PROJECT 2.3: STATISTICAL DOWNSCALING FOR THE NORTH-WEST

Principal Investigator

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Research Question (7)

What can statistical downscaling tell us about observed and projected changes to the climate baselines for the North-West?

Key research findings and highlights

Milestones 2.3.1, 2.3.2 and 2.3.3 are completed. Milestone 2.3.4 is also completed; however some aspects of the assessment of GCM predictors will flow through into Milestone 2.3.5 where GCM predictor bias correction methods will be assessed as a component of the assessment of the ability of forced GCM downscaled time series to reproduce observed weather state sequences and rain gauge statistics.

Milestone 2.3.1. *Report on selection of high-quality daily rainfall gauge networks*

Based on strict data quality requirements to achieve the optimum possible calibration of the non-homogeneous hidden Markov model (NHMM) statistical downscaling model, screening of rainfall gauges in the North-West resulted in the selection of 9 high quality rain gauges in the Kimberley region and 10 in the Pilbara region. See attached appendix for details of the selected stations.

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

NHMMs were calibrated for these two regions and selected stations on a seasonal basis, for the May to October and November to April winter and summer half-years respectively. The successful reproduction of observed rain gauge inter-annual rainfall variability (see appendix) as well as other tests of performance (not shown) are evidence that the calibrated NHMMs account for the linkage between large-scale atmospheric drivers and gauge scale rainfall processes across the range of observed climate experienced by these regions. This gives confidence in these NHMMs suitability for investigating observed and projected changes to climate baselines for the North-West. One caveat is the underestimation of extremely wet seasons in the dry May to October season.

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

The observed trends in rainfall in the Kimberley and Pilbara regions of the North-West can be reproduced by the NHMM statistical downscaling models. These can be related to corresponding changes in the frequencies of NHMM weather states that are physically consistent with changes to the atmospheric predictors, as outlined in the appendix. For the Kimberley region, the rainfall, weather state and atmospheric predictor trends indicate an observed lengthening of the summer wet season, with both an earlier onset and later recession of the wet season (see appendix). The Pilbara region rainfall, weather state and atmospheric predictor trends indicate a drier early winter (May to July), which is interesting given similar trends where found for the South-West in previous IOCI research. For the summer season, trends indicate the influence of a lengthening tropical wet season for the gauges in the north of the Pilbara region (see appendix). The overall consistency of these findings again gives confidence in the suitability of the NHMM for investigating observed and projected changes to climate baselines for the North-West.

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

Five GCMs were assessed and found to reasonably reproduce the probability density functions (PDFs) of the atmospheric predictors required by the selected NHMMs (see appendix). The five GCMs are: GFDL 2.0 and 2.1, MIROC-medres, CSIRO Mk3.5, and MPI-ECHAM5 GCMs. An advantage of selecting these five, in addition to their adequate predictor simulation, is the availability of dynamically downscaled results from these GCMs that will allow direct comparison between NHMM statistically downscaled and CCAM dynamically downscaled projections (see new research opportunities below).

Summary of new linkages to other IOCI 3 Projects

- The North-West stations determined to be high quality in Project 1.4: *Regionally Specific Climate Data and Monitoring for the North-West and South-West to Support the Understanding of Past, Present and Future Climate* can be assessed for use in statistical downscaling with a view to extending the spatial coverage over the region.
- The latest CSIRO GCM runs undertaken for the attribution of observed rainfall trends in Project 2.1: *Observed and Modelled Climate for the North-West* will be statistically downscaled to determine the similarity of observed and modelled weather state and rainfall trends.

Summary of any new research opportunities that have arisen

- A suite of 60km resolution atmospheric climate model (CSIRO CCAM) dynamically downscaled runs for 1961 to 2100 (following the IPCC SRES A2 scenario, forced by five IPCC AR4 GCMs) are now available over Australia, produced for the Tasmanian Climate Futures project. Statistically downscaled projections from these CCAM runs will be compared to those obtained from downscaling the host GCMs directly, to determine whether projections are more consistent when statistical and dynamical downscaling are used together.
- An upcoming overseas visit to McGill University, Montreal and the International Research Center for Climate and Society, Columbia University, New York will focus on collaborative research to address several project milestones extending the NHMM.

List of publications accepted and submitted

Nil

List of IOCI-related presentations at national or international conferences, symposia and workshops

Nil

Appendix to Project 2.3 Milestone Report

Milestone 2.3.1. Selection of high-quality daily rainfall gauge networks

As noted in the IOCI3 2008 Annual Research Report (IOCI, 2010), the rainfall gauge data quality influences statistical downscaling model calibration performance and resultant weather state trends. Rainfall stations for use in statistical downscaling models were thus selected based on minimising the amount of missing data and untagged accumulations for the calibration periods, as outlined in IOCI (2010). This screening led to a relatively small set of higher quality rainfall gauges for the Kimberley (9 gauges) and Pilbara (10 gauges) regions as listed in Table 1 and located as shown in Figure 1 and Figure 2.

Table 1 High Quality Rainfall Gauges for Statistical Downscaling

No.	BoM #	Name	Longitude	Latitude
Kimberley				
1	1021	KALUMBURU MISSION	126.64	-14.30
2	2012	HALLS CREEK A/P	127.66	-18.23
3	2016	LISSADELL	128.55	-16.67
4	2019	MARGARET RIVER	126.86	-18.62
5	3003	BROOME AIRPORT	122.23	-17.95
6	3017	MOUNT HOUSE STATN	125.70	-17.05
7	3024	UDIALLA	123.74	-17.95
8	3027	FOSSIL DOWNS	125.78	-18.14
9	3030	BIDYADANGA	121.78	-18.68
Pilbara				
1	4020	MARBLE BAR COMP	119.75	-21.18
2	4032	PORT HEDLAND A/P	118.63	-20.37
3	5001	COOLAWANYAH	117.81	-21.80
4	5007	LEARMONTH AIRPORT	114.10	-22.24
5	5008	MARDIE	115.98	-21.19
6	5052	KARRATHA STATION	116.68	-20.88
7	6011	CARNARVON AIRPORT	113.67	-24.89
8	6050	WANDAGEE	114.55	-23.76
9	6072	NYANG STATION	115.04	-23.03
10	7059	MOUNT VERNON	118.24	-24.23

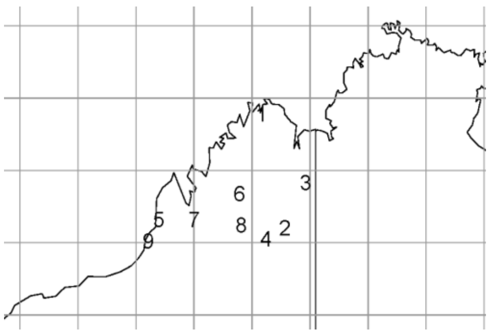


Figure 1 Location of nine rain gauges selected for Kimberley NHMM and atmospheric predictor grid.

