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Regional climate downscaling for the Marine and Tropical Sciences Research Facility (MTSRF) between 1971 and 2000

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September 2007

Australian Government

Department of the Environment and Water Resources

Supported by the Australian Government's
Marine and Tropical Sciences Research Facility
Project 2.5ii.1 Regional climate change projections for tropical rainforests

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This report should be cited as:
Thatcher, M., McGregor, J. and Nguyen, K. (2007) *Regional climate downscaling for the Marine and Tropical Sciences Research Facility between 1971 and 2000*. Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns (12pp.).

Report made available online by the Reef and Rainforest Research Centre Limited for the Australian Government's Marine and Tropical Sciences Research Facility.

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September 2007.

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Acknowledgements

This is part of a wider study on the tropical rainforest region of North Queensland under the Australian Government's Marine and Tropical Sciences Research Facility, implemented by the Reef and Rainforest Research Centre (RRRC) Limited. This work also contributes to the CSIRO climate research program.

Introduction

Coupled ocean-atmosphere Global Circulation Models (GCM), such as CSIRO's Mk3 model, are powerful tools for predicting changes to global climate as a consequence of anthropogenic greenhouse gas emissions. However, given the complexity of the ocean-atmosphere climate system and the massive computational requirements of such a simulation, the Mk3 model output is currently limited to approximately 200 km resolution over Australia. Therefore, although the Mk3 model simulates changes to global climate (e.g., global increases in air temperatures), it does not have sufficient resolution to describe how these global changes may impact the climate at local or regional scales. This is because regional climate behaviour is also strongly influenced by local terrain and land-use in addition to being influenced by the changes in the global climate.

To predict regional climate changes, we use CSIRO's Conformal Cubic Atmospheric Model (CCAM) to dynamically downscale global climate predictions. CCAM is an Atmospheric Global Circulation Model (AGCM) that employs a global stretched grid which enables it to resolve the local climate in detail (e.g., 15 km resolution as used for this report), including the influence of local terrain and land-use. Moreover, CCAM's global stretched grid also enables it to assimilate large scale atmospheric behaviour from the host model (i.e., Mk3 in this case). In this way, CCAM can reconcile the local and global climate behaviour.

This report describes results obtained from the CCAM model after it was used to dynamically downscale the Mk3 model output to 15 km resolution over a target area centred on 17S, 145E for the Marine and Tropical Science Research Facility (MTSRF) project. For this study, 30 years of Mk3 output was used as the host model, with greenhouse emissions corresponding to 1971 to 2000. Specifically we show that the average simulated maximum temperature, minimum temperature and rainfall are consistent with the observed climatology made by the Australian Bureau of Meteorology (BoM) for the months of January, April, July and October. From these results we show that the regional climate for the MTSRF study can be successfully downscaled by CCAM from the Mk3 simulation results.

Description of the Simulation

In this section we describe the methodology used to simulate the regional climate for MTSRF (1971-2000). CCAM simulates the regional climate by stretching its conformal cubic grid (using a Schmidt transform) such that the resultant grid is focused over the target area. To ensure that large-scale atmospheric behaviour is properly assimilated into the regional climate simulation, it is necessary to perform the dynamical downscaling as a two-step process. The first step is to downscale the climate simulated by Mk3 to 60 km resolution over Australia (see Fig. 1). Sea-surface temperatures are specified by Mk3 (after average monthly biases are corrected) since they only change slowly over time relative to the air temperature. The CCAM simulated winds are nudged every six hours by the Mk3 model, but only above 850 hPa and only at length scales greater than 30 degrees. In this way, CCAM determines the behaviour of the atmosphere at length scales smaller than 30 degrees (i.e., for the Australian region), but is constrained to follow Mk3 at larger spatial length scales. Other than the improved resolution of physical and dynamical atmospheric processes, the small scale structure simulated by CCAM is also influenced by spatially varying topography and land-use. Specifically, topography is determined by the Geoscience Australia 250 m digital elevation model dataset and the land-use described by the Graetz 6 km Australian dataset.

