# Probabilistic impacts of climate change on flood frequency using response surfaces I: England and Wales

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# Supplementary Material

## 1. Sensitivity domain definition

The sensitivity domain developed by Prudhomme et al. (2010) relied on use of a single-harmonic function to represent the monthly pattern of changes in precipitation (P) and temperature (T):

$$X(t) = X_{mean} + A \cos [\, 2\pi \, (t - \Phi) / 12 \,] \qquad (1)$$

with $X(t)$ change for month $t$, harmonic mean $X_{mean}$ (mean annual change), harmonic amplitude $A$ (height of peak above mean) and harmonic phase $\Phi$ (month of peak). Analysis of multiple climate model projections for Britain determined appropriate values/ranges for the harmonic function parameters for P and T (Table 1). For P, the phase $\Phi$ was set to 1 (January), leaving only two dimensions of P change ($X_{mean}$ and $A$) each varied in 5% increments between minimum and maximum values (-40% - 60% for $X_{mean}$; 0% - 100% for $A$) to give 525 scenarios of P change. Only eight scenarios of T change were used, each with corresponding potential evaporation (PE) changes. These were combined with each of the P change scenarios, giving a total of 4,200 scenarios (525x8).

**Table 1 Sensitivity domain for changes in precipitation (P), temperature (T) and potential evaporation (PE), for construction of response surfaces.**

| Climate variable | Harmonic phase ($\Phi$) | Harmonic mean ($X_{mean}$) | Harmonic amplitude ($A$) | Scenarios |
|---|---|---|---|---|
| P | January | -40% to 60% | 0 to +120% | All combinations by increments of 5%<br><br>Total: 525 scenarios |
| T | January and August | 1.5°C<br>2.5°C<br>4.5°C | 1.2°C<br>0.8°C<br>1.6°C | Low-Jan and Low-Aug<br>Medium-Jan and Medium-Aug<br>High-Jan and High-Aug |
| | None | 0.5°C; 4.5°C | 0°C | Low-/High-Non-Seasonal (NS)<br><br>Total: 8 scenarios |
| PE | One scenario corresponding to each of the T scenarios (based on the Central-England T series and T-based PE formula of Oudin et al. 2005). | | | Total: 8 scenarios |

## 2. Use of UKCP09 projections

To overlay UKCP09 projections for a river-basin region onto a composite response surface, a single-harmonic function (Section 1) is fitted to each of the 10,000 sets of monthly P changes. Prudhomme et al. (2010) showed, using monthly GCM data, that a single-harmonic function was an appropriate simplification of monthly P changes when accounting for decadal variability. A comparison of the ranges of monthly changes from the 10,000 UKCP09 projections for each region, before and after fitting harmonic functions, suggests that the harmonic function also provides a reasonable approximation to the UKCP09 projections (Figure 1).

Overlaying UKCP09 projections on response surfaces also requires the assumption of a January phase. Histograms of the fitted harmonic phase for each river-basin region show that this assumption is reasonable, as January is the dominant month for all 10 regions (Figure 2). The next most frequent phase is February for all regions except North-West England and (marginally) West Wales, where it is December. Kay et al. (2013) investigate alternative response surfaces, where the phase is set to each month in turn (February-December) and show that, in general, for a February phase the response is similar or slightly smaller than for January, whereas for a December phase the response is similar or slightly greater than for January. Consequently, use of January-phase response surfaces for the North-West England region may slightly under-estimate the impact, due to scenarios where the phase is really December. In contrast, the use of January-phase response surfaces for South-West and South-East England may slightly over-estimate the impact, due to scenarios where the phase is really February. However, it is not thought that this affect will be large and the response type characterisation (Prudhomme et al. 2013) took some account of variation of response surfaces with harmonic phase within its merging of some response types (main text Section 2.1).

## References


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Oudin L, Hervieu F, Michel C, Perrin C, Andreassian V, Anctil F, Loumagne C. 2005. Which potential evapotranspiration input for a lumped rainfall-runoff model? Part 2 — Towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling. *Journal of Hydrology*, **303**, 290-306.

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Prudhomme C, Wilby RL, Crooks S, Kay AL, Reynard NS (2010) Scenario-neutral approach to climate change impact studies: Application to flood risk. *Journal of Hydrology*, **390**, 198-209.

