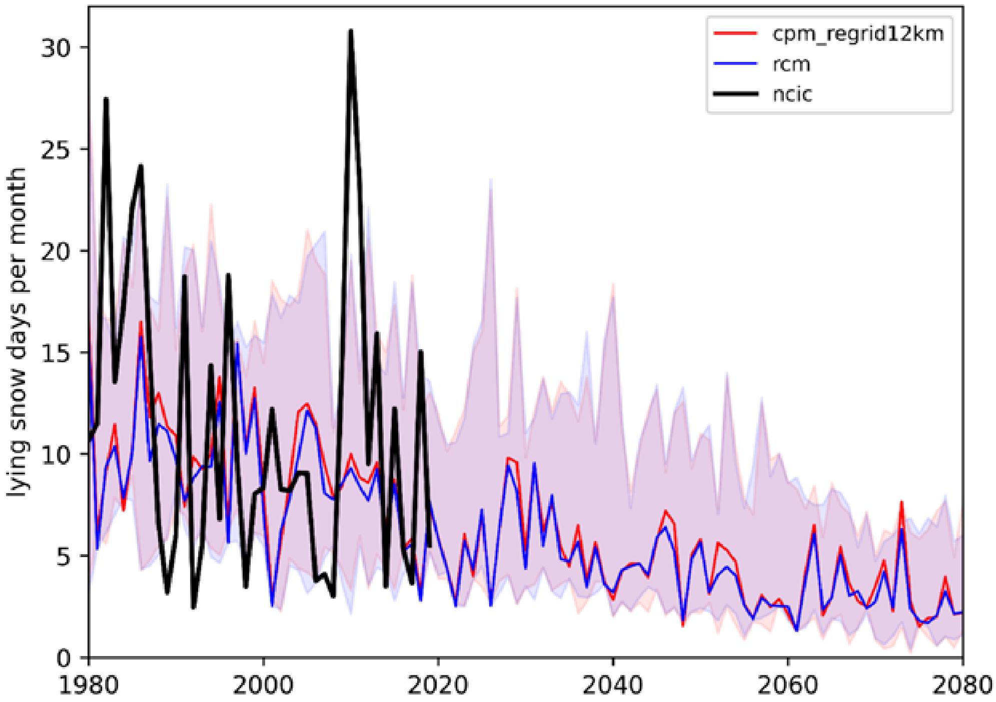
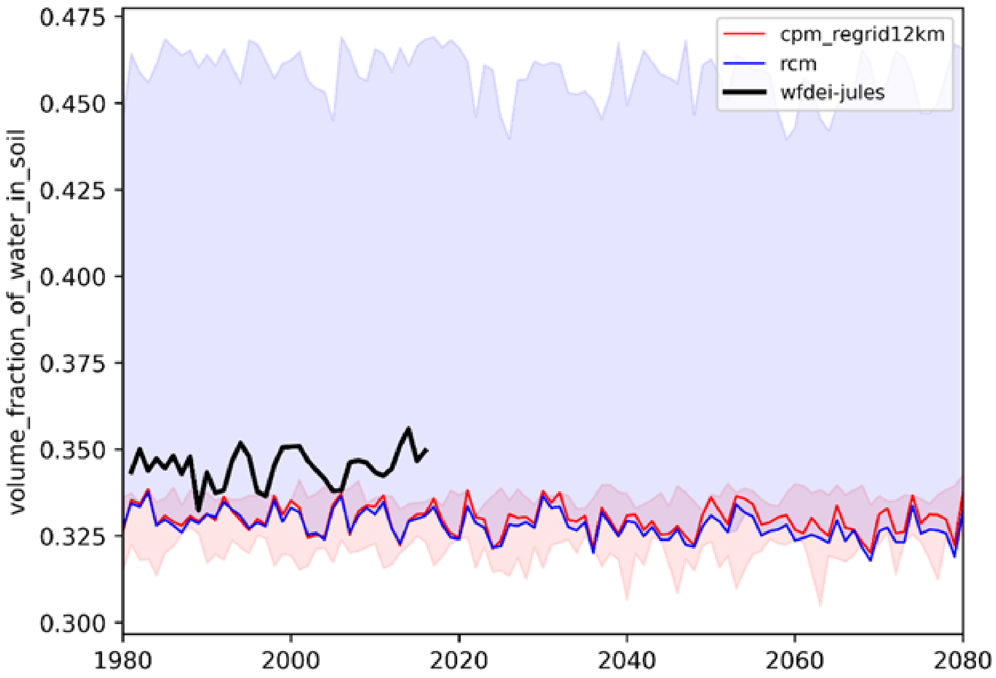


Figure 6. Days of lying snow per month, where a threshold of 0.2mm is used to convert to a 'day' of lying snow. Shows comparison of UKCP Local regridded to 12km grid (CPM, red), UKCP Regional (RCM, blue) and NCIC observations (black). For models, shown is standard member (line) and ensemble member spread (min-max, shaded).



