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Australian climate extremes in the 21st century according to a regional climate model ensemble: Implications for health and agriculture

N. Herold[a,*], M. Ekström[b], J. Kala[c,a], J. Goldie[d,a], J.P. Evans[e]

[a] Climate Change Research Centre & ARC Centre of Excellence for Climate System Science, University of New South Wales, Sydney, Australia
[b] School of Earth and Ocean Sciences, Water Research Institute, Cardiff University, United Kingdom
[c] School of Veterinary and Life Sciences, Environmental and Conservation Sciences, Murdoch University, 6150, WA, Australia
[d] Fenner School of Environment & Society, Australian National University, Acton, ACT, Australia
[e] Climate Change Research Centre & ARC Centre of Excellence for Climate Extremes, University of New South Wales, Sydney, Australia

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A B S T R A C T

The negative impacts of climate extremes on socioeconomic sectors in Australia makes understanding their behaviour under future climate change necessary for regional planning. Providing robust and actionable climate information at regional scales relies on the downscaling of global climate model data and its translation into impact-relevant information. The New South Wales/Australian Capital Territory Regional Climate Modelling (NARCliM) project contains downscaled climate data over all of Australia at a 50 km resolution, with ensembles of simulations for the recent past (1990–2009), near future (2020–2039) and far future (2060–2079). Here we calculate and examine sector-relevant indices of climate extremes recommended by the Expert Team on Sector-specific Climate Indices (ET-SCI). We demonstrate the utility of NARCliM and the ET-SCI indices in understanding how future changes in climate extremes could impact aspects of the health and agricultural sectors in Australia.

Consistent with previous climate projections, our results indicate that increases in heat and drought related extremes throughout the 21st century will occur. In the far future, maximum day time temperatures are projected to increase by up to 3.5 °C depending on season and location. The number of heatwaves and the duration of the most intense heatwaves will increase significantly in the near and far future, with greater increases in the north than south. All capital cities are projected to experience at least a tripling of heatwave days each year by the far future, compared to the recent past. Applying published heat-health relationships to projected changes in temperature shows that increases in mortality due to high temperatures for all cities examined would occur if projected future climates occurred today.

Drought and the number of days above 30 °C are also projected to increase over the major wheat-growing regions of the country, particularly during spring when sensitivity of wheat to heat stress is greatest. Assuming no adaptation or acclimatisation, published statistical relationships between drought and national wheat yield suggest that national yields will have a less than one quarter chance of exceeding the annual historical average under far future precipitation change (excluding impacts of future temperature change and CO_2 fertilization). The NARCliM data examined here, along with the ET-SCI indices calculated, provide a powerful and publicly available dataset for regional planning against future changes in climate extremes.

1. Introduction

Australia is exposed to a variety of climates due to its large size and meridional extent. Northern Australia is dominated by the seasonal migration of the Inter-tropical Convergence Zone (ITCZ) and the summer monsoon, leading to a mean annual precipitation of over 1,000 mm. Central and southern Australia are largely dominated by the subtropical high pressure belt, which is generally associated with clear skies, large sensible heat fluxes and is collocated with Australia's deserts. Conversely, the southern flank of the continent is influenced by wintertime mid-latitude cyclones, which bring substantial precipitation to southern portions of the mainland as well as the western half of Tasmania.

* Corresponding author.
E-mail address: nicholas.herold@unsw.edu.au (N. Herold).

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With such a wide range of climates, Australia also experiences a great diversity of climatic extremes, including heatwaves, floods, droughts and frosts (Westra et al., 2016). Understanding how extremes may change in the future is an important aspect of adaptation planning, as changes to rare but high impact climate events are likely to be a greater challenge to communities compared to changes in the average climate state. For example, while mean temperature in Alice Springs (Fig. 1) over the last half-century has increased from 20.4 to 21.2 °C, over the same period 35 more days each year now experience temperatures exceeding 35 °C. It is likely this latter fact has more serious implications for this community. Nonetheless, relatively small changes in the mean state can also cause climate extremes, such as during drought when persistently lower than normal (but not necessarily extremely low) precipitation leads to severe soil moisture shortages. Different extremes are also known to compound one another, such as the heatwaves that can follow the drying of soils during drought (Alexander, 2011).

Each 'extreme' causes a disruption to the natural and built environment. The nature of damage and the spatial and temporal footprint differs between each type of extreme (e.g. from sub-daily extreme precipitation that occurs locally to multi-year drought that can occur over a large region). Being exposed to a large number of different extremes, numerous socioeconomic sectors in Australia are at risk to adverse changes in their frequency, duration and intensity. For example, the "Millennium drought" (circa 1997–2010) significantly reduced national agricultural production and contributed to a reduction in the industry's GDP contribution from 2.9% to 2.4% (van Dijk et al., 2013). The 2009 Victorian heatwave led to 374 deaths (VGDHS, 2009), more than twice the number caused by the more highly publicised bushfires that it preceded (Teague et al., 2010). More generally, high temperatures throughout the country have been shown to increase morbidity (Bi et al., 2011) and mortality (Coates et al., 2014), as well as decrease labour productivity (Zander et al., 2015) and crop yields (Asseng et al., 2011). Given these diverse impacts there are substantial benefits to be gained from robust projections of climate extremes as well as the development and application of sector-specific climate indices with which to measure them.

