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Comparison of runoff modelled using rainfall from different downscaling methods for historical and future climates

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SUMMARY

This paper: (i) assesses the rainfall downscaled from three global climate models (GCMs) using five downscaling models, (ii) assesses the runoff modelled by the SIMHYD rainfall–runoff model using the downscaled daily rainfall, and (iii) compares the modelled changes in future rainfall and runoff characteristics. The modelling study is carried out using rainfall and streamflow data from eight unimpaired catchments near the headwaters of the Murray River in south-east Australia. The downscaling models used, in increasing order of complexity, are a daily scaling model, an analogue statistical downscaling model, GLIMCLIM and NHMM parametric statistical downscaling models, and CCAM dynamic downscaling model. All the downscaling models can generally reproduce the observed historical rainfall characteristics. The rainfall–runoff modelling using downscaled rainfall also generally reproduces the observed historical runoff characteristics. The future simulations are most similar between the daily scaling, analogue and NHMM models, all of them simulating a drier future. The GLIMCLIM and CCAM models simulate a smaller decrease in future rainfall. The differences between the modelled future runoff using the different downscaled rainfall can be significant, and this needs to be further investigated in the context of projections from a large range of GCMs and different hydrological models and applications. The simpler to apply daily scaling and analogue models (they also directly provide gridded rainfall inputs) can be relatively easily used for impact assessments over very large regions. The parametric downscaling models offer potential improvements as they capture a fuller range of daily rainfall characteristics.

Introduction

Global warming could lead to changes in future runoff characteristics that may require a significant planning response or a change in the way water resources are currently managed. There are numerous studies in the literature on the modelling of climate change impact on runoff. In most of these studies, the hydrological model is first calibrated against historical data, and then driven with a future climate series usually with the same optimised parameter values, and the modelled future and historical runoff are compared to estimate the climate change impact on runoff (Schaake, 1990; Xu, 1999; Chiew and McMahon, 2002; Chiew et al., 2009). Rainfall is the key driver in these hydrological modelling studies and a change in rainfall is generally amplified as a larger percent change in runoff (Wigley and Jones, 1985; Sankarasubramaniam et al., 2001; Chiew, 2006).

The future climate series is usually obtained by analysing results from global climate models (GCMs) that simulate global and regional climate systems (IPCC, 2007). However, GCMs provide information at a resolution that is too coarse to be used directly in hydrological modelling. Various methods have been used to obtain catchment-scale climate series, informed by GCM simulations for the future and current climates, to drive hydrological models. Three commonly used methods are explored in this paper. The first is a daily scaling method that scales the observed historical point or catchment-scale daily rainfall series to obtain a future daily rainfall series by considering changes in the seasonal means and daily rainfall distribution simulated by a GCM (Chiew et al., 2009; Mpelasoka and Chiew, 2009). The second method uses three statistical downscaling techniques that relate synoptic large-scale atmospheric predictors to catchment-scale rainfall (gridded rainfall or point rainfall at multiple sites) based on analysis of historical data, and the relationship is then used to downscale future atmospheric predictors simulated by a GCM to obtain future catchment-scale rainfall. The three statistical downscaling techniques used here are: (i) an analogue technique (Timbal, 2004; Timbal

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et al., 2009); (ii) an implementation of the Generalised LInear Model for daily CLIMate (GLIMCLIM) software package (Chandler, 2002) and (iii) a Non-homogeneous Hidden Markov Model (NHMM) (Hughes et al., 1999). The third method is a dynamic downscaling method that uses a high resolution regional atmospheric model with boundary conditions and far-field nudging provided by a GCM. Fowler et al. (2007) provide a thorough review of downscaling methods with an emphasis on hydrological applications, and Wood et al. (2004), Haylock et al. (2006) and Timbal et al. (2008) provide comparative analysis of future rainfall obtained using statistical and dynamic downscaling methods.

The aims of this paper are to: (i) assess the historical runoff characteristics modelled by a rainfall–runoff model using daily rainfall series obtained from the above downscaling methods against the observed historical runoff characteristics and (ii) compare the future runoff characteristics modelled using future daily rainfall obtained from the different downscaling methods informed by three GCMs. The modelling is carried out using data from south-east Australia. The focus of this paper is mainly on the runoff simulations, and a related paper by Frost et al. (submitted for publication) describes the downscaling methods and discusses the verification of rainfall simulations against historical rainfall in more detail.

The paper is organised as follows. The streamflow, rainfall, reanalysis and GCM data used in the study are first described. This is followed by a description of the downscaling methods, rainfall–runoff modelling and the modelling experiments. The modelling results are then presented followed by a discussion of the relative differences between the downscaling methods and rainfall–runoff simulations and the implications on climate change impact studies.