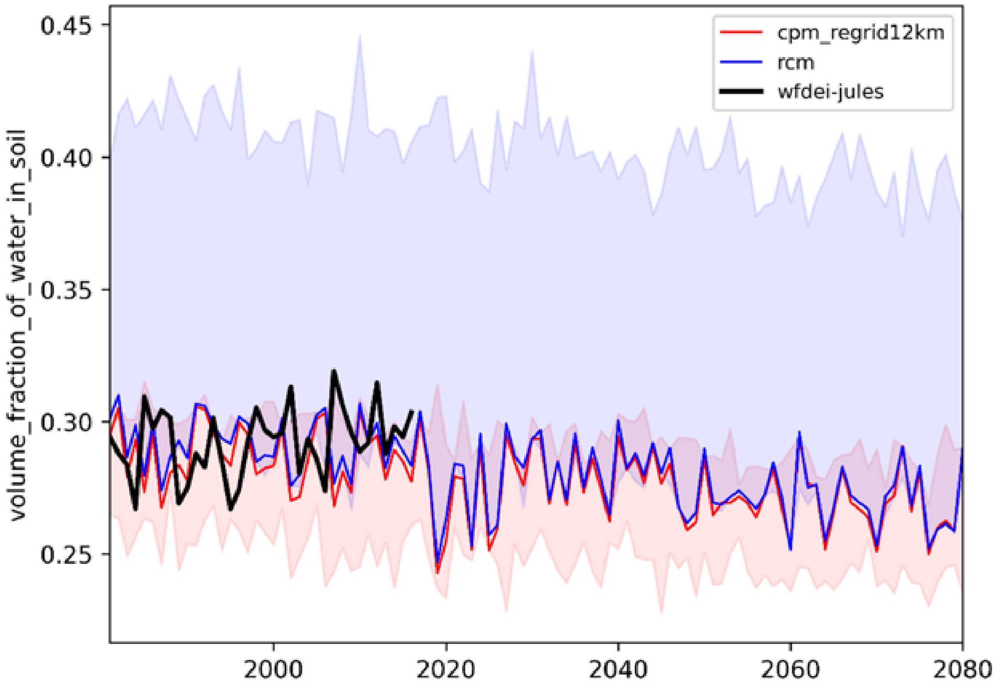


Figure 7. Root zone (top 1m) soil moisture fraction in (top) DJF and (bottom) JJA. Shown is standard member (line) and ensemble member spread (min-max, shaded), for UKCP Local regridded to 12km (CPM, red) and UKCP Regional (RCM, blue). The WFDEI-JULES dataset is shown in black, which is land-surface properties simulated by JULES forced by WATCH (bias-corrected ERA-Interim reanalysis data, Weedon et al 2014) and is a proxy for observed soil moisture.

