PROJECT 3.1: STATISTICALLY DOWNSCALED CLIMATE CHANGE PROJECTIONS FOR THE SOUTH-WEST

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Objectives of Project 3.1

- To complete an assessment of the ability of the GCMs used in the IPCC's Fourth Assessment Report (IPCC AR4) to simulate regional climate for present-day conditions.
- To identify the subset of IPCC GCMs that provide credible simulations of the predictors for the downscaling model under present-day conditions.
- To extend the existing downscaling model for the South-West by incorporating daily minimum and maximum temperatures as output variables.
- Using the above subset of GCMs, three IPCC SRES emission scenarios (B1, A1B and A2), and an existing downscaling model for the South-West, produce at-site climate change projections that can be used for impact and vulnerability assessments by either State agencies alone or in collaboration with IOCI's research providers

Key Research Findings

Milestone 3.1.4

1. Five IPCC 4th Assessment Report GCMs (GFDL 2.0, GFDL 2.1, MIROC3.2medres, CSIRO Mk3.5, and MPI-ECHAM5), selected on the basis of their current climate simulation performance for the predictors required to drive the Nonhomogeneous Hidden Markov Model (NHMM), were

downscaled for the current period 1961-2000 and for 'Mid-century' 2046-2065, and 'End-of-century' 2081-2100 periods for the SRES A2, A1B and B1 scenarios. This has produced 100 stochastic realisations of station daily rainfall and maximum and minimum temperature for each GCM, SRES scenario (temperature for A2 only), and period for 29 stations of the South-West.

2. While there is overall consistency in projected rainfall decreases and temperature increases the range of downscaled changes across the five GCMs, for any particular scenario and period, is relatively large.
3. The downscaled sequences are available to State agencies for use in climate impacts modelling research and investigations. An IOCI3-led initiative is developing a data portal, to be managed and resourced by CSIRO, to provide the downscaled results on-line by 30 June 2012.

Milestone Reports:

Milestone 3.1.1 Report on the performance of IPCC AR4 GCMs for present-day climatic conditions in the South-West

(Completed 31/12/2009)

This milestone was reported on in a previous milestone report (IOCI3 milestone report 1).

Milestone 3.1.2 Interim report on development and testing of the extended downscaling model

(Completed 30/06/2010)

This milestone was reported on in a previous milestone report (IOCI3 milestone report 2).

Milestones 3.1.3 *Final report on development and testing of the extended downscaling model*

(Completed 31/12/2011)

The methodology developed to add the ability to stochastically generate sequences of multi-site daily maximum (T_{max}) and minimum (T_{min}) temperature used here for the South-West was concurrently applied to the North-West, as presented for Milestone 2.3.6. Thus the description of the methodology is the same as that contained in the Milestone 2.3.6 report, and is repeated here so as to make this Project report self-contained.

Conditional on the weather state and multi-site daily rainfall sequences generated by the NHMM, a stochastic weather generator (SWG) approach has been developed and applied to generate stochastic sequences of multi-site daily T_{max} and T_{min}. For the 29 South-West stations used in the NHMM, for the winter (May-October) and summer (November-April) half-years separately, the method first converted the observed daily T_{max} and T_{min} temperature data for each station into a daily temperature mean and range series, i.e. $T_{mean} = (T_{max} + T_{min})/2$ and $T_{range} = T_{max} - T_{min}$. Monthly averages of T_{mean} and T_{range} were then calculated on a wet and dry day basis for each station. Then the daily T_{mean} and T_{range} series were converted into residual series by subtracting the monthly averages corresponding to the wet or dry status of each day. This multi-site residual array is the basis for the generation of multi-site series with the required spatial and temporal correlation. The lag-1 autocorrelation of each station's residual series for T_{mean} and T_{range} is calculated, as is the between-site covariance matrix, to account for temporal and spatial correlation respectively. The covariance is calculated on a weather state basis to account for the different spatial patterns of cross-correlation between the individual stations according the weather state (i.e. rainfall pattern).

Generation of stochastic sequences of T_{max} and T_{min} for current climate conditions uses the following steps. Firstly the multi-site daily rainfall sequences are simulated using the relevant NHMM (i.e. for the station network and season of interest). Then for each day of the simulation a sample of multivariate normal variates is generated with the requisite serial and cross-correlation properties (e.g., as in Richardson 1981) using the lag-1 autocorrelation of each station and the covariance matrix of that day's weather state. The generated variates are the residuals of T_{mean} and T_{range}. They are converted back to realistic values by adding the monthly means, according to the wet dry status of the day. The simulated T_{mean} and T_{range} are then converted back to T_{max} and T_{min} daily values.

TablesTable **1**,

Table 2,

Table 3 and

Table 4 summarise some key statistics (minimum, 25th percentile, median, mean, 75th percentile and maximum) of the observed T_{max} and T_{min} data used in SWG parameter estimation and simulated T_{max} and T_{min} from 100 stochastic realisations (conditional on the weather states and rainfall sequences simulated by the NHMMs driven by the atmospheric predictors as listed in Table 5) for summer and winter half-years respectively. The simulated minimum and maximum values for most cases fall outside the range of the observed values, an expected result given the tables are comparing 100 stochastic realisations to the single 'realisation' of the observed record. In the cases where the SWG minimums (maximums) are not lower (higher) than the observed values (for example, in

Table 3 several stations have a maximum value for observed T_{max} higher than the maximum value simulated across the 100 realisations) the projections of this particular tail of the distribution would be compromised by such deficiencies. This limitation points to the inadequacy of the assumption of normally distributed residuals, with regards to extremes, as discussed at the end of this section.

Table 1: Summary statistics to assess representativeness of SWG output for South-West Summer (November-April) maximum daily temperature.

