PROJECT 2.3: STATISTICAL DOWNSCALING FOR THE NORTH-WEST

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Objectives of Project 2.3

- To use statistical downscaling to link circulation drivers to the behaviour of historical rainfall and temperature at spatial and temporal scales suitable for management and planning.
- To compare observed weather state time series with those obtained from downscaling forced GCMs to assess the ability to reproduce the observed changes and trends.
- To assess the abilities of global and regional climate models to reproduce the atmospheric predictors required for statistical downscaling. (The climate models that perform adequately will be used to drive the downscaling model.)
- To produce high-resolution climate change scenarios 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 2.3.7

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 a 9 station network in the Kimberley and a 10 station network in the Pilbara.

2. The projected rainfall series indicate overall drying across the North-West however a caveat is that the NHMM was not designed to account for increases in very high rainfalls resulting from intensification of tropical cyclones. Thus changes to extreme daily rainfall may not be fully accounted for in NHMM simulations. Temperature projections indicate a decrease in diurnal temperature range.
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 2.3.1 *Report on selection of high-quality daily rainfall gauge networks*

(Completed 30/06/2010)

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

Milestone 2.3.2 *Report on development and testing of downscaling models*

(Completed 30/06/2010)

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

Milestone 2.3.3 *Report on assessment of temporal trends in weather states and at-site rainfall statistics*

(Completed 30/06/2010)

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

Milestone 2.3.4 *Report on assessment of the ability of GCMs to simulate atmospheric predictors required for downscaling*

(Completed 30/06/2010)

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

Milestone 2.3.5 *Report on comparison of forced GCM downscaled time series of weather state sequences and at-site rainfall with the observed*

(Completed 31/12/2010)

This milestone was reported on in the previous milestone report (IOCI3 milestone report 3).

Milestone 2.3.6 *Report on extension of statistical downscaling models to include temperature*

(Completed 31/12/2011)

Stochastic weather generator (SWG) code developed within the project has been applied to extend the NHMM, adding the ability to generate multi-site daily sequences of maximum and minimum temperature concurrent with NHMM simulated daily rainfall sequences. The SWG parameters were determined for the Kimberley and Pilbara station networks for each of the two seasons investigated. For a given station network and season, the method first converted the observed daily maximum (T_{max}) and minimum (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. 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.

The performance of this approach can be assessed by comparing key statistics (minimum, 25th percentile, median, mean, 75th percentile and maximum) of the observed and simulated T_{max} and T_{min} daily series as summarised for the Kimberley stations in Tables Table **1** and Table **2** for Tmax and Tmin for the summer half-year, and respectively Tables Table **3** and

Table 4 for the winter half year. Tables

Table 5, Table **6**, Table **7**and Table **8** are the equivalent summaries for the Pilbara stations. For the SWG simulations 100 stochastic realisations are summarised, and hence it is not unexpected that the minimum and maximum values from these 100 realisations can be smaller or larger than that observed in the single 'realisation' of the station records. Conversely, in the cases where the SWG minimums (maximums) are not lower (higher) than the observed values (for example, in Table 1 several stations have a minimum value for observed Tmax lower than the minimum 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 of SWG simulated Kimberley Summer (November-April) maximum daily temperature.

Station	Observed						100 stochastic simulations					
	Min	25th	Med	Mean	75th	Max	Min	25th	Med	Mean	75th	Max
Kalumburu Mission	24.1	33.5	35.4	35.0	36.7	41.9	23.8	33.4	35.1	35.0	36.7	46.1
Halls Creek A/P	19.4	33.8	36.4	36.1	38.8	45.0	19.2	33.9	36.2	36.1	38.5	49.5
Lissadell	21.0	35.0	37.5	37.2	39.5	45.0	22.7	35.1	37.2	37.2	39.3	50.1
Margaret River	21.5	35.0	37.5	37.1	39.5	45.0	22.1	35.0	37.2	37.2	39.4	48.9
Broome Airport	23.6	32.1	33.3	33.6	34.8	43.6	23.8	32.0	33.6	33.6	35.1	44.5
Mount House Statn	24.5	34.0	36.0	35.7	38.0	45.0	24.1	33.8	35.7	35.7	37.5	46.9
Udialla	24.5	35.0	36.5	36.4	38.0	46.0	24.3	34.7	36.4	36.4	38.1	47.4
Fossil Downs	24.0	35.5	38.0	37.6	40.0	45.5	24.2	35.6	37.6	37.6	39.7	49.4
Bidyadanga	22.0	33.0	34.5	34.9	36.6	47.0	22.3	33.0	34.9	34.9	36.8	47.9

Table 2: Summary statistics of SWG simulated Kimberley Summer (November-April) minimum daily temperature.

Station	Observed						100 stochastic simulations					
	Min	25th	Med	Mean	75th	Max	Min	25th	Med	Mean	75th	Max
Kalumburu Mission	11.5	23.4	24.4	24.1	25.4	29.4	12.2	22.9	24.2	24.1	25.4	33.0
Halls Creek A/P	13.0	22.1	23.7	23.6	25.4	31.6	8.9	21.9	23.7	23.7	25.5	35.2
Lissadell	10.0	23.5	25.0	24.7	26.0	32.0	10.6	23.2	24.8	24.7	26.3	37.1
Margaret River	13.0	23.0	24.0	24.1	25.5	30.5	10.7	22.6	24.2	24.0	25.7	33.2

Broome Airport	13.5	24.0	25.7	25.4	27.2	30.2	11.9	23.7	25.5	25.3	27.1	35.1
Mount House Statn	12.5	22.5	23.5	23.2	24.5	28.5	10.5	22.1	23.5	23.3	24.7	33.0
Udialla	14.5	24.0	25.0	24.9	26.5	30.5	13.5	23.6	25.0	24.9	26.3	34.4
Fossil Downs	13.5	23.5	25.0	24.5	26.0	31.5	11.3	23.1	24.7	24.5	26.1	34.2
Bidyadanga	14.0	23.1	25.0	24.6	26.4	31.5	11.2	23.1	24.7	24.6	26.3	35.3

Table 3: Summary statistics of SWG simulated Kimberley Winter (May-October) maximum daily temperature.

Station	**Observed**						**100 stochastic simulations**					
	Min	**25th**	**Med**	**Mean**	**75th**	**Max**	**Min**	**25th**	**Med**	**Mean**	**75th**	**Max**
Kalumburu Mission	23.4	32.2	33.9	33.8	35.3	41.2	23.0	32.1	33.7	33.8	35.5	44.1
Halls Creek A/P	12.4	27.8	30.9	31.1	34.4	42.6	14.1	27.7	30.7	31.1	34.3	48.9
Lissadell	17.5	30.5	33.5	33.5	36.5	44.5	19.3	30.5	33.2	33.5	36.4	48.8
Margaret River	15.5	29.0	32.0	32.2	35.5	43.5	15.2	28.9	31.8	32.2	35.3	48.5
Broome Airport	19.4	28.8	30.6	30.9	32.7	42.0	17.1	28.9	31.0	31.0	33.0	45.2
Mount House Statn	17.0	30.5	32.5	32.7	35.5	42.0	19.5	30.1	32.4	32.7	35.2	45.8
Udialla	18.5	31.0	33.0	33.1	35.5	43.0	17.3	30.7	33.0	33.1	35.4	47.6
Fossil Downs	17.5	30.5	33.5	33.6	36.5	45.0	17.1	30.7	33.2	33.6	36.4	49.7
Bidyadanga	19.2	29.5	31.5	31.7	34.0	43.2	17.1	29.5	31.8	31.8	34.0	48.3

Table 4: Summary statistics of SWG simulated Kimberley Winter (May-October) minimum daily temperature.