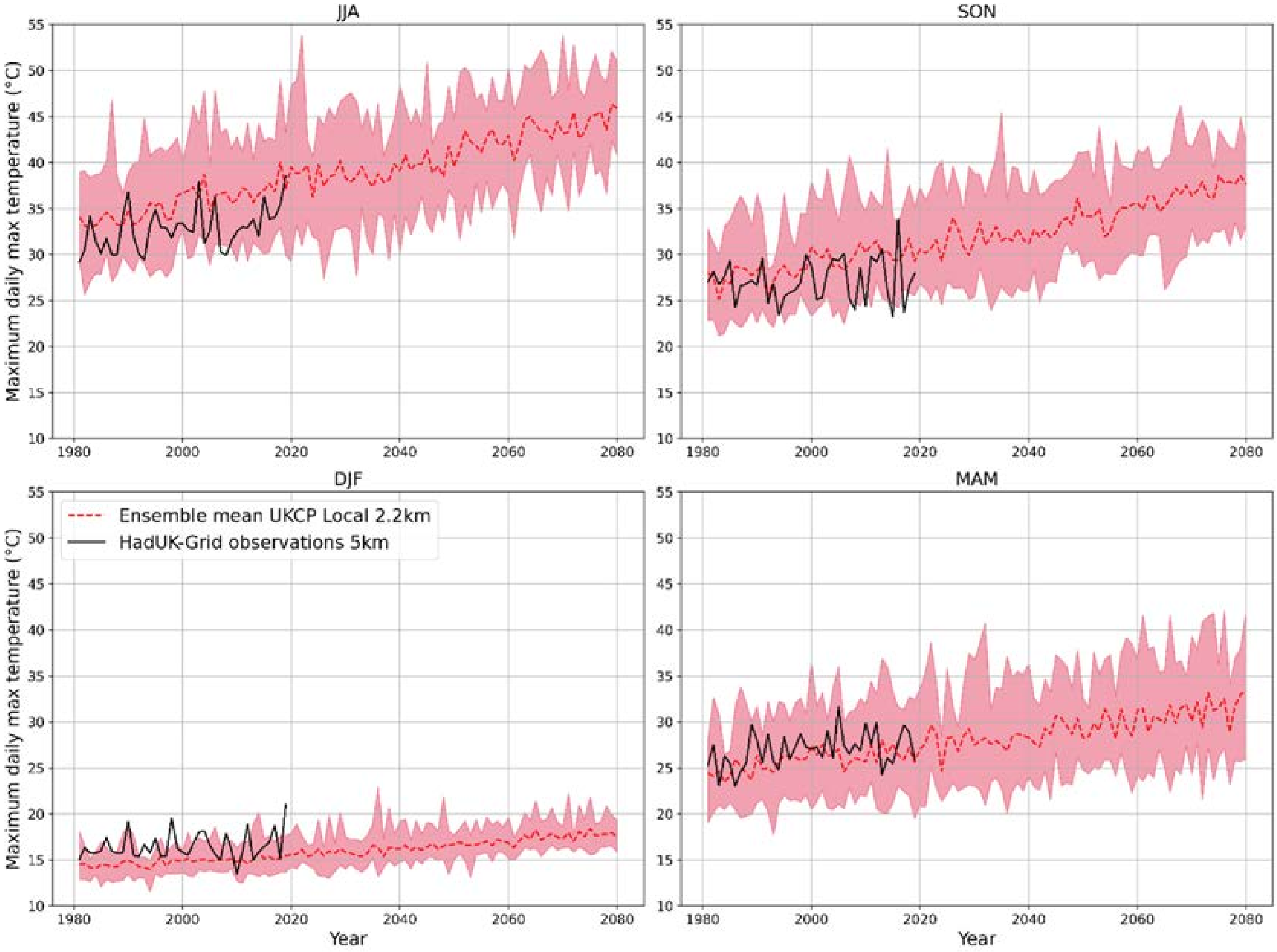


Figure 8. Seasonal maximum value of daily maximum temperature at 2.2km scale for any grid box over the UK in UKCP Local. Shaded pink is ensemble range, with dotted red line the ensemble mean. Also shown (black) are values at 5km scale in the NCIC observations.

