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A comparison of different regional climate models and statistical downscaling methods for extreme rainfall estimation under climate change

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ABSTRACT

In most cases climate change projections from General Circulation Models (GCM) and Regional Climate Models (RCM) cannot be directly applied to climate change impact studies, and downscaling is therefore needed. A large number of statistical downscaling methods exist but no clear recommendations exist of which methods are more appropriate, depending on the application. This paper compares five statistical downscaling methods based on a common change factor methodology using results from four different RCMs driven by different GCMs. Precipitation time series for a future scenario are generated for a location north of Copenhagen for the period 2071–2100 under climate change projections by the scenario A1B. Special focus is given to the changes of extreme events since downscaling methods mainly differ in the way extreme events are generated. There is a significant uncertainty in the downscaled projected changes of the mean, standard deviation, skewness and probability of dry days. Large uncertainties are also observed in the downscaled changes in extreme event statistics. However, three of the four RCMs analysed show an increase in the extreme precipitation events in the future. The uncertainties are partly due to the variability of the RCM projections and partly due to the variability of the statistical downscaling methods. The paper highlights the importance of acknowledging the limitations and advantages of different statistical downscaling methods as well as the uncertainties in downscaling climate change projections for use in hydrological models.

1. Introduction

Global Circulation Models (GCM) are used to project the changes in atmospheric variables under the climate change scenarios defined by the Intergovernmental Panel for Climate Change (IPCC). These climate projections are defined at a coarse grid (approximately 150–300 km) and are often biased and hence cannot be used directly in hydrological models for climate change impact assessments (Fowler et al., 2007). Thus, there is a need for downscaling. There are two main downscaling approaches: dynamic and statistical downscaling.

In dynamic downscaling a Regional Climate Model (RCM) is set up for a region of interest and nested within a GCM. The RCM uses time-varying atmospheric boundary conditions around a finite domain from the GCM (one-way nesting). The RCM resolution is usually around 12–50 km and it accounts for the sub-GCM grid scale forcing by e.g. complex topographical features and land cover heterogeneities in a physically-based way. However, RCMs inherit the biases and other deficiencies of the GCM, and hence further (statistical) downscaling is often needed also for RCM projections.

The basic idea in statistical downscaling is to define a relationship between the large-scale model (either GCM or RCM) and the local climate. The statistical downscaling methods are computationally inexpensive (as compared to dynamic

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downscaling) and can be applied to output from GCMs or RCMs (Wilby et al., 2004). The basic assumption is that the relationship between large and local scale will remain constant in the future. This is the main drawback in statistical downscaling since this basic assumption cannot be verified (Fowler et al., 2007).

A large number of techniques have been developed for statistical downscaling. These can be grouped into three main groups: regression models, weather generators and weather typing schemes (Fowler et al., 2007). Regression models are methods that directly quantify a relationship between the climate variable at local scale (e.g. precipitation) and a set of large-scale atmospheric variables. Stochastic weather generators (WG) are statistical models that are able to simulate weather data based on statistical characteristics of the variable (see e.g. Burton et al., 2008; Kilsby et al., 2007; Semenov and Stratonovitch, 2010). Weather typing consists of grouping days into a finite number of discrete weather types or “states” according to their synoptic similarity (Wilby et al., 2004). GCM or RCM are then used to estimate the change in the frequency of weather types in order to estimate climate change (Fowler et al., 2007).

The occurrence and intensity of extreme events is likely to increase in the future under climate change (Beniston et al., 2007). However, downscaling methods differ in the way extreme events are considered. In general, RCMs do not accurately represent extreme events (Fowler et al., 2007). Regression-based methods and weather typing are also generally inadequate for the simulation of extreme events (Wilby et al., 2002).