Station	Observed						100 stochastic simulations					
	Min	25th	Med	Mean	75th	Max	Min	25th	Med	Mean	75th	Max
Kalumburu Mission	5.0	15.1	18.3	18.0	21.3	28.0	1.9	15.0	17.8	17.9	20.8	33.5
Halls Creek A/P	3.2	13.6	17.0	17.1	20.5	29.5	1.3	13.8	16.8	17.1	20.2	34.1
Lissadell	4.0	15.0	18.5	18.4	22.0	30.0	1.4	15.0	18.1	18.3	21.5	36.5
Margaret River	5.0	13.5	17.0	17.1	20.5	30.5	1.5	13.7	16.7	17.0	20.1	33.8
Broome Airport	5.0	14.0	17.1	17.2	20.4	27.9	1.1	14.1	17.0	17.2	20.1	33.6
Mount House Statn	3.0	12.5	16.0	16.1	19.5	28.5	1.0	12.8	15.8	16.1	19.2	34.1
Udialla	6.0	15.0	17.5	17.7	20.5	28.0	3.7	15.0	17.5	17.7	20.3	33.2
Fossil Downs	4.0	14.0	17.0	17.2	21.0	30.5	1.3	13.9	16.9	17.2	20.3	34.8
Bidyadanga	5.1	14.0	17.0	16.9	19.5	28.0	1.8	14.3	16.8	16.9	19.4	32.9

Table 5: Summary statistics of SWG simulated Pilbara Summer (November-April) maximum daily temperature.

Station	Observed						100 stochastic simulations					
	Min	25th	Med	Mean	75th	Max	Min	25th	Med	Mean	75th	Max
Marble Bar Comp	20.1	37.0	39.8	39.4	42.1	48.0	19.6	36.8	39.5	39.3	42.0	55.5
Port Hedland A/P	20.6	33.9	35.9	36.2	38.4	48.2	20.7	34.0	36.2	36.2	38.4	51.0
Coolawanyah	21.0	35.0	38.0	37.5	40.0	47.0	21.0	35.2	37.7	37.5	39.9	52.1
Learmonth Airport	23.4	33.2	35.8	35.9	38.5	47.4	20.2	33.5	36.0	35.9	38.5	51.4

Mardie	24.7	35.0	37.4	37.5	39.9	50.5	22.6	35.1	37.5	37.5	40.0	52.6
Karratha Station	24.5	34.5	36.5	36.5	38.5	47.0	24.3	34.4	36.6	36.5	38.7	50.5
Carnarvon Airport	21.8	27.7	29.7	30.6	32.8	47.0	18.1	27.9	30.7	30.7	33.4	50.3
Wandagee	23.5	33.5	36.0	36.0	38.5	46.0	20.5	33.6	36.1	36.0	38.5	50.1
Nyang Station	23.2	35.7	38.5	38.3	41.2	49.8	21.2	35.6	38.4	38.3	41.1	55.0
Mount Vernon	22.0	34.5	37.5	37.4	40.5	47.5	19.3	34.6	37.5	37.4	40.3	52.9

Table 6: Summary statistics of SWG simulated Pilbara Summer (November-April) minimum daily temperature.

Station	**Observed**						**100 stochastic simulations**					
	Min	**25th**	**Med**	**Mean**	**75th**	**Max**	**Min**	**25th**	**Med**	**Mean**	**75th**	**Max**
Marble Bar Comp	14.0	23.0	25.0	24.8	26.9	34.2	10.9	22.8	24.8	24.8	26.8	37.1
Port Hedland A/P	12.3	22.2	24.3	23.9	25.9	30.2	11.3	22.0	24.0	23.9	25.8	34.7
Coolawanyah	14.0	22.0	24.0	23.7	25.5	32.5	11.5	21.8	23.7	23.6	25.5	35.2
Learmonth Airport	12.0	19.4	21.5	21.5	23.7	29.5	9.0	19.6	21.7	21.6	23.6	32.3
Mardie	13.0	21.1	23.5	23.2	25.4	32.6	10.7	21.3	23.4	23.2	25.3	36.0
Karratha Station	16.0	23.0	25.0	24.6	26.5	31.5	14.3	22.9	24.7	24.6	26.3	35.6
Carnarvon Airport	12.5	19.4	21.2	21.2	23.0	30.0	9.9	19.4	21.2	21.2	23.0	32.4
Wandagee	13.0	20.0	22.0	21.8	24.0	30.0	10.2	19.9	22.0	21.9	23.9	32.6
Nyang Station	12.7	20.3	22.5	22.5	24.7	32.2	9.9	20.4	22.6	22.5	24.7	35.8

Mount Vernon	10.0	20.5	23.0	22.9	25.5	31.5	7.3	20.4	23.0	22.8	25.3	35.4

Table 7: Summary statistics of SWG simulated Pilbara Winter (May-October) maximum daily temperature.

Station	**Observed**						**100 stochastic simulations**					
	Min	**25th**	**Med**	**Mean**	**75th**	**Max**	**Min**	**25th**	**Med**	**Mean**	**75th**	**Max**
Marble Bar Comp	13.6	27.5	30.7	31.1	34.5	44.5	12.9	27.5	30.7	31.1	34.6	50.1
Port Hedland A/P	16.0	27.7	30.0	30.4	32.7	44.0	14.7	27.6	30.3	30.4	33.1	45.7
Coolawanyah	14.5	25.5	28.5	28.9	32.0	41.5	13.8	25.4	28.4	28.9	32.1	47.0
Learmonth Airport	17.0	24.6	27.0	27.5	29.9	42.6	12.6	24.5	27.2	27.4	30.1	43.3
Mardie	16.4	28.3	30.6	31.0	33.5	44.1	15.0	28.2	30.8	30.9	33.6	46.3
Karratha Station	18.0	27.0	29.5	29.8	32.0	43.0	16.3	27.1	29.7	29.8	32.4	45.7
Carnarvon Airport	14.6	22.3	24.0	24.5	26.1	39.8	12.1	22.3	24.4	24.4	26.6	39.7
Wandagee	16.0	24.0	26.5	27.0	29.5	40.5	12.5	24.2	26.8	27.0	29.6	42.2
Nyang Station	15.2	25.5	28.3	28.7	31.5	42.5	12.2	25.5	28.5	28.6	31.6	45.4
Mount Vernon	15.0	23.0	26.5	27.0	30.5	41.5	10.3	23.2	26.6	26.9	30.4	46.7

Table 8: Summary statistics of SWG simulated Pilbara Winter (May-October) minimum daily temperature.

Station	**Observed**						**100 stochastic simulations**					
	Min	**25th**	**Med**	**Mean**	**75th**	**Max**	**Min**	**25th**	**Med**	**Mean**	**75th**	**Max**
Marble Bar	2.0	13.3	16.0	16.2	19.0	29.4	-0.3	13.3	16.1	16.2	19.0	34.1

Comp												
Port Hedland A/P	4.3	12.9	15.5	15.5	18.0	25.7	1.6	13.0	15.5	15.5	18.0	30.7
Coolawanyah	5.0	12.0	15.0	14.9	17.5	26.5	1.6	12.3	14.8	14.9	17.5	30.6
Learmonth Airport	3.8	11.5	13.8	13.8	16.2	24.3	1.0	11.5	13.8	13.8	16.1	28.7
Mardie	4.4	12.1	14.7	14.8	17.5	25.0	1.1	12.4	14.8	14.9	17.3	29.9
Karratha Station	7.0	14.0	16.5	16.5	19.0	26.5	3.4	14.2	16.5	16.6	18.9	30.4
Carnarvon Airport	2.8	10.8	13.4	13.4	16.1	22.7	-1.4	10.9	13.4	13.4	15.8	27.8
Wandagee	3.5	11.0	13.5	13.3	16.0	22.5	0.5	10.9	13.2	13.3	15.6	27.7
Nyang Station	2.0	11.2	13.7	13.8	16.4	24.4	-0.2	11.3	13.7	13.7	16.2	30.6
Mount Vernon	0.5	8.5	11.5	11.8	15.0	25.5	-2.7	8.7	11.6	11.8	14.8	28.4

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 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 (for the five GCMs used) and are incorporated within the SWG as monthly additive changes, calculated 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 SWG covariance matrices derived from the observed data. The simulated T_{mean} and T_{range} are then converted back to T_{max} and T_{min} daily values.

Thus magnitudes of future change in SWG generated scenarios are 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 in addition 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 2.3.7 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.

Milestone 2.3.7 *Dissemination of climate change scenarios for daily rainfall and temperature at multiple sites*

(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 for a 9 station network in the Kimberley and a 10 stations network in the Pilbara. 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. The NHMMs selected for these regions are summarised in Table 9.

Table 9: Number of weather states and predictors of selected NHMMs. Winter is May-October and Summer is November-April.

Kimberley		**Pilbara**	
Winter	4 States	Winter	4 States
	MSLP		East - West MSLP gradient
	East - West MSLP gradient		Easterley wind speed @ 700 hPa
	DTD* @ 700 hPa		DTD @ 700 hPa
Summer	4 States	Summer	4 States
	North - South MSLP gradient		East - West MSLP gradient
	Northerly wind speed @ 850 hPa		Easterley wind speed @ 850 hPa
	DTD @ 850 hPa		DTD @ 700 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 network and season of interest.

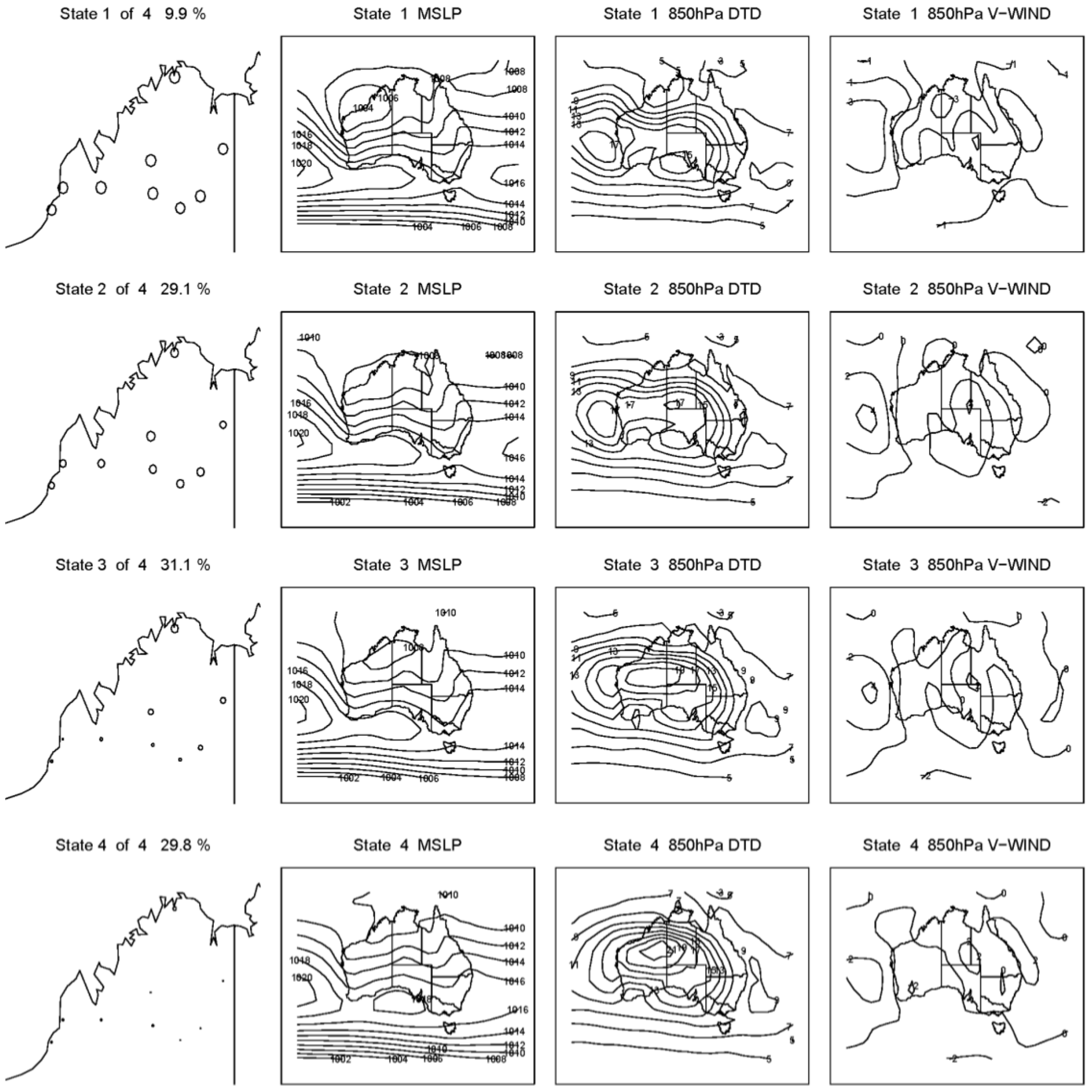
State 1 of 4 9.9 %
State 1 MSLP
State 1 850hPa DTD
State 1 850hPa V-WIND
State 2 of 4 29.1 %
State 2 MSLP
State 2 850hPa DTD
State 2 850hPa V-WIND
State 3 of 4 31.1 %
State 3 MSLP
State 3 850hPa DTD
State 3 850hPa V-WIND
State 4 of 4 29.8 %
State 4 MSLP
State 4 850hPa DTD
State 4 850hPa V-WIND

Figure 1 and

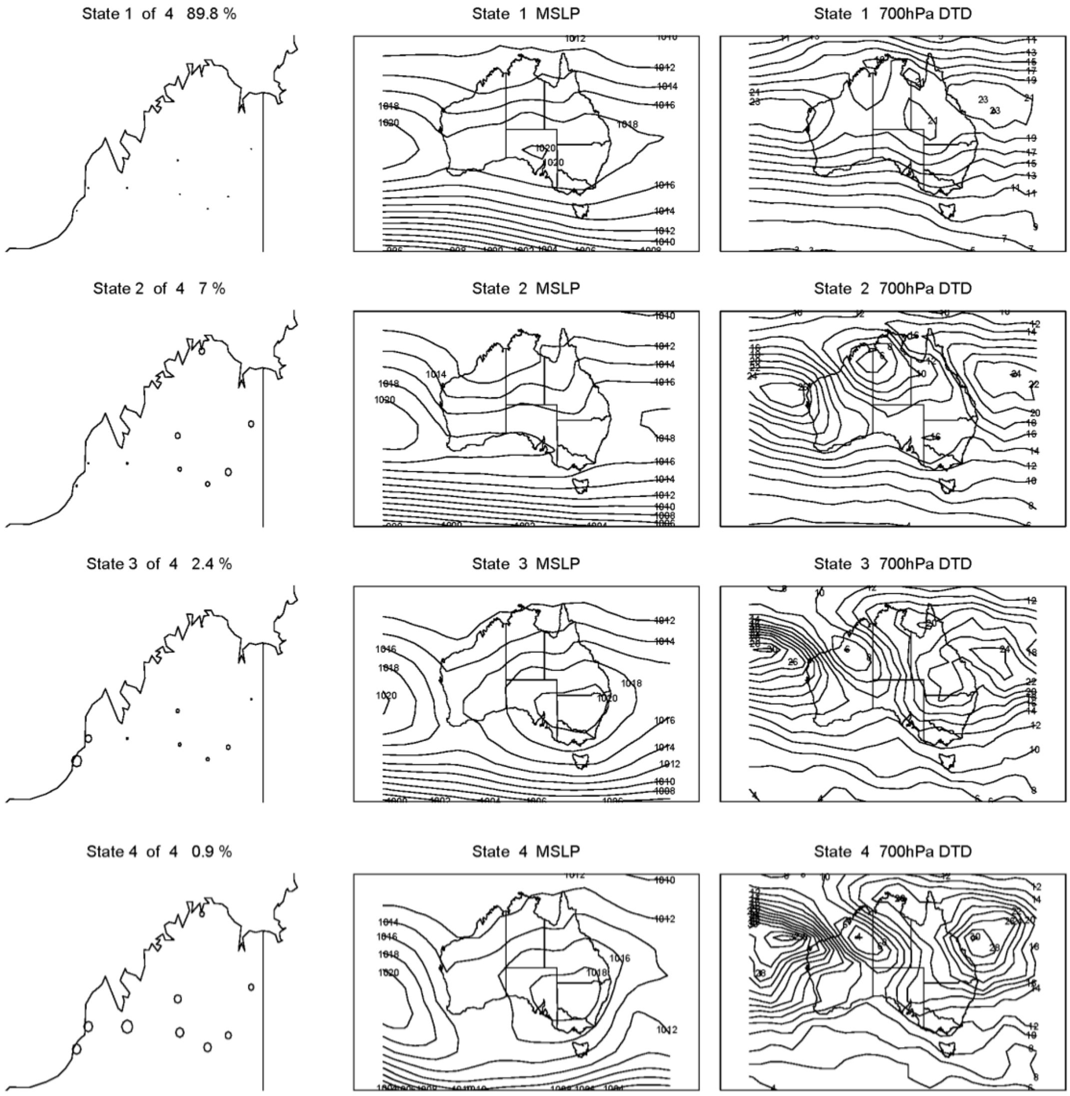

Figure 2 show the Kimberley summer and winter NHMM weather states, respectively. Corresponding to these Figures are projected changes in the frequencies of these states, summarised in Table 10 and

Table 11 for summer and winter respectively.

For the summer (wet-season) there are consistent projections of a decrease in the wet State 1 for all GCMs, albeit varying in magnitude of reduction, and State 2 for 4 of the 5 GCMs by the end of century. State 3 is projected to increase for all GCMs, and the driest State 4 is ambiguous with one GCM indicating a decrease, two about the same, and two an increase in frequency by end of century (Table 10). A caveat to note is that this region can intermittently receive significant summer rainfall from tropical cyclones which, while projected to increase in intensity, may not be adequately accounted for in NHMM simulations. Little change is projected for winter season weather state frequencies (

Table 11).

Table 10: Kimberley summer weather state frequencies. '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 stochastic NHMM simulations).

State	Current	GFDL 2.0	GFDL 2.1	MIROC	Mk3.5	MPI
1	0.09	0.10 0.10 0.09	0.10 0.10 0.08	0.09 0.10 0.06	0.10 0.06 0.05	0.10 0.10 0.09
2	0.28	0.30 0.31 0.32	0.33 0.31 0.30	0.34 0.37 0.30	0.31 0.25 0.24	0.32 0.30 0.30
3	0.31	0.30 0.31 0.34	0.28 0.29 0.32	0.28 0.30 0.31	0.29 0.33 0.34	0.28 0.29 0.32
4	0.31	0.29 0.27 0.26	0.30 0.30 0.30	0.29 0.24 0.33	0.29 0.36 0.37	0.30 0.31 0.30

Table 11: Kimberley winter weather state frequencies (A2 scenario for projections)

State	Current	GFDL 2.0	GFDL 2.1	MIROC	Mk3.5	MPI
1	0.86	0.87 0.87 0.87	0.87 0.88 0.88	0.87 0.89 0.90	0.87 0.89 0.89	0.87 0.88 0.88
2	0.09	0.09 0.09 0.08	0.09 0.09 0.08	0.09 0.07 0.06	0.09 0.08 0.08	0.09 0.08 0.08
3	0.03	0.03 0.03 0.03	0.03 0.03 0.03	0.03 0.03 0.03	0.03 0.03 0.03	0.03 0.03 0.03
4	0.01	0.01 0.01 0.01	0.01 0.01 0.01	0.01 0.01 0.01	0.01 0.01 0.01	0.01 0.01 0.01

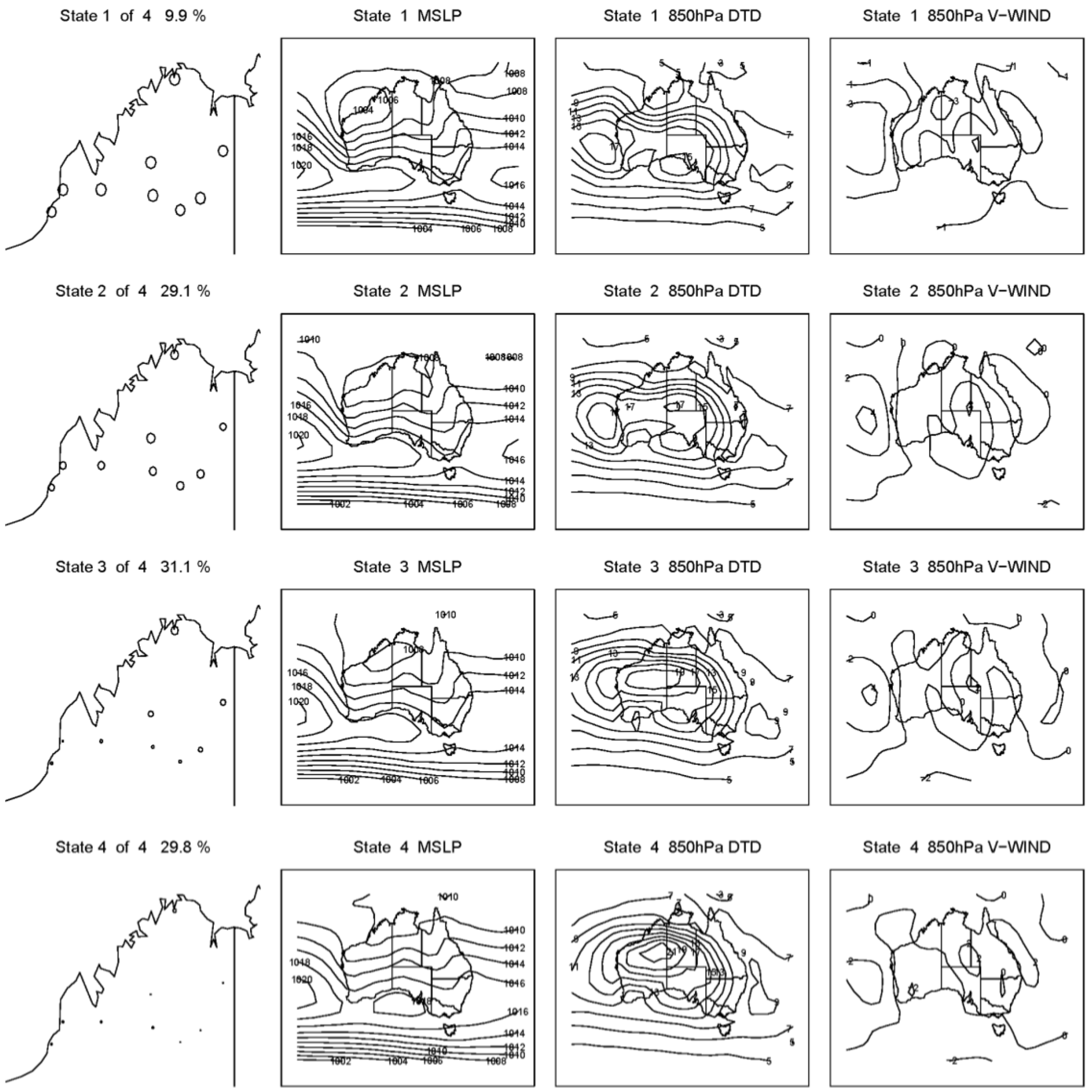

Figure 1: Kimberley summer weather states as mean precipitation probability maps and corresponding composite atmospheric predictor plots.

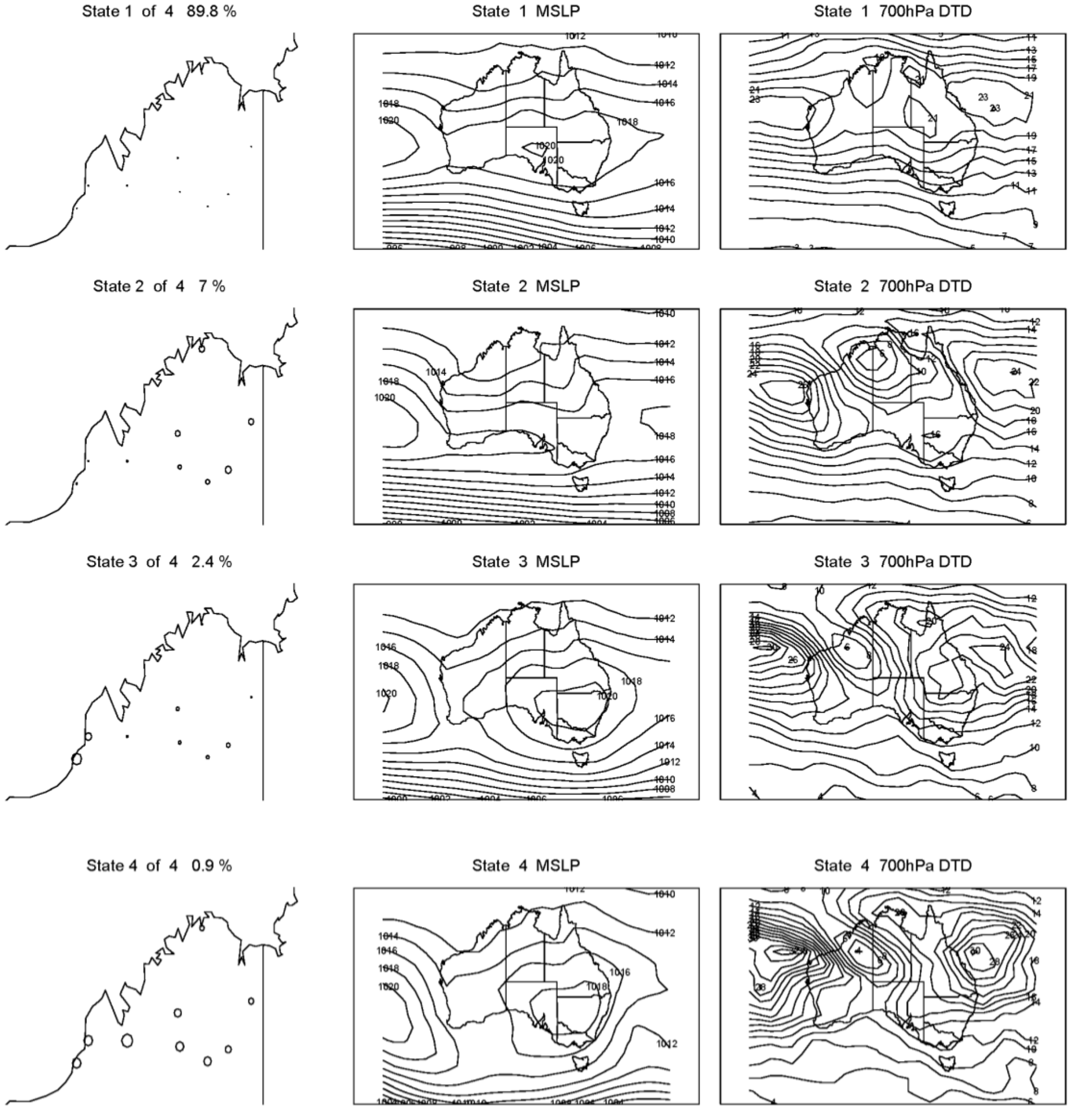

Figure 2: Kimberley winter weather states as mean precipitation probability maps and corresponding composite atmospheric predictor plots.

The projected changes in Pilbara summer season weather state frequencies (Table 12) indicate the continued dominance of the dry State 3 that increases for 4 of the 5 GCM downscaled results (one, GFDL2.0, unchanging). State 1, a pattern slightly wetter in the south, increases for 2 GCMs and decrease for 3. State 2, alternately slightly wetter in the north, decreases slightly or remains the same for all GCMs. The wetter (wettest in the north) State 4 pattern is projected to decrease by all GCMs. For winter, there is little change projected in the downscaled frequencies of all the states (

Table 13).

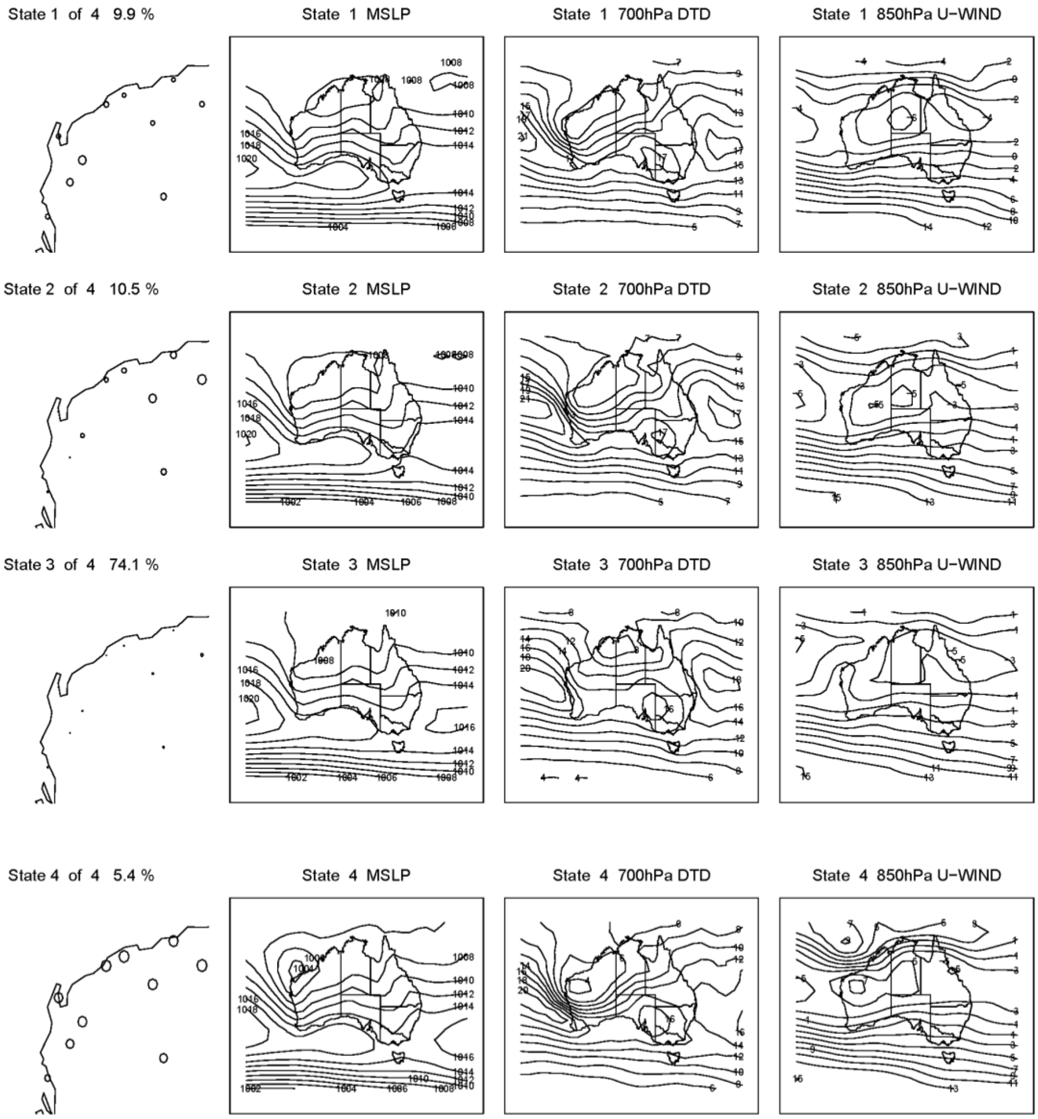

Figure 3: Pilbara summer weather states as mean precipitation probability maps and corresponding composite atmospheric predictor plots.

Table 12: Pilbara summer weather state frequencies (A2 scenario for projections)

State	Current	GFDL 2.0	GFDL 2.1	MIROC	Mk3.5	MPI
1	0.11	0.12 0.13 0.14	0.12 0.13 0.13	0.11 0.10 0.09	0.11 0.09 0.08	0.12 0.10 0.10
2	0.11	0.11 0.11 0.11	0.12 0.11 0.10	0.13 0.13 0.11	0.12 0.10 0.09	0.11 0.11 0.10
3	0.73	0.70 0.70 0.70	0.69 0.69 0.72	0.69 0.71 0.75	0.71 0.77 0.80	0.70 0.73 0.74
4	0.05	0.07 0.06 0.05	0.07 0.08 0.05	0.06 0.06 0.05	0.05 0.04 0.03	0.07 0.06 0.06

Table 13: Pilbara winter weather state frequencies (A2 scenario for projections)

State	Current	GFDL 2.0	GFDL 2.1	MIROC	Mk3.5	MPI
1	0.04	0.04 0.05 0.05	0.04 0.05 0.05	0.05 0.05 0.05	0.05 0.04 0.04	0.05 0.05 0.05

2	0.07	0.07 0.07 0.08	0.07 0.08 0.08	0.07 0.08 0.08	0.07 0.07 0.06	0.07 0.08 0.08
3	0.67	0.66 0.66 0.65	0.66 0.65 0.65	0.66 0.65 0.65	0.66 0.67 0.68	0.66 0.65 0.66
4	0.22	0.22 0.22 0.22	0.22 0.22 0.22	0.22 0.23 0.22	0.22 0.22 0.21	0.22 0.22 0.22

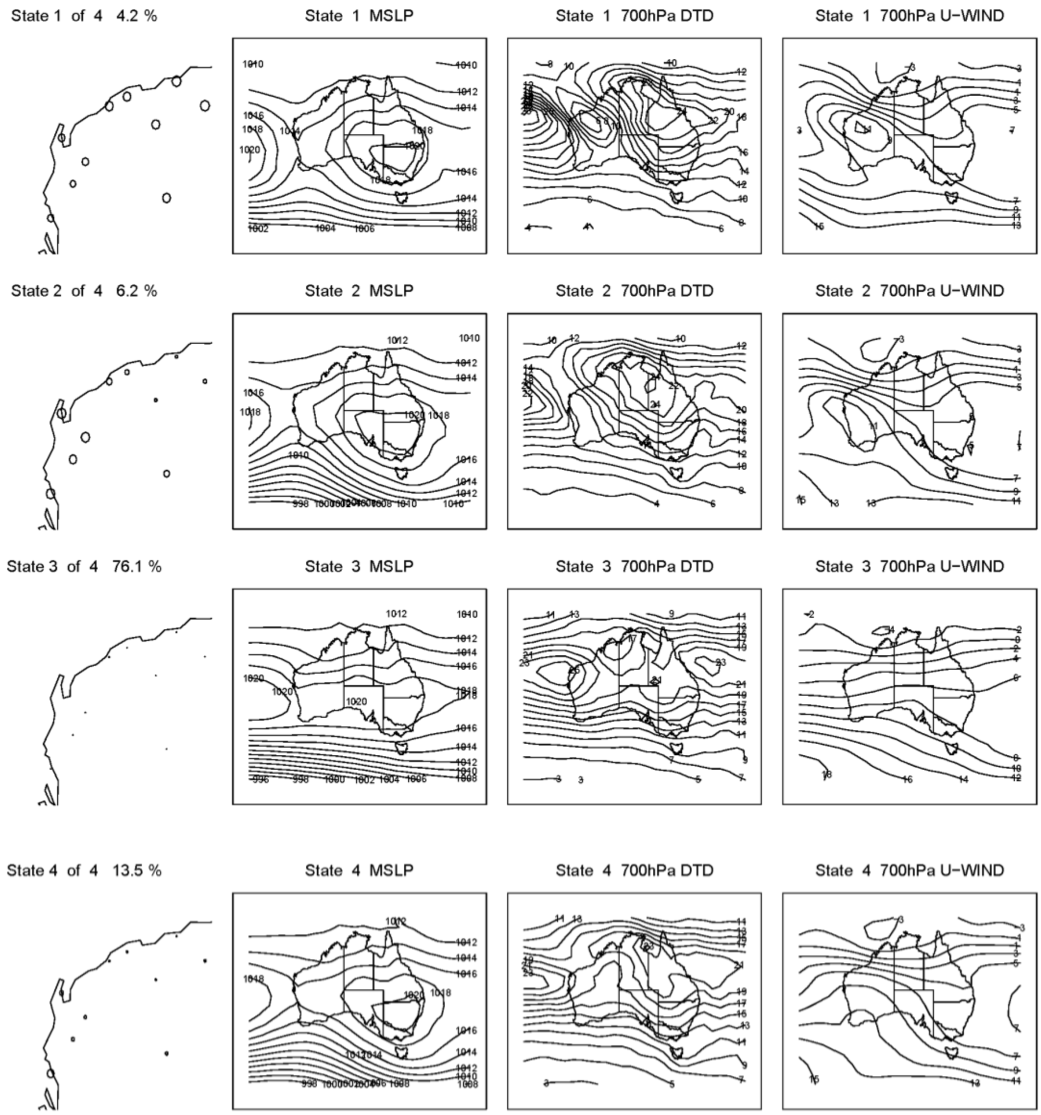

Figure 4: Pilbara winter weather states as mean precipitation probability maps and corresponding composite atmospheric predictor plots.

Table 14: Projected mean annual rainfall as proportion of 1961-2000 climatology

Kimberley

	B1_mid	A1B_mid	A2_mid	B1_end	A1B_end	A2_end
gfdl2.0	0.91	0.88	1.05	0.96	0.87	0.97
gfdl2.1	0.96	0.90	0.99	0.96	0.84	0.89
miroc	0.95	0.96	1.03	0.97	0.94	0.79

mk35	0.74	0.76	0.74	0.71	0.71	0.67
mpi	0.99	0.98	0.97	0.94	0.85	0.92
			Pilbara			
gfdl2.0	0.91	0.83	0.96	1.00	0.88	0.90
gfdl2.1	0.96	0.89	1.05	0.90	0.81	0.87
miroc	0.95	0.93	0.95	0.97	0.91	0.84
mk35	0.85	0.76	0.86	0.79	0.76	0.72
mpi	0.99	0.99	0.96	0.90	0.87	0.91

Table 14 presents the mean projected changes in annual rainfall for the two regions. The majority of projections indicate decreased rainfall (i.e. proportions less than 1.0). The CSIRO Mk3.5 GCM produces significantly drier projections than the other GCMs with most of this projected change having occurred by mid century. The degree by which drying increases between mid and late century is both GCM and SRES scenario dependent, with a somewhat consistent signal emerging. In most cases projections from both the A1B and A2 scenarios are drier than those from B1 for end of century.

For several of the GCMs the A1B results are drier than the A2 results, indicating that GCM predictor decadal variability places a significant role and thus emphasising that GCM projected changes are not solely dominated by a response to enhanced greenhouse gas forcing. The range of results, and thus uncertainty, for a particular SRES scenario and period is significantly reduced when using the four more consistent GCMs (CSIRO Mk3.5 being the drier outlier).

The probability distributions of annual rainfalls for current and projected climate are compared in Figure 5 and Figure 6 for the Kimberley and Pilbara regions respectively. For the Kimberley stations, the A1B or A2 for end of century produces the most significant change with most GCMs producing a more peaked distribution (i.e. decreased variance) that is drier than the current period (Figure 5). For the Pilbara stations there is also a shift to drier conditions for the end of century simulations whereas only two GCMs produce a more peaked distribution (Figure 6).

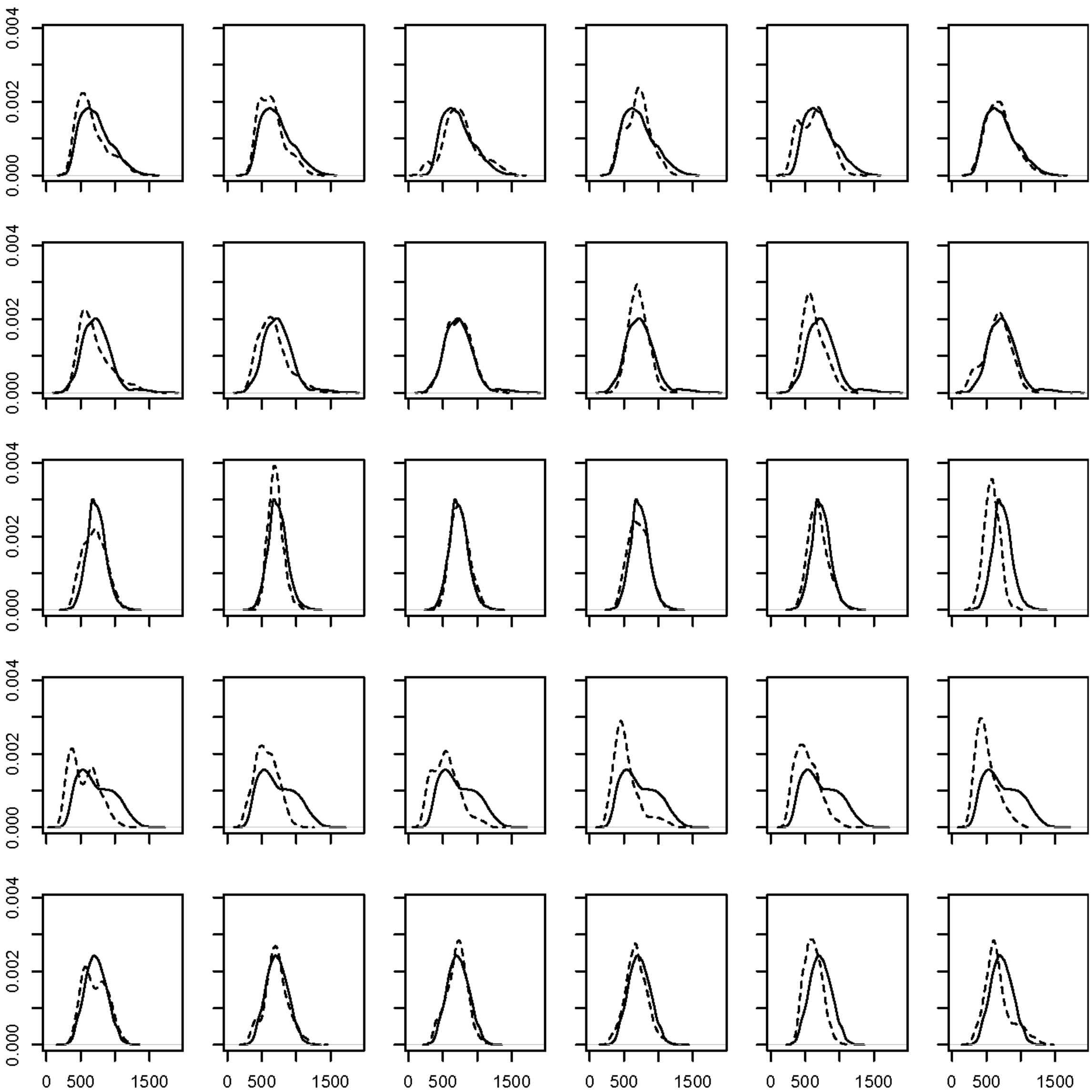

Figure 5: Probability densities of annual rainfalls (mm) downscaled from 5 GCMs (rows top to bottom: GFDL2.0, GFDL2.1, MIROC-medres, CSIRO Mk3.5 and MPI-ECHAM5) for 6 SRES scenario and period combinations (columns left to right: B1 mid-century, A1B mid-century, A2 mid-century, B1 end-century, A1B end-century 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 9 Kimberley stations.