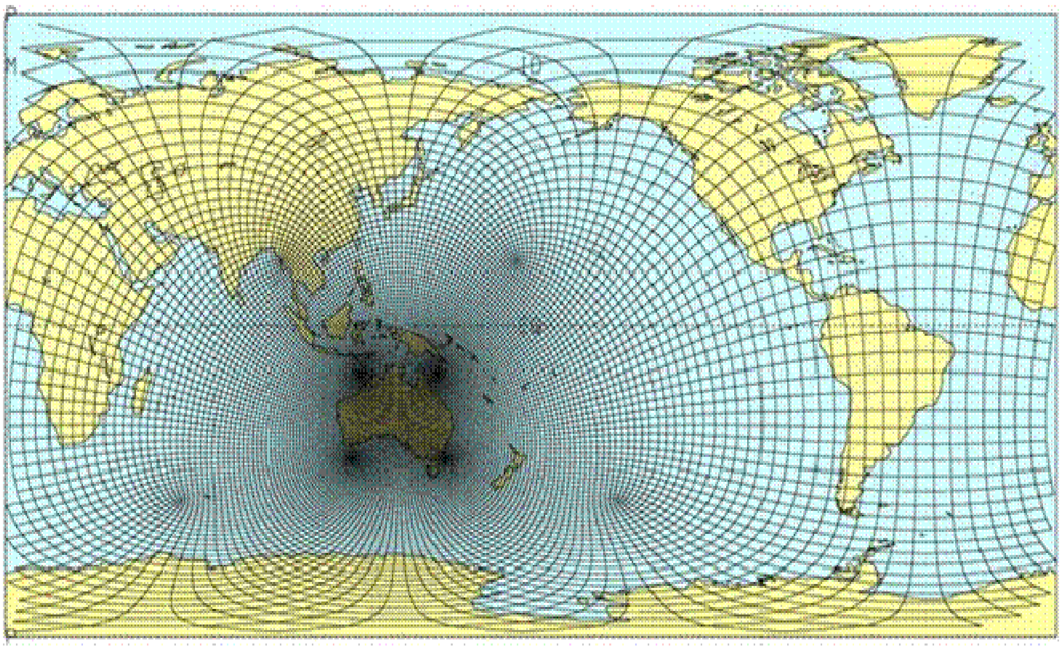

Figure 1: Plot of the 60 km resolution grid used by CCAM to downscale over Australia.

Once the Mk3 climate simulation results for 1971-2000 have been dynamically downscaled to 60 km resolution over Australia, the next step is to downscale CCAM's 60 km simulation results to 15 km resolution over a target area centred on 17S, 145E (see Fig. 2). This is essentially a repeat of the process used to calculate the 60 km regional climate, but resolving atmospheric and surface processes at 15 km resolution. In this case, the simulated winds, temperature, mixing ratio and surface pressure are all nudged at scales greater than 7.5 degree resolution and at every six hours from the 60 km CCAM simulation. As a consequence of the finer spatial and temporal resolution, the simulation of the regional climate at 15 km can take up to 8 times as much computational effort as the 60 km resolution simulation.

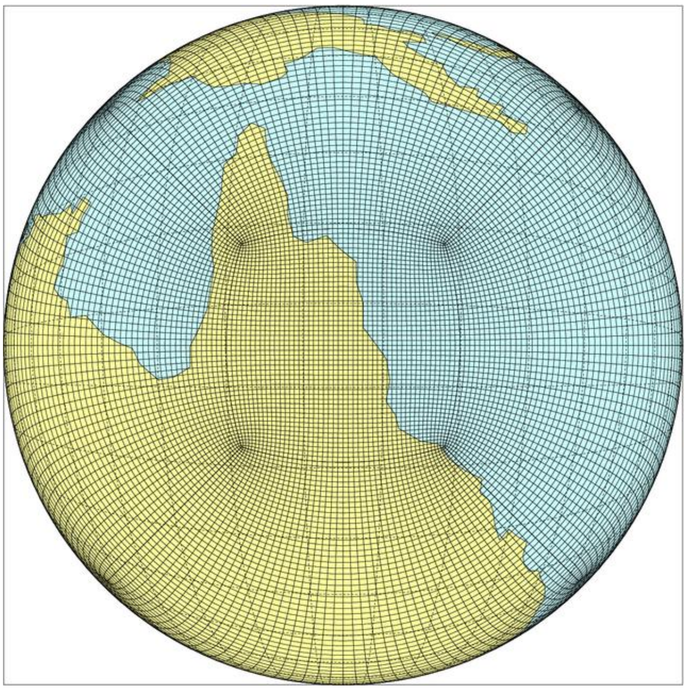

Figure 2: Plot of the 15 km resolution grid used by CCAM for the downscaling results discussed in this report.

