Climatic and catchment drivers of monthly water temperature of UK rivers

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1 Introduction

Water temperature is a key control on many river processes including ecology and biogeochemistry. Consequently, the effect of climate change on river and stream temperature is a major scientific and practical concern. River thermal sensitivity to climate change/ variability is controlled by complex drivers that need to be unravelled to better understanding patterns of spatio-temporal variability and the relative importance of different controls to inform water and land management, specially climate change mitigation and adaptations strategies. To address these research gaps, we ***aim***: (1) to quantify the relative importance of different climatic drivers of water temperature across a set of UK 'benchmark' monitoring sites; and (2) to assess the effect of basin properties as modifiers of the climate-temperature relationships. Previous UK studies focussed either on a limited number of monitoring sites or climatic drivers.

2 Data and Methods

Water Temperature (WT) data

Dependent Variable

Data collated across several long-term UK national capability projects, totalling 35 sites with a nationwide coverage (see Figure s 1-3)

Variable periods and temporal resolutions

Modelled climate forcing data Joint UK Land-Environment Simulator (JULES)

6 x Independent Variables:

Air Temperature (AT), Short Wave Radiation (SWR), Long Wave Radiation (LWR), Wind Speed (WS), Specific Humidity (SH), Precipitation (P)

Daily, 1-km gridded, 1971-2007 period

Extraction of JULES cells corresponding with WT sites

Seasonal WT series
(i.e. 3-month averages)

December–February winter, March–May spring, June–August summer, September–November autumn

Seasonal JULES variables series
(i.e. 3-month averages)

December–February winter, March–May spring, June–August summer, September–November autumn

Multi-Level Modelling (MLM) Approach

MLM allows to pool data from all sites while accounting for the hierarchical structure in the data, e.g. observations from same site, sites on same river

MLM provides two components:
Overall response , i.e. 'fixed effect': same coefficients for all sites (all predictors)
Site-specific response , i.e. 'random effects': coefficients can vary per site (specified predictors only)

Model selection for random effects

With all predictors included in fixed effects, various formulation for random effects are ranked using Akaike Information Criterion (corrected for small datasets i.e. AICc) and the one with lowest AICc retained

Model selection for fixed effects via Multi-Model Inference (MMI)

Robust model selection: AICc computed for all combinations of predictors, good models selected i.e. models within 4 pts of lowest AICc rather a single best model, average model computed

Output: five models

All Seasons = one model for whole series (seasonal time-step)
Winter, Spring, Summer, Autumn: one model per season (e.g. annual time-step)

Generic WT response for all drivers: Table 1
Site-specific response for selected drivers: Figures 1 to 3

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Table 1 Overall response for the five average models (overall response)
[RI is the variable Relative Importance in the MMI selection process; ranging from 1 (variable included in all sets of good models) to 0 (never included)]

	All Seasons		Winter		Spring		Summer		Autumn	
	Coef.	*RI*	Coef.	*RI*	Coef.	*RI*	Coef.	*RI*	Coef.	*RI*
AT	0.5824	*1.00*	0.3955	*1.00*	0.6815	*1.00*	0.4969	*1.00*	0.6860	*1.00*
SWR	0.0055	*1.00*	0.0193	*1.00*	0.0073	*1.00*	0.0077	*0.64*	0.0003	*1.00*
LWR	-0.0149	*1.00*	0.0008	*0.13*	0.0107	*0.18*	-0.0246	*0.52*	-0.0053	*0.25*
WS	-0.1348	*1.00*	-0.1014	*0.68*	-0.1228	*0.63*	-0.3028	*1.00*	0.0552	*0.33*
SH	0.4664	*1.00*	0.6658	*1.00*	0.2241	*0.34*	0.2903	*0.53*	0.1360	*0.37*
P	0.0011	*0.26*	0.0049	*0.15*	-0.0107	*0.38*	-0.0004	*1.00*	-0.0111	*0.41*

