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Change-signal impacts in downscaled data and its influence on hydroclimate projections

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ABSTRACT

Downscaling is the process by which output from global climate models is translated to finer resolution regional scale projections often used in impact studies. Many fundamentally different techniques can be used, each with different capabilities of resolving or representing sub-gridscale processes. The different formulations can lead to variations in the downscaled output with consequential impacts in the interpretation of future change. Here, future runoff is estimated for six catchments in the Australian state of Victoria using five different regional rainfall projection products. We investigate how differences in rainfall input manifest in a selection of regionally important hydroclimate metrics. Overall, annual runoff is projected to decline under most methods, but seasonal changes are more uncertain reflecting differences in the rainfall change signal for different downscaled products. Whilst change in flow metrics are mostly consistent with rainfall change factors, changes in low flow (e.g. 7-day minimum flow) show considerable uncertainty, especially for drier, ephemeral catchments. Results from empirical (simple) scaling of climate observations generally lie within the range of more complex downscaling methods. However, empirical scaling is unable to provide meaningful information on spatial heterogeneity in the change signals, as well as for several metrics of rainfall and runoff. Other downscaling methods can potentially provide information on these, but the large uncertainty remains a problem, as well as our currently poor understanding of method-related biases.

1. Introduction

Planning for the future is an integral part of managing water resources (Poff et al., 2016), even more so in regions with large natural variability and periodically scarce supply. Such are the conditions in southeast Australia, where long-term trends show an ongoing decline of cool season (April to October) rainfall since the early 1990s (Hope et al., 2016). Since the cool season is the ‘filling season’ for regional reservoirs in southeast Australia, there is concern among water users that the observed decline may continue into future decades (Potter and Chiew, 2009, 2011; Potter et al., 2011). The current national climate projections for the region suggest high confidence in drying in southern Australia, particularly in spring (September to November) as a response to shifts in westerlies and strengthening of the subtropical ridge (CSIRO and Bureau of Meteorology, 2015). These findings further enhance concern for future water supply in the region.

To provide meaningful information for water resource impact assessments, the coarse spatial signal from global climate models (GCMs) needs to be downscaled to finer resolution scales (i.e. point or catchment scale). Because downscaling methods vary in technical formulation and complexity, for some variables and regions, downscaling methods can produce very different results. Many downscaling comparisons have been conducted to demonstrate and understand the plausible range of projections in downscaling ensembles (see, e.g. Fowler et al., 2007; Chiew et al., 2010; Chen et al., 2011; Frost et al., 2011; Grose et al., 2015; Sunyer et al. 2015).

The State Government of Victoria (Australia) provides guidance about future change to runoff for water corporations, catchment management authorities and industries to manage and plan for long-term risks to water supply (DELWP, 2016). Guidance for a 50-year time horizon is contained in the State’s Water Supply and Demand (WSD) plans, a document that is revised every 5 years. The most recent hydroclimate projections supporting the WSD planning considered both GCM projected change and observed decadal variability. The GCM based projections used climate change information from 42 models from the fifth Climate Model Intercomparison Project (CMIP5, Taylor et al., 2012), downscaled to the region using a change factor approach (Potter et al., 2016). However, as recently shown by Ekström et al

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Table 1
Downscaling methods available for this study. © 2018 CSIRO. All Rights Reserved.

Downscaling method	Emissions scenario	Historical	Future	Ensemble size	Spatial resolution	Reference
Empirical scaling	RCP8.5[1]	1986–2005	2060–2079	42	0.05° × 0.05°	Potter et al. (2016)
Statistical analogues (SDM)	RCP8.5[1]	1986–2005	2060–2079	22	0.05° × 0.05°	Timbal et al. (2009, 2011); Teng et al. (2012a)
Non-homogenous Hidden Markov Model (NHMM)	RCP8.5[1]	1986–2005	2060–2079	19	Catchment-based	Charles et al. (1999); Fu et al. (2013a)
Conformal-Cubic Atmospheric Model (CCAM)	RCP8.5[1]	1986–2005	2056–2075	6	0.5° × 0.5°	McGregor and Dix (2008)
Weather Research and Forecasting model (WRF)	SRESA2[2]	1990–2009	2060–2079	4 × 3[3]	0.1° × 0.1°	Evans et al. (2014a)

[1] RCP8.5 is the high emission Representative Concentration Pathway (RCP) (van Vuuren et al., 2011) used by the latest generation of GCMs in the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2012).

[2] SRES A2 is the high emission scenario in the Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000) used by the previous generation of GCMs (CMIP3).

[3] 4 GCMs with 3 different physics scheme configurations of WRF.