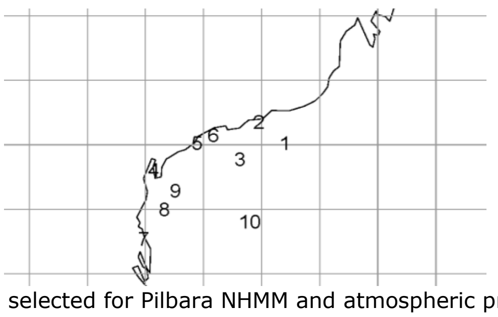


Figure 2 Location of ten rain gauges selected for Pilbara NHMM and atmospheric predictor grid.

Milestone 2.3.2. Development and testing of downscaling models

Calibrating the nonhomogeneous hidden Markov model (NHMM) for a rain gauge network, on a seasonal basis, involves determining the number of weather states (i.e. a small set of distinct multi-site daily rainfall spatial patterns) and set of atmospheric predictors. NCEP/NCAR Reanalysis (NNR) daily mean sea level pressure (MSLP) and, at 850, 700 and 500 hPa levels, winds, humidity and temperature for 1958 to 2008 were extracted for the NNR 2.5° by 2.5° grid (e.g., as shown in Figure 1 and Figure 2) for the domain 107.5° to 132.5° East and 10° to 30° South (11 by 9 NNR grids). These candidate predictors were chosen with reference to their availability from IPCC AR4 GCMs, for which only limited daily fields are archived for current (1961-2000), mid-century (2046-2065) and end-of-century (2081-2100) periods.

Initial predictor screening used correlation analysis between daily series of station rainfall and each candidate atmospheric predictor for each grid and adjacent grid differences (i.e. gradients). More advanced statistical predictor selection techniques, currently under development, were also applied to determine which combinations of predictors relate to observed daily rainfall variability (Phatak, 2010). The optimum combination of number of weather states and atmospheric predictors was determined using the Bayesian Information Criterion, resulting in the selection of the following models:

Kimberley Summer (Nov-Apr) 5 weather states, 3 atmospheric predictors:

- Northeast-Southwest gradient in MSLP
- North-South gradient in 850hPa level Westerly wind speed
- 850hPa level Specific humidity

Winter (May-Oct) 3 weather states, 4 atmospheric predictors:

- Northeast-Southwest gradient in MSLP
- East-West gradient in 850hPa level Westerly wind speed
- 700hPa level Specific humidity
- Total-totals (a measure of atmospheric stability)

Pilbara Summer (Nov-Apr) 5 weather states, 3 atmospheric predictors

- East-West gradient in MSLP
- 850hPa level Specific humidity
- 500hPa level Dewpoint temperature depression

Winter (May-Oct) 5 weather states, 4 atmospheric predictors

- MSLP
- 850hPa level Northerly wind speed
- 850hPa level Specific humidity
- 850hPa level Dewpoint temperature depression

Examples of the selected NHMM's reproduction of the observed rain gauge year-to-year rainfall variability are shown in Figures Figure 3 to Figure 6, for the driest and wettest rain gauges for each season for the Kimberley and Pilbara May-October and November-April seasons respectively. For the Kimberley region the May-October season is very dry and, although the NHMM can simulate a lot of the interannual variability, there are observed peaks that are underestimated (e.g., 1973, 1974, 1975, 1978, 1993, 1997 and 2004 for Fossil Downs in Figure 3). The interannual variability of the much wetter November-April season is much better captured (Figure 4). This confirms the applicability of the NHMM in a region where a lot of the rainfall events would be convectively, rather than synoptically, driven. For the Pilbara region, overall the NHMMs perform well for both seasons. There is underestimation of several wet peaks for Carnarvon in November-April (the dry station for this season, Figure 6) in the 1960s, 1974 and 1999, likely related to intense short lived weather systems not well captured by the NHMM predictors.

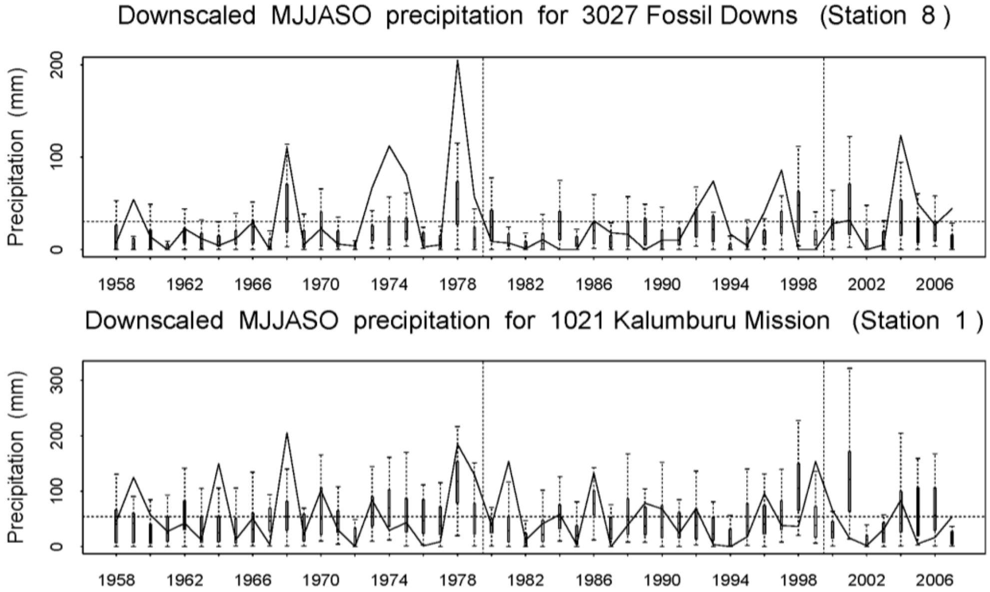


Figure 3 Observed (solid line) vs downscaled (box-plots) May-October precipitation amounts for driest (upper plot) and wettest (lower plot) Kimberley NHMM rain gauges. The box–plots depict the range of 100 simulation trials (the edges of the box represent the 25 percentile and the 75 percentile of the simulations). The horizontal dashed line is the long term observed mean. The vertical dashed line delineates the calibration period (1980 to 1999) from the validation period.

