RCM Potential Evaporation error: description and experiments to show effect on eFLaG simulations

1 Background

Within the Hydro-JULES programme, python code was developed in 2020 to estimate short grass potential evaporation (PE) from meteorological data using the Penman-Monteith formulation (Robinson et al. 2022). The method aimed to emulate short grass PE from MORECS (Hough & Jones 1997) as closely as possible, particularly by using monthly varying stomatal resistance, leaf-area index etc., but it built upon the CHESS-PE calculation (Robinson et al. 2020).

Like CHESS-PE, the code produces both 'potential evapotranspiration' (PET) and 'potential evapotranspiration with interception' (PETI). However, the interception component is implemented in a different way in the new code compared to CHESS-PE, again to replicate MORECS. One important difference is that MORECS includes an enhancement of interception in non-winter months (to allow for rainfall likely occurring in multiple shorter events through the day).

The code was applied to derive PE using data from the UKCP18 Regional Climate Model (RCM) perturbed-parameter ensemble (PPE) (Murphy et al. 2018). The resulting PET and PETI datasets were published on EIDC ('Hydro-PE UKCP18 RCM'; Robinson et al. 2021). For the eFLaG project, a variation of the Hydro-PE UKCP18 RCM PETI dataset was produced. This applied bias-correction to the precipitation data before use within the interception calculation, in the same way as the precipitation was bias-corrected before use in eFLaG.

2 PE Issue

A bug was recently discovered in the original Python PE code which affected PETI datasets made after the original 'Hydro-PE UKCP18 RCM' dataset, including that made for eFlaG.

After the interception enhancement was applied for non-winter months, the code should have limited total interception to not exceed precipitation. But the limit was not applied resulting in interception exceeding precipitation for some days. This only affected non-winter days with small, non-zero, precipitation rates. The result is that, overall, the interception correction to PET is slightly overestimated.

To investigate if this bug significantly effects the eFLaG projections, the original Python PE code was modified to fix the identified bug, and the PETI dataset was remade and then used to generate a representative subset of the original river flow and groundwater level projections. The effects with respect to PETI, river and groundwater projections are outlined below.

The PETI data and associated river flow and groundwater level simulations used in eFLaG are referred to using the label "eFLaG PETI". The equivalent data using the fixed Python code are referred to using the label "corrected PETI".

3 Effect on PETI

3.1 Overall effect on PETI

An analysis of the overall effect of the bug on large-area mean PETI in each month (averaged over 1980-1990) shows that the difference is small, both compared to the overall PETI and to the uncertainty range from the RCM PPE (Figure 1). The correction reduces PETI mainly in the summer months (by ~0.025–0.045 mm/d on average, or up to ~2% of total PETI), with no difference at all in the winter months.