CCAM is a hydrostatic model with two-time-level semi-implicit time differencing. It uses semi-Lagrangian advection with bi-cubic horizontal interpolation and total-variation-diminshing vertical advection. For this report we have used 18 vertical levels and a C48 grid which has 6 panels of 48 x 48 horizontal grid points. The model employs an implicit cloud scheme developed by Rotstayn [1], a land-surface scheme by Kowalczyk [2] and a cumulus convection scheme devised by McGregor [3]. Details concerning model dynamics can be obtained from McGregor [4].

Simulation Results

In this section we summarise the results of the regional climate study for MTSRF after dynamically downscaling from Mk3 to CCAM. We then compare the simulation results to the Australian BoM gridded observed average maximum temperature, minimum temperature and rainfall climatology datasets. From these results, we attempt to assess the ability of Mk3 and CCAM to predict a realistic regional climatology for the period from 1971 to 2000.

Before comparing the results of CCAM's dynamical downscaling, it is first useful to compare the Mk3, CCAM 60 km and CCAM 15 km simulation output. Figure 3 compares the rainfall output from all three simulations for the month of January. In particular, note the more than 10 fold increase in spatial detail in the CCAM 15 km simulation compared to the Mk 3 output, as evidenced by the modelled rainfall along the Queensland coast. Although partially due to the improved resolution of topography and land-use, the additional rainfall detail is also a consequence of the improved resolution of atmospheric physics and dynamics.

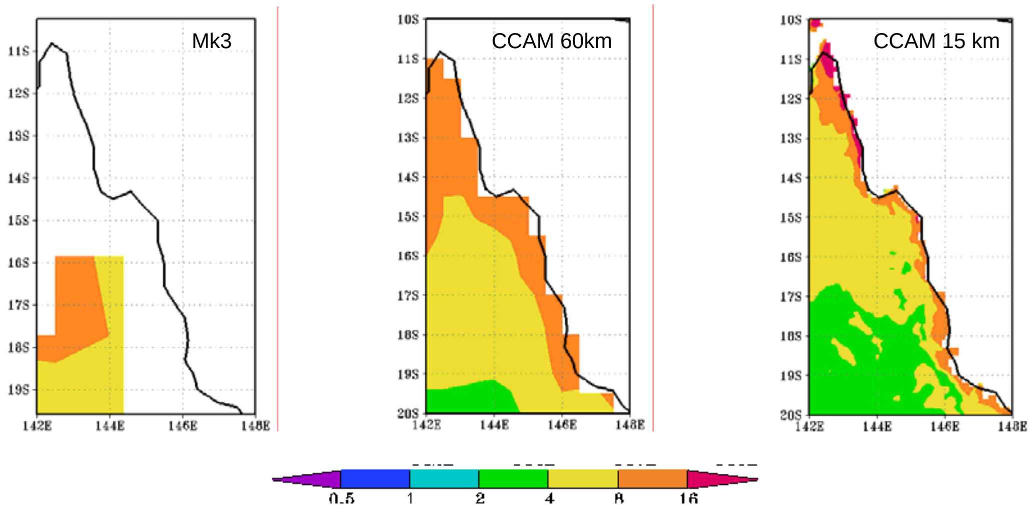

Figure 3: Comparison between simulation resolution of Mk3, CCAM at 60 km resolution and CCAM at 15 km (used for the MTSRF study). Average rainfall in mm/day is shown in this example.

In Figure 4 we compare the average maximum temperatures for the months of January, April, July and October as downscaled by CCAM with the BoM observed gridded datatsets. Note that the broad seasonal variation is correctly captured by the simulation, as well as the broad horizontal variation related to coastal and orographic detail. The maximum temperatures simulated along the northern Queensland coast above 14S appear to be cooler than observed. Nevertheless, the other coastal regions (i.e., below 14S) are accurately simulated.