Projections of climate extremes over Australia from global climate models have all indicated increases in hot extremes and decreases in cold extremes over the course of the 21st century. Alexander and Arblaster (2009, 2017) conducted comprehensive reviews of projected changes in climate extremes over Australia based on the third and fifth phases of the Coupled Modelling Intercomparison Project (CMIP3 and CMIP5, respectively; Meehl et al., 2007; Taylor et al., 2011). Based on the highest emission scenarios in CMIP5 these authors showed significant increases in all hot extremes for most locations in the future, as well as significant increases in dry days and significant decreases in annual precipitation over southwest Western Australia and the central east coast (Alexander and Arblaster, 2017). Results consistent with these have been found in other CMIP5 (Sillmann et al., 2013; Cowan et al., 2014) and CMIP3 analyses (Mpelasoka et al., 2008; Perkins and Pitman, 2009; Alexander and Arblaster, 2009; Kirono et al., 2011). Remarkably, CMIP5 data suggest that day time temperature extremes that currently occur every 20 years will occur every 5 or fewer years by the middle of the century (IPCC, 2012).

While General Circulation Models (GCM's) capture many aspects of large scale climate change well (IPCC, 2013), studies of changes in extremes and their impact on society require finer spatial resolutions and sometimes more processes (e.g. convective storms) than are available in GCMs. Dynamical and statistical downscaling have typically been used to bridge the resolution gap (Ekström et al., 2015). Existing high resolution dynamically downscaled projections over south-eastern Australia indicate that by 2020–2039 the frequency of heatwaves will significantly increase over most areas compared to 1990–2009, and by 2060–2079 the amplitude of the hottest heatwaves will also significantly increase (Argüeso et al., 2015). Conversely, mean heatwave temperatures may decrease in the future in some southeast Australian coastal regions due to a disproportionate increase in mild versus severe heatwaves (Argüeso et al., 2015). The same projections suggest that future changes in extreme

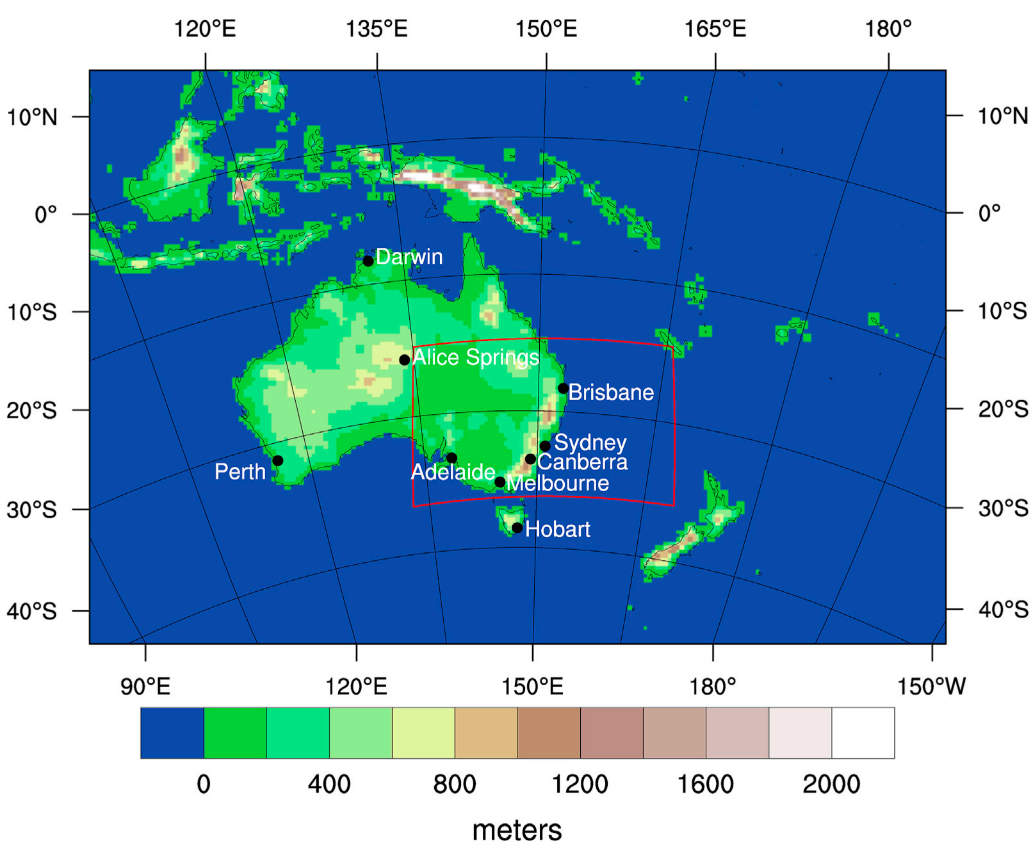

Fig. 1. The 50 km resolution model domain of the NARCliM project; the red box shows the outline of an inner finer resolution (10 km) domain. In the interest of estimating indices for continental Australia, only output from the 50 km resolution domain is used. See section two for details. Locations referenced in this study also shown.(For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)