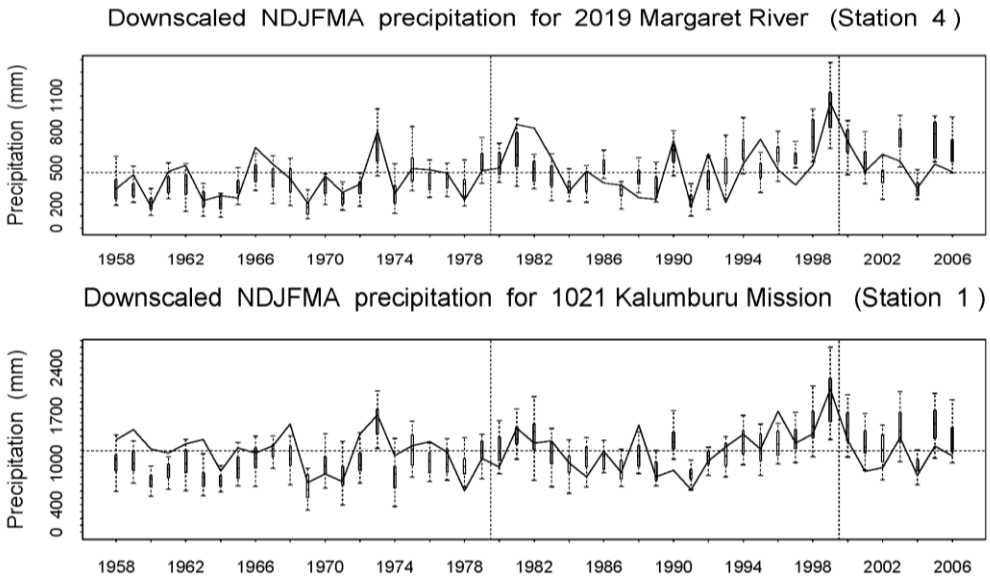


Figure 4 Observed (solid line) vs downscaled (box-plots) November-April precipitation amounts for driest (upper plot) and wettest (lower plot) Kimberley NHMM rain gauges. The box–plots depict the range of 100 simulation trials (the edges of the box represent the 25 percentile and the 75 percentile of the simulations). The horizontal dashed line is the long term observed mean. The vertical dashed line delineates the calibration period (1980/1 to 1999/2000) from the validation period.

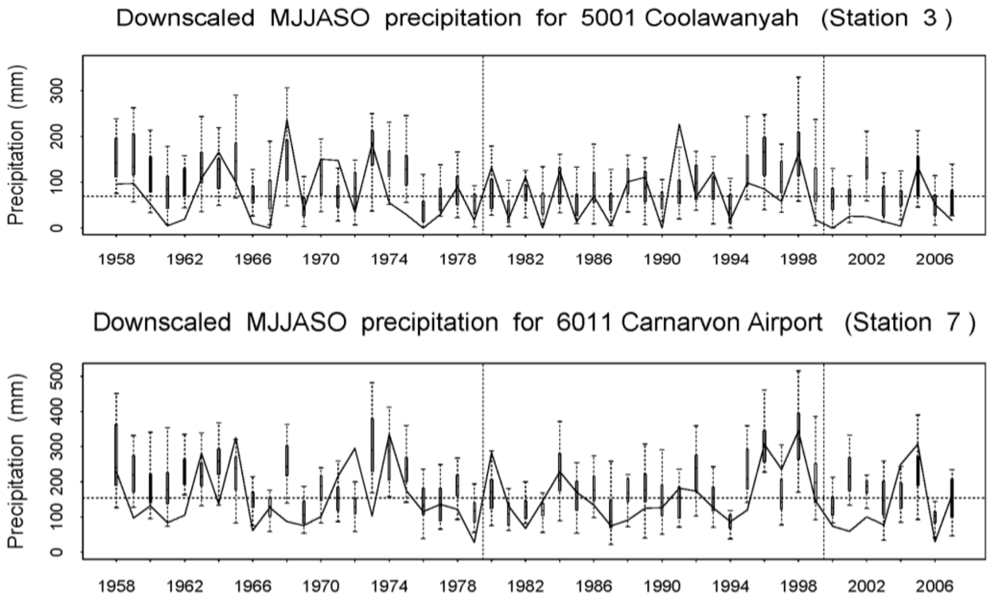


Figure 5 Observed (solid line) vs downscaled (box-plots) May-October precipitation amounts for driest (upper plot) and wettest (lower plot) Pilbara NHMM rain gauges. The box–plots depict the range of 100 simulation trials (the edges of the box represent the 25 percentile and the 75 percentile of the simulations). The horizontal dashed line is the long term observed mean. The vertical dashed line delineates the calibration period (1980 to 1999) from the validation period.

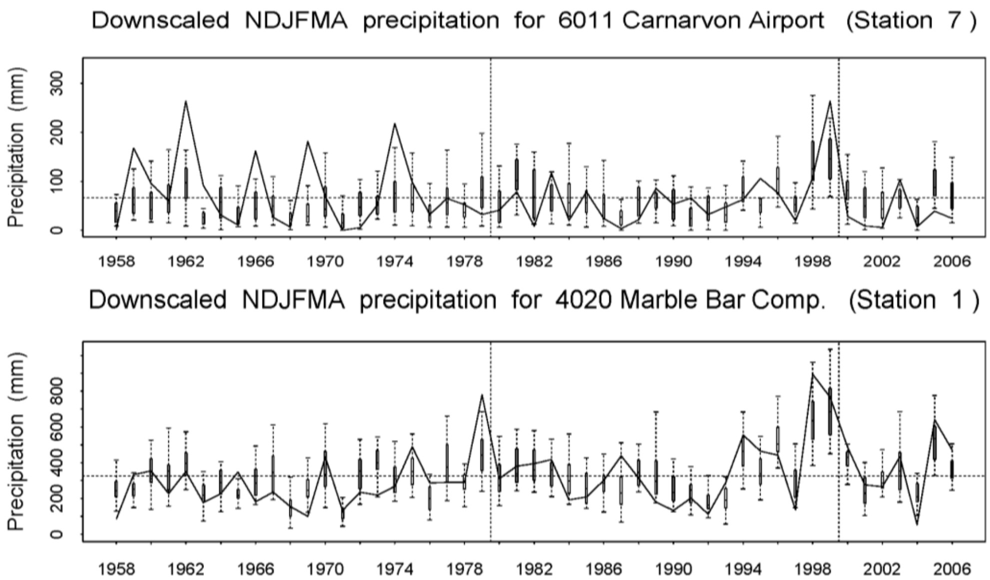


Figure 6 Observed (solid line) vs downscaled (box-plots) November-April precipitation amounts for driest (upper plot) and wettest (lower plot) Pilbara NHMM rain gauges. The box–plots depict the range of 100 simulation trials (the edges of the box represent the 25 percentile and the 75 percentile of the simulations). The horizontal dashed line is the long term observed mean. The vertical dashed line delineates the calibration period (1980/1 to 1999/2000) from the validation period.

