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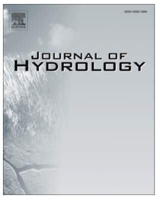

Modelling runoff with statistically downscaled daily site, gridded and catchment rainfall series

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SUMMARY

Statistical downscaling has mainly been used for site (point) scales to provide daily rainfall series for climate change impact studies. The objectives of this study are to compare three methods of applying statistical downscaling to catchment rainfall and evaluating their hydrological response with a hydrological model: (a) statistically downscaling to sites and then interpolating to gridded rainfall which is accumulated to catchment average rainfall; (b) statistically downscaling to catchment average rainfall directly; and (c) statistical downscaling to grid cells and then accumulating to catchment average rainfall. Results indicate that statistical downscaling can be successfully applied at catchment average and grid cell scales. All three methods of application performed similarly for a range of rainfall characteristics, with directly downscaled catchment average rainfall producing a relatively better result for extreme daily rainfall indices. However, hydrological simulation indicated that the direct downscaling of catchment average rainfall did not have any advantages over the other two downscaling application methods in terms of the runoff statistics evaluated. In addition, all three methods of downscaling application could simulate the spatial correlation of daily and annual runoff across the nine focus catchments investigated. The advantages and limitations of applying statistical downscaling to the assessment of hydrological response to climate change are also discussed.

1. Introduction

Water resource management and planning increasingly need to incorporate the effects of global climate change and variability in order to predict future supplies (Bates et al., 2008). Therefore future climate, particularly rainfall, is of utmost interest to resource management, agriculture, and water-users. This is particularly true for the Murray–Darling Basin (MDB) in south-eastern Australia, which has recently experienced a severe, decade-long drought, i.e., the 1997–2009 "Millennium" drought (Potter et al., 2010). Given the MDB covers 1,059,000 square kilometres or 14% of Australia's land area, is home to over 2 million people, and produces nearly 40% of the value of Australian agricultural production, the potential climate change and its associated hydrological impacts have been paid significant attention by the Australian government (CSIRO, 2010; Yu et al., 2010). There is a concern that the observed low rainfall and runoff during the recent dry sequence is enhanced by climate change thus there is great interest in possible future scenarios (CSIRO, 2010; Chiew et al., 2011).

Coupled general circulation models (GCMs), mathematical models of the general circulation of a planetary atmosphere and ocean, are the primary tool to simulate present climate and project future climate (Christensen et al., 2007). GCM outputs can be useful in understanding future global climatic changes for given scenarios of greenhouse gas emissions. However, they currently do not provide reliable information on scales below 100–200 km (Meehl, 2007), on which hydrological processes typically occur (Kundzewicz, 2007). In particular, GCMs cannot resolve circulation patterns leading to hydrological extreme events (Maraun, 2010). Therefore, higher-resolution scenarios are required for key meteorological variables such as rainfall in order to investigate the impacts of climate change on hydrological process and water availability (Maraun, 2010).

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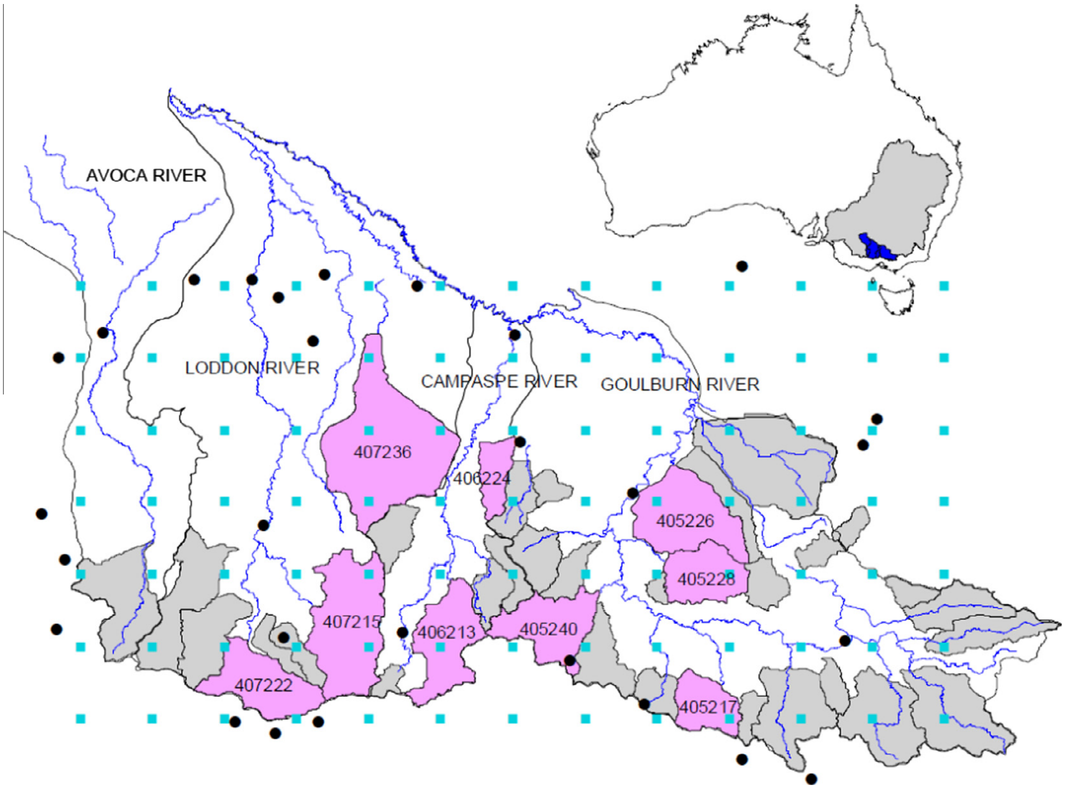