Data

Study area and streamflow data

The study area is in south-east Australia near the headwaters of the Murray River. Daily streamflow data from eight relatively unimpaired catchments are used (Fig. 1). The catchment areas range between 100 and 1600 km^2. Most of the catchments have less than 1% missing data over the model calibration period of 1986–2005. The mean annual rainfall in the catchments ranges from 500 to 1300 mm and the proportion of mean annual rainfall that becomes runoff ranges from 5% to 50% (Fig. 1). Most of the runoff is generated in the winter half (May–October) of the year.

Observed rainfall

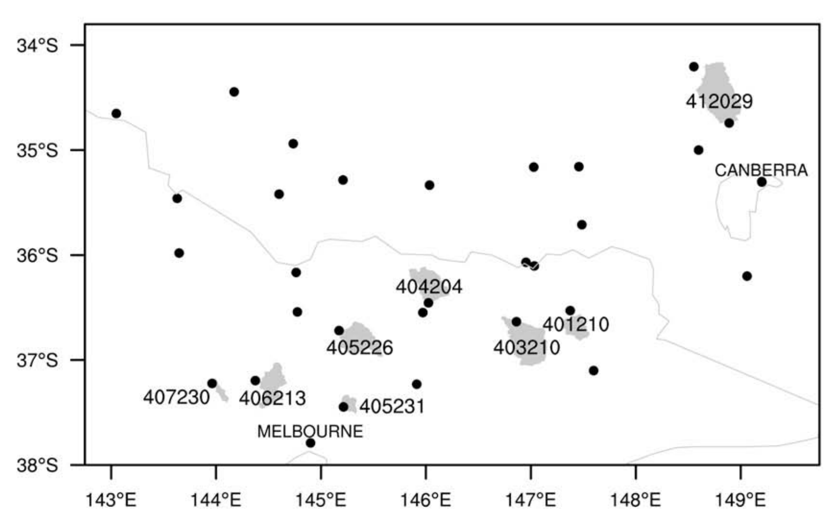
Two types of observed daily rainfall data (recorded as 24-h accumulations to 0900) from 1961–2005 are used. The first is point rainfall from 30 locations (Fig. 1) with high quality daily rainfall data observed by the Australian Bureau of Meteorology over the model calibration period of 1986–2005 (Frost et al., submitted for publication). The second is daily rainfall over 0.05° grids from the ‘SILO Data Drill’ of the Queensland Department of Natural Resources and Water (http://www.nrw.qld.gov.au/silo; Jeffrey et al., 2001). The SILO Data Drill provides surfaces of daily rainfall and other climate data for 0.05° grids across Australia, interpolated from point measurements made by the Australian Bureau of Meteorology. The gridded rainfall data are used with the CCAM dynamic downscaling model outputs and the point rainfall data are used with the other downscaling methods.

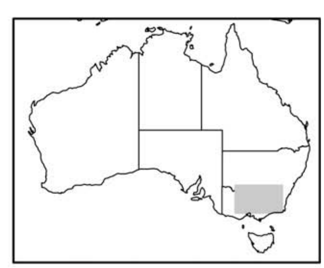
Reanalysis data for atmospheric predictors

The atmospheric predictor data for 1986–2005 used to calibrate the downscaling methods come from the NCEP/NCAR reanalysis data at 2.5° grids (Kalnay et al., 1996; http://www.cdc.noa.gov/cdc/reanalysis/). The ten candidate predictors considered are mean sea level pressure, geopotential heights at 500, 700 and 850 hPa, dew point temperature depression at 500, 700 and 850 hPa, and specific humidities at 500, 700 and 850 hPa. Daily values of the predictors, averaged over 24 h are used to be consistent with the 24-h observed daily rainfall data.

GCM data

Daily simulations of rainfall and the above atmospheric predictors from three GCMs (GFDL 2.0, CSIRO MK3.5 and MRI) for 1961–2000 and 2046–2065 are used. The GCM data are extracted from the Program for Climate Model Diagnosis and Intercomparison (PCMDI) website (http://www-pcmdi.llnl.gov) and interpolated to the 2.5° NCEP/NCAR reanalysis data grid. The 2046–2065 data used is for the SRES A2 greenhouse gas emission scenario (IPCC, 2007).





Catchment	Area (km^2)	Mean annual rainfall (mm)	Mean annual runoff (mm)
401210	416	1049	516
403210	1238	1257	406
404204	748	586	46
405226	818	557	83
405231	187	1188	227
406213	644	742	130
407230	161	588	65
412029	1540	726	71

Fig. 1. Study area showing locations of catchments, rainfall stations and 1986–2005 mean annual rainfall and runoff.