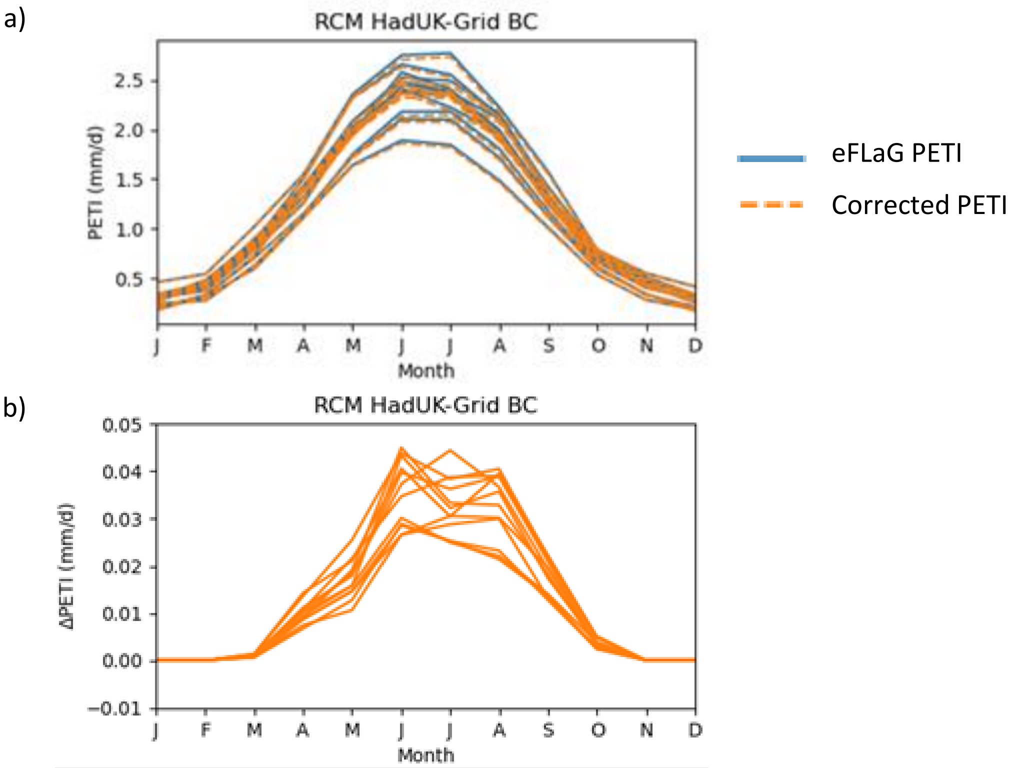

Figure 1 Comparison of UKCP18 RCM PETI used in eFlaG and corrected RCM PETI, averaged over all land grid boxes for 1980-1990, for the 12 RCM PPE ensemble members. a) The PETI monthly climatologies for the original PETI (solid blue lines) and corrected PETI (dashed orange lines). b) The difference between the original and corrected monthly climatologies (original minus corrected).

3.2 Effect on catchment-average PETI

An analysis of the impact of the bug on catchment-average PETI over the full period also showed that the difference was small relative to daily PETI values and mainly impacted summer months (Figure 2). This figure only shows results for RCM ensemble member 01, with the other ensemble members showing a very similar result. The majority of the PETI data is not impacted by the fix (all catchments show a median change in PETI of 0.00 mm/day for all RCM ensemble members). Where PETI is impacted by the fix the changes tend to be small, with mean changes to daily PETI of -0.5% to -1.2% over these example catchments and all ensemble members. The largest PETI differences are up to around -0.4mm/day (or -15%).

