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Multi-site downscaling of heavy daily precipitation occurrence and amounts

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Abstract

This paper compares three statistical models for downscaling heavy daily precipitation occurrence and amounts at multiple sites given lagged and contemporaneous large-scale climate predictors (such as atmospheric circulation, thickness, and moisture content at the surface, 850 and 500 hPa). Three models (a Radial Basis Function (RBF) Artificial Neural Network (ANN), Multi Layer Perceptron (MLP) ANN and a Conditional Resampling Method (SDSM)) were applied to area-average and station daily precipitation amounts in northwest (NWE) and southeast (SEE) England. Predictor selection via both stepwise multiple linear regression and compositing confirmed vorticity and humidity as important downscaling variables. Model skill was evaluated using indices of heavy precipitation for area averages, individual sites and inter-site behaviour.

When tested against independent data (1979–1993), multi-site ANN models correctly simulated precipitation occurrence 80% of the time. The ANNs tended to over-estimate inter-site correlations for amounts due to their fully deterministic forcing, but performance was marginally better than SDSM for most seasonal-series of heavy precipitation indices. Conversely, SDSM yielded better inter-site correlation and representation of daily precipitation quantiles than the ANNs. All models had greatest skill for indices reflecting persistence of large-scale winter precipitation (such as maximum 5-day totals) or dry-spell duration in summer. Overall, predictability of daily precipitation was greater in NWE than SEE.

Keywords: Downscaling; Precipitation; Multi-site; Diagnostics

1. Introduction

General Circulation Models (GCMs) are instrumental to projections of global climate change. However, their coarse spatial resolution (typically ∼300 km) limits their usefulness for regional impact studies. As a consequence techniques have been developed to ‘downscale’ coarse GCM output to the finer spatial scales required for impact assessment. Overviews of downscaling approaches have been provided elsewhere (see Giorgi and Mearns, 1991; von Storch et al., 1993; Hewitson and Crane, 1996; Wilby and Wigley, 1997). The methods dealt with in this paper are regression-based but, to date, relatively few have

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been explicitly developed for heavy precipitation at multiple sites.

Regression-based downscaling methods use empirical relationships between local scale predictands and regional scale predictor(s). Individual downscaling schemes differ according to the choice of mathematical transfer function, predictor variables or statistical fitting procedure. To date, linear and non-linear regression, artificial neural networks (ANNs), and canonical correlation have all been used to derive predictor–predictand relationships (e.g. Conway et al., 1996; Crane and Hewitson, 1998; Schubert and Henderson-Sellers, 1997). The main strength of regression methods is the relative ease of application, coupled with their use of observable trans-scale relationships. Unfortunately, regression models seldom explain all of the observed climate variability (especially in precipitation series). Regression methods also assume stationarity of model parameters under future climate conditions, and scenarios are known to be highly sensitive to the choice of predictor variables and statistical transfer function (Winkler et al., 1997). Furthermore, downscaling future extreme events using regression methods is problematic since these phenomena, by definition, often lie at the margins or beyond the range of the calibration data set.

To date, there have been relatively few examples of ANNs applied to climate downscaling and even fewer to the task of multi-site precipitation modelling. Table 1 lists examples of previous studies showing mixed success by ANNs for downscaling daily precipitation amounts. Possible explanations include the simplistic treatment of days with zero amounts and/or the highly skewed distribution of wet-day amounts biasing the training process towards small, or even negative, values. In this paper, we address this problem via a two-stage modelling procedure using Radial Basis Function (RBF) ANNs (Broomhead and Lowe, 1988; Moody and Darken, 1989) and Multi Layer Perceptron (MLP) ANNs (Rumelhart and McClelland, 1986). Analogous to conventional weather generation techniques, precipitation is modelled using separate occurrence and amounts processes (Wilks and Wilby, 1999). We are particularly interested in the ability of the ANNs to downscale indices of heavy daily precipitation (defined herein as $\geq$90th percentile amount). By way of a reference point, results from the ANNs are compared with those produced by a conditional resampling method (Wilby et al., 2003).

Having introduced the principle features of the ANNs and resampling procedure, part one of this investigation describes methods of predictor variable selection. Three approaches were compared: stepwise multiple linear regression (SWLR), a compositing procedure, and a Genetic Algorithm (GA). In part two, the three downscaling methods are used to predict daily precipitation at multiple sites in northwest (NWE) and southeast (SEE) England. All models were evaluated against indices of heavy daily precipitation and multi-site behaviour using data that were not employed in model calibration.

2. Model descriptions and data

Unlike previous studies, we model each site simultaneously rather than training downscaling models on a site by site basis (Table 1). The main advantage of this approach is the capture of both the temporal and spatial dependency of multi-site precipitation by model weights. Previous studies have favoured MLP networks so, in order to provide a comparison, the less well-known RBF network has also been used. One advantage of the type of RBF network employed here is the speed of training (a few seconds) in comparison to the MLP.

2.1. Radial basis function (RBF) networks

The RBF network consists typically of two layers, where the hidden layer nodes contain prototype vectors (or basis centres), which are in effect hidden layer weights. The distance between the input and the prototype vector determines the activation level of the hidden layer with the non-linearity provided by a basis function. The activation function in the output layer can be non-linear, however, training is considerably faster if an ordinary linear weighted sum of these activations are performed, and this approach was consequently adopted. Mathematically the output from the final layer node(s) y_k (for the kth output node) is