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Spatio-temporal analysis of extreme river flow

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Abstract. *A quantile regression model is proposed to assess spatio-temporal trends and seasonality in extreme river flow in Scotland over the period 1^{st} January 1996 to 31^{st} December 2013. The model is built in a generalized additive model framework that allows inclusion of three-variate smooth functions to account for space-time interaction effects. The results suggest a clear East/West gradient in the 95^{th} quantile of river flow that is in agreement with previous studies.*

Keywords. *Quantile regression; P-splines; PIRLS.*

1 Introduction

Recent studies [1, 5] report increases in both frequency and intensity of extreme events such as flooding. Climate change impacts are expected to vary spatially and to result in changes in river flows, the extremes of which are critical for flood risk estimation. Identification of patterns in extreme river flow behaviour, mainly in the form of seasonality and long term trends, is essential for planning purposes so that changes can be identified and decisions appropriately made to avoid or alleviate any negative impacts.

We introduce a new framework for spatio-temporal quantile regression [3], exploiting the flexibility of P-splines. The regression model is built as an additive model that includes smooth functions of time and space, as well as space-time interaction effects, and can be easily extended to incorporate potential covariates. Model parameters are estimated using a penalized iterative reweighed least squares approach instead of linear programming methods, classically used in quantile parameter estimation. The model is illustrated on a data set of daily river flows in 98 rivers across Scotland over the period 1^{st} January 1996 to 31^{st} December 2013.

2 Data

Daily river flow data for 98 gauging stations, shown in Figure 1, were provided by the Scottish Environment Protection Agency (SEPA) and the National River Flow Archive (NRFA) over the period 1^{st} January 1996- 31^{st} December 2013.

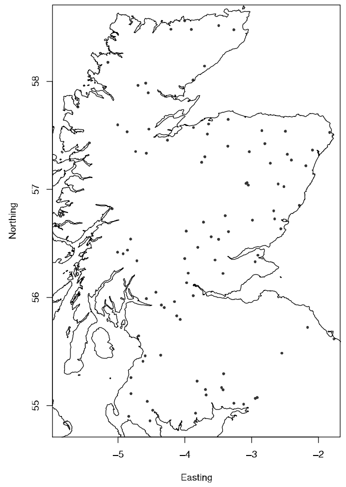

Figure 1: Location of the 98 selected gauging stations.

3 The model

Quantile regression [4] allows estimation of the relationship between response and explanatory variables at any percentile of the distribution of the response (conditioned on the explanatory variables). As a result, rates of change in the response variable can be estimated for the whole distribution and not only in the mean. The conditional quantile can be expressed as $Q_Y(\tau|X=x) = F_Y^{-1}(\tau|X=x)$, where $\tau \in (0,1)$, Y is the response variable with cumulative distribution function F_Y and $X = (X_1, \ldots, X_p)$ is a vector of explanatory variables [4, 2].

We propose the following model:

$$Q_{y_i}(\tau|t_i, d_i, z_i) = s_1(t_i) + s_2(d_i) + s_3(z_i) + s_4(t_i, d_i) + s_5(t_i, z_i) + s_6(d_i, z_i), \quad (1)$$

where $s_1(t)$, $s_2(d)$ are smooth functions of time and day of the year and $s_3(z)$ is a bivariate smooth function of easting and northing coordinates, accounting for the temporal, seasonal and spatial trends in river flow. The terms $s_4(t,d)$, $s_5(t,z)$ and $s_6(d,z)$ represent the time-season, space-time and space-season interactions, respectively. Estimating Model (1) involves minimizing a sum of weighted absolute deviations, where the weights are asymmetric functions of τ. In the classic quantile regression literature, linear programming methods are used for doing so [4]. We introduce an alternative approach by approximating the absolute residuals with the squared residuals; this way, model estimation can be done using the penalized iterative reweighed least squares (PIRLS) approach; see [3] for details.

4 Results and Discussion

We estimate Model (1) with $\tau = 0.95$ and $\log(\text{daily flow})$ as the response variable, t=time (1996 to 2013), d=day within the year (1 to 365) and z=(easting, northing). Each univariate smooth term is re-expressed as a linear combination of B-spline basis functions, while interaction terms can be built using the tensor product of the marginal basis functions. We add a penalty term to control the amount of smoothness, and impose a periodicity constrain on the seasonal component.

The estimated temporal trend is fairly flat, while the seasonal effect shows lower values during the summer, as expected. The estimated spatial pattern suggests a slight East-West gradient, with greater values on the Western side. Regarding the interaction effects, the seasonal effect varies considerably over space, and in some years is very different from the rest. Overall, the results suggest that trends in the 95^{th} quantile of river flow are not homogeneous across Scotland; this information might prove useful in decision making, for example, to provide more accurate flood warnings.

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