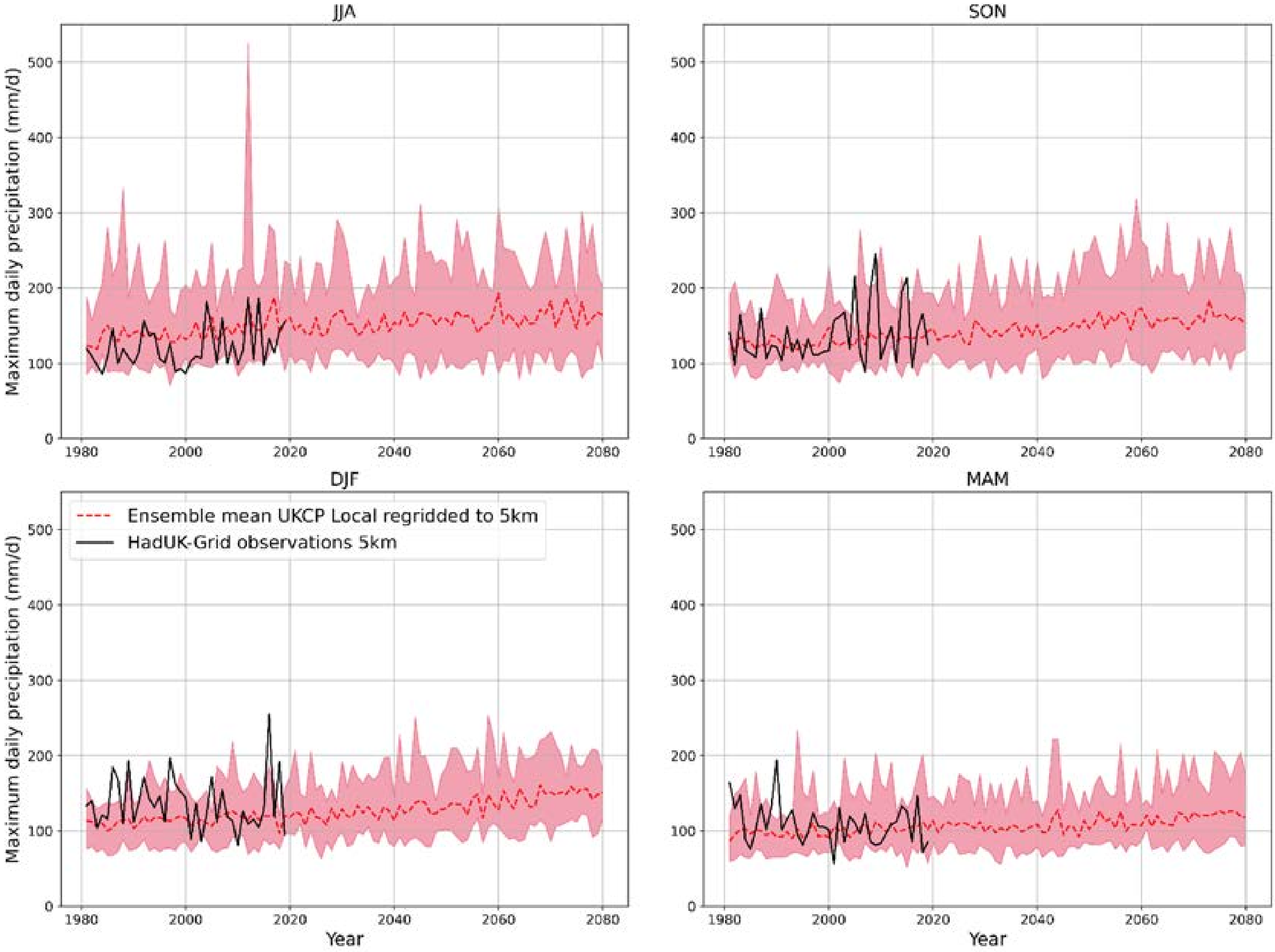


Figure 9. Seasonal maximum value of daily precipitation at the 5km scale for any grid box over the UK in UKCP Local. Shaded pink is ensemble range, with dotted red line the ensemble mean. The NCIC gridded observations also at 5km resolution are shown in black.