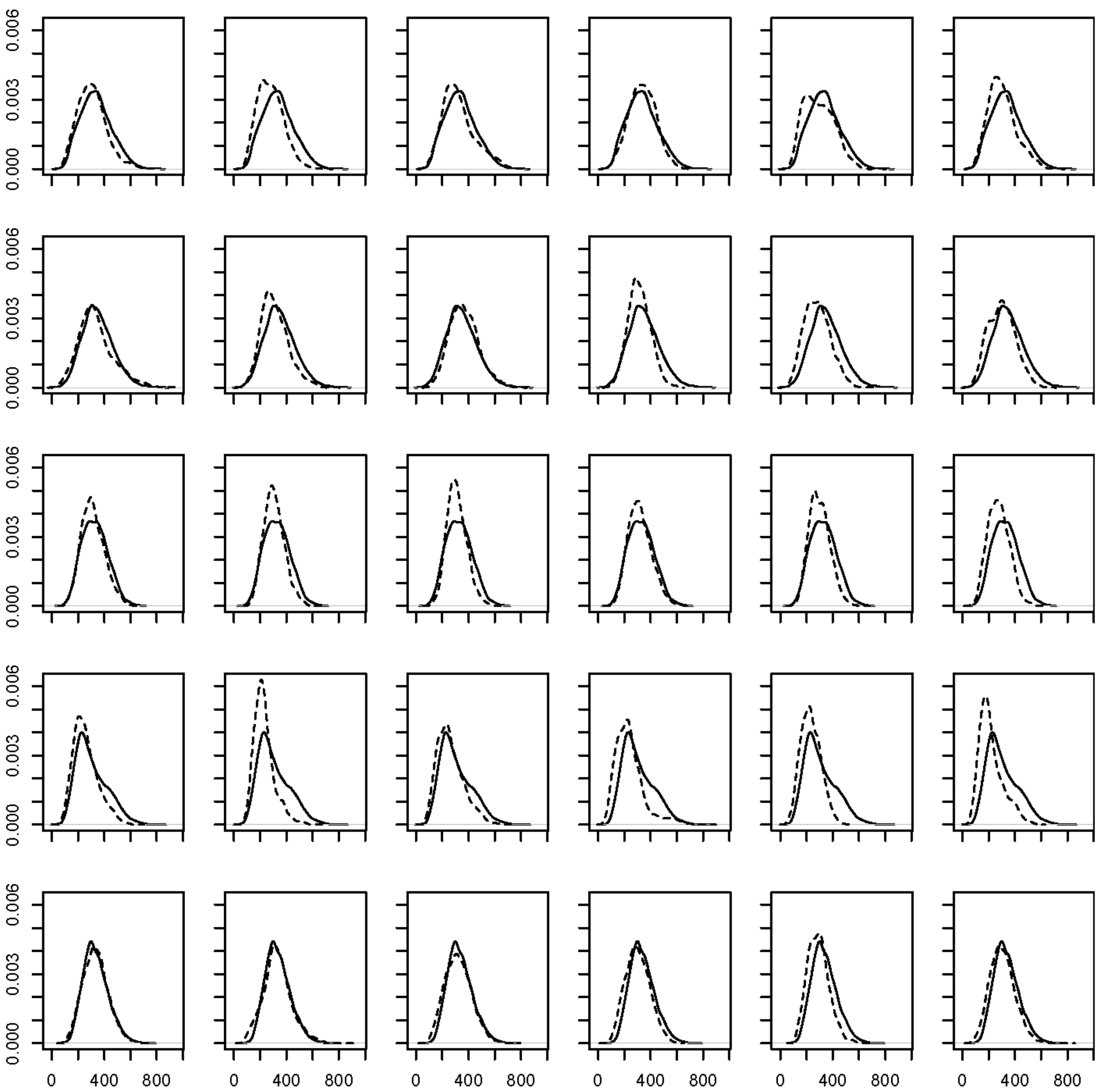

Figure 6: Probability densities of annual rainfalls (mm) downscaled from 5 GCMs (rows top to bottom: GFDL2.0, GFDL2.1, MIROC-medres, CSIRO Mk3.5 and MPI-ECHAM5) for 6 SRES scenario and period combinations (columns left to right: B1 mid-century, A1B mid-century, A2 mid-century, B1 end-century, A1B end-century 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 10 Pilbara stations.

The projected changes in the annual average maximum and minimum daily temperature obtained from downscaling to the Kimberley and Pilbara station networks are shown in

Table 15. As expected, the projected increases are larger for the end of century compared to mid century. In all cases the CSIRO Mk3.5 downscaled results project the largest warming. The Kimberley minimum temperature changes are all larger than (or equal to) the corresponding maximum temperature projected changes for all GCMs, indicating a decrease in diurnal temperature range.

For the Pilbara, four of the downscaled GCMs project a greater increase in maximum temperature than minimum for mid century, in contrast for end of century all five project a greater (or equal) increase in minimum temperature compared to maximum, again indicating a decrease in diurnal temperature range.

Table 15: Projected mean annual temperature changes in °C (relative to 1961-2000).

	Kimberley			Pilbara		
Tmax		A2_mid	A2_end		A2_mid	A2_end
	gfdl2.0	2.5	4.2	gfdl2.0	2.9	3.9
	gfdl2.1	2.1	3.8	gfdl2.1	2.2	3.9
	miroc	1.8	3.6	miroc	2.0	3.8
	mk35	2.7	4.6	mk35	3.2	4.6
	mpi	1.8	4.2	mpi	2.1	4.1
Tmin		A2_mid	A2_end		A2_mid	A2_end
	gfdl2.0	2.5	4.7	gfdl2.0	2.2	4.1
	gfdl2.1	2.2	4.2	gfdl2.1	2.1	4.2
	miroc	2.4	4.8	miroc	2.3	4.5
	mk35	2.7	4.9	mk35	2.4	4.6
	mpi	2.0	4.7	mpi	1.9	4.4

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 IOCI4.

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.

Ruff TW, Neelin JD (2012) Long tails in regional surface temperature probability distributions with implications for extremes under global warming. *Geophys. Res. Lett.* 39:L04704. doi:10.1029/2011GL050610.

IOCI 3 Milestone Status Report

Theme and Project Number: 2.3 **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)
2.3.1 Report on selection of high-quality daily rainfall gauge networks	30/06/2010	Milestone completed	None
2.3.2 Report on development and testing of downscaling models	30/06/2010	Milestone completed	None
2.3.3 Report on assessment of temporal trends in weather states and at-site rainfall statistics	30/06/2010	Milestone completed	None
2.3.4 Report on assessment of the ability of GCMs to simulate atmospheric predictors required for downscaling	30/06/2010	Milestone completed	None
2.3.5 Report on comparison of forced GCM downscaled time series of weather state sequences and at-site rainfall with the observed	31/12/2010	Milestone completed	None

2.3.6 Report on extension of statistical downscaling models to include temperature	31/12/2011	Milestone completed	None
2.3.7 Dissemination of climate change scenarios for daily rainfall and temperature at multiple sites	31/12/2011	Research completed, dissemination by 30/06/2012	None