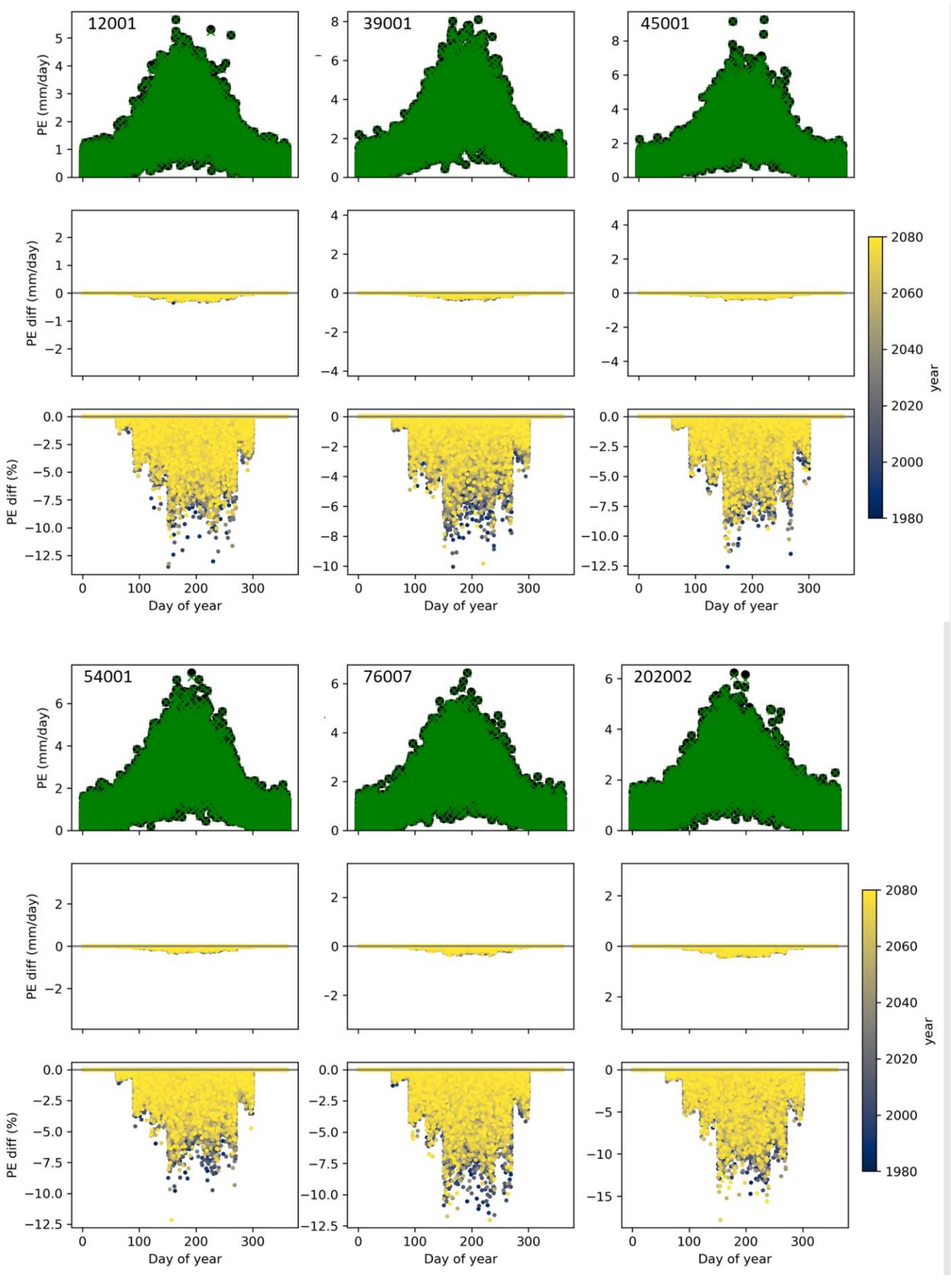

Figure 2 Comparison of UKCP18 RCM catchment-average PETI used in eFLaG (black dots) and corrected catchment-average PETI (green crosses), covering 1980-2080 for RCM ensemble member 01. Results are given for six catchments: 12001 Dee at Woodend; 39001 Thames at Kingston; 45001 Exe at Thorveton; 54001 Severn at Bewdley; 76007 Eden at Sheepmount; 202002 Faughan at Drumahoe. Top plots show all PETI values from 1980-2080, with eFLaG PETI values given as

black dots and corrected values as green crosses. Middle and bottom plots show the difference (corrected PETI minus eFLaG PETI).

4 Effect on simulated catchment river flows

The PDM river flow models were re-run using the corrected catchment-average PETI. The difference this makes to the modelled flow is small, as discussed below.

4.1 Effect on river flow time series

Figure 3 shows time series of PDM river flows calculated with the eFLaG PETI and the corrected PETI for a single year and a single RCM ensemble member. The differences in river flow are sufficiently small that the hydrographs produced using eFLaG PETI are almost entirely obscured by the hydrographs produced using corrected PETI (upper graphs in Figure 3). As expected from the nature of the PETI correction, such differences as do occur (middle graphs in Figure 3) tend to be positive (the corrected flows tend to be slightly higher) with proportionally greater change during summer months, especially following periods where modest rainfall has fallen on to a dry catchment (see lower graphs). Overall, the typical percentage change in flow is 0.33%, calculated as the median over sites of the median percentage change in flow over all years and all RCM ensemble members. Calculated over earlier years (1983-2012) the typical percentage change in flows is slightly higher, 0.37%, dropping to 0.28% in later years (2050-2079). Note that the changes displayed in the middle graphs of Figure 3 are in fact notably larger than typical (the median difference here is 0.55%), primarily due to the selection of the RCM13 ensemble member.