(2016), there is emerging evidence of a regional change signal in available downscaling products that is not reflected in GCM-based projections for southeast Australia. The nature of this change signal differs between different downscaling products making it difficult for users of these datasets to assess their relative value in comparison to the GCM based projections.

If using climate change projections for policy guidance, researchers need to carefully consider the choice of methods used and sources of information. Of primary importance is the representation of key sources of uncertainty in global climate change information, and secondly, ensuring that the method or methods used to derive a regional resolved projection have the capacity to translate the aspect of change relevant to the application (e.g. to spell duration or extremes). The key sources of uncertainty are found in: (1) the emission scenarios used for the global climate modelling (uncertainties about the species and rate of greenhouse gas (GHG) emissions); (2) the models used to simulate the climate response to the changing GHG emissions (aspects of model structure and parameter schemes that influence the models ability to simulate the climate); and (3) natural climate variability (the ability of the model to simulate the full range variability in the climate not arising from emission forcing). To attempt to represent these sources of uncertainty, researchers can consider GCM output using a range of emission scenarios (such as the Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011), and consider the use of a large number of GCMs (to sample model ability to simulate forced and internal climate variability).

Each additional manipulation of data adds some level of uncertainty to the outcomes, such as the downscaling step and the impact modelling itself. For example, many hydrological models are conceptual models, relying on a robust calibration to provide good estimates of streamflow. Under changing climate conditions these assumptions may no longer hold. This challenge is often referred to as the non-stationarity problem, discussed at length by several authors (Milly et al., 2008; Potter et al., 2013; Saft et al., 2016; Chiew et al., 2017). An additional concern for projections is the choice of baseline period. This is the choice of time window for which the future data is compared and represents the future climate (see e.g., Timbal et al., 2016; Potter et al., 2016). Further details on the production of climate change datasets and the impact on policy guidance is detailed in Harris et al. (2014) and Ekström et al (2016).

In this study, we examine rainfall from the five different downscaled datasets that are currently available for six representative catchments in the State of Victoria. The aim is to quantify differences in rainfall projections by different available downscaled climate change datasets, and further examine how such differences manifest in metrics derived from streamflow modelled using the different downscaled datasets. The ensemble of datasets is an ensemble of opportunity, representing all downscaled datasets available for the region in 2017. Because of the opportunistic nature of this ensemble, there is some variation in the use of emission scenario, CMIP archive and slight difference in time horizons. However, all selected projections have the common purpose of illustrating regional climate change for a far-future time horizon under a high-emission scenario, and the ensemble represents the current information available to researchers, planners and purveyors of climate change information.

Section 2 outlines the downscaling methods, climate data and hydrological modelling used in this study. Section 3 presents changes in mean annual and seasonal rainfall across Victoria, annual and seasonal runoff for six study catchments, and changes in key rainfall and runoff metrics, as well as the differing spatial resolution of the different downscaling methods and the potential for providing within-catchment climate information. Section 4 discusses limitations of the study and directions for future research, and Section 5 gives conclusions and recommendations.

2. Data and methods

2.1. Downscaled rainfall datasets

There are many fundamentally different approaches used to achieve a finer resolved climate projection. It is well established that different methods can influence what aspects of the GCM 'change signal' are translated to the finer resolved downscaled data set (e.g. Fowler et al., 2007; Chen et al., 2011; Ekström et al., 2015). Briefly, downscaling methods can be categorised as: (1) empirical downscaling or 'change-factor methods', which apply projected changes in the distribution of GCM rainfall to observed (point or catchment-scale) climate data; (2) statistical downscaling methods, which use statistical relationships based on observed data and apply these on GCM output to derive a local variable estimate; and (3) dynamical downscaling methods, typically involving regional climate models (RCMs) that simulate physical processes at a finer spatial scale using boundary conditions from a host GCM.

This study considers all currently available downscaled datasets in south-eastern Australia with output that is readily available for hydrological modelling (Table 1). The datasets are produced by different research initiatives across the region: the Victorian Climate Initiative (Hope et al., 2016) and its predecessor, the South Eastern Australian Climate Initiative (CSIRO, 2012), the New South Wales and Australian Capital Territory Regional Climate Modelling (NARCliM) project (Evans et al., 2014a), and two datasets created to support the national climate projections (CSIRO and Bureau of Meteorology, 2015). The methods used to create these datasets are fundamentally different ranging from empirical scaling to dynamical downscaling. Furthermore, there are some differences in the projected time horizon, GCM selection and emission scenario used (Table 1). Table 2 provides a full list of the GCMs downscaled by each method. Mean annual regional rainfall for

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