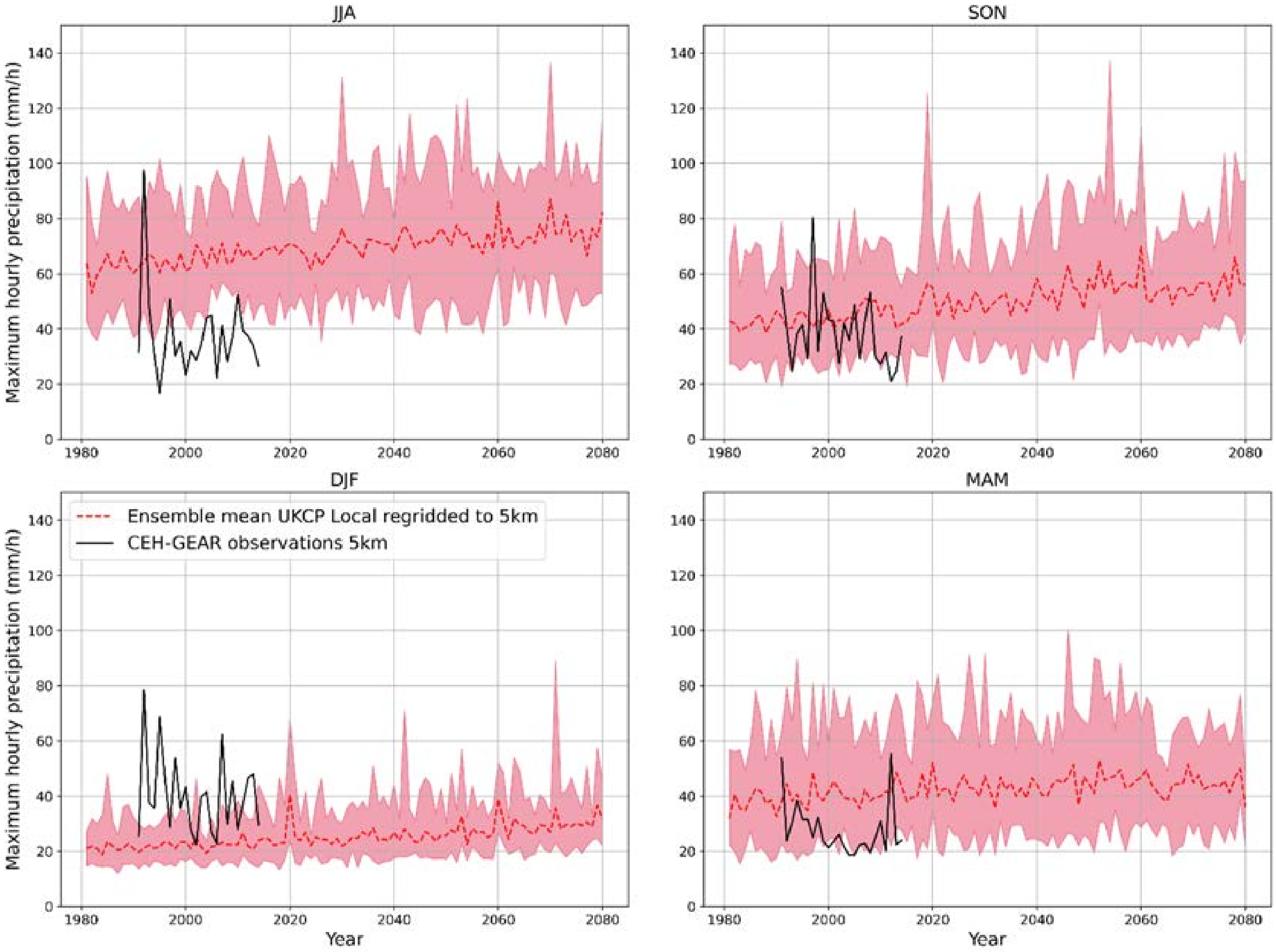


Figure 10. Seasonal maximum value of hourly precipitation at 5km scale for any grid box over the UK in UKCP Local. Shaded pink is ensemble range, with dotted red line the ensemble mean. The CEHGEAR-1h gridded observations also at 5km resolution are shown in black.

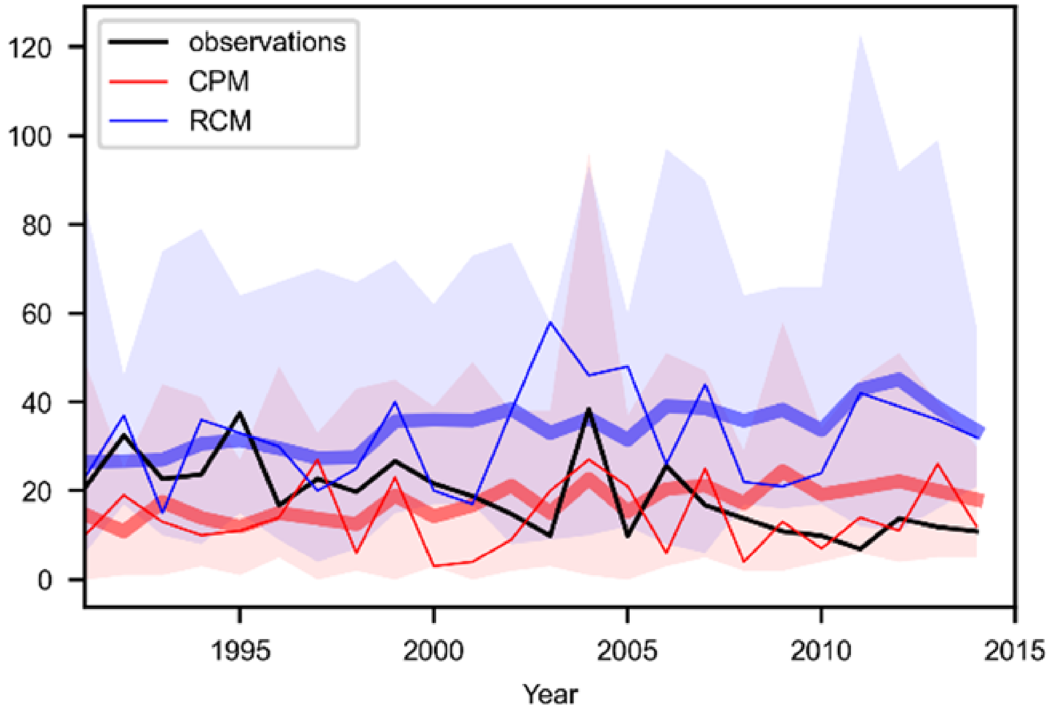


Figure 11. Number of events per year across the UK exceeding 20mm/h at the 12km scale. Threshold exceedances occurring within a UK subregion on the same day are considered part of a single event. Results are shown for CEHGEAR observations (black), and UKCP Local (CPM, red) and UKCP Regional (RCM, blue) for the standard member (thin line), ensemble mean (thick line) and ensemble min-max range (shaded) for 1991-2014. The standard member is illustrative of the variability in an individual realisation. (From Kendon et al, N Comms, 2023)