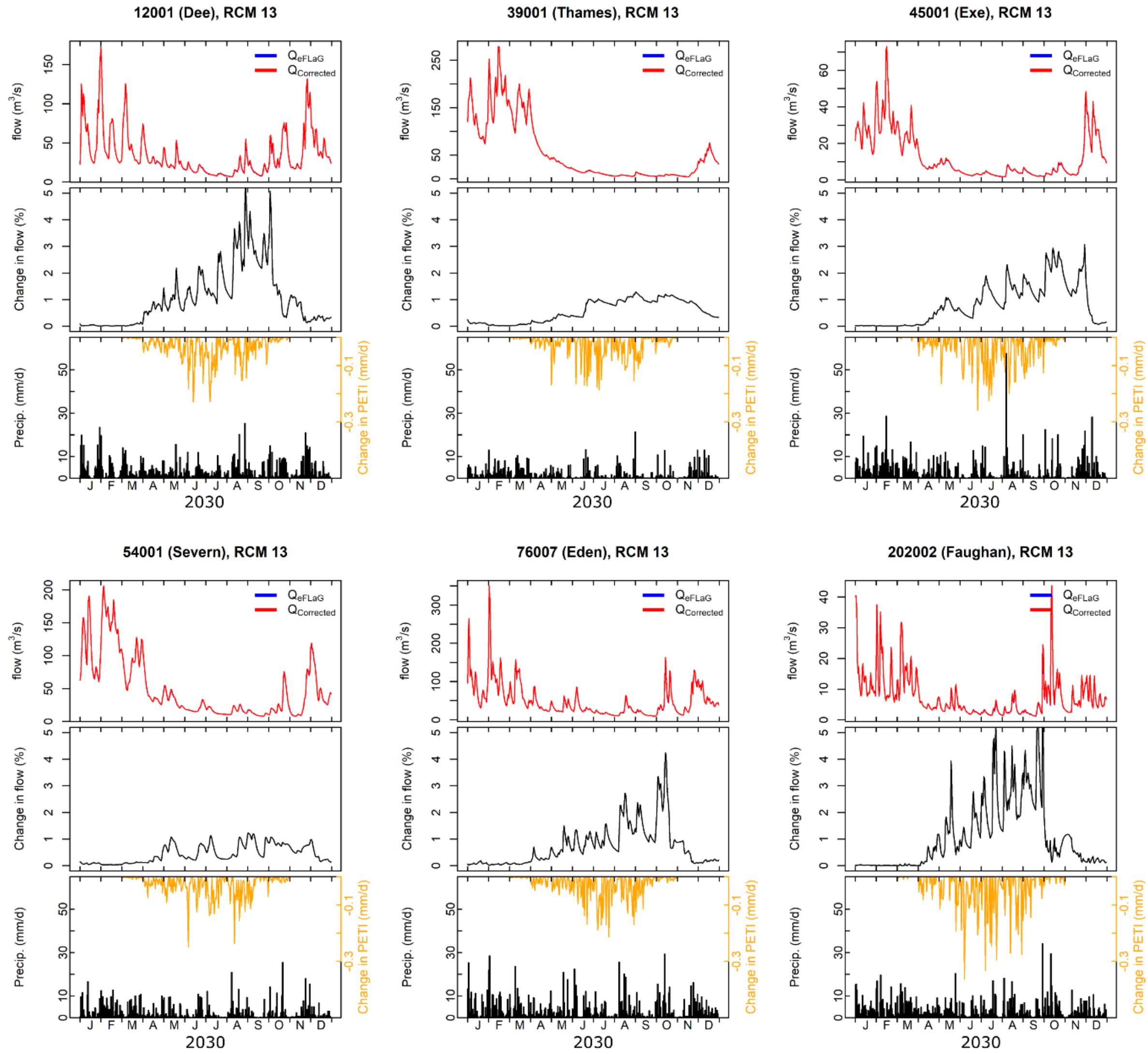

Figure 3. Comparisons of modelled PDM river flows for six example catchments. Shown for a single selected RCM ensemble member that displays larger than typical changes in the modelled river flow (RCM 13) and for a single year (2030). Upper graphs: Hydrographs of modelled flow using the eFLaG PETI (Q_{eFLaG}, blue), and the corrected PETI ($Q_{corrected}$, red). Note that the flows using eFLaG PETI are almost entirely obscured by the flows using corrected PETI. Middle graph: The percentage change in flow ($100\% \times (Q_{corrected} - Q_{eFLaG})/Q_{eFLaG}$). Lower graph: The daily precipitation input with snow melt (black) with the change in PETI (corrected - eFLaG) shown using the right axis (orange).

