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Downscaling and correction of regional climate models outputs with a hybrid geostatistical approach

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ABSTRACT

This paper presents an approach to downscaling of climate models based on a combination of Generalised-additive-models and geostatistics. The paper aims at increasing the usefulness of Climate Models by creating data sets with a spatio-temporal resolution appropriate for applications of environmental models at the management scale. Simulations of climate change available from global and regional climate models require downscaling and bias correction for hydrological or ecological applications. The paper assess the effectiveness of the approach applied to monthly means of temperature and rainfall, to predict soil wetness conditions. The main focus was on reconstructing the spatial structure of the landscape. The climate model data were firstly downscaled using a geo-statistical approach combining generalised additive models (GAMs) with kriging, making use of the covariates to reproduce the spatial pattern. The downscaled climate model data were corrected for bias using interpolated meteorological ground station data (1961–1999). In general the downscaling approach provided lower RMSE and closer reproduction of the variogram structure. The use of the bias corrected downscaled data improved the results of the model used to predict soil wetness, increasing the validation metrics. The approach is completely implemented in open-source software, in particular GRASS-GIS and R.

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1. Introduction

Assessment of climate change effects is an integral part of hydrological and ecological studies. The Intergovernmental Panel on Climate Change [IPCC] developed climate scenarios that take into account different quantities of greenhouse gas emission which then inform global and regional climate models (CMs) (van Vuuren et al., 2011; IPCC, 2001). These CMs have rather coarse spatial resolutions, often not suitable for landscape or watershed scale studies of physical, ecological and hydrological processes where the morphological configuration of the landscape is often a driving factor. It is therefore important to have the climate data at a spatial resolution comparable with the underlying process (Fowler et al., 2007).

Downscaling is the process of transferring the climate information from a climate model with coarse spatial resolution to the finer resolution required as input by other models (e.g. hydrological ones) that address the effects of climate at a more detailed scale. A common approach to downscaling that is adequate for many applications is to use statistical methods (Flint and Flint, 2012; Schomburg et al., 2011; Fowler et al., 2007). In general the process of downscaling involves the reconstruction of the spatial variation of a (climatic) variable when only the value at the coarser resolution is available (Bierkens et al., 2000). However, the downscaling procedure can be driven and improved using covariates available at the target finer resolution by building a relationship between the variable of interest and the covariate data. The relationships are not always linear, therefore methods that are able to deal with non-linearity are preferred (Malone et al., 2012). The integration with geostatistical techniques can produce more accurate predictions at a finer spatial resolution.

In addition, CM outputs usually provide biased representations of observed data (Moberg and Jones, 2004; Christensen et al., 2008) and need to be corrected to match observed values and to improve future projections. Bias correction is a term used to describe methods to reduce the differences between observed and modelled data. Bias correction methods have been shown to significantly improve the utility of climate model data in many studies (e.g. Bordoy and Burlando, 2013; Teutschbein et al., 2011; Teutschbein and Seibert, 2012; Muerth et al., 2013). Their complexity ranges from simple methods, i.e. simple linear transformations (Lenderink et al., 2007), to much more complex, such as Bias Correction and Spatial Disaggregation (Wood et al., 2004). To convert the results of the coarse scale and biased CM outputs for input into local scale models, there needs to be a systematic process of downscaling and bias correction to produce new data sets that correctly represent the patterns and values of the CMs but at a scale applicable to landscape level studies (Flint and Flint, 2012).

The aim of this paper was to assess the effectiveness of a new downscaling approach, applied to monthly means of temperature and rainfall, to predict soil wetness conditions and the main focus was on reconstructing the spatial structure of the landscape.

The temporal resolution of CM data is often high (daily or hourly) and this is important for hydrological or crop production modelling. However many of the ecological or land use models do not require such high temporal resolution data. We chose to test the downscaling and correction of temporally-aggregated data, i.e. monthly means over a period of years, for models that do not require high temporal resolution.

2. Overview of the methodological approach

The area used in this study is located in the North-East of Scotland (about 12,100 km^2, Fig. 1). It has a variety of landscapes and soils and it includes large river catchments and the Cairngorm mountains, with some of the highest peaks in Scotland. The differences in landscapes were chosen to test the response of models to different combinations of covariates and climatic conditions.

The environmental application selected was modelling the number of days a soil is waterlogged in a year (wet days in the following text), in order to be able to predict the impact of future climate on this important variable. A data set for present conditions was available from Lilly and Matthews (1994). This variable does not require a high temporal resolution, but the spatial resolution is important to provide information about the landscape patterns and their changes to be used in further modelling. Fig. 2a shows the approach followed for the modelling of wet days (Section 4.2) and Fig. 2b details the climate data preparation: