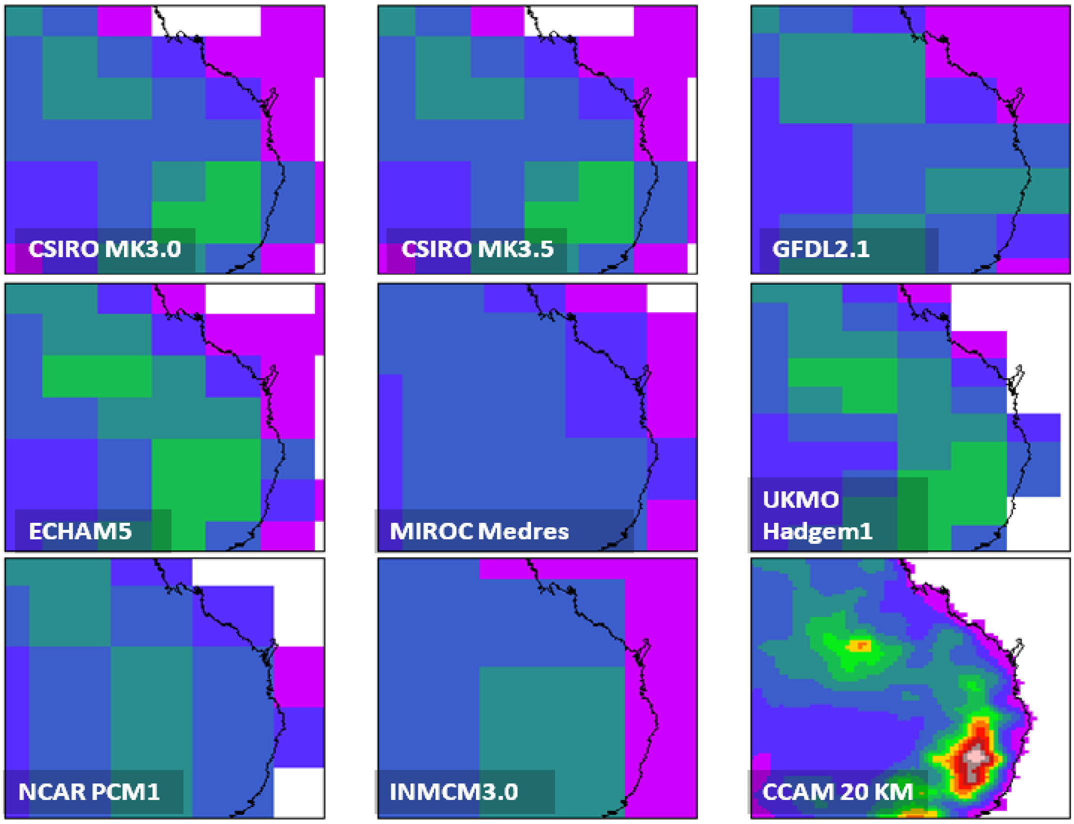
Numerical Simulation of Current Climate Conditions for South East Queensland

Kim C. Nguyen and John L. McGregor

August 2012



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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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Enquiries should be addressed to:

The Urban Water Security Research Alliance
PO Box 15087
CITY EAST QLD 4002

Ph: 07-3247 3005
Email: Sharon.Wakem@qwc.qld.gov.au

Project Leader – Wenju Cai
CSIRO Marine and Atmospheric Research
ASPENDALE VIC 3195

Ph: 03-9239 4419
Email: Wenju.Cai@csiro.au

Authors: 1 – CSIRO

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Cover Photograph:

Description: Surface elevation (m) for the GCMs and for CCAM at 20 km resolution.
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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

C. Davis

Chris Davis
Chair, Urban Water Security Research Alliance

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EXECUTIVE SUMMARY

Extreme events such as flood, drought, bushfire and heat wave often cause loss of life and damage to the economy. The frequency, intensity and duration of these extreme events are unlikely to be the same in the future (IPCC, 2007). There is a need to inform policy makers of future changes in the above extreme events. One method of doing so is by numerical climate simulations. There are uncertainties associated with this approach. The uncertainties arise from many sources, such as estimation of greenhouse gas emissions, model physical parameterisations and model resolution. One way to better understand uncertainties is by performing ensembles of multiple numerical climate simulations with different forcings.

This report validates climate model results, comparing the ensemble mean against observations. The ensemble mean is produced by the CSIRO Conformal Cubic Model (CCAM) forced by sea surface temperatures (SST) of nine CMIP3 global climate models (GCMs).

We performed nine numerical simulations for the South East Queensland (SEQ) climate for the period 1971-2100 using CCAM. The nine simulations were performed over the course of four years:

1. CSIRO MK3.0 (2007);
2. CSIRO Mk3.5 (2008);
3. GFDL2.1, MIROC-Medres and ECHAM5 (2009); and
4. UKMO-HadCM3, UKMO-Hadgem1, INMCM3_0 and NCAR_CCSM3_0 (2010).

For this study, CCAM is first set up on a quasi-uniform grid having a resolution of about 200 kilometres (km) square over the whole globe. It is run for 140 years, forced by bias-corrected SSTs from the above nine coupled Global Climate Models (GCMs) for years corresponding to 1971-2100 using the A2 emission scenario.

The CCAM 200 km quasi-uniform global simulations are further downscaled by CCAM to a fine scale 20 km resolution over the eastern part of Australia. Rainfall, temperature and other meteorological variables for a region bounded by 33–21°S and 145–155°E are extracted from the 20 km resolution dataset and analysed.

The ensemble present-day model results for rainfall and maximum and minimum screen temperature are compared to available observations from the Australian Bureau of Meteorology (BOM).

This summary is based on the CCAM ensemble mean; the results will be different when comparing individual ensemble members of the CCAM simulations.

For comparing the fine resolution (20 km) CCAM output with the host GCM output (at a scale of 200 km), the GCM output has been re-gridded where necessary to the observed finer resolution.

Generally, the CCAM 20 km resolution simulation produces better patterns for rainfall and maximum/minimum temperatures than the coarse-resolution GCM simulation. An obvious advantage of the fine resolution climate simulations is to better resolve and simulate these variables over high terrain and coastal regions. For rainfall, the CCAM pattern distribution better resembles observations than its host GCM, with higher rainfall over the coast and less rainfall inland, although CCAM produces a larger positive rainfall bias compared to the GCM. For the simulated maximum and minimum temperatures, CCAM better resolves the local surface features which helps to reduce the minimum temperature bias along the coast and in elevated regions.

The validating pattern correlations of the rainfall and maximum and minimum temperature from the CCAM 20 km simulations are high, from 0.83 to 0.95; and the CCAM pattern correlations are slightly larger than those of the host GCMs. As is typically found for ensembles, the ensemble mean of the GCMs performed better than the individual GCM members (Nguyen *et al.*, 2011).

This good agreement with the observation patterns motivated the authors to further validate the rainfall and maximum and minimum temperatures at the following two sites - Toowoomba and Brisbane. Toowoomba is an agricultural region, approximately 150 km inland from Brisbane; Brisbane is a coastal urban site.

At Brisbane, CCAM over-predicts the rainfall. The largest bias is seen in March (5 mm/day); however the largest percentage bias is around 65% from October to February. The largest maximum temperature bias is around -2.5°C and the largest minimum temperature bias is around +3.5°C for June to September.

At Toowoomba, CCAM under-predicts the observed rainfall, except for September. The largest rainfall bias is around 65% for August and September. The maximum temperature bias at Toowoomba is less than 1°C, and the largest error in the minimum temperature is around 1°C.

At both sites, CCAM maximum and minimum temperatures are in better agreement with the observed when compared to predictions from the host GCMs. However, the agreement for CCAM rainfall is slightly worse than the host GCM rainfall for Brisbane.

1. INTRODUCTION

The duration, frequency and intensity of periods of exceptionally dry or exceptionally wet conditions are key inputs to urban infrastructure planning. These characteristics of exceptional events are unlikely to be stationary over the coming century. As such, there is strong demand for projected changes in exceptional events in order to inform policy in fields such as water management, agriculture and urban development. This study uses a high spatial resolution regional circulation model to produce such projections for South East Queensland (SEQ).

Current and future climate over the Australian continent from 1971 to 2100 for the A2 emission scenario, as described in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4, IPCC 2007), is simulated at quasi-uniform 200 kilometre (km) scale resolution with the CSIRO Conformal-Cubic Atmospheric Model (CCAM), driven by nine Global Climate Models (GCMs): CSIRO Mk3.0, CSIRO Mk3.5, GFDL2.1, ECHAM5, MIROC-Medres, UKMO HadCM3, UKMO-Hadgem1, NCAR CCSM3 and INMCM3.0. These nine coupled GCMs drive the CCAM simulations with their bias-corrected sea surface temperatures (SST) and sea-ice.