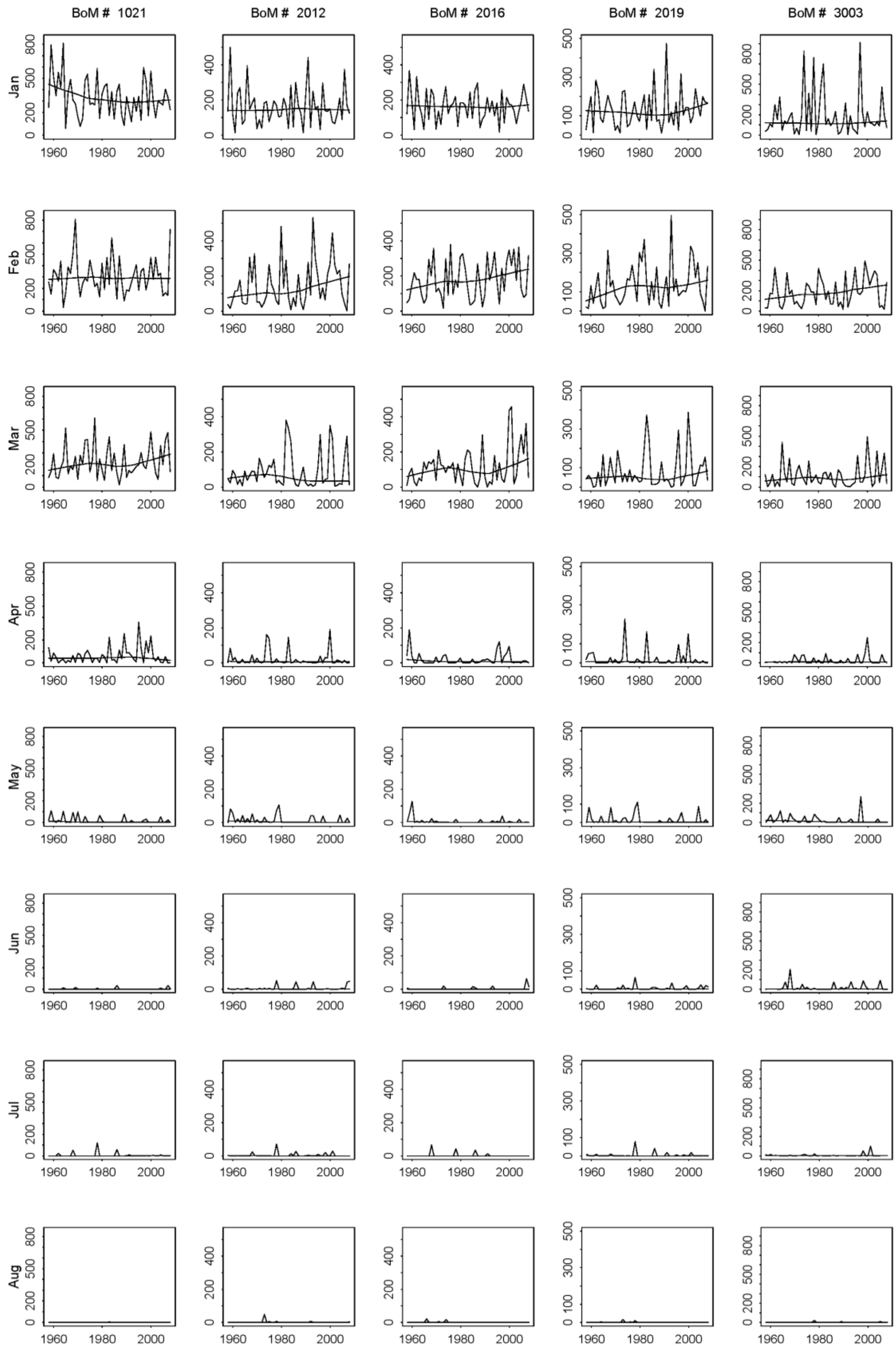
Milestone 2.3.3. Assessment of temporal trends in weather states and at-site rainfall statistics

The strong seasonality in Kimberley rainfall is highlighted in the rain gauge monthly rainfall time-series (Figure 7 and Figure 8) with a large proportion of annual rainfall occurring in December-March period encompassed within the November-April NHMM calibration season. Thus the 3-State May-October Kimberley NHMM is dominated by the dry State 2 occurring on 88.5% of days (Figure 11). Although there is large interannual variability, there does not appear to be strong trends in the May-October weather state frequencies overall (Figure 15) or on a monthly basis (Figure 17). The corresponding monthly atmospheric predictor time-series (Figure 23) indicate a gradual increase in the Northeast minus Southwest mean sea level pressure (MSLP) gradient for all May-October months. There is also some indication of increasing East minus West 850 hPa level westerly wind gradient in May-August with 700 hPa level specific humidity and total-totals decreasing for these months. There is a slight contrast of increasing specific humidity and total-totals trends for the September and October months (Figure 23).

For the November-April Kimberley NHMM (5-states, Figure 12) the driest state (State 5) occurs only 21.4% of days. The dominant state (State 3, 39% of days) is the second driest of the five states. The overall weather state frequency time-series (Figure 16) show an increasing trend for the three wetter states (States 1, 2 and 4) and corresponding decreased frequency for the drier states (States 3 and 5). The picture is more complicated when examining state trends on a monthly basis. Corresponding with observed rain gauge monthly trends (Figure 7 and Figure 8), there are noticeable increases in the wet states and decreases in the dry states for December. This perhaps indicates earlier breaks to the season and decreases for the dry states in March indicate longer wet seasons (Figure 18). These trends correspond with increased 850 hPa level specific humidity (i.e. the quantity of moisture in the lower atmosphere) seen for these months (Figure 24). It will be interesting to see, in the next phase of research undertaken in this project, whether downscaling from historically forced GCMs produces similar trends.

The Pilbara also has an extensive dry season, although not as distinct as that of the Kimberley region (contrast Figure 7 and Figure 8 with Figure 9 and Figure 10). The drier May-October season NHMM weather states are shown in Figure 13, with the driest state (State 2) occurring on 81.4% of days. There is an increasing trend for the dry state and a slight decrease in the wettest state (State 4) although this state has a low mean frequency, occurring only 1.8% of days (Figure 19). Monthly weather state trends show the increase in the dry state has occurred early in the season (May to July; Figure 21). Correspondingly MSLP and 850 hPa level dewpoint temperature depression (DTD, a measure of how close to saturation the lower atmosphere is) have both increased for these months (Figure 25).

For the November-April Pilbara NHMM, the driest state (State 3 of 5) is also dominant occurring on 66.7% of days (Figure 14). The frequency of this dry state has decreased since about 1990 with wetter states (particularly State 4 which is wettest for the north Pilbara gauges) increasing in frequency (Figure 20). The monthly trends show the dry state decrease in March and April (Figure 22) could indicate longer tropical wet seasons, as was the case for the Kimberley. The increasing trends in February to April 850 hPa level specific humidity and (less pronounced) decreasing February and March 500 hPa level DTD are consistent with the weather state trends, although April DTD increases indicating a less saturated upper atmosphere for this month (Figure 26).


BoM # 1021
BoM # 2012
BoM # 2016
BoM # 2019
BoM # 3003
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
1960
1980
2000

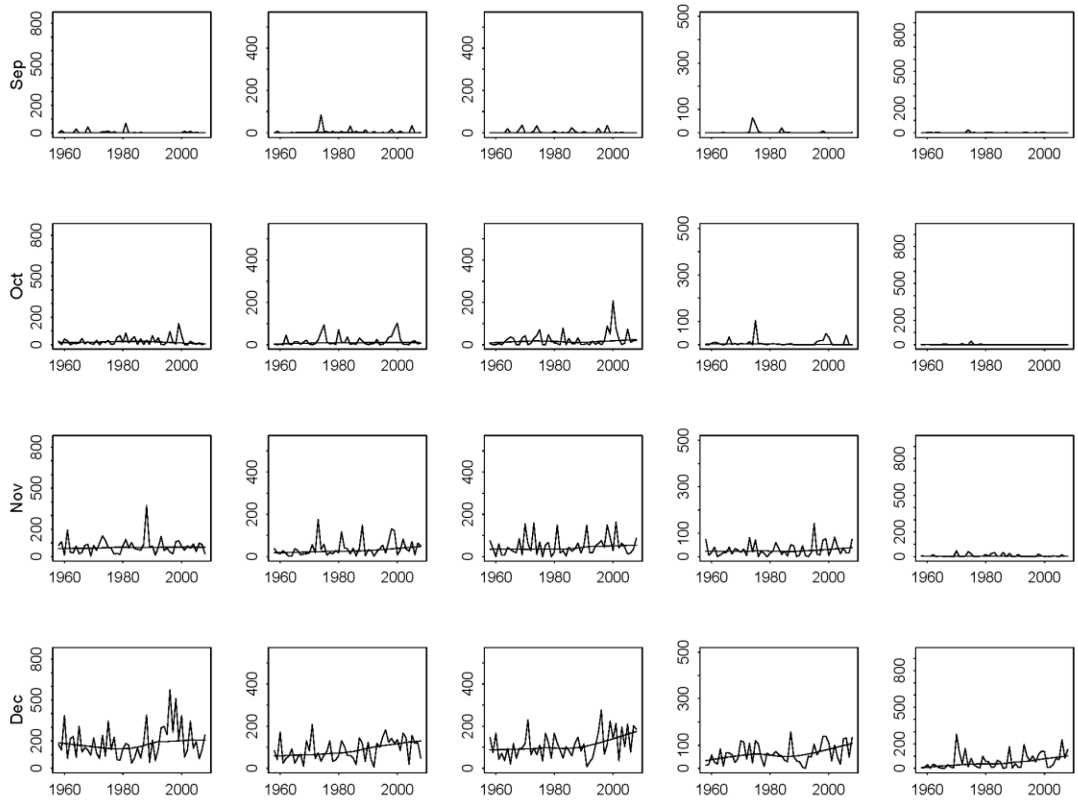
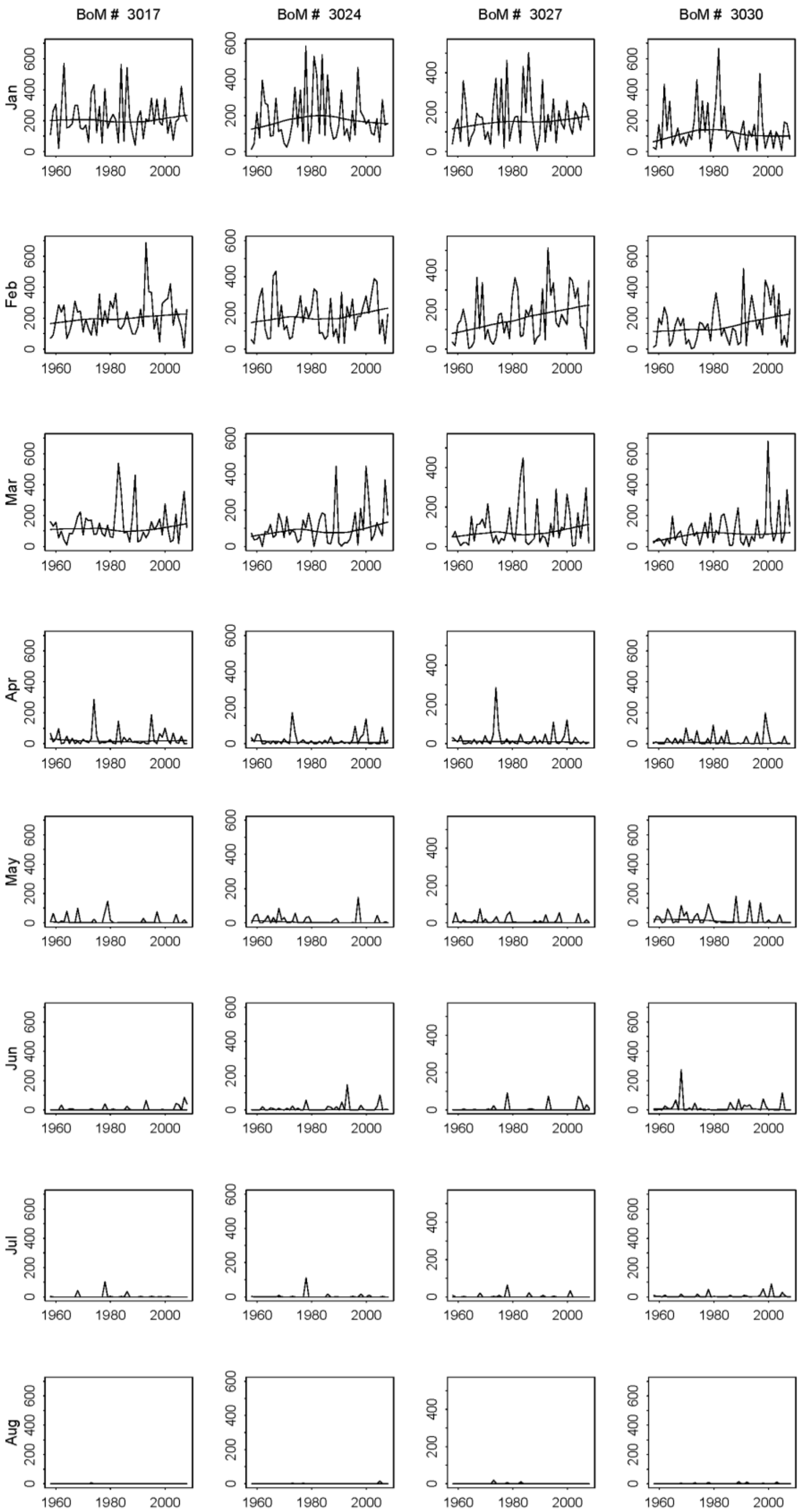


Figure 7 Monthly time-series of Kimberley gauge rainfall (Stations 1 to 5).


BoM # 3017
BoM # 3024
BoM # 3027
BoM # 3030
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
0
200
400
600
1960
1980
2000

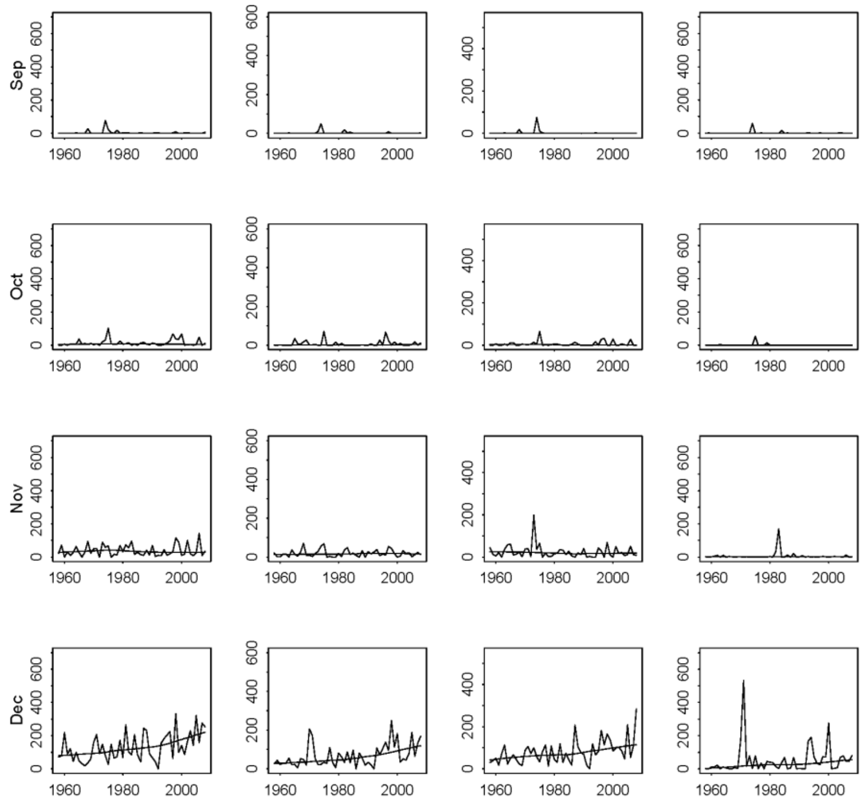
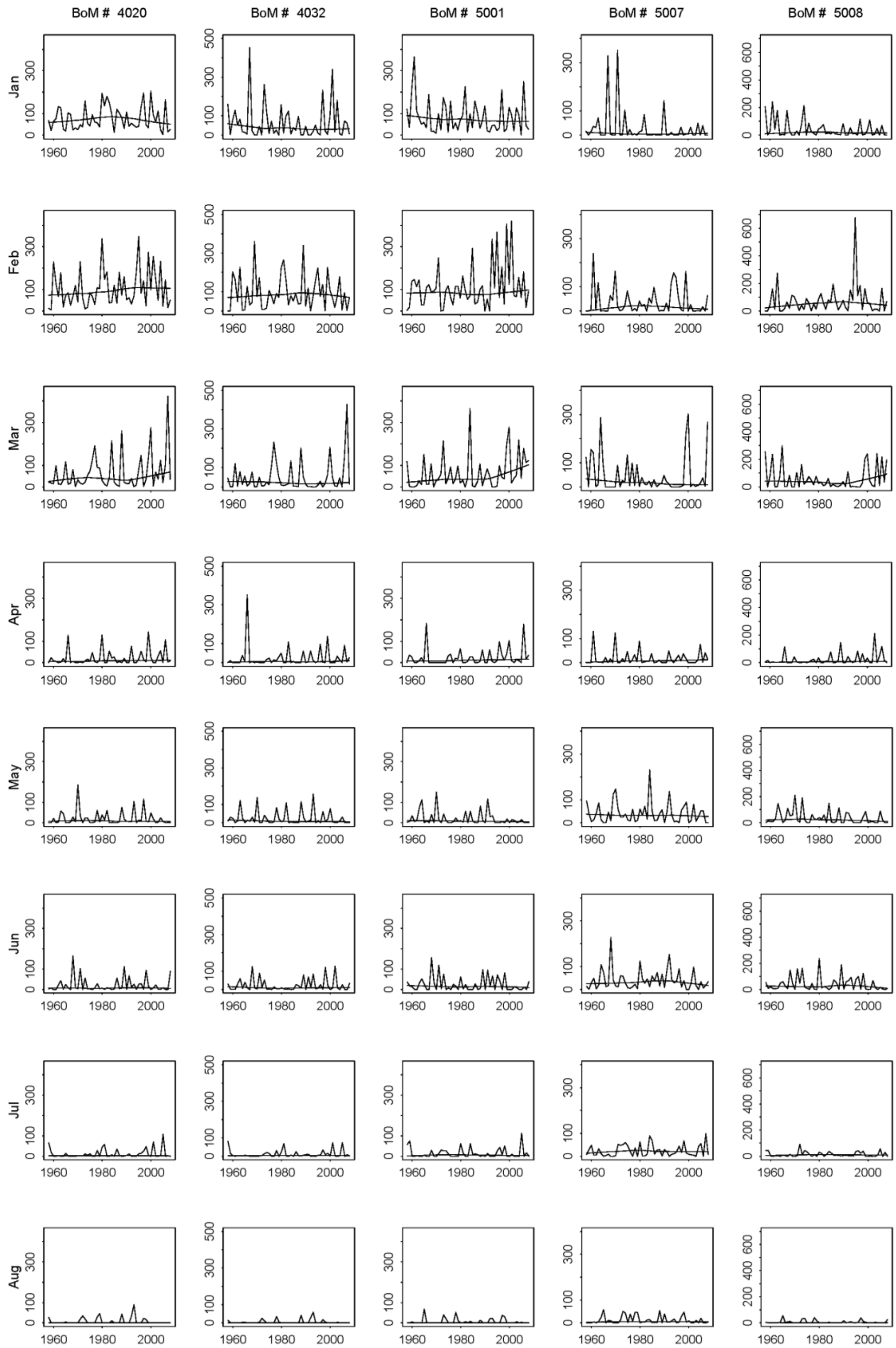


Figure 8 Monthly time-series of Kimberley gauge rainfall (Stations 6 to 9).


BoM # 4020
BoM # 4032
BoM # 5001
BoM # 5007
BoM # 5008
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
1960
1980
2000

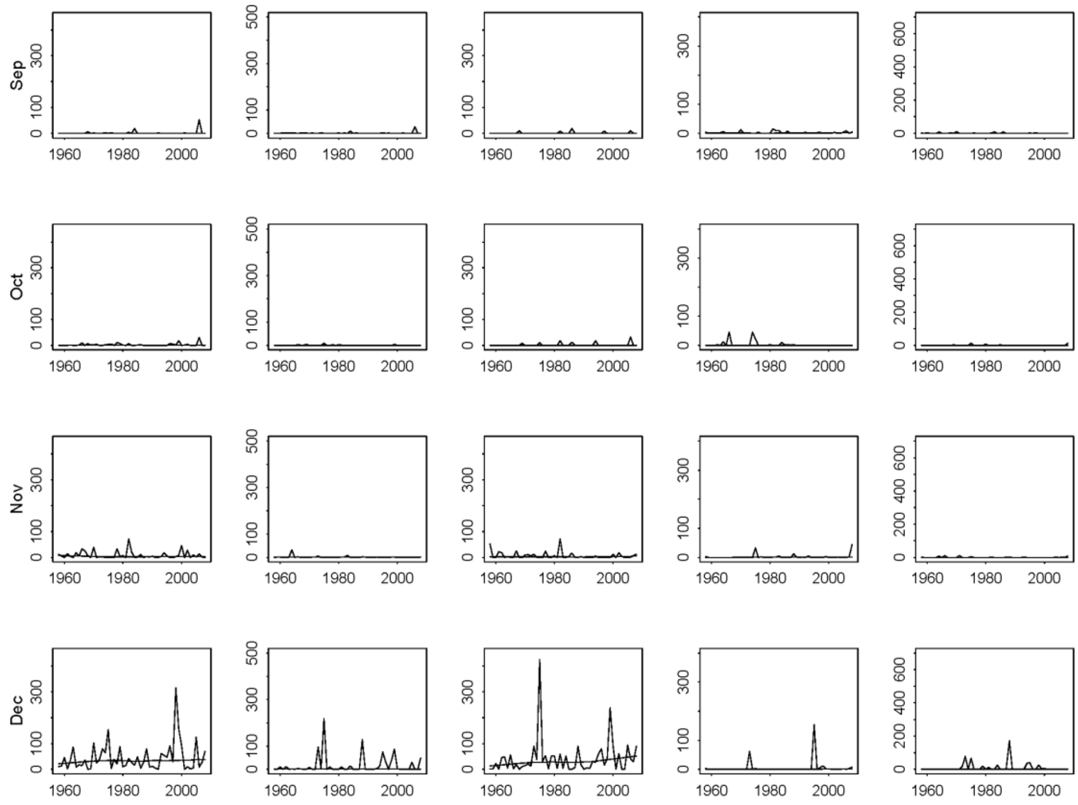
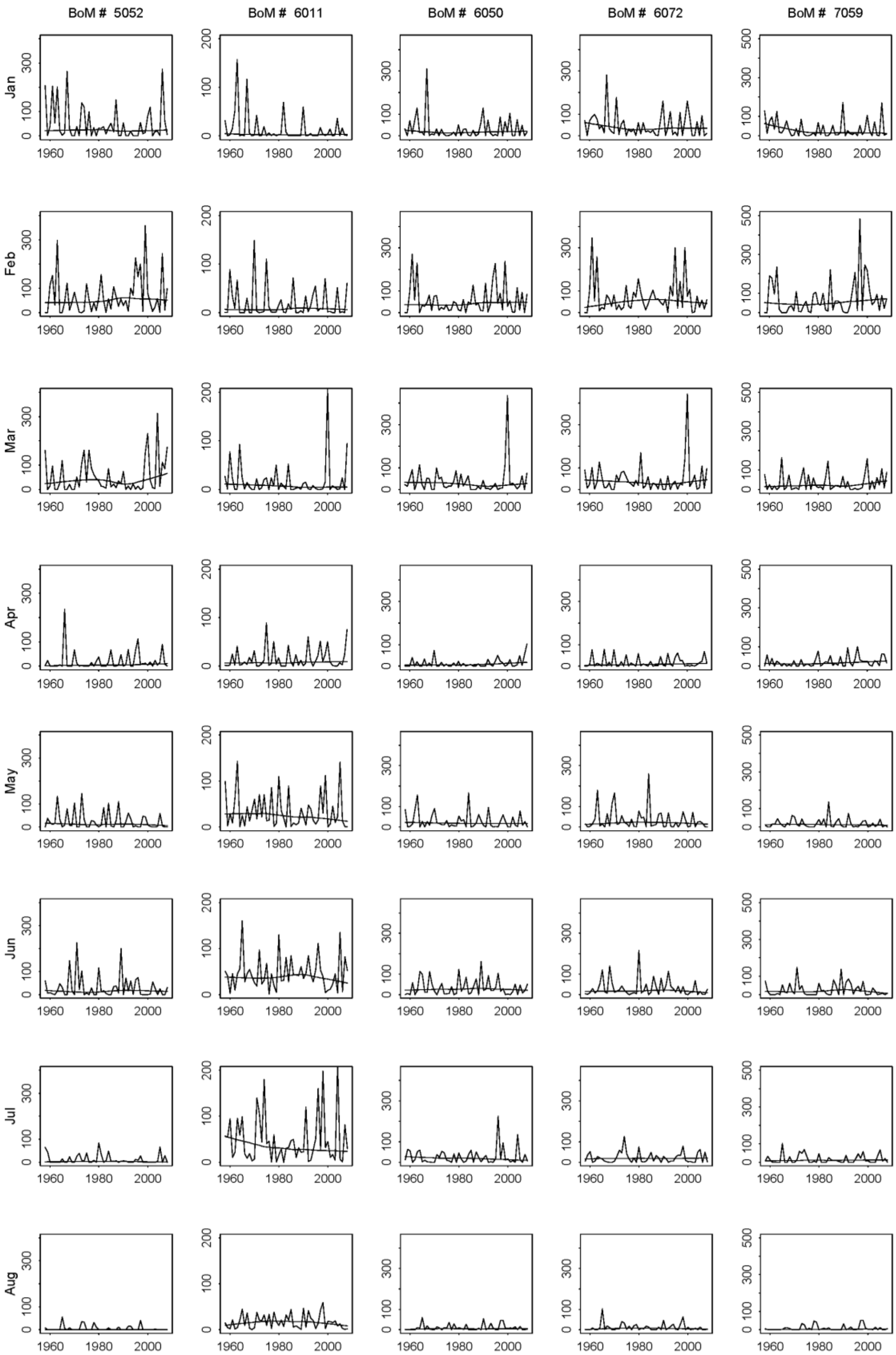


Figure 9 Monthly time-series of Pilbara gauge rainfall (Stations 1 to 5).