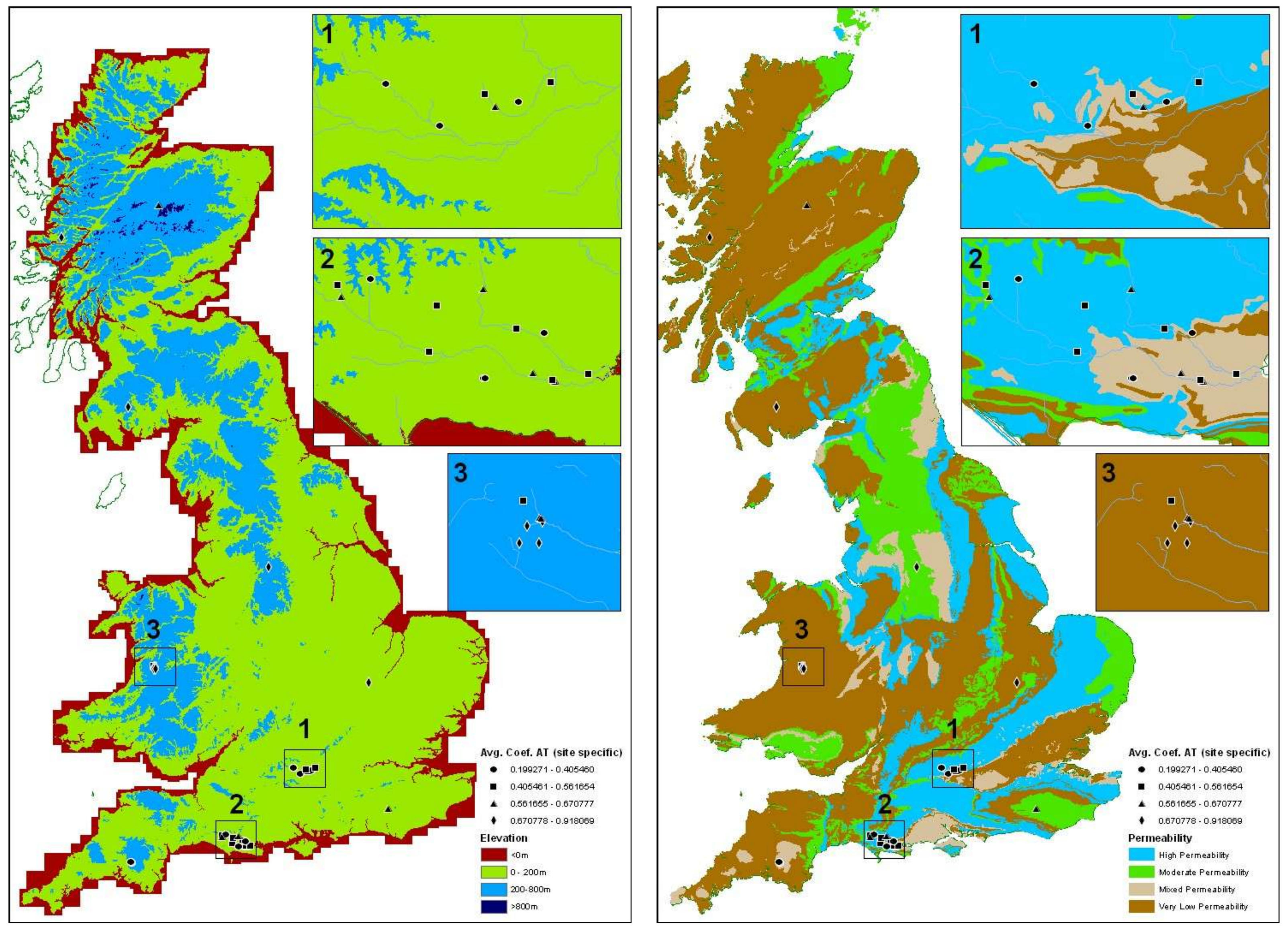

Figure 1 Mapping of site-specific air temperature (AT) coefficients in the 'All Seasons' model (classified per quartiles) against elevation (left) and permeability (right)