Station	**Observed**						**100 stochastic simulations**					
	Min	**25th**	**Med**	**Mean**	**75th**	**Max**	**Min**	**25th**	**Med**	**Mean**	**75th**	**Max**
Dalwallinu	14.0	27.7	31.7	31.6	35.6	45.7	11.1	28.2	31.8	31.7	35.3	51.8
Wongan Hills R. S.	12.7	26.6	30.5	30.6	34.5	47.5	9.8	27.1	30.8	30.7	34.3	51.8
Chidlow	13.0	24.5	28.5	28.6	32.5	45.0	10.0	25.1	28.7	28.6	32.2	48.7
Gingin	14.0	25.0	28.5	28.9	32.5	45.5	11.0	25.7	29.0	29.0	32.3	48.0
Perth Airport	14.2	25.0	28.6	29.1	32.6	46.7	11.1	25.7	29.1	29.1	32.5	48.1
Jarrahdale	11.5	24.0	27.5	27.8	31.5	44.5	8.0	24.4	27.9	27.9	31.4	49.1
Mundaring Weir	13.0	25.0	29.0	29.1	33.0	46.0	10.0	25.7	29.2	29.2	32.7	48.8
Serpentine	13.0	24.5	28.0	28.5	32.0	45.0	9.8	25.2	28.5	28.5	31.8	47.7
Wungong Dam	12.0	24.0	28.0	28.1	31.5	45.0	8.8	24.8	28.2	28.2	31.6	47.8
Yanchep Park	14.5	24.5	27.0	27.9	31.0	45.5	11.8	24.8	27.9	27.9	31.1	46.3
Wanneroo	14.0	24.5	27.5	28.0	31.0	46.0	11.0	24.8	28.0	28.0	31.3	47.6
Bridgeto	12.	22.	26.	26.7	30.	43.	8.6	23.	26.	26.8	30.	47.

wn	6	8	2		4	5		3	8		2	2
Cape Leeuwin	13.1	20.9	22.2	22.4	23.6	39.5	11.1	20.7	22.5	22.5	24.2	35.3
Cape Naturaliste	13.2	21.7	23.6	24.3	26.5	38.7	10.5	21.8	24.3	24.3	26.8	40.2
Donnybrook	11.2	24.0	27.5	27.8	31.3	43.5	9.1	24.5	27.8	27.8	31.1	45.9
Dwellingup Forestry	10.0	22.7	26.6	26.7	30.4	43.5	6.9	23.3	26.8	26.7	30.2	46.3
Mandurah Composite	15.0	24.0	27.0	27.7	31.0	44.0	11.1	24.6	27.7	27.7	30.8	46.0
Pemberton Forestry	10.6	20.4	23.3	24.1	27.3	43.2	7.9	20.8	24.1	24.1	27.4	44.7
Collie	11.5	23.5	27.0	27.3	31.0	43.5	8.3	23.8	27.3	27.3	30.7	46.4
Wokalup R. S.	14.1	23.9	27.4	27.7	31.1	43.6	9.8	24.4	27.7	27.7	31.0	46.1
Bencubbin	13.9	27.1	31.3	31.2	35.3	46.0	11.1	27.6	31.3	31.3	35.0	53.3
Cunderdin	12.1	26.8	30.5	30.8	34.6	47.8	9.8	27.3	30.9	30.8	34.5	52.2
Kellerberrin Composite	12.8	26.5	30.4	30.5	34.4	45.8	9.6	27.0	30.6	30.5	34.2	50.8

Merredin R.S.	13.0	26.5	30.5	30.5	34.5	46.0	9.5	27.0	30.7	30.6	34.2	52.0
Corrigin	10.4	25.0	28.6	28.9	32.6	45.2	7.7	25.4	29.0	29.0	32.6	50.2
Darkan	9.5	23.0	26.5	27.0	30.5	43.0	6.8	23.5	27.1	27.0	30.6	46.4
Katanning	10.3	23.3	26.6	27.1	30.8	43.7	7.1	23.6	27.2	27.2	30.7	49.4
Lake Grace	11.8	24.2	27.6	28.1	31.7	45.4	8.6	24.6	28.2	28.1	31.7	49.7
Wandering	10.4	24.6	28.2	28.6	32.4	43.7	7.9	25.1	28.7	28.6	32.2	49.0

Table 2: Summary statistics to assess representativeness of SWG output for South-West Summer (November-April) minimum daily temperature.

Station	**Observed**						**100 stochastic simulations**					
	Min	**25th**	**Med**	**Mean**	**75th**	**Max**	**Min**	**25th**	**Med**	**Mean**	**75th**	**Max**
Dalwallinu	3.6	13.4	15.8	16.0	18.5	28.4	0.6	13.5	16.1	16.0	18.6	30.8
Wongan Hills R. S.	3.4	13.0	15.4	15.5	18.0	28.0	0.7	13.0	15.6	15.6	18.1	31.3
Chidlow	3.0	12.0	14.0	14.2	16.5	25.5	1.0	12.0	14.3	14.3	16.6	27.5
Gingin	4.5	13.0	15.5	15.5	18.0	27.0	1.8	13.3	15.6	15.6	17.9	30.8
Perth Airport	3.6	13.1	15.6	15.7	18.1	28.7	-0.1	13.2	15.7	15.7	18.2	31.8
Jarrahdale	2.5	11.5	14.0	14.0	16.0	25.5	0.1	11.7	14.0	14.0	16.3	27.1
Mundaring Weir	3.5	13.0	15.0	15.1	17.5	27.0	1.7	12.8	15.1	15.1	17.4	28.2
Serpentine	4.0	13.0	15.0	15.2	17.5	27.5	1.8	13.0	15.2	15.2	17.5	28.0
Wungong Dam	3.0	12.5	14.5	14.6	17.0	26.5	1.0	12.4	14.7	14.7	16.9	27.5
Yanchep Park	6.0	14.5	16.5	16.4	18.5	26.0	3.7	14.3	16.5	16.5	18.6	30.8
Wanneroo	5.0	14.0	16.0	16.1	18.0	27.0	2.9	13.9	16.1	16.1	18.3	30.4
Bridgetow	0.0	8.5	11.	11.5	14.	23.	-	8.8	11.	11.5	14.	28.

n			6		6	2	5.1		5		1	2
Cape Leeuwin	4.5	14.8	16.2	16.1	17.5	23.4	4.0	14.7	16.2	16.1	17.6	25.6
Cape Naturaliste	5.4	12.7	14.5	14.7	16.4	27.0	3.3	12.8	14.7	14.7	16.6	26.4
Donnybrook	1.3	10.4	13.0	13.0	15.7	25.6	-3.5	10.4	13.0	13.0	15.6	29.5
Dwellingup Forestry	0.2	10.7	13.0	13.0	15.2	25.4	-3.0	10.7	13.0	13.0	15.3	27.1
Mandurah Composite	4.5	13.5	15.7	15.8	18.0	26.5	3.1	13.7	15.9	15.9	18.1	29.5
Pemberton Forestry	-0.8	10.2	12.3	12.3	14.4	25.0	0.0	10.3	12.3	12.3	14.3	25.9
Collie	2.0	10.5	12.5	12.7	15.0	24.0	-2.2	10.4	12.7	12.7	15.0	26.5
Wokalup R. S.	2.6	11.7	14.3	14.2	16.7	28.6	-0.9	11.8	14.3	14.2	16.7	29.6
Bencubbin	3.2	13.0	15.7	15.8	18.5	29.0	0.4	13.2	15.9	15.9	18.6	31.4
Cunderdin	4.4	12.7	15.0	15.1	17.4	28.0	0.6	12.8	15.2	15.2	17.7	29.5
Kellerberrin Composite	2.9	12.5	14.9	14.9	17.4	28.5	-2.4	12.4	15.0	15.0	17.6	31.4

Merredin R.S.	3.1	12.8	15.5	15.4	18.0	29.0	-1.5	12.8	15.5	15.5	18.1	30.7
Corrigin	2.6	11.4	13.8	13.8	16.0	29.0	-1.5	11.4	13.9	13.8	16.3	29.0
Darkan	1.5	9.5	12.0	12.0	14.5	24.0	-2.1	9.7	12.0	12.0	14.3	26.6
Katanning	1.5	10.0	12.4	12.3	14.5	25.2	-2.5	10.2	12.4	12.3	14.6	25.7
Lake Grace	2.1	11.3	13.6	13.6	15.7	27.2	-0.3	11.3	13.6	13.6	15.9	28.0
Wandering	-0.2	9.9	12.6	12.4	15.2	24.1	-4.5	9.8	12.5	12.5	15.2	29.8

Table 3: Summary statistics to assess representativeness of SWG output for South-West Winter (May-October) maximum daily temperature.

Station	**Observed**						**100 stochastic simulations**					
	Min	**25th**	**Med**	**Mean**	**75th**	**Max**	**Min**	**25th**	**Med**	**Mean**	**75th**	**Max**
Dalwallinu	10.2	17.0	19.5	20.3	22.8	38.2	6.7	17.2	20.1	20.3	23.2	40.3
Wongan Hills R. S.	10.2	16.2	18.6	19.4	21.8	37.4	6.3	16.4	19.2	19.4	22.2	38.0
Chidlow	9.5	15.5	17.5	18.2	20.0	35.0	6.3	15.7	18.1	18.2	20.6	34.3
Gingin	11.5	17.0	19.0	19.6	21.5	36.5	6.8	17.2	19.5	19.6	21.9	34.8
Perth Airport	11.5	17.8	19.5	20.0	21.7	35.9	8.1	17.8	19.9	20.0	22.2	35.1
Jarrahdale	10.0	15.5	17.5	17.9	19.5	33.5	5.8	15.5	17.8	17.9	20.1	33.6
Mundaring Weir	11.0	17.0	18.5	19.2	21.0	36.0	7.5	16.8	19.1	19.2	21.5	35.0
Serpentine	12.0	17.0	19.0	19.3	21.0	35.0	7.7	17.1	19.2	19.3	21.4	33.6
Wungong Dam	11.0	16.0	18.0	18.6	20.5	34.5	6.6	16.2	18.4	18.5	20.7	33.6
Yanchep Park	12.5	18.0	20.0	20.1	21.5	36.0	9.0	18.1	20.1	20.1	22.1	33.9
Wanneroo	12.0	17.5	19.5	19.7	21.5	36.5	8.3	17.6	19.6	19.7	21.7	33.3
Bridgeto	9.0	15.	17.	17.7	19.	31.	5.7	15.	17.	17.7	19.	32.

wn		6	4		4	8		6	7		8	4
Cape Leeuwin	11.6	16.5	17.8	17.9	19.0	29.4	9.4	16.4	17.8	17.9	19.2	27.4
Cape Naturaliste	11.0	16.5	18.0	18.1	19.5	28.4	9.1	16.5	18.0	18.0	19.6	28.1
Donnybrook	10.3	16.6	18.3	18.7	20.3	32.7	7.3	16.6	18.6	18.7	20.7	33.3
Dwellingup Forestry	9.4	15.0	16.7	17.3	19.0	32.8	5.2	15.0	17.1	17.2	19.4	32.1
Mandurah Composite	12.3	17.5	19.0	19.5	21.0	34.5	8.5	17.5	19.4	19.5	21.4	32.9
Pemberton Forestry	8.4	14.9	16.6	16.9	18.6	29.9	6.1	14.9	16.9	16.9	18.9	29.9
Collie	9.5	15.5	17.0	17.6	19.5	32.5	6.8	15.5	17.5	17.6	19.7	31.8
Wokalup R. S.	9.5	16.6	18.3	18.7	20.4	32.5	8.2	16.7	18.6	18.7	20.6	31.8
Bencubbin	9.4	16.5	19.1	19.9	22.6	38.0	4.9	16.7	19.7	19.9	23.0	39.9
Cunderdin	10.6	16.8	19.1	19.8	22.1	38.1	6.1	16.9	19.7	19.8	22.6	38.3
Kellerberrin Composite	10.0	16.5	18.9	19.6	22.0	37.9	5.1	16.5	19.4	19.6	22.5	38.1

Merredin R.S.	9.9	16.0	18.5	19.5	22.0	37.5	4.9	16.3	19.3	19.5	22.5	39.4
Corrigin	9.5	15.3	17.6	18.3	20.5	37.0	4.2	15.4	18.2	18.3	21.1	36.2
Darkan	8.0	14.5	16.5	16.8	18.5	33.0	4.7	14.4	16.7	16.8	19.1	33.1
Katanning	8.4	14.8	16.8	17.3	19.3	34.7	5.2	14.8	17.2	17.3	19.8	34.6
Lake Grace	8.4	15.3	17.5	18.2	20.3	37.1	5.8	15.5	18.1	18.2	20.9	36.5
Wandering	8.6	15.5	17.5	18.1	20.0	34.6	4.8	15.5	17.9	18.1	20.5	34.8

Table 4: Summary statistics to assess representativeness of SWG output for South-West Winter (May-October) minimum daily temperature.

Station	**Observed**						**100 stochastic simulations**					
	Min	**25th**	**Med**	**Mean**	**75th**	**Max**	**Min**	**25th**	**Med**	**Mean**	**75th**	**Max**
Dalwallinu	0.0	6.1	8.3	8.3	10.4	21.6	-3.1	6.2	8.4	8.4	10.5	23.7
Wongan Hills R. S.	0.0	6.0	8.0	8.2	10.3	19.9	-3.1	6.1	8.2	8.2	10.3	23.4
Chidlow	-1.0	5.9	8.0	7.8	10.0	19.0	-3.4	5.8	7.8	7.9	9.9	22.6
Gingin	-1.5	7.5	9.5	9.3	11.5	21.0	-3.3	7.3	9.3	9.3	11.3	23.6
Perth Airport	-0.3	7.5	9.7	9.6	11.7	20.8	-2.8	7.4	9.6	9.6	11.7	24.2
Jarrahdale	-1.0	5.5	8.0	7.9	10.0	17.5	-4.0	5.8	7.9	7.9	9.9	23.7
Mundaring Weir	-0.5	7.0	9.0	8.8	11.0	20.5	-2.9	6.7	8.8	8.8	10.8	22.7
Serpentine	0.0	7.0	9.5	9.2	11.5	19.0	-3.0	7.1	9.2	9.2	11.3	23.8
Wungong Dam	-0.5	6.5	8.5	8.6	10.5	18.5	-3.6	6.6	8.6	8.6	10.6	22.8
Yanchep Park	1.0	9.0	11.0	10.7	12.5	21.0	-1.0	8.8	10.7	10.7	12.6	24.7
Wanneroo	0.5	8.5	10.5	10.2	12.0	20.0	-1.5	8.2	10.2	10.2	12.2	24.4
Bridgetow	-	3.6	6.0	6.1	8.6	16.	-	3.8	6.1	6.1	8.4	22.

n	4.0					7	7.7					2
Cape Leeuwin	3.5	10.8	12.3	12.2	13.8	20.0	3.3	10.7	12.1	12.2	13.6	22.8
Cape Naturaliste	4.0	9.6	11.3	11.3	12.9	19.8	1.3	9.6	11.2	11.2	12.8	22.7
Donnybrook	-3.0	4.7	7.2	7.3	9.8	17.7	-6.3	4.9	7.2	7.3	9.6	24.4
Dwellingup Forestry	-3.4	4.5	7.0	7.0	9.6	18.0	-7.2	4.6	7.0	7.0	9.3	23.6
Mandurah Composite	0.9	8.4	10.5	10.3	12.5	21.0	-1.7	8.3	10.4	10.3	12.4	24.4
Pemberton Forestry	0.2	6.5	8.2	8.3	10.0	19.0	-3.3	6.5	8.3	8.3	10.0	21.3
Collie	-2.0	4.5	7.0	7.0	9.5	17.5	-5.1	4.9	7.0	7.1	9.2	22.2
Wokalup R. S.	-0.1	6.9	9.1	9.1	11.4	19.9	-4.1	6.9	9.1	9.1	11.3	24.6
Bencubbin	-4.3	5.2	7.8	7.8	10.1	22.7	-5.6	5.4	7.8	7.8	10.1	24.0
Cunderdin	-3.1	5.2	7.6	7.6	9.9	20.3	-4.6	5.4	7.6	7.7	9.8	23.5
Kellerberrin Composite	-3.2	4.5	7.4	7.2	9.8	19.5	-6.0	4.9	7.3	7.3	9.7	24.5

Merredin R.S.	-2.5	4.5	7.5	7.3	10.0	21.9	-6.9	4.9	7.3	7.4	9.8	24.3
Corrigin	-3.8	3.5	6.4	6.4	9.0	18.9	-8.2	3.9	6.4	6.4	8.9	23.7
Darkan	-3.0	4.0	6.0	6.2	8.5	16.5	-5.9	4.0	6.1	6.2	8.3	21.8
Katanning	-2.0	4.4	6.6	6.7	9.0	18.0	-5.9	4.6	6.7	6.7	8.8	21.4
Lake Grace	-2.0	5.0	7.2	7.3	9.5	20.3	-5.4	5.1	7.3	7.3	9.4	22.4
Wandering	-3.8	2.8	5.8	5.8	8.7	18.0	-8.3	3.2	5.8	5.8	8.4	24.0

For future projections under global warming scenarios, the stochastic generation is built upon the same approach as outlined above, with the CCAM dynamical downscaling projections (for the five GCMs used) of T_{mean} and T_{range} change superimposed to the observed seasonal cycle within the SWG generation method. The CCAM simulated changes for each station's location are extracted from the respective CCAM runs and are incorporated within the SWG as monthly changes, again on a wet and dry day basis. To avoid discontinuities between months, a smoothed fit to the seasonal cycle of projected changes is used. Assessment of changes in covariance of CCAM projections produced implausible results, in that some projected changes appeared physically unrealistic (e.g. reductions of 90% or more), and hence it was determined that changes in covariance as projected by CCAM could not be used to modify the observed covariance matrices. The simulated T_{mean} and T_{range} incorporating the additive CCAM changes are then converted back to T_{max} and T_{min} daily values.

Thus magnitudes of future change in SWG generated scenarios result from the CCAM mean monthly changes and not a direct function of the changes in weather state frequency. Originally it was envisaged that the T_{max} and T_{min} seasonal cycles would be differentiated on a weather state basis. However, in addition to potential problems with small sample sizes producing unreliable estimates – as some states occur very infrequently in certain months – this would have added an unwarranted climate change signal to that obtained from superimposing the CCAM mean monthly changes. That is, as the changes from the CCAM projections encompass circulation changes as simulated by CCAM, additional changes due to the change in frequency of the weather states would not be an independent source of change.

A limitation of the current approach may restrict the usefulness of the daily projected series for applications requiring accurate projections of changes in extreme daily temperatures. As the SWG approach applied is based on a multivariate normal distribution, the tails of the distributions are potentially not adequately representative of extreme values (e.g., see Ruff and Neelin 2012). Other IOCI3 projects address the issue of projecting extreme temperature changes.

This Milestone has focussed on methodological development of SWG code, the application of which is presented in Milestone 3.1.4 below. As noted below, only CCAM projections for the SRES A2 scenario (for the five GCMs used) were available and hence the SWG code has been limited to the application of one scenario from CCAM.

Milestones 3.1.4 Dissemination of multiple realisations of daily rainfall and temperature series for changed climate conditions for the South-West

(Research completed – dissemination to be completed by 30/06/2012)

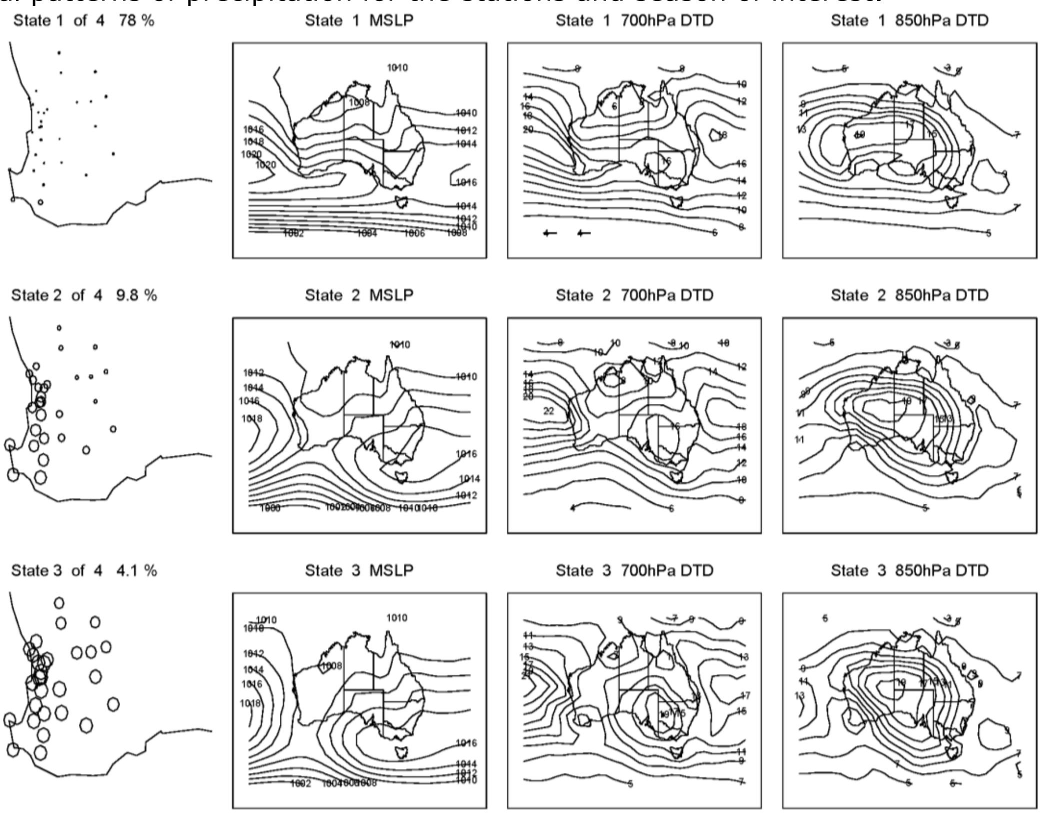
As noted in the Key Research Findings, the NHMM has been used to generate 100 stochastic realisations of downscaled daily precipitation and maximum and minimum temperature for an ensemble of five GCMs, three periods, and three SRES scenarios (one SRES scenario for temperature) for a network of 29 stations across the South-West. These results will be disseminated as 'csv' files on a station by station basis via the CSIRO Research Data Service (RDS) with links, as well as supporting documentation, available from the IOCI website. NHMMs were calibrated and selected on a summer (Nov-Apr) and winter (May-Oct) half-year basis, as summarised in Table 5.

Table 5: Number of weather states and predictors of selected NHMMs

Winter (May-Oct)	6 States	Summer (Nov-Apr)	4 States
	MSLP		MSLP
	North - South MSLP gradient		North - South MSLP gradient
	DTD @ 700 hPa		DTD @ 700 hPa
			DTD @ 850 hPa

* DTD = Dew-point Temperature Depression: air temperature minus dew-point temperature.

The projections can be assessed by comparing current and projected weather state frequencies. The weather states of a NHMM correspond to the dominant spatial patterns of precipitation for the stations and season of interest.



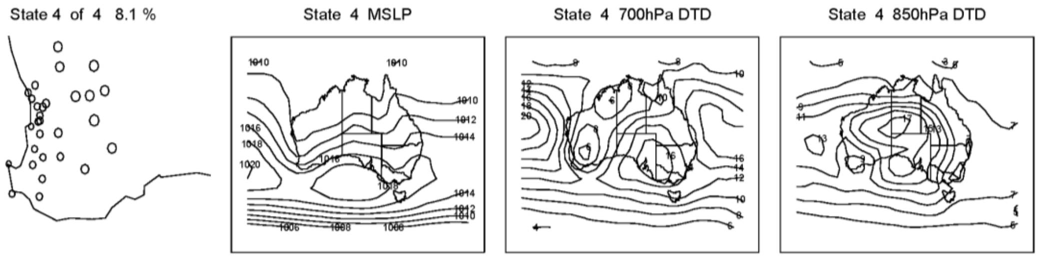


Figure 1 shows the summer half-year (Nov-Apr) weather states, highlighting the dominance of the dry State 1 occurring 78% of days during the calibration period. Table 6 (A2 downscaled projections) indicates all downscaled GCMs are projecting an increase in State 1 with corresponding decreases in the various wet states 2 to 4. The magnitudes of projected changes are consistent across the five GCMs.

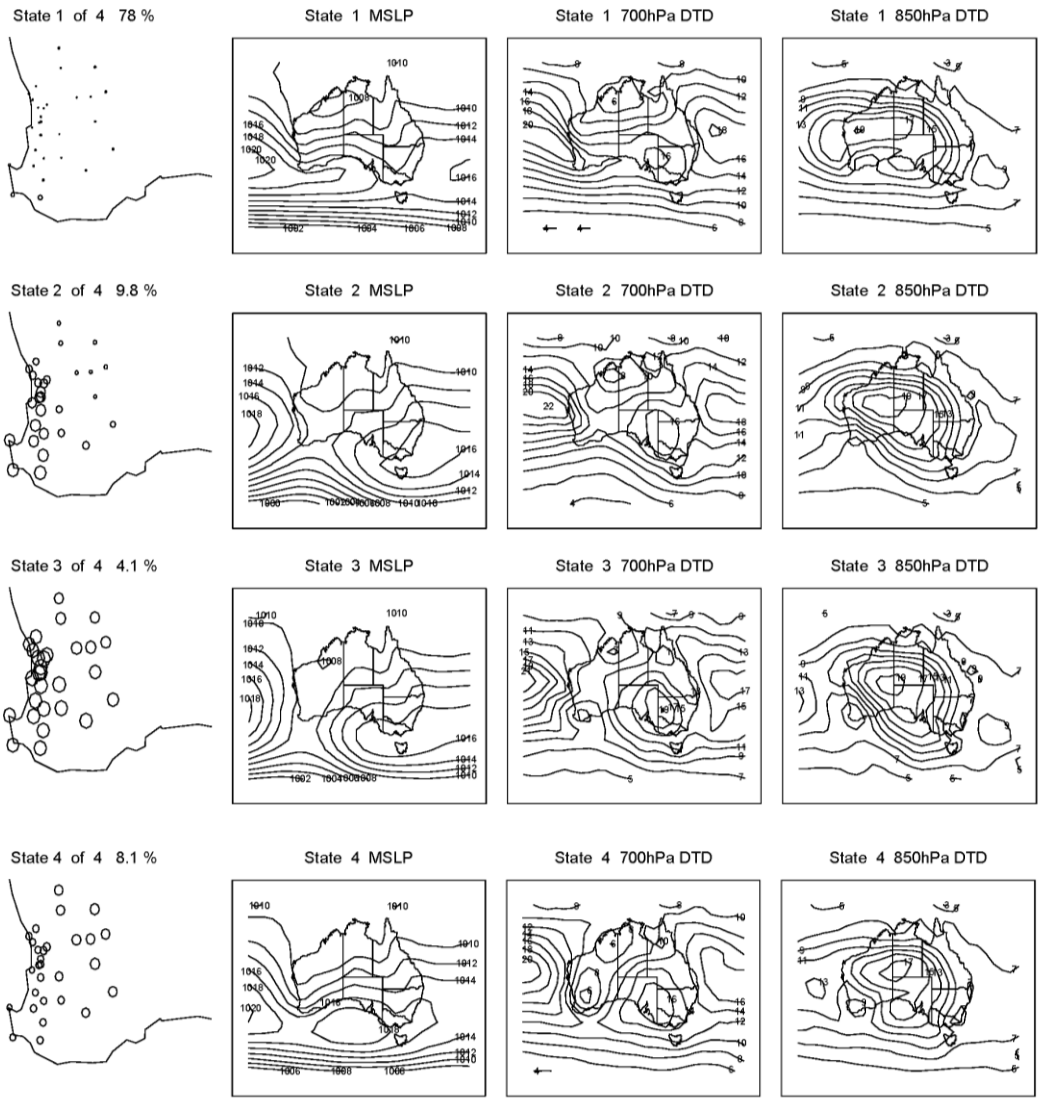


Figure 1: Summer weather states as mean precipitation probability maps and corresponding composite atmospheric predictor plots.

Table 6: Summer weather state frequencies (A2 scenario for projections). 'Current' refers to NCEP/NCAR reanalysis downscaled results for 1961-2000. The three numbers for a State/GCM are the current and for the A2 scenario mid- and –end of century the projected state frequencies (mean of 100 simulations).

State	Current	GFDL 2.0	GFDL 2.1	MIROC	Mk3.5	MPI
1	0.75	0.75 0.79 0.82	0.75 0.78 0.79	0.74 0.78 0.80	0.75 0.79 0.83	0.74 0.76 0.79

2	0.11	0.11 0.10 0.09	0.10 0.10 0.09	0.11 0.10 0.09	0.11 0.10 0.08	0.11 0.10 0.09
3	0.05	0.05 0.04 0.03	0.06 0.04 0.04	0.06 0.04 0.04	0.05 0.04 0.03	0.06 0.05 0.04
4	0.09	0.09 0.07 0.06	0.09 0.08 0.07	0.10 0.08 0.08	0.09 0.07 0.06	0.09 0.08 0.07

