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RCM rainfall for UK flood frequency estimation. I. Method and validation

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Abstract

Regional Climate Models (RCMs) are a significant improvement over Global Climate Models (GCMs) in terms of their representation of rainfall at the spatial and temporal scale required for flood modelling. This paper presents the use of catchment rainfall and potential evaporation data derived directly from RCM data, as input to a spatially generalised continuous simulation rainfall-runoff model, for 15 catchments across Great Britain. The RCM (HadRM3H) is based on a ~25 km grid across Europe and, rather than being nested within a GCM, is driven with boundary conditions determined by 15 years' of data from the ECMWF's global model for the period 1979–1993 (ERA-15). As the latter model continually assimilates observations of surface and atmospheric weather elements, output from the RCM can be expected to match observed conditions to a reasonable extent, enabling a direct comparison with simulations using observed input data. The rainfall-runoff model simulates continuous flow time-series, from which flood frequency curves are derived using a standard peaks-over-threshold method. The study covers return periods up to about 10 years (due to limited data availability) and relatively small catchments (<500 km^2).

Overall, flood frequency curves derived using RCM inputs compare well with those using observed rainfall and evaporation inputs, although with a slight tendency to underestimate. Only two catchments show particularly bad underestimation however, which is due to their input RCM rainfall being significantly lower than that observed. Flood frequency estimation errors are in fact closely related to errors in annual average rainfall amounts for the RCM, which future improvements to the RCM will hopefully overcome.

Keywords: Regional climate models; Flood frequency; Rainfall-runoff model; Spatial generalisation

1. Introduction

The coarse spatial resolution of Global Climate Models (GCMs), and the greater uncertainty surrounding their outputs at a fine temporal resolution, particularly for precipitation, means that they are generally not appropriate for direct flood modelling using a continuous simulation rainfall-runoff model. Roy et al. (2001) use extreme GCM rainfall in an event-based model for very large catchments, to infer effects on high flows, as they consider that extreme GCM rainfall may match observations more closely

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than mean daily precipitation. However, as antecedent conditions are critical in determining the effects of rainfall on flows, such event studies are not ideal, and continuous hydrological models, which automatically account for antecedent conditions, are preferable, but the generation of appropriate continuous precipitation and potential evaporation inputs under current and future conditions is a difficult problem.

For the UK, where even the largest river catchments are smaller than a GCM grid box, and where local topography plays a vital role in determining rainfall patterns, a GCM's basic representation of topography is a severe limitation to their practical use. Spatial interpolation can be used to represent the outputs on a finer grid (Hulme and Jenkins, 1998; UKCIP98), but this does not incorporate any extra information. Disaggregation of GCM rainfall onto a catchment can also be achieved using an empirical exponential model (Wheater et al., 1999), which is capable of mimicking the spatial memory and temporal dependence of real rainfall.

The standard method used as an alternative to the direct use of GCM data is to derive proportional or absolute changes in rainfall from the GCM data and to apply these changes to baseline observed climate. Such methods have been used to examine the potential impacts of future climate change on flooding (Crooks et al., 1996; Prudhomme et al., 2002; Reynard et al., 2001; Schreider et al., 2000). The changes are usually derived from monthly GCM time-series, so methods of applying the changes to daily (or even sub-daily) data are required. The method chosen affects the outcome of the subsequent hydrological modelling quite significantly, and there is no right or wrong answer to how it should be done.

Another alternative is to use the GCM-derived changes to infer changes in the parameters of a weather generator, which can then be used to simulate rainfall time-series under current and future climates for use as input to continuous hydrological models (Schreider et al., 2000; Tung, 2001). However, such methods rely on the ability of the random element of the weather generator to simulate a wider range of conditions than may be available in the observed record used for model development. These methods can also be overly influenced by any problems in the historical record, such as missing data. Another option is provided by statistical downscaling, in which relationships are developed between large-scale, GCM-generated atmospheric variables and observed rainfall series (e.g. Wilby et al., 2002). These regression relationships are then applied, using current- and future-climate GCM data, to generate long time-series of rainfall under current and future conditions, assuming the relationships remain valid under future conditions. Muller-Wohlfeil et al. (2000) use a combination of statistical downscaling and a weather generator, which they term 'expanded downscaling', to generate input for a spatially distributed hydrological model for a catchment in northern Germany. The combined method is developed to overcome the low variability seen in generated time-series, particularly for rainfall, when using statistical downscaling alone, but still relies on current relationships being applicable in the future.

The recent advent of Regional Climate Models (RCMs) nested within GCMs (dynamic downscaling) has greatly improved matters, by providing more regional detail without an unreasonable increase in computing time. Being more physically based than statistical methods, RCMs are less likely to be affected by non-stationarity of model assumptions, although they do involve parameterization schemes for some smaller scale processes. Mearns et al. (1999) provide a comparison of climate change scenarios from an RCM and using statistical downscaling, and find substantial differences.

In 2002 the UK Climate Impacts Programme (UKCIP) released a new set of climate scenarios for the UK (UKCIP02, Hulme and Jenkins, 2002), based on the $\sim$50 km grid of HadRM3. These scenarios are now widely used in the UK for climate change impact studies, although they are generally presented simply as proportional changes in the climate variables. To date there has been little direct use of RCM data for impact studies, despite the fact that RCM rainfall is significantly better than that simulated by the GCM (Durman et al., 2001; Huntingford et al., 2003). In this paper, a spatially generalised version of the Probability Distributed rainfall-runoff model (PDM) of Moore (1985, 1999; see Section 2.1) is run with input data derived directly from the Hadley Centre RCM. The rainfall-runoff model simulates continuous time-series of flow at a catchment outlet, at an hourly time-step, given input time-series of hourly