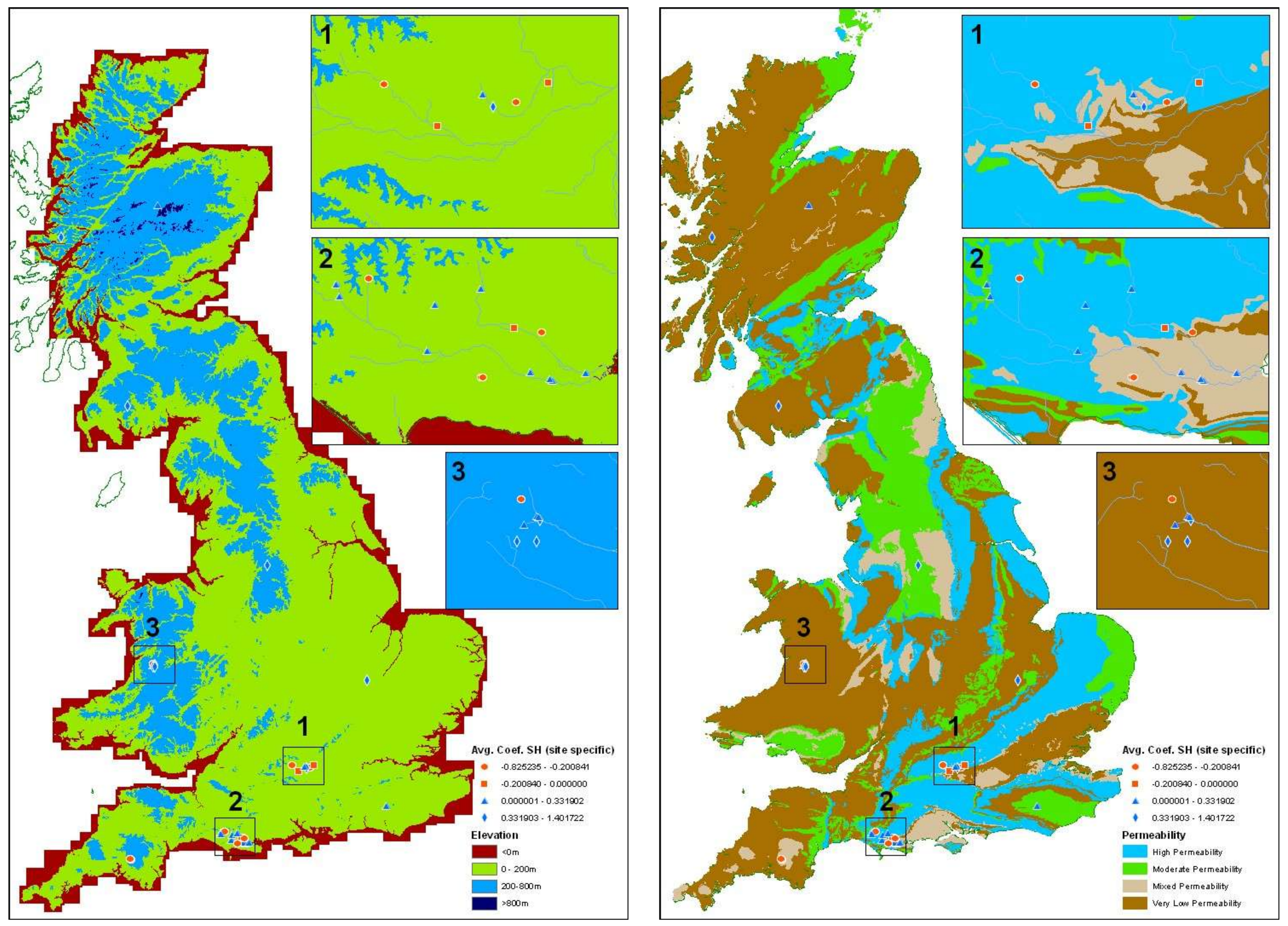

Figure 3 Mapping of site-specific specific humidity (SH) coefficients in the 'Winter' model (red symbols for negative coefficients, blue for positive coefficients) against elevation (left) and permeability (right)

3 Model outputs

The number of models contributing to each final model as selected by MMI were: All Seasons = 2; Winter = 4; Spring = 12; Summer = 6; Autumn = 14. RI is the relative importance of each variable calculated as the sum of the AICc weights (i.e. re-scaled AICc scores) of the contributing models. For example, All Seasons is based on two models with AICc weights 0.74 and 0.26; P is only included in the model with weight = 0.26 while the others are in both models.

Overall response: Table 1 features the coefficients of the average models [e.g. the slope for AT All Seasons (0.5854) is the average of the AT slope from the two models selected by MMI] .

Site-specific responses: The following variables were included as 'random effects' (i.e. variables for which different sites have different coefficients): All Seasons = AT and SWR; Winter = SH; Summer = P; Autumn = SWR; Spring no variables retained. These site-specific coefficients were mapped against elevation and permeability to explore basin modification of the WT-Climate relationship (Figures 1-3; only models showing some pattern are displayed).