4.2 Effect on river flow indices

A range of flow quantiles (from Q30 equating to moderately high flows to Q90 representing low flows) have been calculated to assess the impact of the changing PETI data driving PDM on flows across the regime. Quantiles have been calculated for each rolling 30-year window in the eFLaG dataset, with the value in 2020 reflecting flows over the 1991-2020 timeframe, values in 2021 reflecting flows over the 1992-2021 timeframe, and so on. Results are presented in Figure 3 for 6 catchments across the UK.

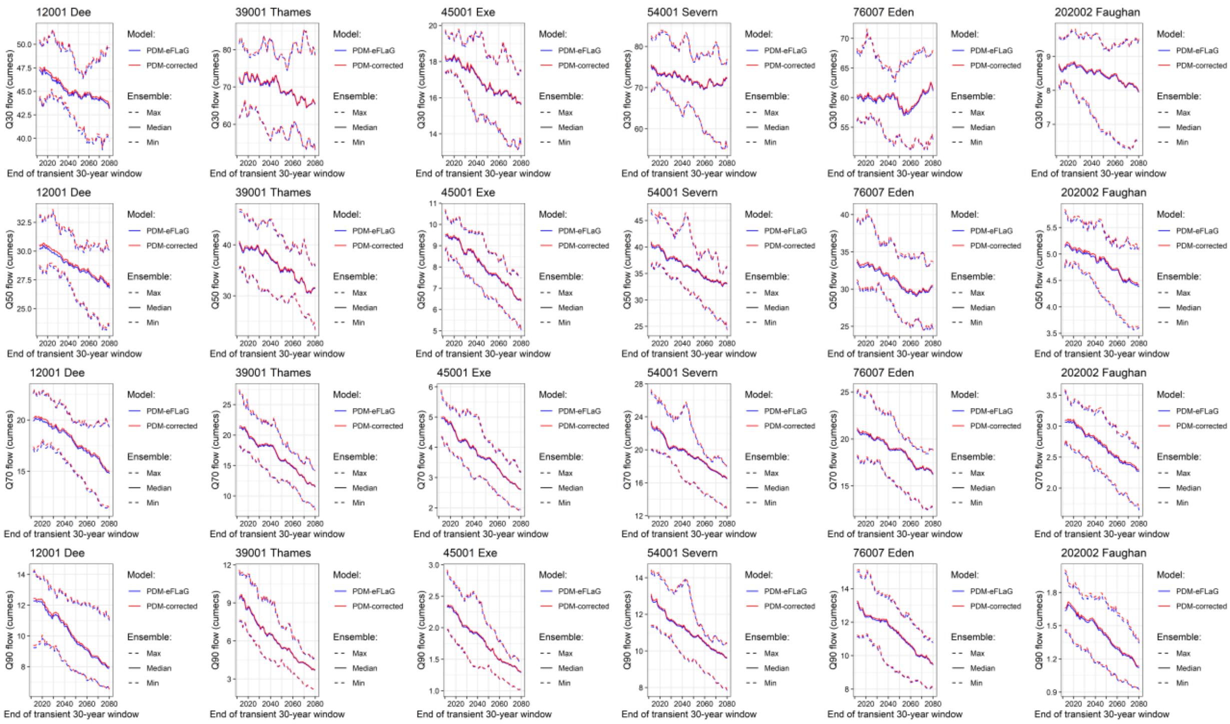

Figure 3 Transient river flow quantiles (top row Q30, second row Q50, third row Q70, fourth row Q90) for 6 UK catchments in columns from left to right: 12001 Dee at Woodend; 39001 Thames at Kingston; 45001 Exe at Thorveton; 54001 Severn at Bewdley; 76007 Eden at Sheepmount; 202002 Faughan at Drumahoe.

The results in Figure 3 clearly indicate the very minimal effect that changing PETI has had on river flow simulations in PDM. In all catchments, ensemble maxima, median and minima track consistently through the 21st century and any differences are negligible. These differences are certainly not of the magnitude that would suggest anything other than consistently declining river flows out into the far future. Indeed, the climate model ensemble spread (indicated by the difference between the ensemble maxima and minima) is substantially greater than the differences between PDM data when driven by the two PETI datasets.