The CCAM uniform-grid global simulation is further downscaled to about 20 km resolution for the SEQ region. The downscaling process produces output for a comprehensive range of variables on a sub-daily time-scale at a resolution of around 20 km over much of eastern Australia. The meteorological variables for a region bounded by 33–21°S and 145–155°E are extracted from this dataset and analysed.

The model description is provided in Section 2 of this report. Results of the simulations for both model resolutions are discussed in Section 3, for present-day conditions (1971-2000).

2. EXPERIMENTAL DESIGN

For the past decade, CCAM has been the mainstay of CSIRO dynamical downscaling (McGregor 1996, 2005a, 2005b; McGregor and Dix 2001, 2008). CCAM is a full atmospheric GCM formulated on the conformal-cubic grid. CCAM includes a fairly comprehensive set of physical parameterisations. More details on the model description are given by Nguyen *et al.* (2011).

In the current study, downscaling involves several steps. First, monthly SST biases are calculated from the nine selected AR4 GCMs (Nguyen *at el.* 2011) (Table 1).

Table 1: The nine GCMs, their country of origin and approximate horizontal resolution.

GCM	Country of Origin	Approximate Horizontal Resolution (km)
ECHAM5/MPI	Germany	170
GFDL_CM2.1	USA	200
CSIRO MK3.0	Australia	170
CSIRO MK3.5	Australia	170
UKMO-Hadgem1	United Kingdom	200
UKMO-HadCM3	United Kingdon	275
MIROC Medres	Japan	250
INMCM3.0	Russia	500
NCAR CCSM3_0	USA	150

Second, CCAM is run at quasi-uniform global 200 km scale resolution, driven only by the bias-corrected, interpolated SSTs and the sea-ice concentrations from the host GCMs. Note that no further atmospheric forcing from the GCM was applied to produce the downscaled 200 km CCAM simulations, since the atmospheric wind, temperature and moisture fields in the host GCMs are influenced by the non-bias-corrected SSTs, and can therefore have potential inconsistencies with the bias-corrected SSTs used in CCAM. The runs were completed for the time period 1971-2100. All the CCAM runs used the same time-varying distributions as the GCMs for equivalent CO_2, ozone and aerosol forcing as specified in the 20th century for the A2 emissions scenario. As with most of the CMIP3 GCMs, only the direct effect of aerosols was included in the CCAM simulations.

The CCAM quasi-uniform global simulation is further downscaled by CCAM to a finer, 20 km resolution over the SEQ region. Figure 1 shows CCAM's coarse-resolution (left) and fine-resolution grids (right) over the SEQ region. To provide a further degree of consistency with the host CCAM simulation, a digital filter (Thatcher and McGregor, 2008) is applied every six hours to replace selected broad-scale (with length scale exceeding about the width of Australia) fields of CCAM with the corresponding fields of the coarse CCAM simulation. Those fields are MSL pressure, moisture, temperature and the wind components above 900 hPa.

The CCAM results are compared with the observed rainfall and maximum and minimum temperatures supplied by the Bureau of Meteorology (BOM). Validating total cloud cover is from the International Satellite Cloud Climatology Project (ISCCP D2) from 1986-1991, and other variables are from the National Centre for Environmental Prediction (NCEP).

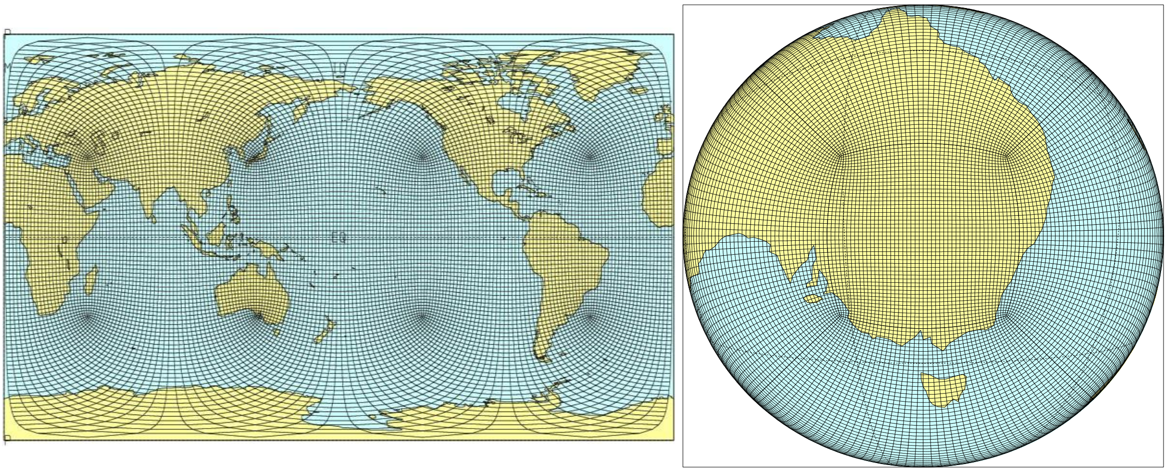

Figure 1: CCAM grids having quasi-uniform global 200 km resolution (left), and 20 km resolution over eastern Australia (right).

2.1 CCAM Grid Set Up

The surface elevations for the GCM and CCAM grids are depicted in Figure 2. The coarse orography of the GCM shows a smooth surface with maximum elevation of about 400 m; NCAR PCM1, INMCM3.0 and MIROC Medres, in particular, are unable to represent the higher elevations. Furthermore, in the GCMs, the land extends into the nearby ocean grid points. The elevation in the fine-resolution CCAM simulation (Figure 2, lower right panel) shows more detail, with its maximum surface elevation almost three times that of the coarse-grid GCMs.

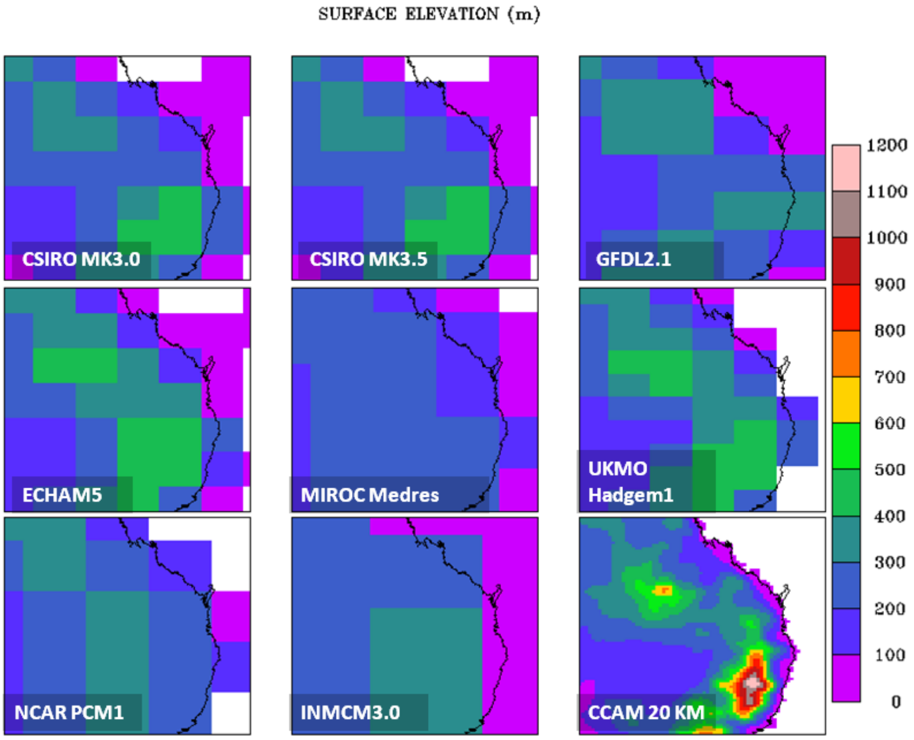

Figure 2: Surface elevation (m) for the GCMs and for CCAM at 20 km resolution.

2.2 Sea Surface Temperature Bias Corrections

Figures 3 and 4 show January and July SST biases from the host GCMs. In all GCMs, it is clearly seen that there is a cold bias along the equator in both months. Along the east coast of Australia, some GCMs show a cold bias (CSIRO MK3.0 and MIROC Medres, July), whereas others show a warm bias.

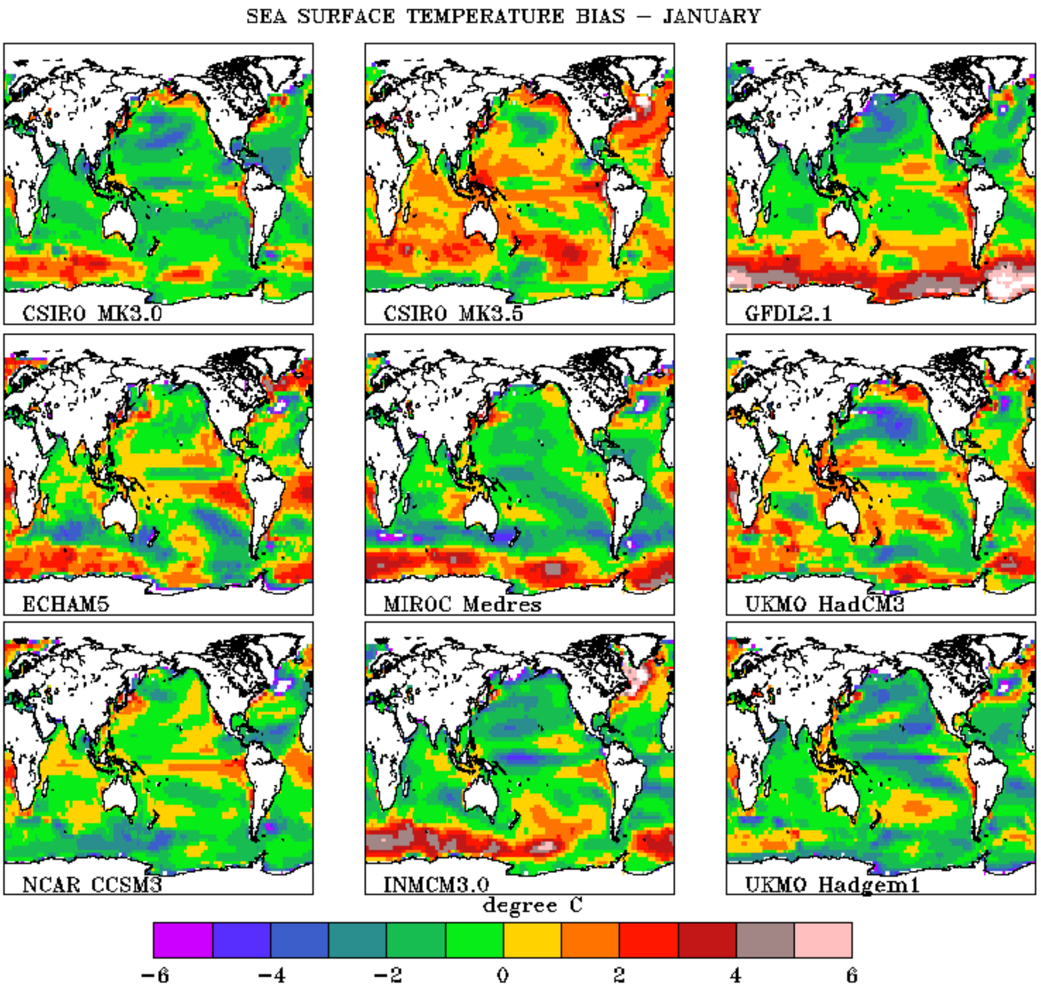

Figure 3: January SST biases (°C) of the host GCMs.

Rainfall over SEQ is influenced by many factors, such as the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) or the Inter-decadal Pacific Oscillation (IPO) (Cai and Rensch, 2011). Their study shows the important role SSTs have in predicting rainfall over the Australian east coast. In January (Figure 3), along the Australian east coast (averaged over 40°S-10°S, 155°E-180°E), the largest warm bias is 1.2°C (CSIRO MK3.5) and the largest cold bias is -1.3°C (CSIRO MK3.0). Over the Nino3.4 region (averaged over 5°S-5°N, 170°W-120°W), the largest warm bias is 0.8°C (CSIRO MK3.5), whereas the largest cold bias is -2.7°C (UKMO Hadgem1).

In July (Figure 4), eight out of nine GCMs have a cold bias along the Australian east coast; the largest cold biases are seen in the hosts INMCM3.0 (-1.64°C), CSIRO MK3.5 (-1.5°C) and the MIROC Medres (-1.2°C). All GCMs show cold biases over the Nino3.4 region, with large cold biases seen in MIROC Medres (-3.0°C), CSIRO MK3.0 (-2.3°C) and UKMO Hadgem1 (-2.3°C). These SST biases shown for January and July over the Nino3.4 region in the Pacific provide strong support for the bias-correction SST technique used in CCAM before downscaling.

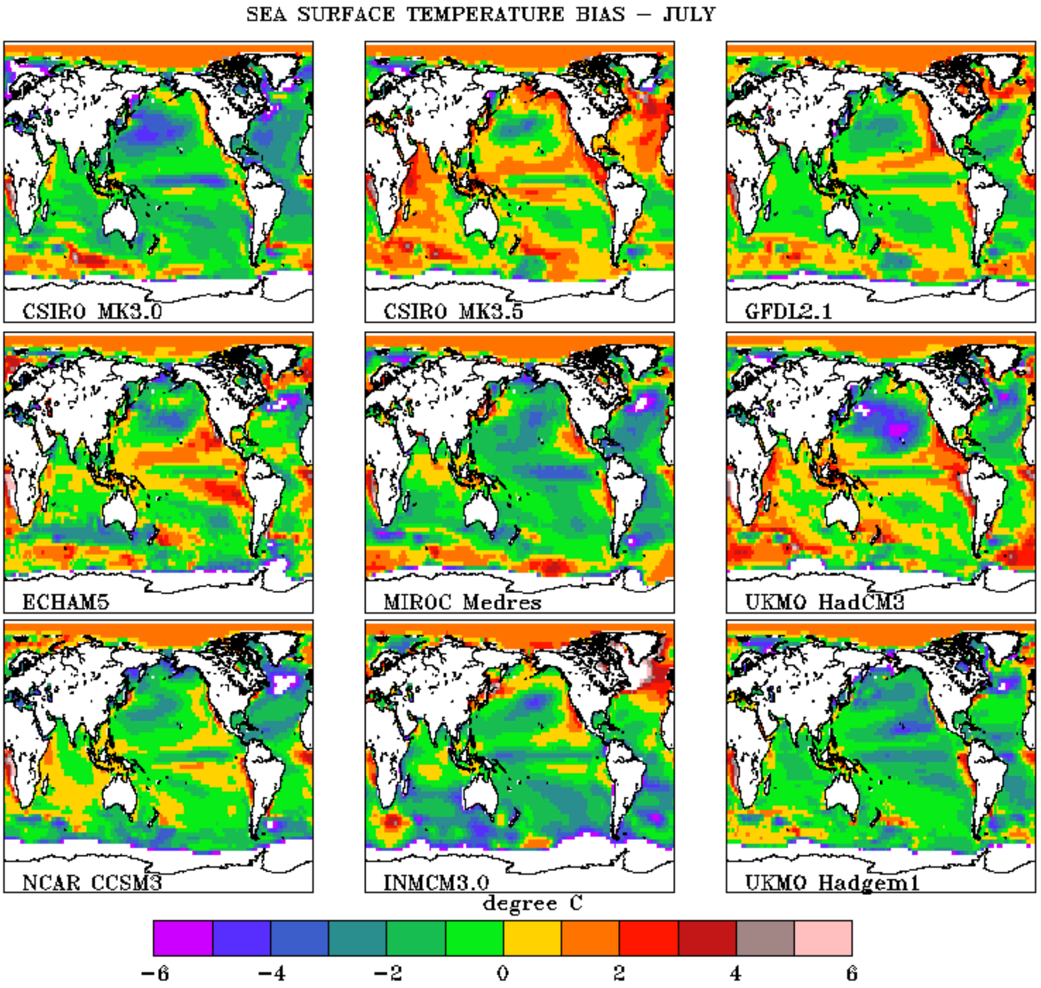

Figure 4: **July SST biases (°C) of the host GCMs.**

3. RESULTS AND DISCUSSIONS

3.1 Model Validation

In this section, a comparison of the host GCMs and CCAM 20 km model results and observations is made for available variables, in particular rainfall, maximum and minimum temperature and cloud cover. Wind speed at 10 m, solar radiation at the surface, near surface relative humidity and pan evaporation are discussed only for the fine-resolution simulations. In general, the fine resolution mimics the coarse CCAM 200 km results. However, the fine resolution simulations better resolve elevation and coastal features. Therefore the CCAM 200 km results will not be discussed separately. The model validation for the current climate condition is carried out for the ensemble-mean results.

3.1.1. Coarse-Resolution GCM Compared to Fine-Resolution CCAM Results for Current Conditions (1971-2000)

High-quality observations from the Australia Bureau of Meteorology (BOM) together with coarse GCMs and fine-resolution (20 km) CCAM results are shown in Figures 5, 6 and 7, for rainfall, maximum and minimum screen temperatures (respectively).

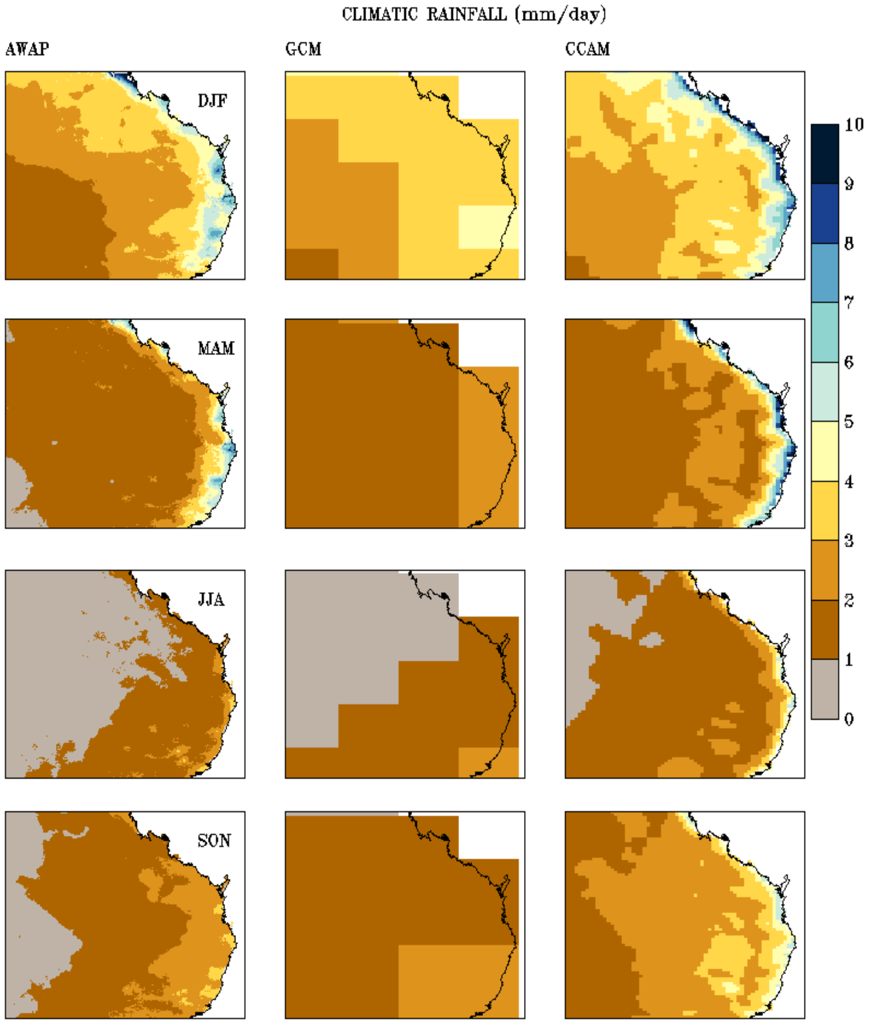

Figure 5: Current climate condition (1971-2000) for rainfall (mm/day): observed (left), the ensemble mean of coarse GCM (centre) and the ensemble mean of fine-resolution (20 km) CCAM (right).

Figure 5 shows that rainfall is high along the coast, and less inland. Due to the coarse resolution of the GCMs, varying from 5 degrees (INMCM3_0) to 1.5 degrees (NCAR_CCSM3_0), the GCMs are unable to resolve the coastal rainfall. We see that the fine-resolution simulations are not just a copy of the host GCM, but provided more detailed structures, particularly for rainfall along the coastal strip (Figure 5) and the temperatures over high terrain (Figures 6 and 7). An obvious advantage of the fine resolution is seen over orography and the improvement of the pattern distribution in both maximum and minimum temperatures (Figures 6 and 7 respectively).

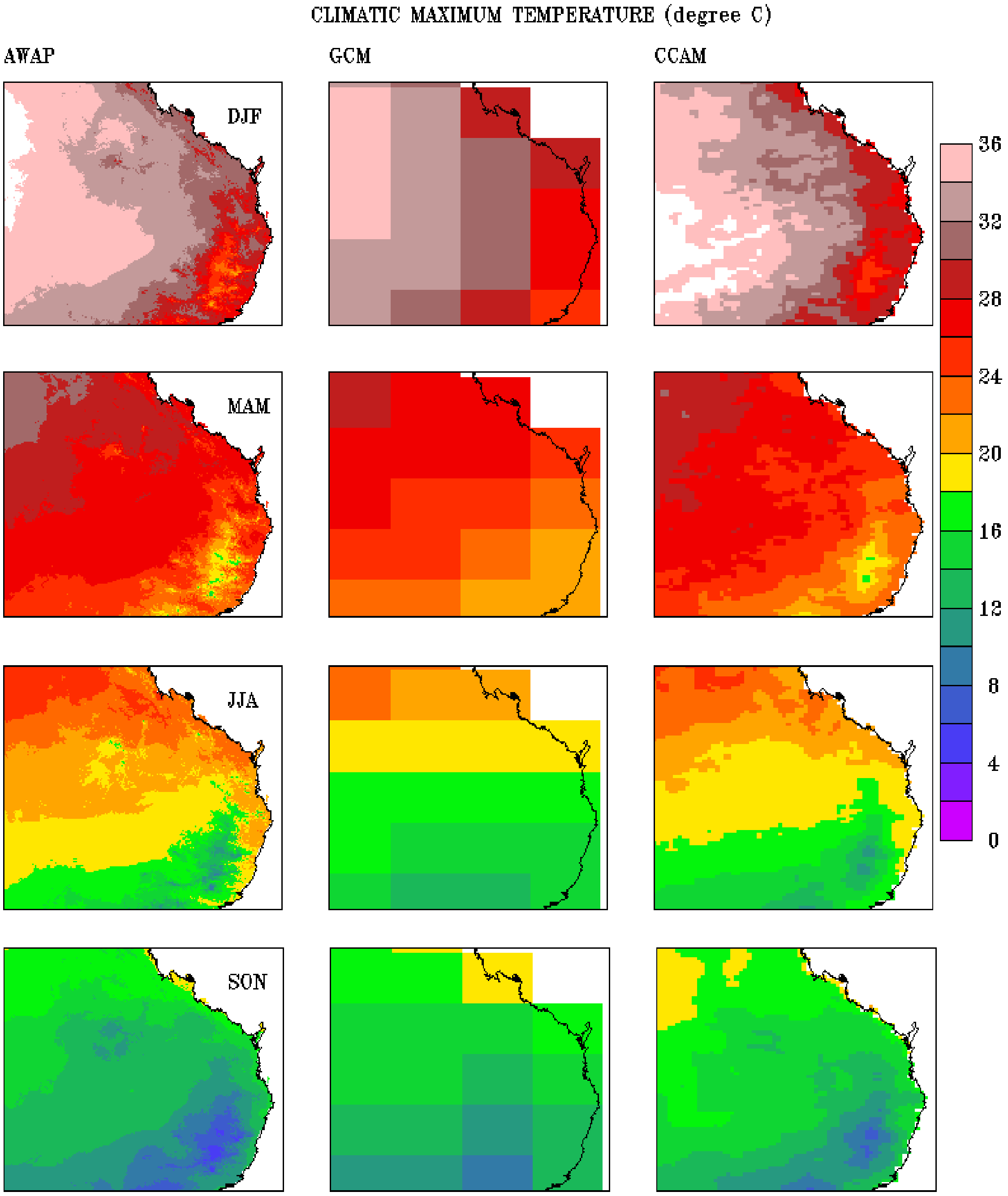

Figure 6: **As in Figure 5 but for the maximum temperature (° C).**

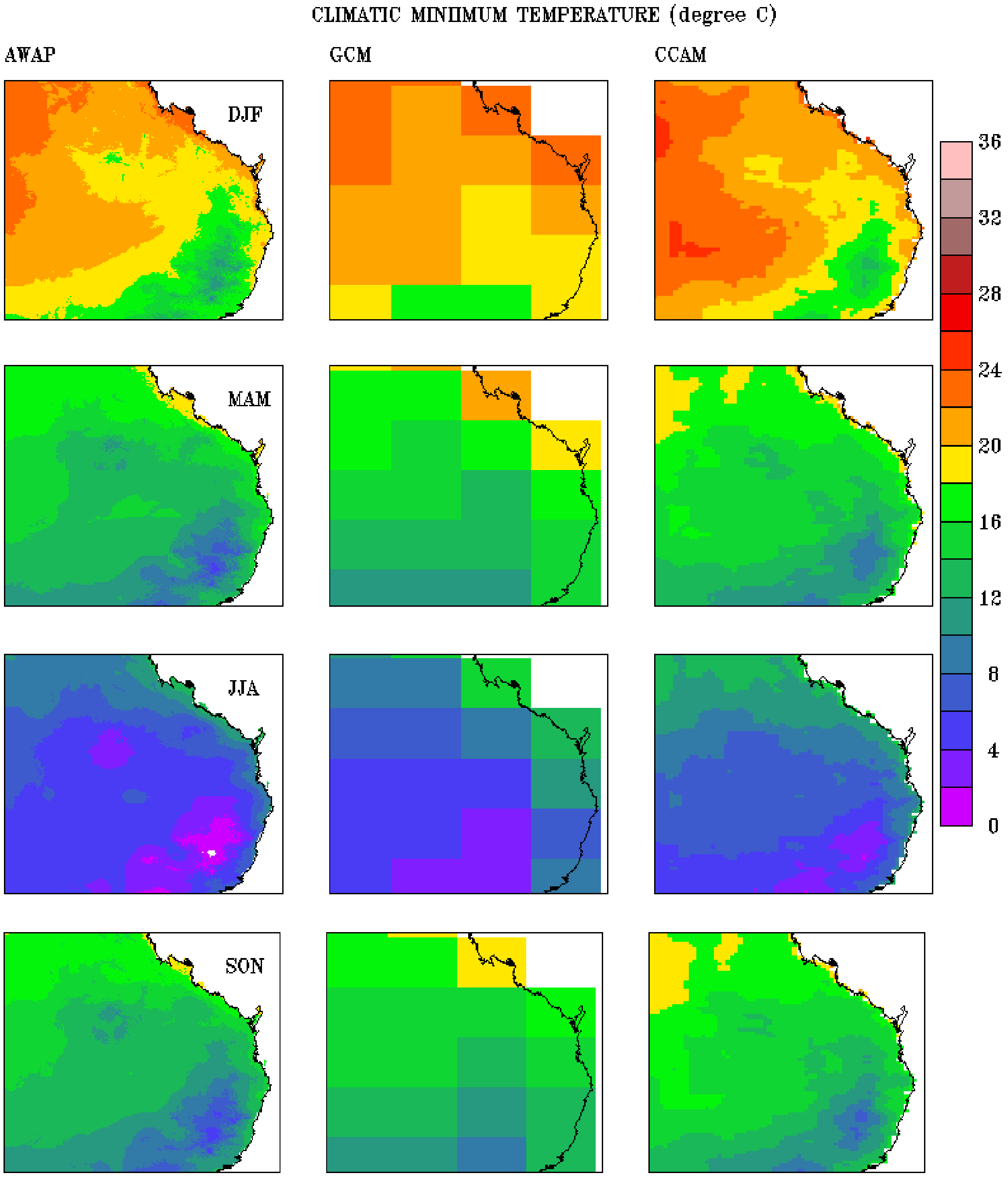

Figure 7: **As in Figure 5 but for the minimum temperature (°C).**

Host GCM (re-gridded onto the CCAM grid) and CCAM 20 km ensemble-mean biases (CCAM minus host GCM) are shown in Figure 8 for rainfall. The CCAM 20 km ensemble-mean rainfall over-estimates the observations for all seasons over most of the domain, except over the high terrain where it slightly under-estimates the observations. Surprisingly, the host GCM ensemble-mean rainfall produces slightly less bias compared to the CCAM 20 km runs.

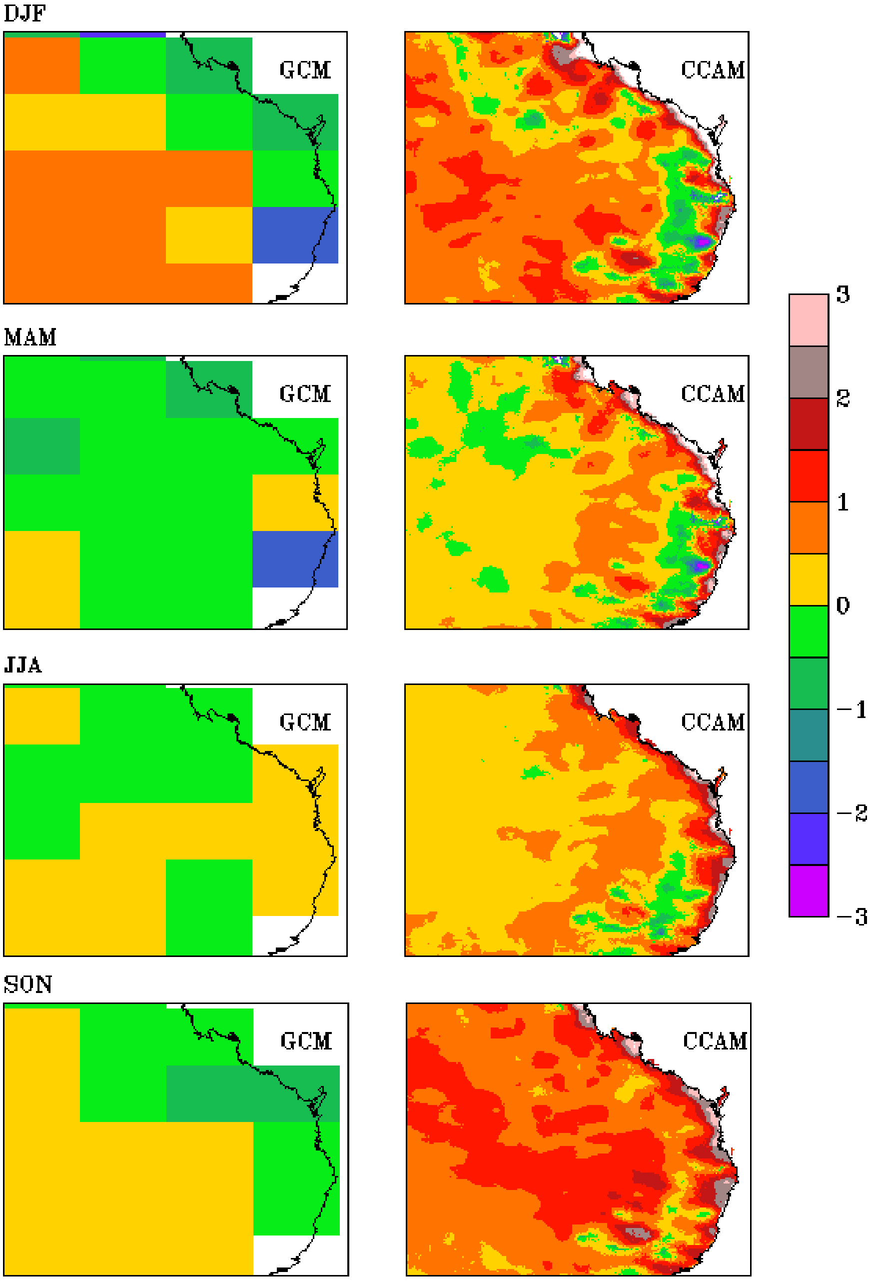

Figure 8: **Four-season rainfall (mm/day) bias for current climate (1971-2000) for the ensemble mean of coarse GCM (left) and the ensemble mean of fine-resolution (20 km) CCAM (right) bias, where bias is model minus observations.**

However, the maximum and minimum temperature biases (Figures 9 and 10 respectively) are larger compared to those in CCAM 20 km, up to 7°C for minimum temperatures along the east coast in the host-GCM ensemble. This is due to unresolved resolution of the coastal strip. In general, both the host GCM and CCAM ensembles show a cold bias in maximum temperature (except for the bottom left domain in DJF and SON in CCAM) and a warm bias in minimum temperature. The pattern correlations of the ensemble mean of the rainfall and maximum/minimum temperature, for both host GCM and CCAM, with the observations are high (from 0.75 to 0.95) over the SEQ region, where CCAM patterns slightly better resemble the observations. As is typically found for ensembles, the ensemble mean of the GCMs performed better than the individual GCM members (Nguyen *et al.* 2011). Note that due to availability of the GCM data, the ensemble-GCM maximum/minimum temperatures were calculated for only seven GCMs.

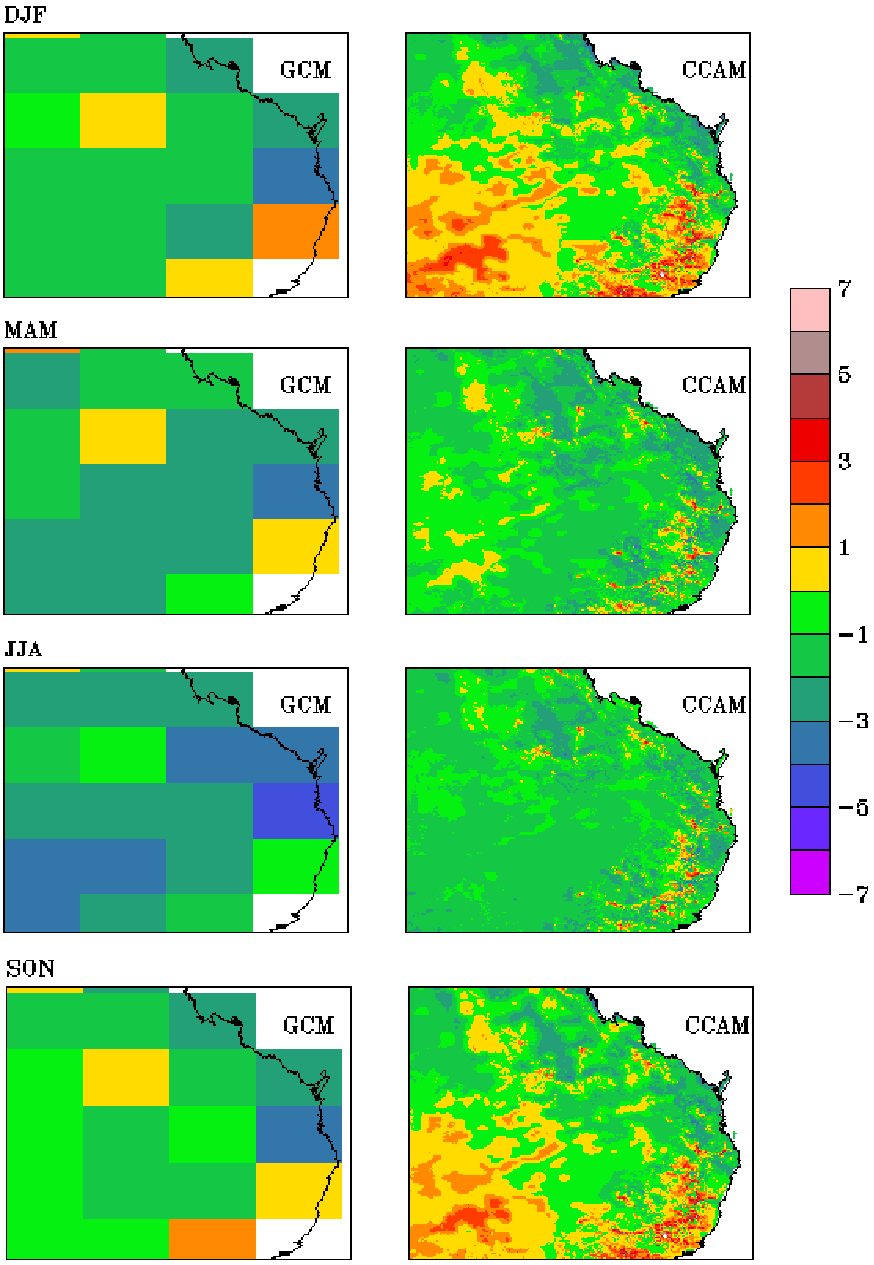

Figure 9: **As in Figure 8 but for the maximum temperature bias (°C).**

This good agreement with the observations, as demonstrated by the pattern correlations, motivated the authors to further validate the rainfall, maximum and minimum temperatures at the two sites - Toowoomba and Brisbane. Toowoomba is an agricultural region, approximately 150 km inland from Brisbane; Brisbane is a coastal urban site.

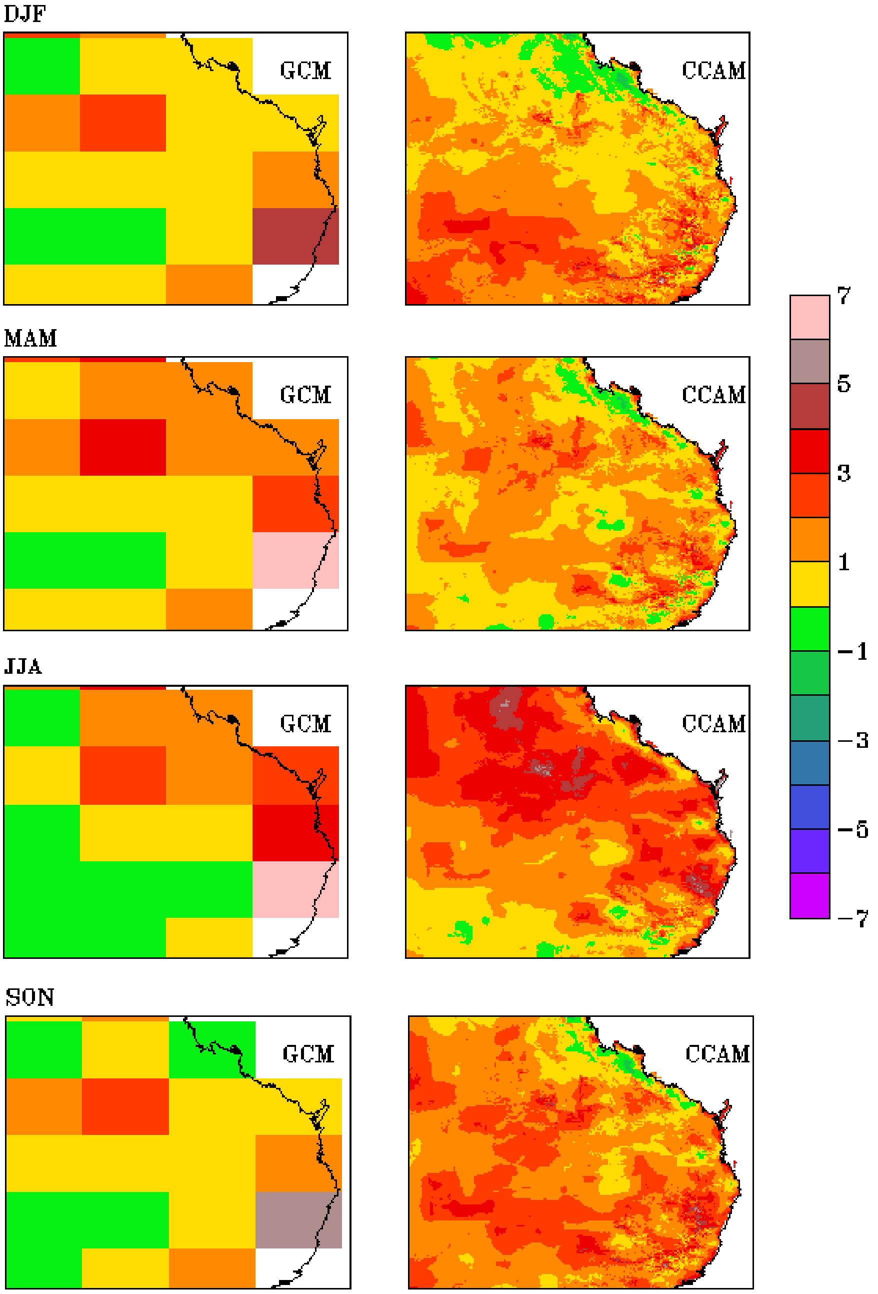

Figure 10: **As in Figure 8 but for the minimum temperature bias (°C).**

3.1.2. Current Climate Conditions at Toowoomba and Brisbane Sites

Two sites are studied to examine how well the model captures the spatial distribution at grid point locations (Figures 11, 12 and 13). We select the nearest grid points to Toowoomba and Brisbane; they are (27.54°S, 151.93°E) and (27.42°S, 153.11°E), respectively. At both locations, CCAM and the host GCM capture well the seasonality of rainfall and maximum/minimum temperatures. In particular, there is high rainfall during October to April for Brisbane and from October to February for Toowoomba (Figure 11).

At Toowoomba (Figure 11), both models produce similar rainfall bias, within 1 mm/day with the largest percentage error being 65% for August and September. At Brisbane, CCAM is not superior to the host GCMs for rainfall (Figure 11). CCAM overestimates rainfall for all months; the bias in rainfall is 2-4 mm/day, except for March, where it is 5 mm day^{-1}.