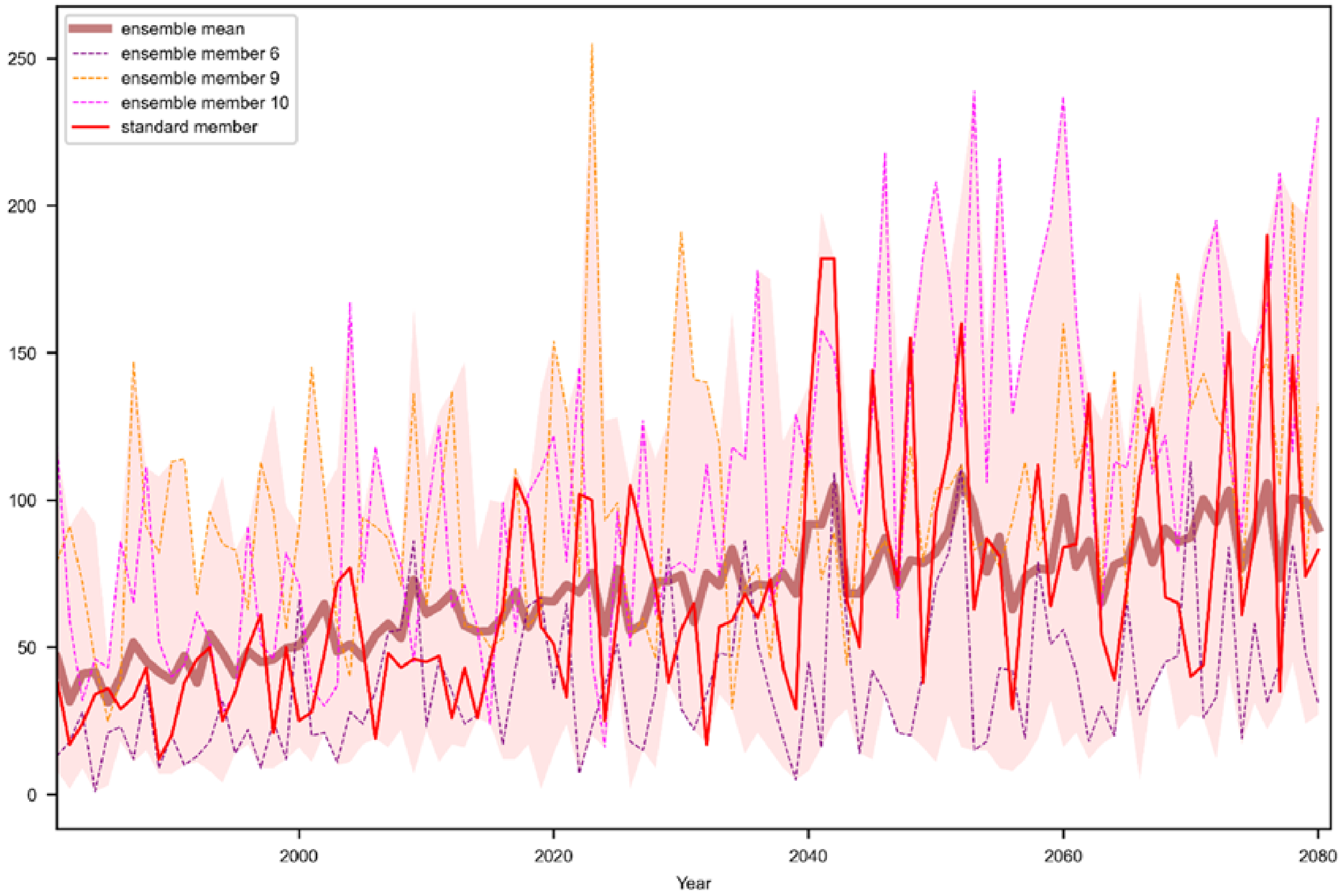


Figure 12. Number of rainfall events per year exceeding 30mm/h across the UK in UKCP Local for 1981-2080. Results are shown for the standard member (red line) and three other example ensemble members (dashed purple, orange and magenta lines), as illustrative of the variability in an individual realisation. Also shown is the ensemble mean (thick dark red line) and ensemble min-max range (shaded). Results are for hourly rainfall averaged over 5km grid box. Threshold exceedances occurring within a UK subregion on the same day are considered part of a single event.

