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Extreme river flow dependence in Northern Scotland

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Various methods for the spatial analysis of hydrologic data have been developed recently. Here we present results using the conditional probability approach proposed by Keef et al. [Appl. Stat. (2009): 58,601-18] to investigate spatial interdependence in extreme river flows in Scotland. This approach does not require the specification of a correlation function, being mostly suitable for relatively small geographical areas. The work is motivated by the Flood Risk Management Act (Scotland (2009)) which requires maps of flood risk that take account of spatial dependence in extreme river flow. The method is based on two conditional measures of spatial flood risk: firstly the conditional probability $P_C(p)$ that a set of sites $Y = (Y_1, ..., Y_d)$ within a region C of interest exceed a flow threshold Q_p at time t (or any lag of t), given that in the specified conditioning site $X > Q_p$; and, secondly the expected number of sites within C that will exceed a flow Q_p on average (given that $X > Q_p$). The conditional probabilities are estimated using the conditional distribution of $Y|X = x$ (for large x), which can be modeled using a semi-parametric approach (Heffernan and Tawn [Roy. Statist. Soc. Ser. B (2004): 66,497-546]). Once the model is fitted, pseudo-samples can be generated to estimate functionals of the joint tails of the distribution of (Y, X). Conditional return level plots were directly compared to traditional return level plots thus improving our understanding of the dependence structure of extreme river flow events. Confidence intervals were calculated using block bootstrapping methods (100 replicates).

We report results from applying this approach to a set of four rivers (Dulnain, Lossie, Ewe and Ness) in Northern Scotland. These sites were chosen based on data quality, spatial location and catchment characteristics. The river Ness, being the largest (catchment size 1839.1km^2) was chosen as the conditioning river. Both the Ewe (441.1km^2) and Ness catchments have predominantly impermeable bedrock, with the Ewe's one being very wet. The Lossie(216km^2) and Dulnain (272.2km^2) both contain significant areas of glacial deposits. River flow in the Dulnain is usually affected by snowmelt. In all cases, the conditional probability of each of the three rivers (Dulnain, Lossie, Ewe) decreases as the event in the conditioning river (Ness) becomes more extreme. The Ewe, despite being the furthest of the three sites from the Ness shows the strongest dependence, with relatively high ($>$0.4) conditional probabilities even for very extreme events ($>$0.995). Although the Lossie is closer geographically to the Ness than the Ewe, it shows relatively low conditional probabilities and can be considered independent of the Ness for very extreme events (> 0.990). The conditional probabilities seem to reflect the different catchment characteristics and dominant precipitation generating events, with the Ewe being more similar to the Ness than the other two rivers. This interpretation suggests that the conditional method may yield improved estimates of extreme events, but the approach is time consuming. An alternative model that is easier to implement, using a spatial quantile regression, is currently being investigated, which would also allow the introduction of further covariates, essential as the effects of climate change are incorporated into estimation procedures.