Fig. 1. Study region and 28 rainfall sites (black circles), 91 grid cells (blue square), and 38 (nine pink filled catchments are used for hydrological simulations) catchments used for this study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Downscaling techniques have been developed to resolve the scale discrepancy between climate change scenarios and the resolution required for impact assessment. This is based on the assumption that large-scale circulation patterns have a strong influence on local-scale weather (Maraun, 2010). Two approaches to downscaling are commonly used. *Dynamical downscaling* nests a regional climate model (RCM) into a GCM to represent finer resolution atmospheric physics within a limited area of interest or a stretched grid GCM of finer resolution over the area of interest. *Statistical downscaling* involves the modelling of relationships between local-scale climate variables and large-scale atmospheric processes (Mehrotra and Sharma, 2006). Each of these two downscaling techniques has its advantages and disadvantages, with a major limitation of dynamical downscaling that RCMs only provide meaningful information on precipitation extremes on the scale of a few grid cells, with considerable noise on the individual grid cell scale (Fowler and Ekström, 2009).

Statistical downscaling is more widely used than dynamic downscaling for climate change hydrological applications due to several pragmatic advantages: (a) Statistical downscaling does not require significant computing resources and can generate many realisations (stochastically). This advantage allows users to generate a large ensemble of climate realisations to explore hydrological response to a large range of GCM projections and global warming scenarios, and to explore uncertainties in statistical downscaling parameterization and natural climate variability (Wilby et al., 2004). In contrast, dynamic downscaling needs significant computing resources, which makes it difficult to simulate many realizations to quantify the range of uncertainty; (b) Statistical downscaling can be more easily and directly fitted to reproduce the observed rainfall statistics important for runoff generation, because it can calibrate and validate the model for the salient observed rainfall statistics. As dynamic downscaling is not calibrated for rainfall characteristics it requires bias correction to produce rainfall with characteristics approximating those observed (Corney et al., 2010).

Catchment average rainfall is important for a variety of hydrological applications, such as the assessment of climate change impacts on regional hydrological regimes and water availability. Statistical downscaling, as a useful tool to provide daily rainfall series, has not been extensively used for grid or catchment scale modelling, a comparison of which is the objective of this study. We will explore statistical downscaling to site, catchment and gridded rainfall datasets. The downscaled rainfall results are then used with a lumped catchment scale hydrological model, SIMHYD (Chiew et al., 2002), to assess the modelled runoff results.

2. Methods and data

2.1. Study region

The study region comprises several catchments of the southern MDB in south-eastern Australia (Fig 1), i.e., Loddon, Avoca, Campaspe, and Goulburn rivers. This study region has been selected as: (1) The MDB has recently experienced a long decadal drought with unprecedented decline in the streamflow (Potter et al., 2010; Potter and Chiew, 2011); and (2) the nonhomogeneous hidden Markov model (NHMM) stochastic daily downscaling model has previously been shown to perform well in this region in terms of various rainfall statistics (Frost et al., 2011; Fu and Charles, 2011; Fu et al., in press).

2.2. Statistical downscaling model – NHMM

The NHMM models multi-site patterns of daily precipitation occurrence and amounts as a finite number of 'hidden' (i.e. unobserved) weather states (Hughes et al., 1999; Charles et al., 1999).