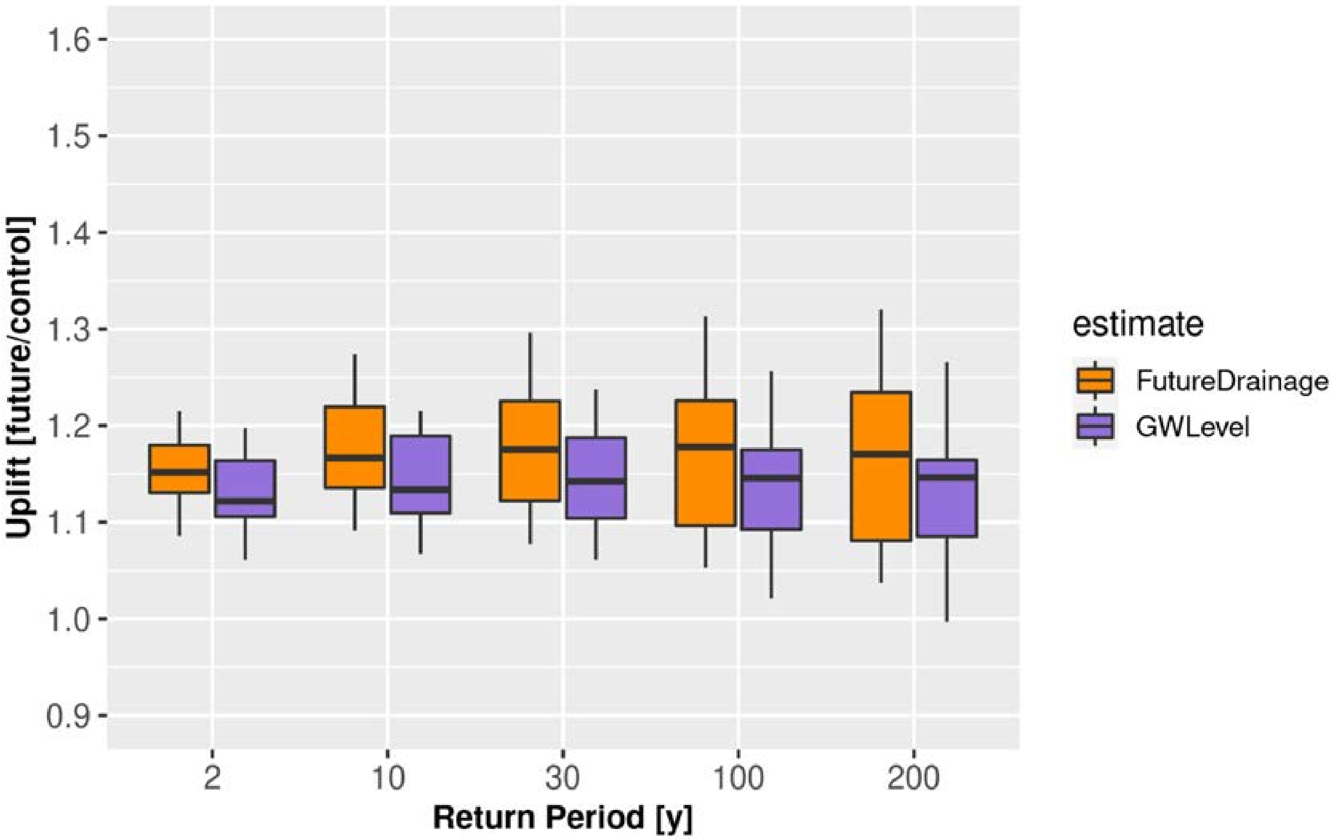


Figure 13. Uplifts in hourly precipitation as a function of return period for 2°C global warming world. The global warming level (GWLevel) results (purple) correspond to the uplifts to precipitation with respect to a 1981-2010 baseline for a 2°C global warming world, corresponding to the future 30-year period with a 1.39°C global mean temperature rise since the 1981-2010 baseline. This assumes a 0.61°C global warming in 1981-2010 compared to pre-industrial (following Arnell et al, 2021). The time of reaching the 2°C global warming level varies for each ensemble member but approximately corresponds to the 30-year period 2015-2045. The Future-Drainage results (orange) give uplifts for a given future period (2021-2040), similarly centred on 2030, compared a 1981-2000 baseline. In the Future-Drainage approach, the same year range is used for each ensemble member. Results are for hourly precipitation at the 5km scale. The box and whiskers illustrate the spread in uplifts across the 12-member UKCP Local ensemble, showing the median (central line), 25th to 75th percentile range (box) and 5th to 95th percentile range (whiskers). Note the Future-Drainage project only publicly released uplifts for 2050 and 2070, and not 2030.