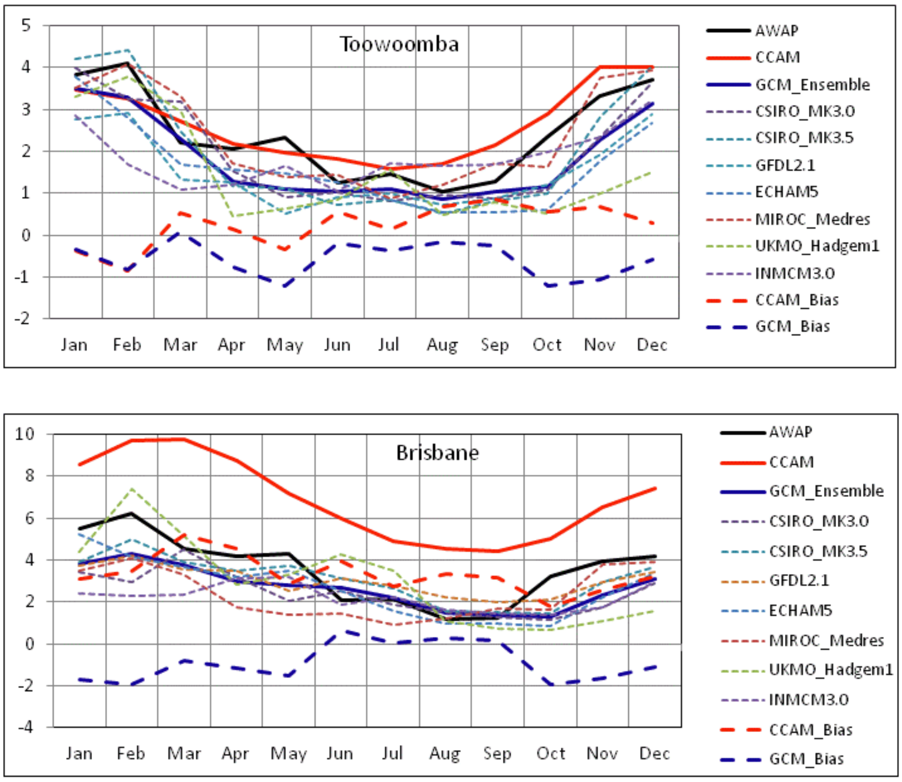

Figure 11: Current climate condition for rainfall rate at the nearest grid points to Toowoomba (27.54°S, 151.93°E) and Brisbane (27.42°S, 153.11°E) simulated by CCAM 20 km, where thin dashes are the host GCM and long-thick dashes are GCM biases (Blue) and CCAM bias (red).

CCAM produces a temperature bias of about 1°C for both maximum and minimum temperatures. Whereas the host GCMs produce similar maximum biases to those of CCAM, they produce larger (+2°C to +3°C) minimum temperature biases than those of CCAM.

At Brisbane, CCAM is superior to the host GCMs for maximum and minimum temperatures (Figures 12 and 13). This over-prediction of rainfall using CCAM (Figure 11) leads to under-estimation of the maximum temperature, as seen in the top right panel of Figure 12. In contrast, CCAM over-predicts the minimum temperature, with large errors of around 3°C during the winter months.

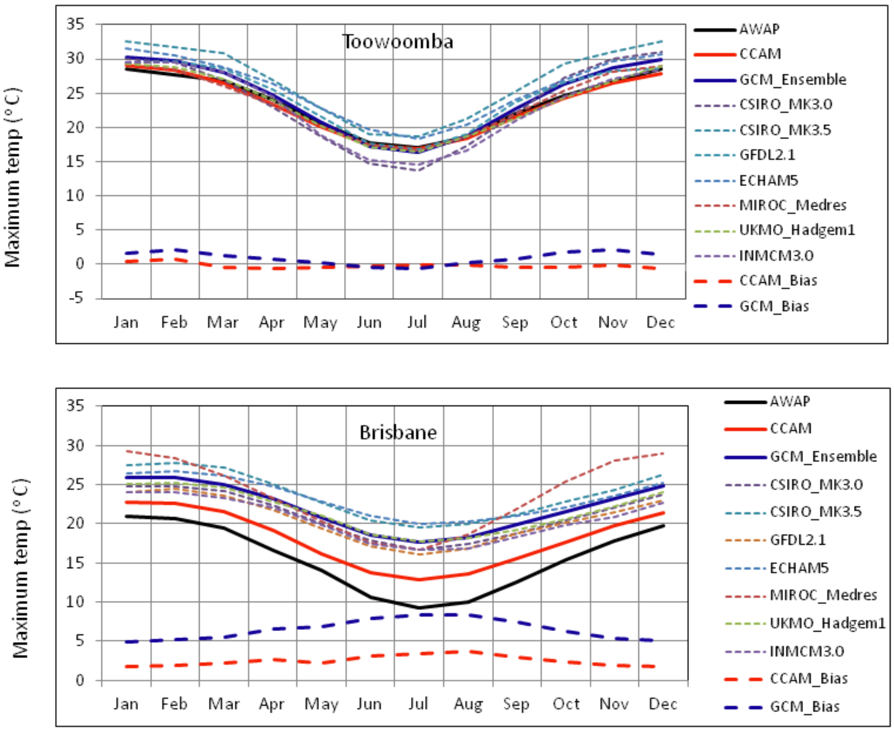

Figure 12: As in Figure 11 but for maximum temperatures.

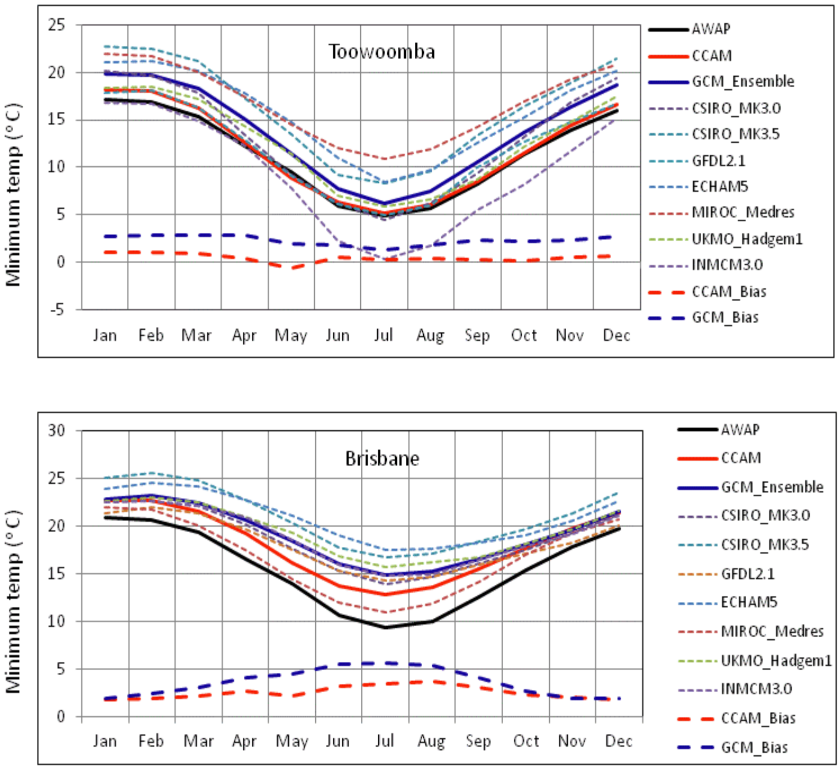

Figure 13: As in Figure 11 but for minimum temperatures.

3.1.3. Total Cloud Cover

Observed and CCAM total cloud cover fraction is shown in Figures 14 and 15 respectively for the four seasons. It is seen that CCAM produces slightly less clouds than observations except for June-July-August (JJA). This may be due to the soil moisture being too dry in CCAM. Probably, part of the maximum temperature positive bias in December-January-February (DJF) and September-October-November (SON) is due to the under-estimation of the total cloud cover, in particular for the inland region.