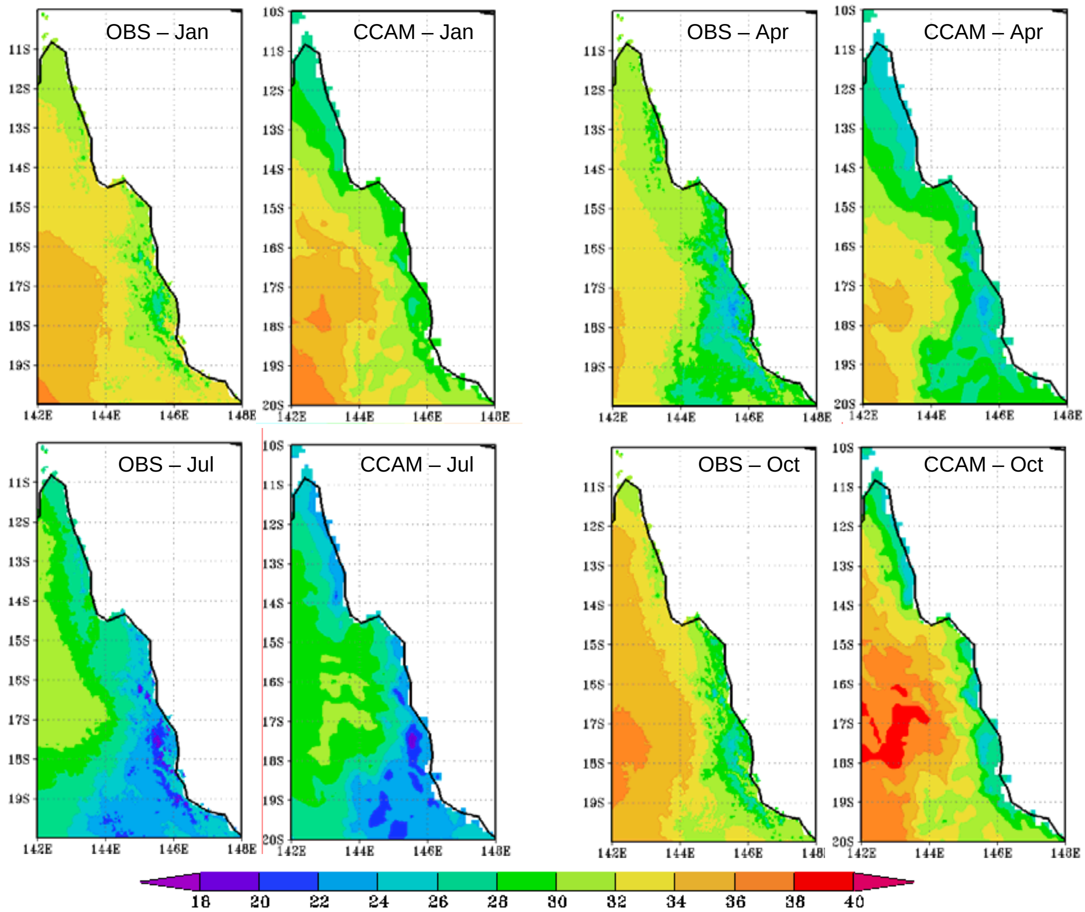

Figure 4: Comparison of observed (OBS) and downscaled (CCAM) average maximum temperatures in degrees Celsius for the MTSRF 15 km CCAM simulation after downscaling from Mk3 between 1971 and 2000.

Figure 5 compares the minimum temperatures as downscaled by CCAM with the BoM observations. As for the average maximum temperatures we note that the simulated seasonal variation in average minimum temperatures is consistent with the observations. However, the simulated temperatures tend to exhibit a cool bias compared to the observed climatology.