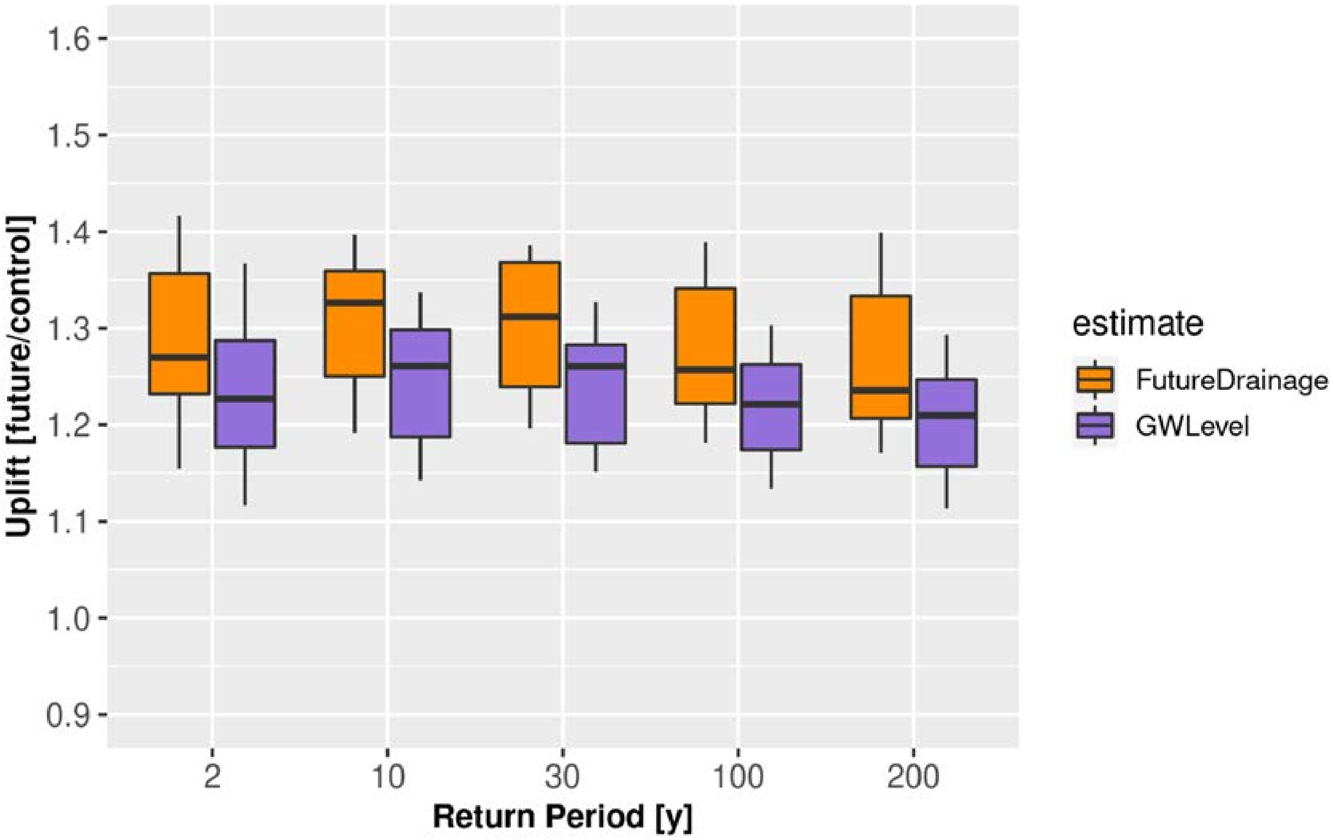


Figure 14. Uplifts in hourly precipitation as a function of return period for 4°C global warming world. As Fig 13, but for uplifts to precipitation with respect to a 1981-2010 baseline for a 4°C global warming world, corresponding to the future 30-year period with a 3.39°C global mean temperature rise since the 1981-2010 baseline. The time of reaching the 4°C global warming level varies for each ensemble member but approximately corresponds to the 30-year period 2050-2080. The Future-Drainage results give uplifts for a given future period (2061-2080), centred 5 years later and compared a 1981-2000 baseline. In the Future-Drainage approach, the same year range is used for each ensemble member.

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