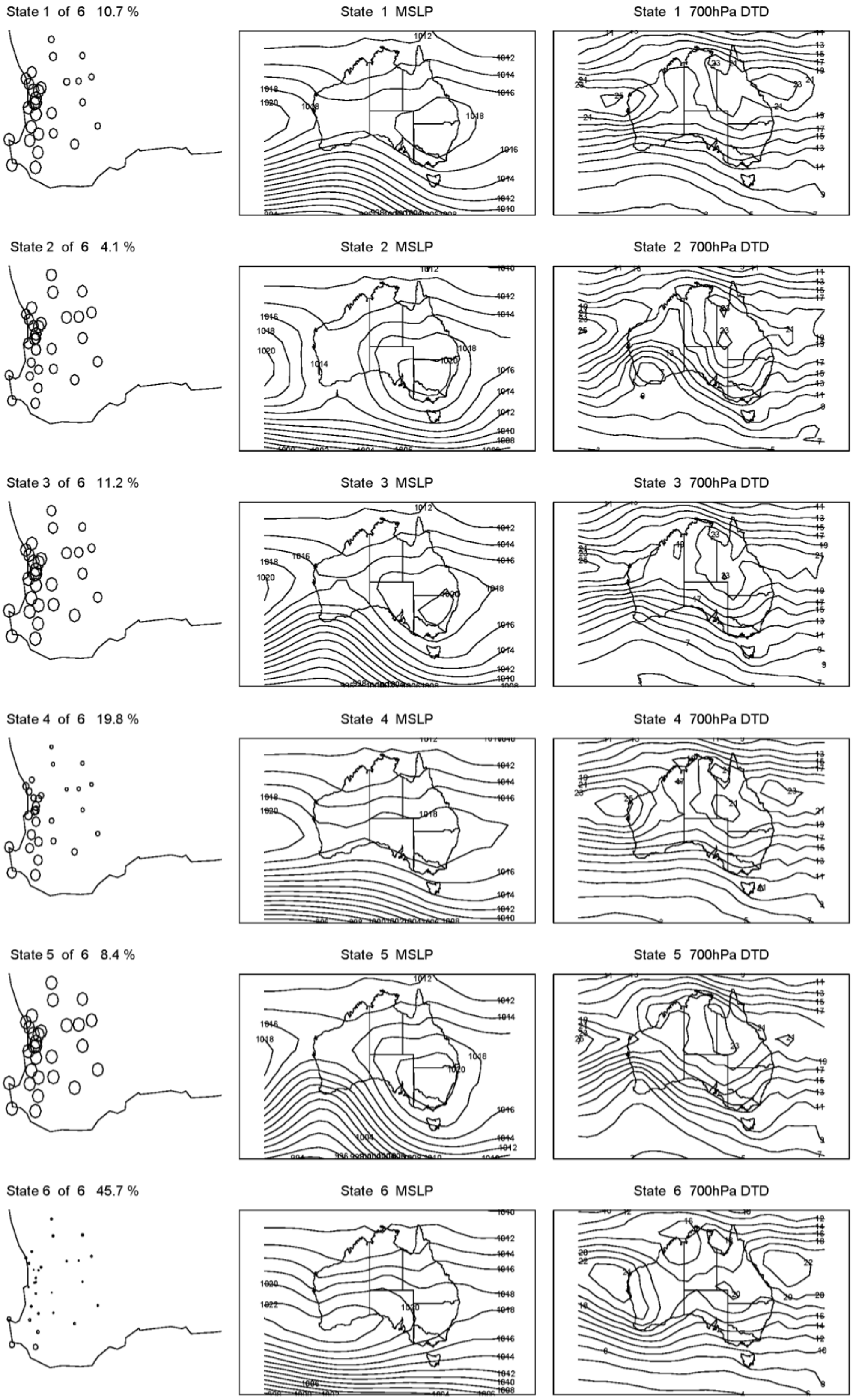


Figure 2: Winter weather states as mean precipitation probability maps and corresponding composite atmospheric predictor plots

For winter, the 6-State NHMM patterns are summarised in Figure 2 with relatively large projected increases in the dry State 6 (Table 7) and decreases in all the other various wet states, particularly 1, 3 and 5 which encompass the three wettest states. In regard to these projected changes, Mk3.5 is an outlier in that it doesn’t project as severe a drying trend as the other four GCMs.

Table 7: Winter weather state frequencies (A2 scenario for projections). 'Current' refers to NCEP/NCAR reanalysis downscaled results for 1961-2000. The three numbers for a State/GCM are the current and for the A2 scenario mid- and –end of century the projected state frequencies (mean of 100 simulations).

State	Current	GFDL 2.0	GFDL 2.1	MIROC	Mk3.5	MPI
1	0.10	0.10 0.08 0.06	0.10 0.08 0.06	0.10 0.07 0.07	0.10 0.09 0.09	0.10 0.08 0.07
2	0.04	0.04 0.03 0.02	0.04 0.03 0.02	0.04 0.03 0.03	0.05 0.04 0.04	0.04 0.03 0.02
3	0.12	0.12 0.09 0.06	0.12 0.08 0.06	0.12 0.08 0.07	0.11 0.10 0.10	0.12 0.09 0.07
4	0.20	0.19 0.19 0.16	0.19 0.18 0.15	0.19 0.17 0.17	0.20 0.19 0.20	0.19 0.18 0.17
5	0.09	0.09 0.06 0.04	0.09 0.05 0.04	0.09 0.06 0.05	0.09 0.08 0.07	0.09 0.07 0.05
6	0.44	0.45 0.56 0.66	0.46 0.58 0.67	0.46 0.59 0.61	0.46 0.50 0.51	0.46 0.54 0.62

The precipitation simulations are summarised in terms of mean annual changes averaged across the 29 South-West stations (Table 8). It is evident that the range across the five GCMs produces considerable uncertainty in the downscaled results. However some consistent patterns do emerge. Firstly, all projections indicate a drier climate for SWWA (i.e. the proportions are less than 1.0 for all GCMs, SRES scenarios and periods). For the end of century, by which time the three SRES scenarios have diverged, all five GCMs indicate greater rainfall reductions for the A1B and A2 scenarios compared to their respective B1 results. Four of the five indicate the A2 scenario produces the largest change (the exception being GFDL 2.1, which produces a larger change for A1B). Results for a particular SRES scenario and period are often consistent across four of the GCMs, with the CSIRO Mk3.5 the outlier simulating less drying.

The changes summarised as mean values in Table 8 are averages across all simulation years and stations. To get a more detailed view of the projected changes their probability distribution is also of interest, as shown in Figure 3. This again highlights the differences across the five GCMs. The shifts in the future period distributions to drier conditions are evident, as well as an often concurrent reduction in spread (i.e. reduced variance) particularly for the A1B and A2 end of century projections (last two columns).

Table 8: Projected mean annual rainfall as a proportion of 1961-2000 climatology

	B1_mid	A1B_mid	A2_mid	B1_end	A1B_end	A2_end
gfdl2.0	0.86	0.70	0.73	0.77	0.64	0.57
gfdl2.1	0.79	0.67	0.73	0.72	0.54	0.57
miroc	0.83	0.84	0.72	0.78	0.71	0.67
mk35	0.90	0.92	0.89	0.94	0.83	0.80
mpi	0.86	0.88	0.82	0.79	0.68	0.64