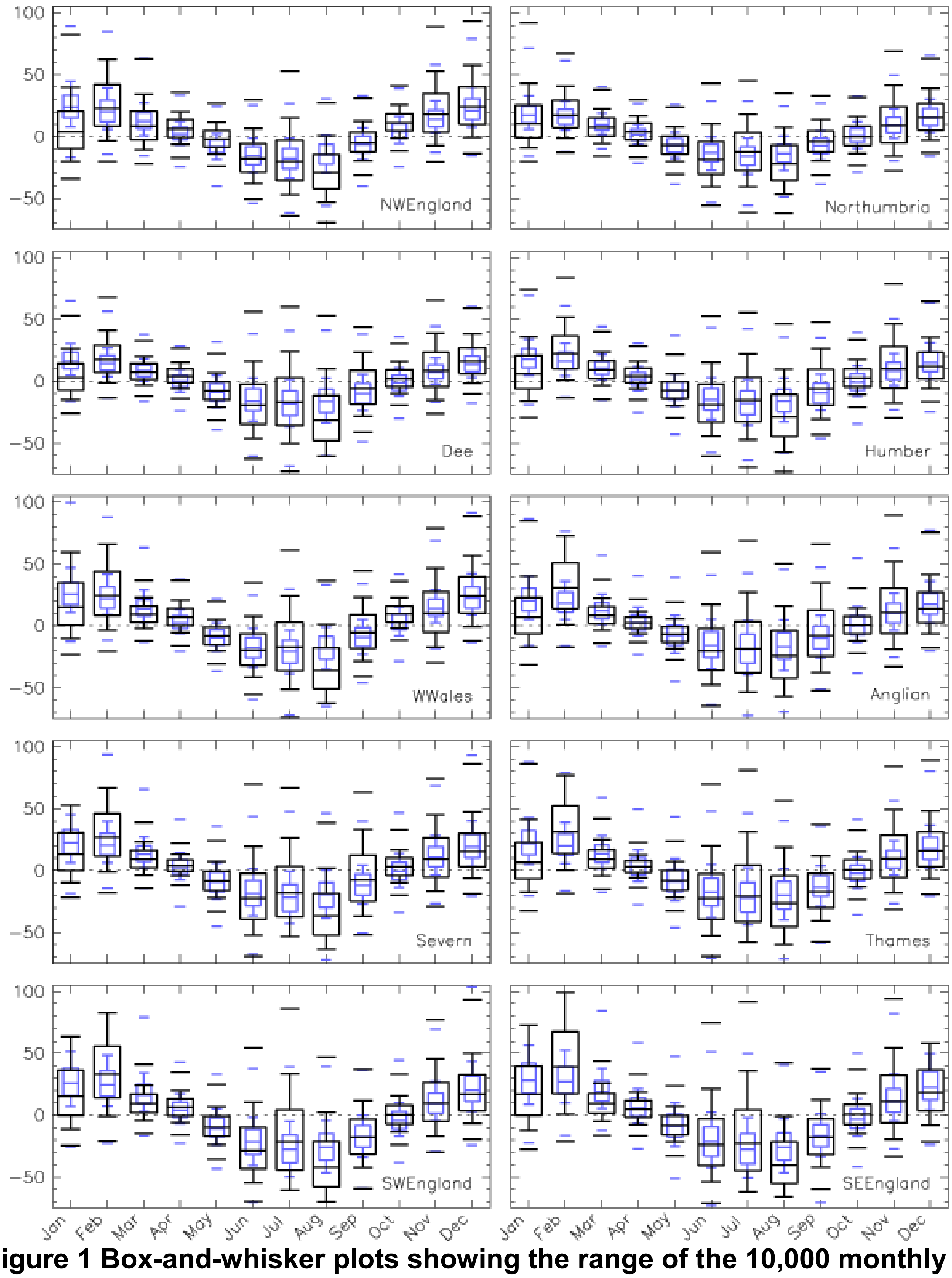


**Figure 1 Box-and-whisker plots showing the range of the 10,000 monthly P percentage changes (2080s Medium) for each river-basin region in England and Wales, using the UKCP09 Sampled Data as provided (wider boxes; black) and after fitting harmonic functions (narrower boxes; blue). Boxes indicate the 25$^{th}$–50$^{th}$–75$^{th}$ percentile range; whiskers indicate the 10$^{th}$–90$^{th}$ percentile range; additional markers indicate minima and maxima (if within the plotted range -75%–105%).**