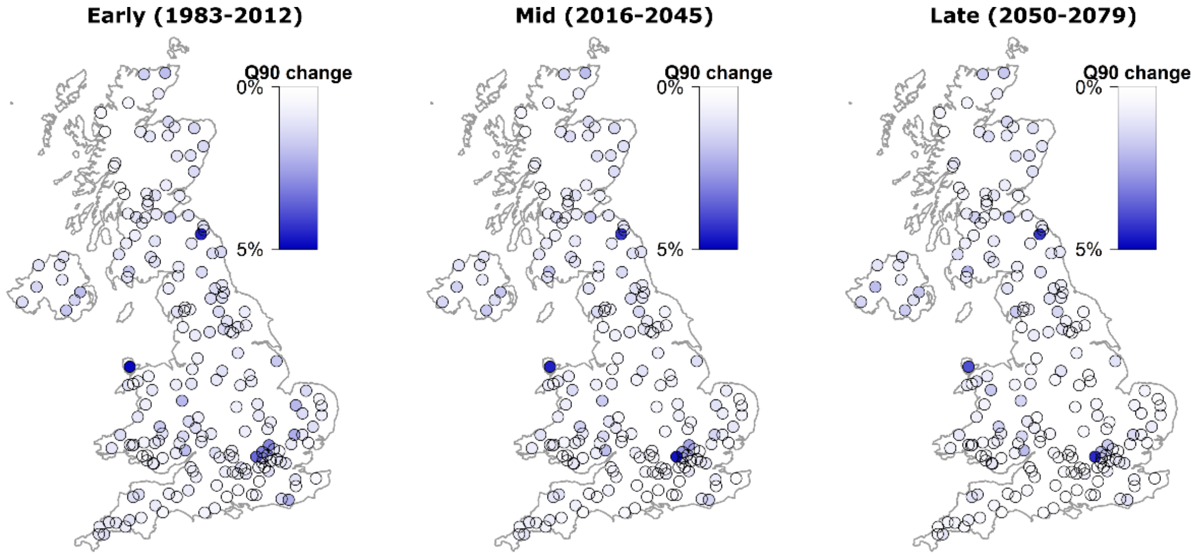

Figure 4: map of catchment outlets shaded according to the percentage change in modelled PDM Q90 flows calculated over all RCM ensembles and three 30-year periods: Early (1983-2012), Mid (2016-2015) and Late (2050-2079).

Figure 4 focusses on the changes in Q90 (low flows). Generally, the changes are small – typically 0.8% - calculated as the median change across sites of Q90 calculated using flows all years (1983-2080) and all RCM ensemble members. The changes also tend to be reasonably consistent across the three periods shown – the correlation (across sites) between changes in Q90 for the Early and Late periods is $r = 0.86$. All percentage changes are less than 5%, with changes of greater than 4% obtained only for sites 21023 (Leet Water at Coldstream), 39127 (Misbourne at Little Missenden) and 102001 (Cefni at Bodffordd). The percentage changes at these sites are roughly consistent across the three periods and may reflect an over sensitivity to changes in PETI in the PDM models used there – specifically, these are all "Full" PDM models with unusually low values for the "b" parameter controlling the soil store distribution, while 39127 is a known "difficult" site.

5 Effect on simulated groundwater levels

The AquiMod groundwater models were re-run using the corrected catchment-average PETI. The difference this makes to the simulated groundwater levels and derived groundwater level indices is small, as discussed below.

5.1 Effect on groundwater level time series

Figure 5 shows time series of AquiMod groundwater levels calculated with eFLaG and corrected PETI for the years 2030-2040 and a single RCM ensemble member. The differences in groundwater level are sufficiently small that the AquiMod-corrected hydrographs (upper graphs) entirely obscure the AquiMod-eFLaG ones. Differences between the two simulations are always at the scale of centimetres (lower graphs).

