Synoptic airflow and UK daily precipitation extremes
Development and validation of a vector generalised linear model

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Abstract We develop a vector generalised linear model to describe the influence of the atmospheric circulation on extreme daily precipitation across the UK. The atmospheric circulation is represented by three covariates, namely synoptic scale airflow strength, direction and vorticity; the extremes are represented by the monthly maxima of daily precipitation, modelled by the generalised extreme value distribution (GEV). The model parameters for data from 689 rain gauges across the UK are estimated using a maximum likelihood estimator. Within the framework of vector generalised linear models, various plausible models exist to describe the influence of the individual covariates, possible nonlinearities in the covariates and seasonality. We selected the final model based on the Akaike information criterion (AIC), and evaluated the predictive power of individual covariates by means of quantile verification scores and leave-one-out cross validation. The final model conditions the location and scale parameter of the GEV on all three covariates; the shape parameter is modelled as a constant. The relationships between strength and vorticity on the one hand, and the GEV location and scale parameters on the other hand are modelled as natural cubic splines with two degrees of freedom. The influence of direction is parameterised as a sine with amplitude and phase. The final model has a common parameterisation for the whole year. Seasonality is partly captured by the covariates themselves, but
mostly by an additional annual cycle that is parameterised as a phase-shifted sine and accounts for physical influences that we have not attempted to explicitly model, such as humidity.

**Keywords** Extreme precipitation · Synoptic airflow · United Kingdom · Extreme value statistics · Vector generalised linear model · Akaike information criterion · Cross validation · Quantile skill scores · Model selection · Model validation

**AMS 2000 Subject Classifications** Primary—62F07; Secondary—62P12

1 Introduction

It is no coincidence that a favorite pastime of the British is chatting about the weather. Exposed to the Atlantic, just at the edge between the major storm tracks to the north and a rather mild climate further to the south, the British Isles brave the elements. Heavy rainfall and subsequent flooding are a common threat causing an average annual damage of £1 billion (Hall et al. 2005). Analysing precipitation data, Osborn et al. (2000) and Maraun et al. (2008) found positive trends in the contribution of heavy precipitation events to the total winter precipitation throughout the last century. Owing to anthropogenic global warming, the intensity of extreme precipitation is projected to further increase over the UK (Fowler et al. 2005; Ekström et al. 2005).

To accurately project regional changes in extreme precipitation, it is important to understand which processes, and how these processes, control precipitation, and then to assess how accurately these relationships are represented by climate models used for the projections. In the UK, precipitation is strongly affected by the synoptic scale atmospheric circulation, which can be represented by airflow strength, direction and vorticity (Jenkinson and Collison 1977; Jones et al. 1993). Airflow strength describes how fast an airmass moves across the country, airflow direction where the airmass originates, and airflow vorticity whether a cyclone or an anticyclone is passing. The airflow strength is closely linked to the large scale North Atlantic Oscillation (NAO, e.g., Marshall et al. 2001): the gradient in atmospheric pressure between Iceland and the Azores drives storm tracks towards Northern Europe.

In this paper, we develop a statistical model based on extreme value statistics (Coles 2001; Embrechts et al. 1997; Leadbetter et al. 1983, for applications in hydrology and climatology see e.g. Katz et al. 2002; Naveau et al. 2005) that describes how local precipitation extremes are influenced by the synoptic scale atmospheric circulation. Extreme value statistics provides three main approaches for modeling the extremes of a process: the block maxima approach, which divides a time series into blocks of equal length, and approximates the probability distribution of the maxima by the generalised extreme value distribution; the peak over threshold approach, which approximates the magnitude of excesses over a large threshold by a generalised Pareto distribution; and the point process approach, which in addition to the magnitude of excesses also models their timing. Here, we choose the block