This paper compares five statistical downscaling methods, including two statistical correction methods (change in mean and change in mean and variance methods) which belong to the group of regression models and three weather generators (WG). The change in mean and change in mean and variance methods are relatively simple and straightforward methods commonly used in climate change impact assessments. Weather generators are based on more complex stochastic models that consider a larger number of statistics in the downscaling and are, in general, more adequate for extreme events generation. The three WGs considered are a Markov chain model, a semi-empirical model and the Neyman-Scott Rectangular Pulses (NSRP) model.

All five downscaling methods are based on a common change factor methodology. Climate model data are first used to derive changes in statistical characteristics of the climate variable, which are then used as inputs to the downscaling methods. The change factors depend on the GCM/RCM used. This study compares the change factors estimated using four different RCM-GCM combinations. RCM data with a grid resolution of 25 km from one of the main multi-model climate change projects, ENSEMBLES (van der Linden, and Mitchell, 2009), are used in this study.

Daily precipitation data from a rain gauge station north of Copenhagen for the period 1979–2007 is downscaled. Transient climate simulations from the four RCM models for the period 1951–2100 (ENSEMBLES, 2009) are used to estimate statistical changes in precipitation data, which are subsequently used in the statistical downscaling methods to generate time series for a future climate. Changes from the period 1978–2008 (defined as a 30-year period representing the period with observed data) and the future A1B scenario for the period 2071–2100 are estimated from the transient RCM simulations.

2. Methodology

Fig. 1 shows the steps followed in this comparison study. Four different RCMs driven by two GCMs are used in order to calculate Change Factors (CFs). The observed data and the CFs are then used as input to the statistical downscaling methods and used to generate time series for the future scenario.

2.1. Change factors

The CF method is based on calculating the change for one or more statistics from the control (St^{RCMcon}) to the future scenario (St^{RCMfut}) using the information contained in the RCM simulations. The values of the statistics for the future (St^{Fut}) are then estimated by superimposing the changes on the observed statistic (St^{Obs}). This method assumes that the RCM represents better the change from the present to the future climate, rather than the absolute values of the variables (Fowler et al., 2007).

Change factors are calculated for all the statistics that are used in the downscaling method. In some studies, change factors for high order moments have been derived from the estimated change in mean (see Burlando and Rosso, 1991). Eq. (1) is used to calculate changes in mean, standard deviation, skewness and changes in the length of wet and dry spells while Eq. (2) is used to calculate the change factors of the probability of dry days, the dry–wet and wet–wet transition probabilities and autocorrelation. Eq. (2) is applied to these statistics to ensure that the estimated value (referred to as St in Eq. (2)) for the future period will remain in the interval [−1, 1].

$$CF = \frac{St^{RCMfut}}{St^{RCMcon}}; St^{Fut} = St^{Obs} \cdot CF \tag{1}$$

$$CF_{f(St)} = \frac{f\left(St^{RCM\ fut}\right)}{f\left(St^{RCM\ con}\right)}; St^{Fut} = f^{-1}\left(f\left(St^{Obs}\right) \cdot CF_{f(St)}\right); \quad f(St) = \frac{St}{1-abs(St)} \tag{2}$$

In order to account for annual variability the downscaling methods are applied on a monthly basis, hence CFs are calculated separately for each month.

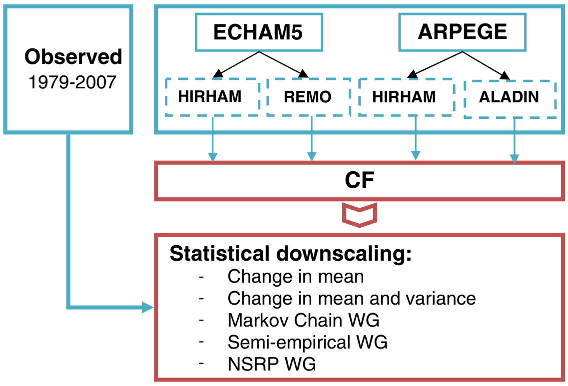

Fig. 1. GCMs, RCMs and statistical downscaling models applied in the comparison study.