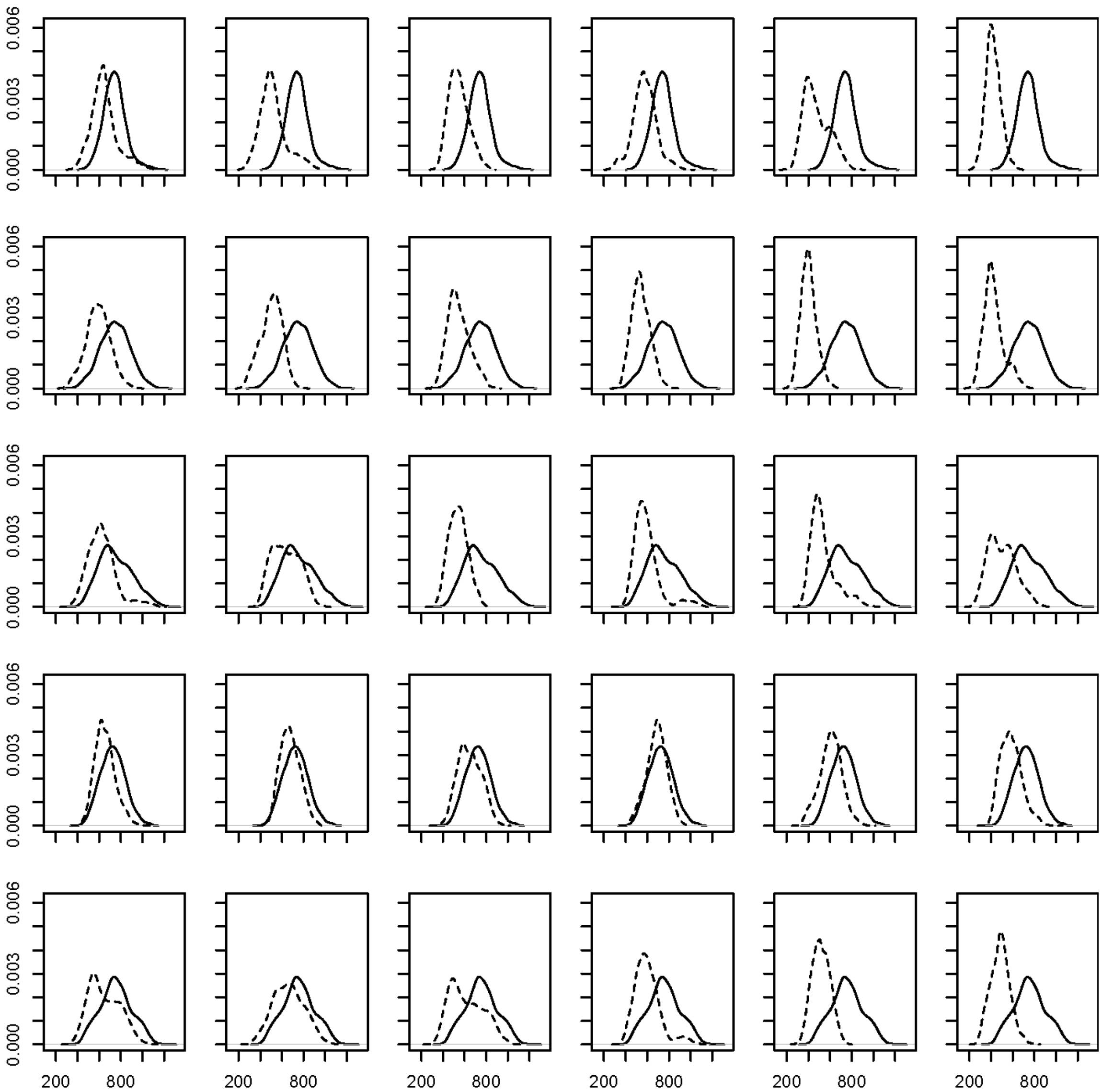


Figure 3: Probability densities of annual rainfalls (mm) downscaled from 5 GCMs (rows top to bottom: GFDL2.0, GFDL2.1, MIROC-medres, CSIRO Mk3.5 and MPI-ECHAM5) for 6 SRES scenario and period combinations (columns left to right: B1 mid-century, A1B mid-century, A2 mid-century, B1 end-century, A1B end-century and A2 end-century). The solid line is downscaled from the current climate run of each GCM and is repeated across each row. The dashed line is the projected data for the particular GCM, SRES scenario and period. Results are for annual rainfalls averaged across the 29 South-West stations.

The sequences of daily weather states and multi-site rainfall simulated by the NHMM were used as input to a conditional stochastic weather generator model to simulate series of maximum and minimum temperatures for the SWWA station network. This model conditioned daily temperatures on the weather state and the wet/dry status of rainfall for each station on that day. The correlations between the temperature variables at the station and between the stations are taken into account, and the projected changes in temperature are superimposed on this observed data structure using results generated by CSIRO CCAM dynamic downscaling using the same five GCMs for the SRES A2 scenario. The ability to generate correlated rainfall and temperature daily series is an advantage over techniques that produce downscaled variables independently as it means that the generated daily series are physically realistic and hence more suitable for use in impacts modelling (e.g. crop yield models).

Table 9 summarises the mean changes in annual daily maximum and minimum temperature projected by the coupled NHMM – weather generator. While there is variation across the GCMs there is a reasonable degree of consistency. Downscaling from the CSIRO Mk3.5 gives the largest warming. Whether the maximum or minimum temperatures show the greatest projected increase is not consistent across the five GCMs, with four of the five projecting maximum temperature to increase more (or be equal) than minimum temperature for both projection periods. The MIROC model is the exception, projecting the smallest maximum temperature increases and second largest minimum temperature increases. The CSIRO Mk3.5 downscaled temperature projections show the greatest warming for maximum and minimum temperatures for both mid and end of century.

Table 9: Projected mean annual temperature changes for SRES A2 in ^{o}C (relative to 1961-2000).

Tmax

	Mid-century	End-century
gfdl2.0	2.1	3.5
gfdl2.1	1.7	3.4
miroc	1.5	2.6
mk35	2.4	4.2

mpi	1.7	3.5

Tmin

	Mid-century	End-century
gfdl2.0	1.7	3.0
gfdl2.1	1.7	3.2
miroc	2.0	3.5
mk35	2.2	4.1
mpi	1.6	3.3

Summary of new linkages to other IOCI3 Projects

None

Summary of any new research opportunities that have arisen

Collaboration with Dr Richard Chandler, University College London, in (i) quantifying GCM uncertainty and (ii) improving stochastic downscaling of multivariate daily weather is on-going and will be applied in a future research program for Western Australia, if funding is made available.

List of Publications Accepted and Submitted

None

List of IOCI-Related Presentations at National of International Conferences, Symposia and Workshops

None

Summary of Progress Status

All milestones have been completed on time. Data dissemination is the only remaining task, as outlined in a separate report.

References

Richardson CW (1981) Stochastic simulation of daily precipitation, temperature, and solar radiation. *Water Resour. Res.* 17:182–190. doi:10.1029/WR017i001p00182.

IOCI 3 Milestone Status Report

Theme and Project Number: 3.1 **Principal Investigator(s):** S. Charles

To be Completed for First Annual Report, and Included in Subsequent Annual Reports		To be Completed for First Annual Report and Updated in Subsequent Annual Reports	
Milestone description	Target completion date	Progress against milestone (1- 3 dot points)	Recommended changes to research plan (1- 3 dot points)
3.1.1 Report on the performance of IPCC AR4 GCMs for present-day climatic conditions in the South-West	31/12/2009	Milestone completed.	None
3.1.2 Interim report on development and testing of the extended downscaling model	30/06/2010	Milestone completed.	None
3.1.3 Final report on development and testing of the extended downscaling model	31/12/2011	Milestone completed	None
3.1.4 Dissemination of multiple realisations of daily rainfall and temperature series for changed climate conditions for the South-West	31/12/2011	Research completed. Dissemination to be completed by 30/06/2012.	None