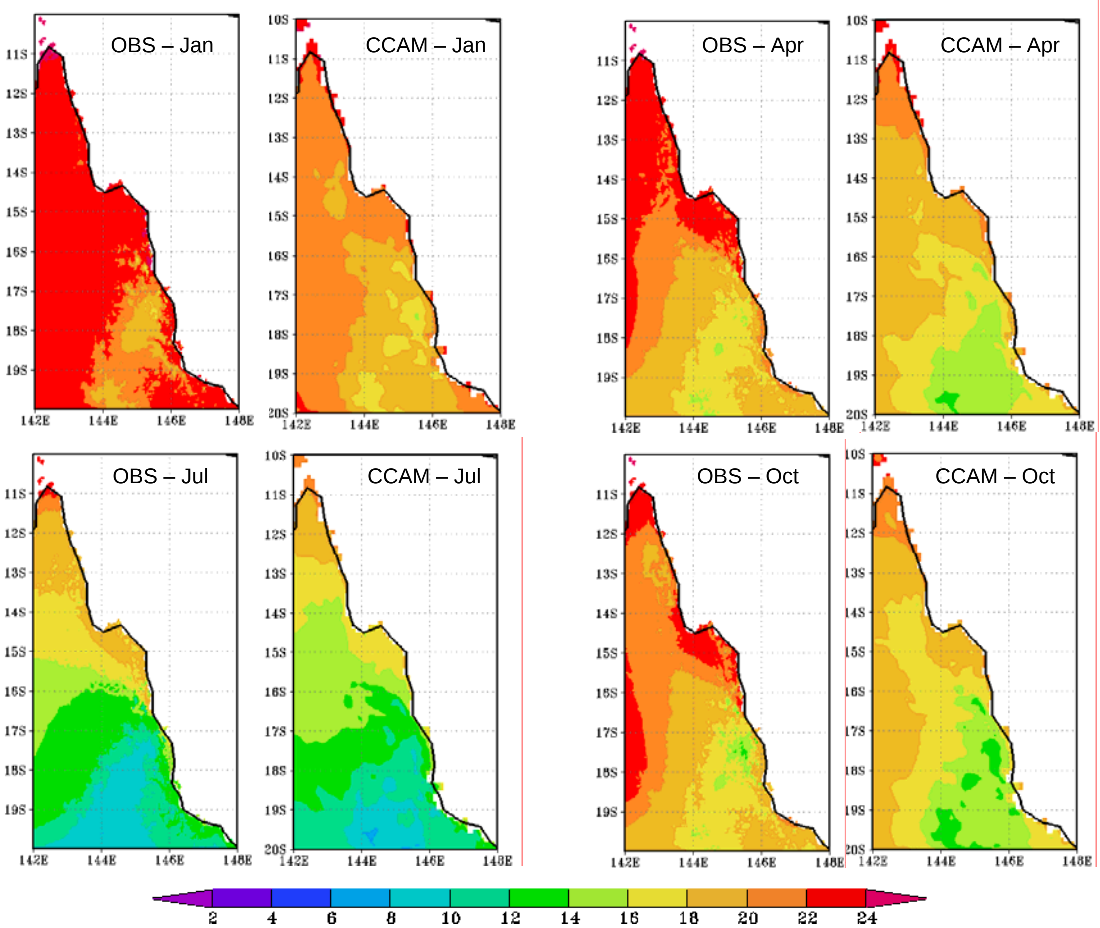

Figure 5: Comparison of observed (OBS) and downscaled (CCAM) average minimum temperatures in degrees Celsius for the MTSRF 15 km CCAM simulation after downscaling from Mk3 between 1971 and 2000.

Finally in Figure 6 we consider the average monthly rainfall as modelled by CCAM and compare it to the BoM observations. Rainfall tends to be more difficult to simulate than temperatures, due to its dependence on complex physical processes. The CCAM downscaled January rainfall is drier than that shown by the BoM observations, although otherwise the seasonal behaviour is largely captured. In particular, the higher coastal rainfall is generally well captured by the simulation.