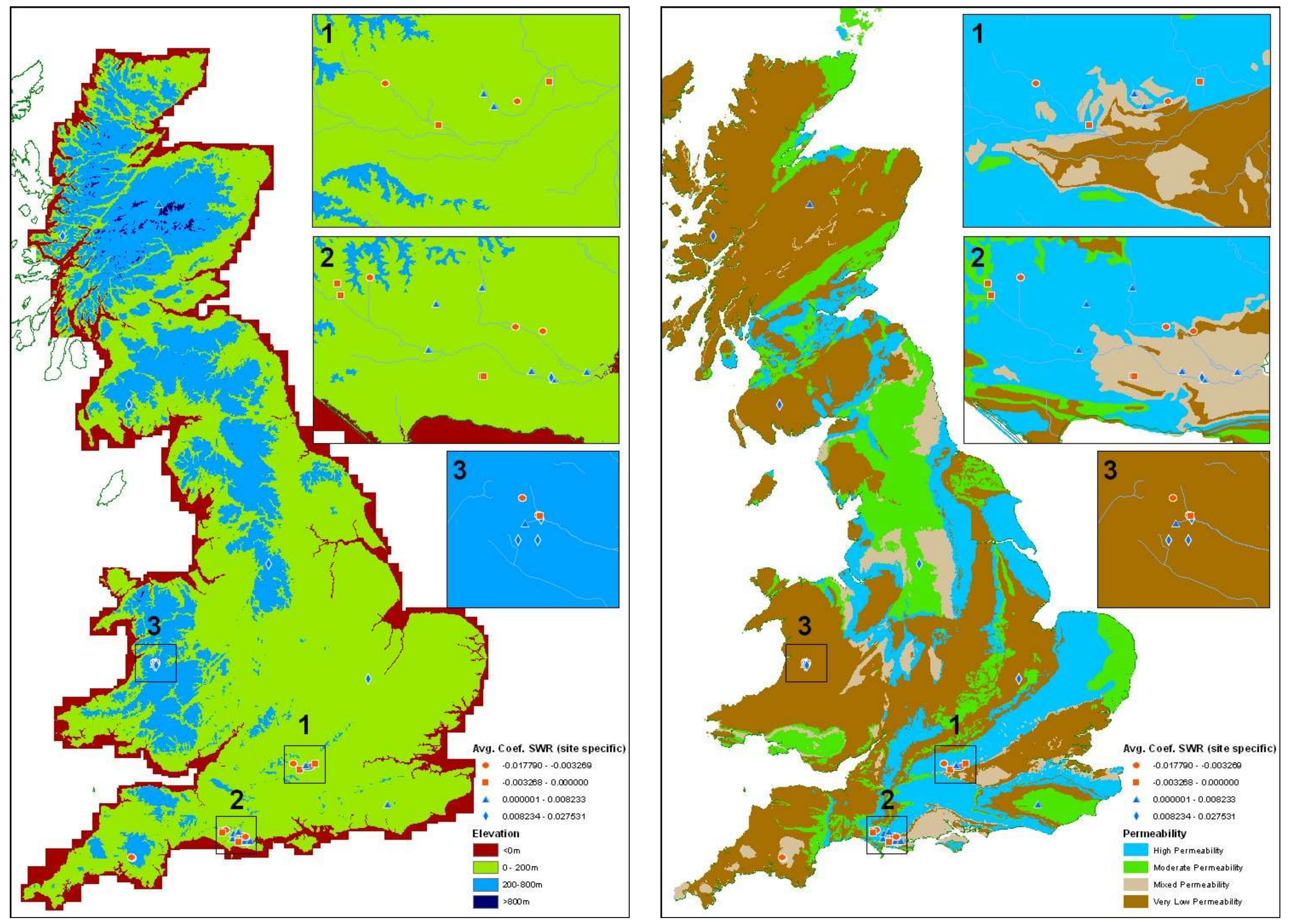

Figure 2 Mapping of site-specific shortwave radiation (SWR) coefficients in the 'Autumn' model (red symbols for negative coefficients, blue for positive coefficients) against elevation (left) and permeability (right)

4 Overall responses: relative importance of climatic drivers (Aim 1)

- AT and SWR are the most important variables (AT RI = 1 for all models; SWR RI = 1 for most models)
- Other variables have some influence across all seasons, with highest coefficient (absolute value) and highest RI as follows: Winter = SH; Summer = LWR and WS; Summer = P (highest RI only)
- AT, SWR and SH have positive coefficient for all models (i.e. a consistent warming effect on water temperature) while LWR, WS and P have positive and negative coefficients (i.e. a warning or cooling effect depending on season)
- The variable effect changes in strength depending on season (e.g. AT effect is lowest in Winter and Summer, and highest in Spring and Autumn)
- The varying coefficients and RI may reflect the range of processes controlling WT, with different controls and processes dominating at different times of year

5 Site-specific responses: basin properties modify climate-WT relationships (Aim 2)

Exploratory mapping of site-specific coefficients for the selected predictors against elevation and permeability (chosen due to their known role in modifying hydro-climatological links) show the following patterns:
- All Seasons AT: sites with high coefficient tend to be upland and impermeable basins
- Winter SH: sites with high positive (negative) coefficient tend to be impermeable (permeable) basins
- Autumn SWR: sites with high positive coefficient tend to be upland basins

These findings are indicative of the role of basin properties as modifiers of climate controls on river temperature, although limited to certain variables (AT, SH, and SWR) and with no clear pattern for Spring and Summer. Current research is focused on additional basin properties and understanding the chain of causality (i.e. elevation and permeability may be surrogates for other co-varying properties).