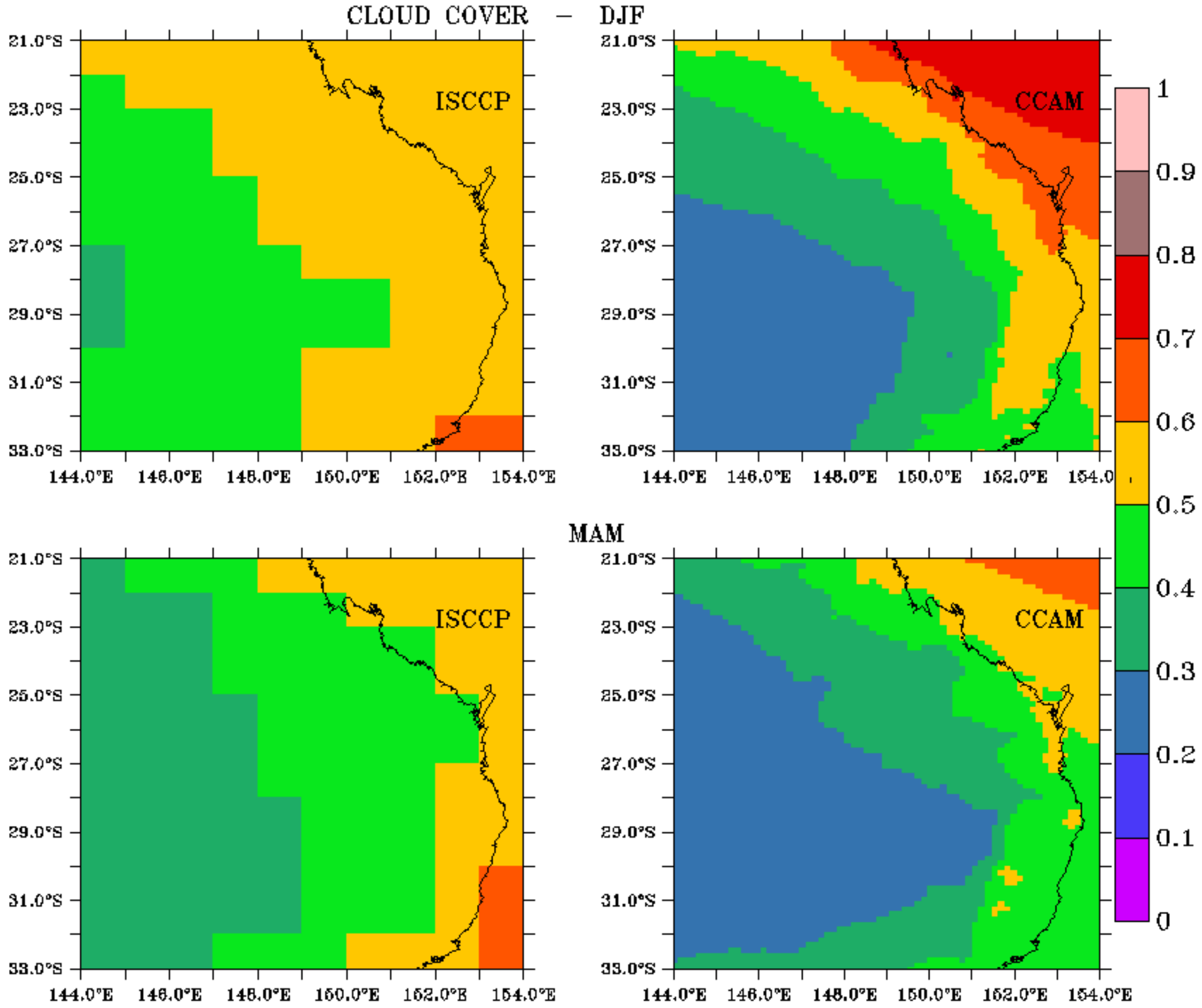

Figure 14: Total cloud cover for December to February (DJF) and March to May (MAM); with observation on the left and CCAM on the right panel.

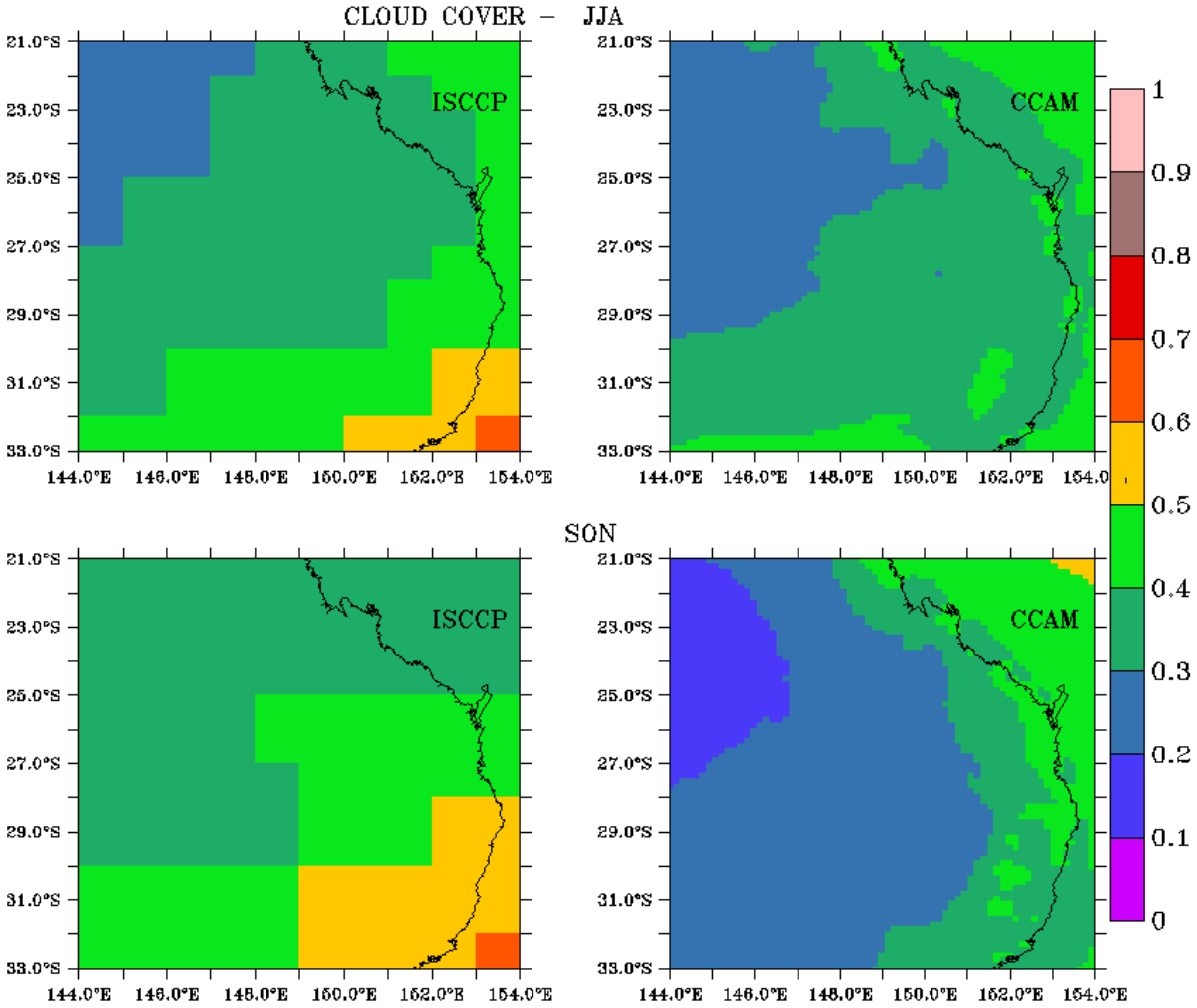

Figure 15: As in Fig 14 but for June to August (JJA) and September to November (SON).

REFERENCES

Cai, W. and P. Rensch (2012). The 2011 southeast Queensland extreme summer rainfall: A confirmation of a negative Pacific decadal oscillation phase?, *Geo. Res. Lett.*, 39, L08702.

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds)]. IPCC, Geneva, Switzerland, xxxpp.

McGregor, J.L., H.B. Gordon, I.G. Watterson, M.R. Dix and L.D. Rotstayn (1993). The CSIRO 9-level atmospheric general circulation mode*, CSIRO Div. Atmospheric Research Tech. Paper No. 26*, 89 pp.

McGregor, J.L. (2003). A new convection scheme using a simple closure, In *"Current issues in the parameterization of convection"*, BMRC Research Report 93, 33-36.

McGregor J.L. (1996). Semi-Lagrangian advection on conformal-cubic grids, *Mon Weather Rev,* 124: 1311-1322.

McGregor J.L. (2005a). Geostrophic adjustment for reversibly staggered grids, Mon Weather Rev, 133: 1119-1128.

McGregor J.L. (2005b). C-CAM: Geometric aspects and dynamical formulation [electronic publication], *CSIRO Atmospheric Research Technical Paper 70*, 43 pp.

McGregor, J. L. and M. R. Dix (2001). The CSIRO conformal-cubic atmospheric GCM, *In IUTAM Symposium on Advances in Mathematical Modelling of Atmosphere and Ocean Dynamics*, P. F. Hodnett (Ed.), Kluwer, Dordrecht, 197-202.

McGregor, J.L. and M.R. Dix (2008). An updated description of the Conformal-Cubic Atmospheric Model, In *High Resolution Simulation of the Atmosphere and Ocean*, eds. K. Hamilton and W. Ohfuchi, Springer, 51-76.

Nguyen K.C., J.J. Katzfey and J.L. McGregor (2011). Global 60 km simulation with CCAM: Evaluation over the tropics, *Climatic Dynamics*, doi: 10.1007/s00382-011-1197-8.

Thatcher, M. and J.L. McGregor (2008). Using a scale-selective filter for dynamical downscaling with the conformal cubic atmospheric model, *Mon. Wea. Rev.*, 137, 1742-1752.

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