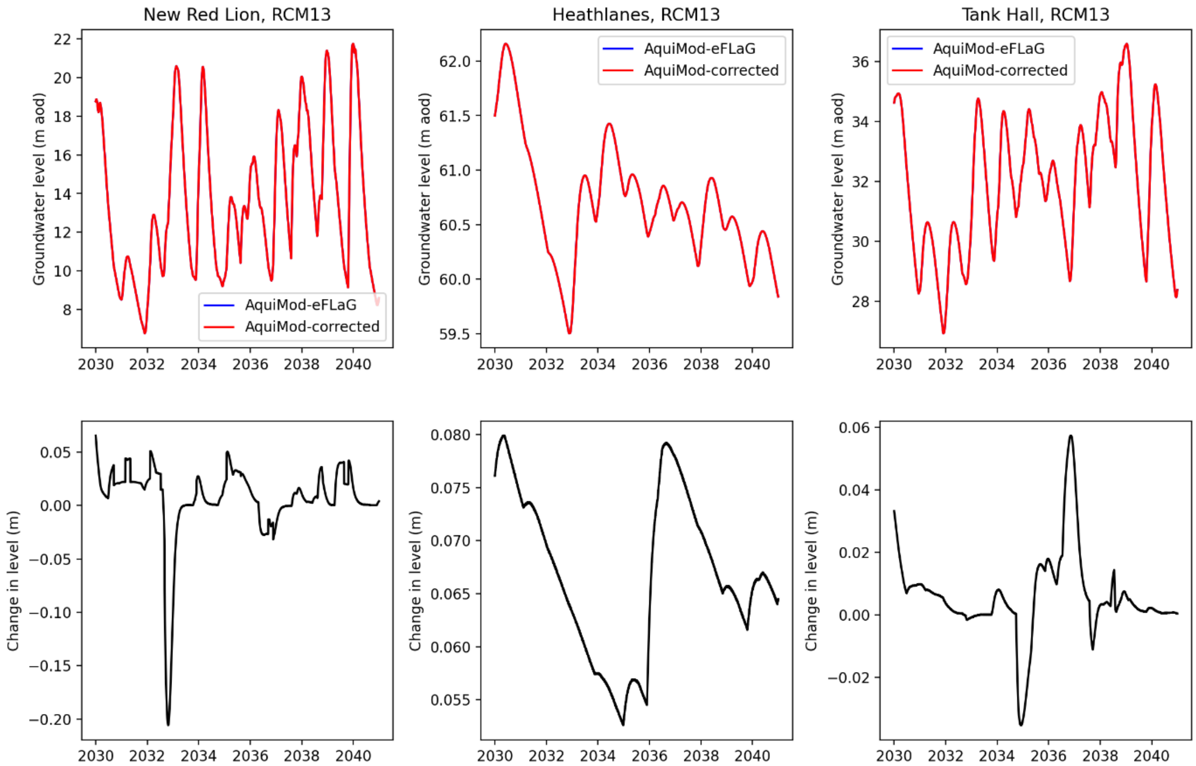

Figure 5. Comparisons of simulated AquiMod groundwater levels for three boreholes in different hydrogeological settings which show contrasting behaviour: New Red Lion, (Lincolnshire Limestone), Heathlanes (Permo-Triassic sandstone, Shropshire), Tank Hall (Chalk) shown for RCM 13 over the years 2030-2040. Upper graphs: Hydrographs of simulated groundwater level using the eFLaG PETI, and the corrected PETI. Lower graphs: Difference in groundwater level simulations driven by eFLaG and corrected PETI.

5.2 Effect on groundwater level indices

A range of groundwater level quantiles (from L30 equating to moderately high levels to L90 representing low levels) have been calculated to assess the impact of using the corrected PETI data on groundwater levels across the regime. Quantiles have been calculated for each rolling 30-year window in the eFLaG dataset, with the value in 2020 reflecting levels over the 1991-2020 timeframe, values in 2021 reflecting levels over the 1992-2021 timeframe, and so on. Results are presented in Figure 6. As with the river flows, the results show that substituting the eFLaG PETI for the corrected PETI has minimal impact on the quantiles of the AquiMod groundwater level simulations. For all boreholes and quantiles, the ensemble maxima, median and minima track consistently through the 21st century and any differences are negligible.

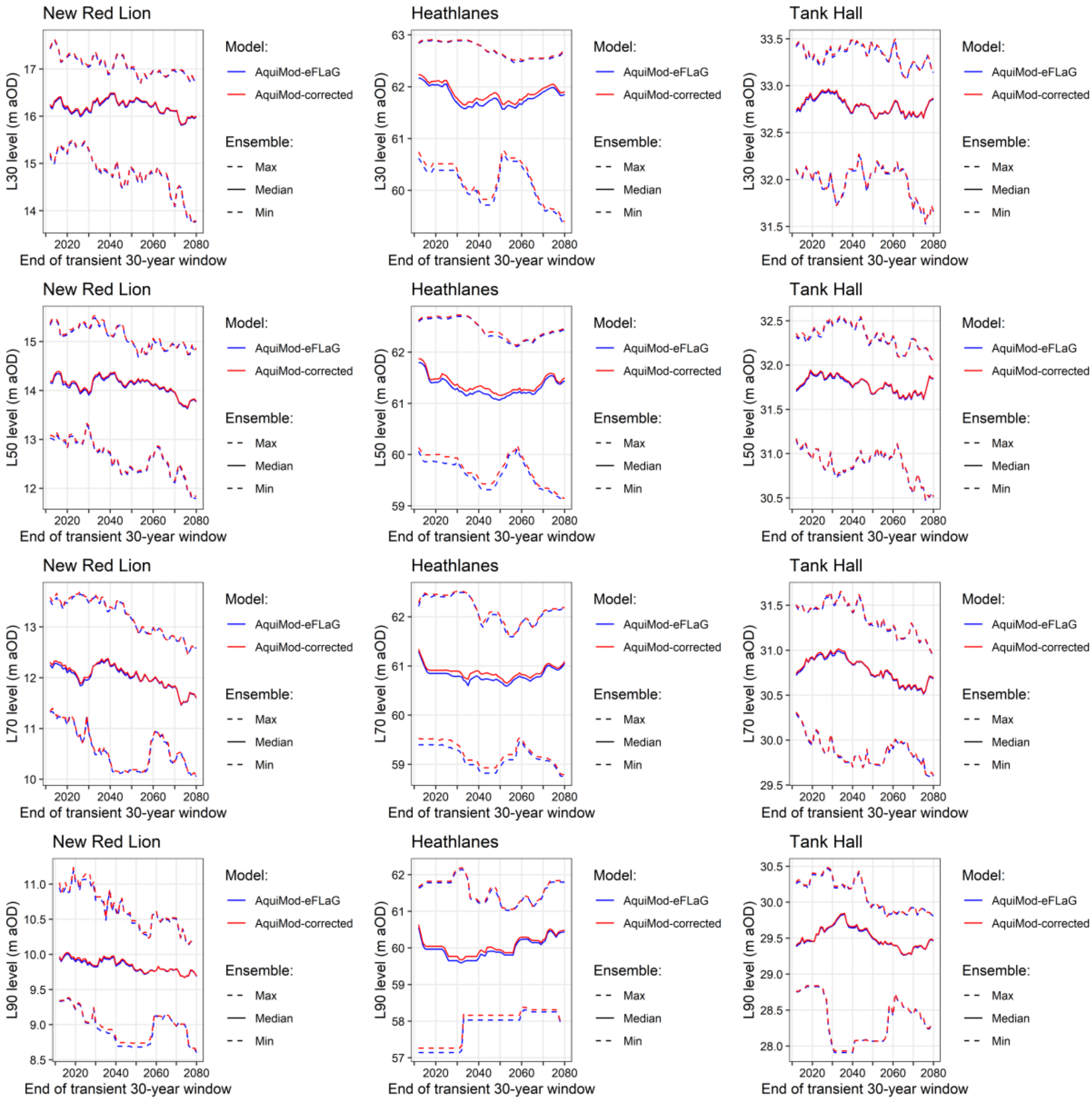

Figure 6. ***Transient groundwater level quantiles (top row L30, second row L50, third row L70, fourth row L90) for* three boreholes in different hydrogeological settings which show contrasting behaviour: New Red Lion, (Lincolnshire Limestone), Heathlanes (Permo-Triassic sandstone, Shropshire), Tank Hall (Chalk)*.***

6 Conclusions and actions

Given the negligible effect on the PETI, and the minimal propagation of this error into river flows and groundwater, we conclude that despite this error in the input dataset, the eFLaG dataset can be used with confidence, and considered a realistic simulation of future hydrology for any obvious practical purpose. The impact of the error is very small, especially in the context of the much more substantial uncertainties arising from RCM ensemble member and hydrological modelling, as discussed in the eFLaG data paper, as well as other sources of uncertainty not considered in the eFLaG modelling framework.

7 References

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