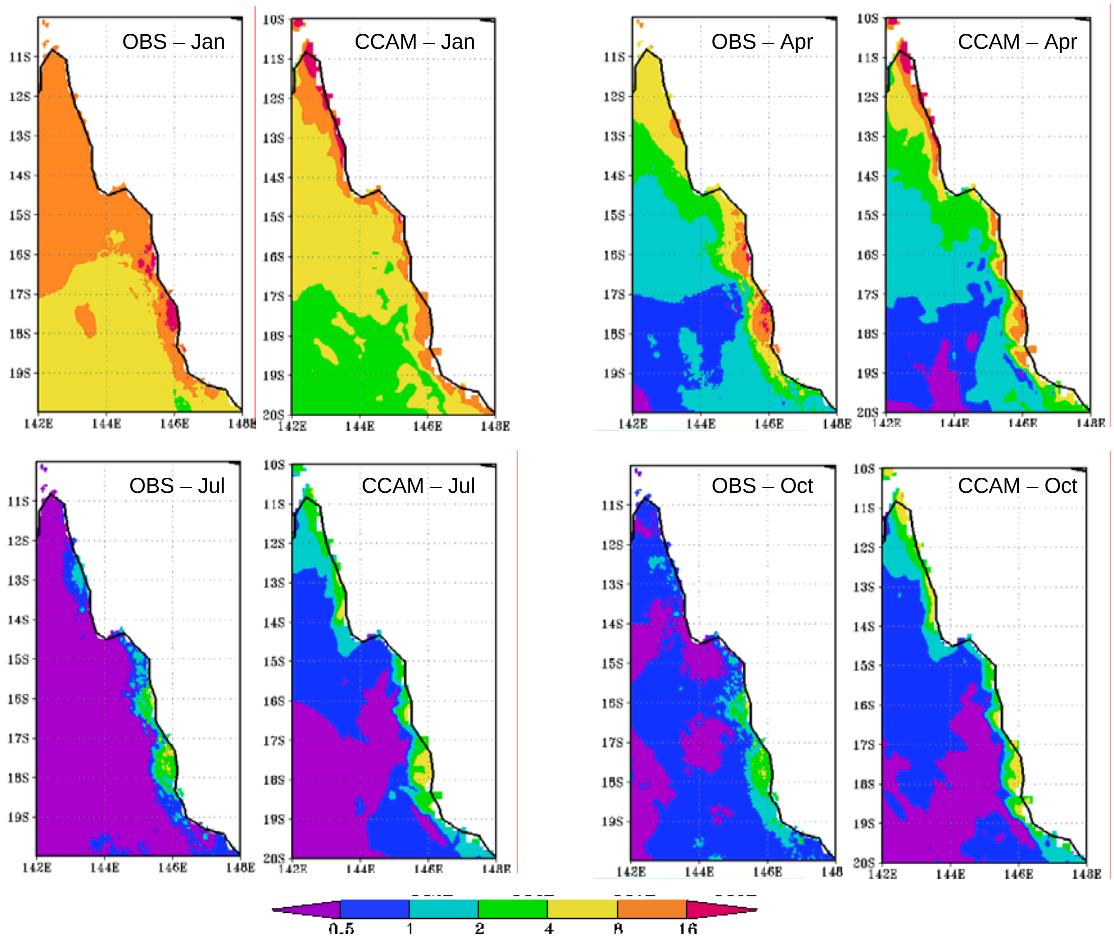

Figure 6: Comparison of observed (OBS) and downscaled (CCAM) average rainfall in mm/day for the MTSRF 15 km CCAM simulation after downscaling from Mk3 between 1971 and 2000.

On the basis of the results shown in Figures 4 to 6, we can conclude that CCAM has downscaled the regional climate (downscaled from Mk3) between 1971 and 2000 with reasonable accuracy. There is some evidence of biases in the minimum temperatures and the January rainfall tends to be drier than observed. However, seasonal variations are generally well simulated and the climate behaviour on the Queensland coast below 14S also seems to be accurately simulated.

Conclusions

In this report we examine the ability of CCAM to downscale Mk3 simulated climate between the years 1971 and 2000 to 15 km resolution for the domain 142E to 148E and 10S to 20S. The regional climate was downscaled in a two-step process by first downscaling to 60 km resolution from Mk3, and then downscaling to 15 km resolution from the 60 km resolution CCAM simulation.

To validate the results, we have compared the average simulated maximum temperatures, minimum temperatures and rainfall for 1971-2000 to the observed climatology as reported by the Australian BoM. Simulated maximum temperatures, minimum temperatures and rainfall were found to correctly capture the seasonal behaviour. However, inland maximum temperatures appear to be cooler than observed for the northern Queensland coast (i.e., north of 14S) where the rainfall is higher than the observed climatology. Minimum temperatures also exhibit a cool bias and the January rainfall is drier than observed. Otherwise, the simulated climate is in good agreement with the BoM observations

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