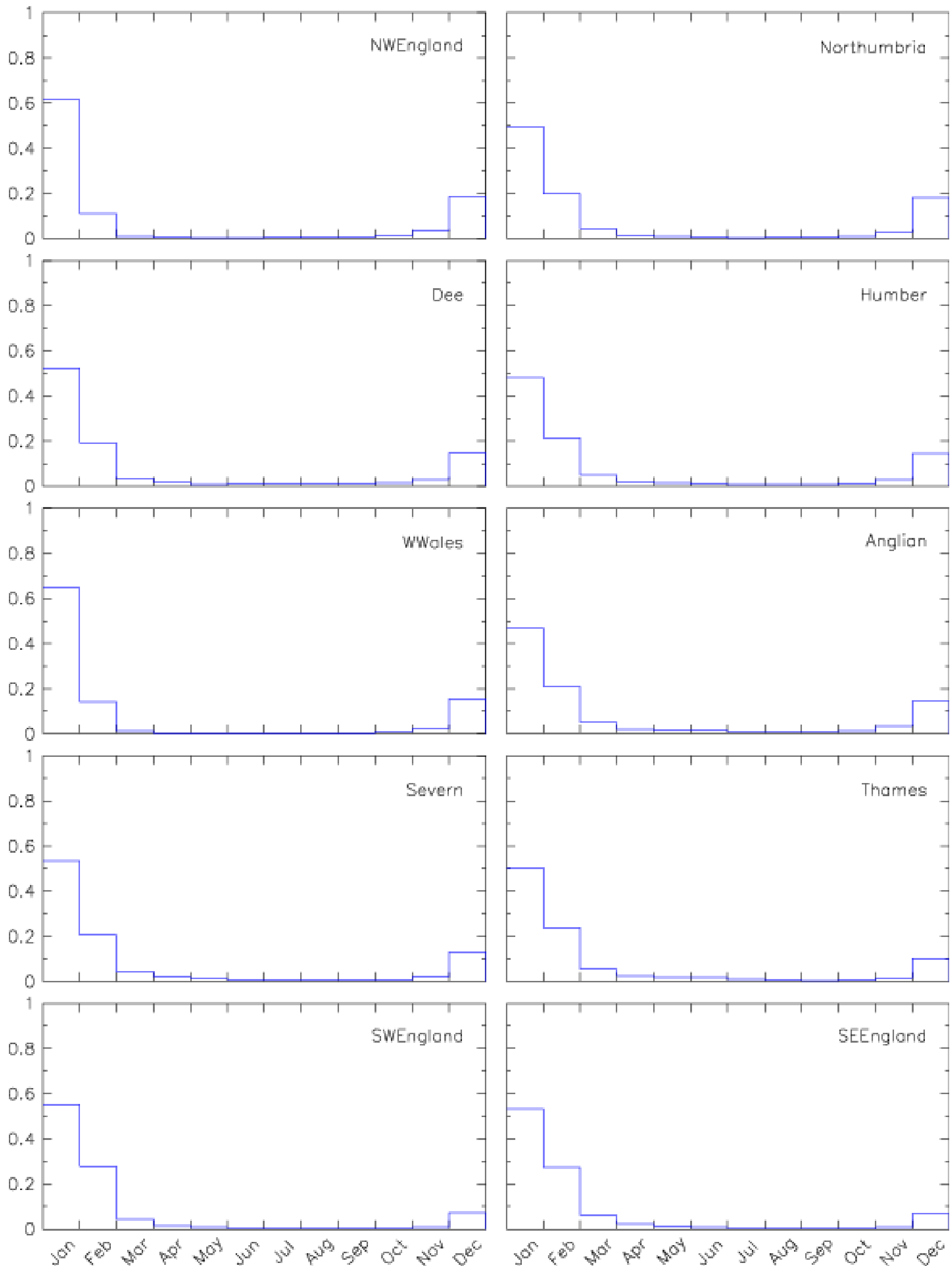


**Figure 2 Histograms of P harmonic phase for the 10,000 UKCP09 projections (2080s Medium) for each river-basin region in England and Wales.**