BoM # 5052
BoM # 6011
BoM # 6050
BoM # 6072
BoM # 7059
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
1960
1980
2000

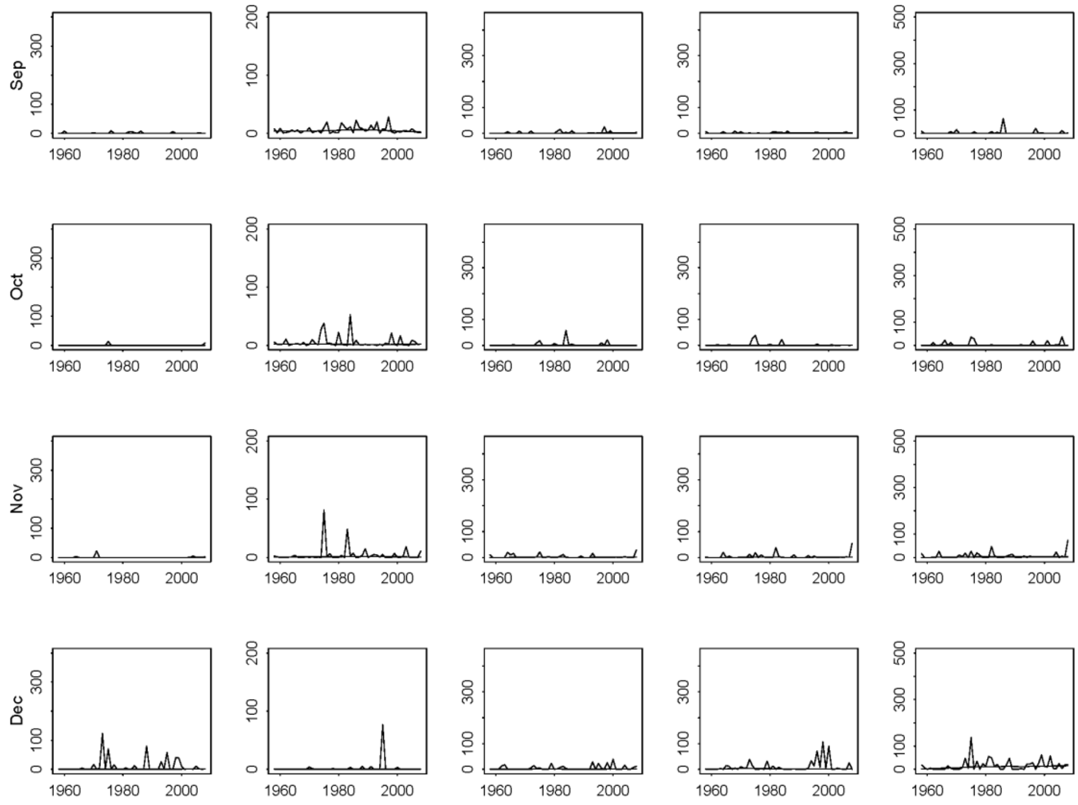


Figure 10 Monthly time-series of Pilbara gauge rainfall (Stations 6 to 10).

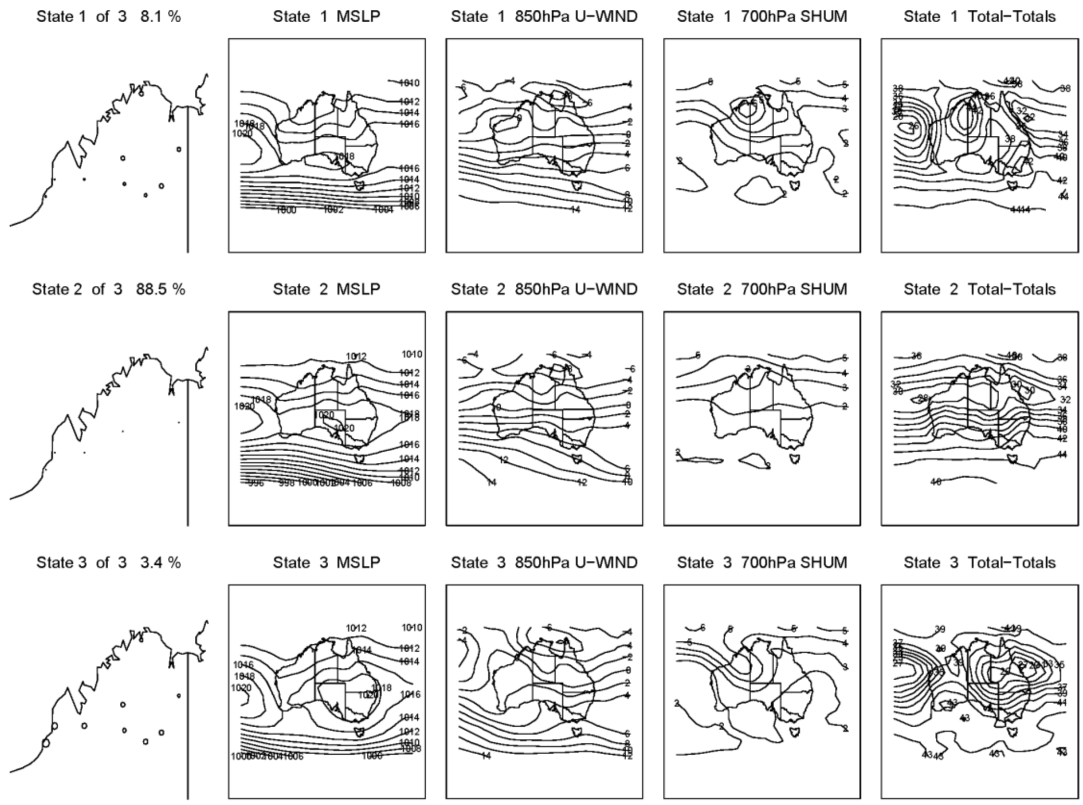


Figure 11
Kimberley May-October NHMM rainfall weather states (diameters of circles proportional to probability of a wet-day) and associated atmospheric predictor fields.

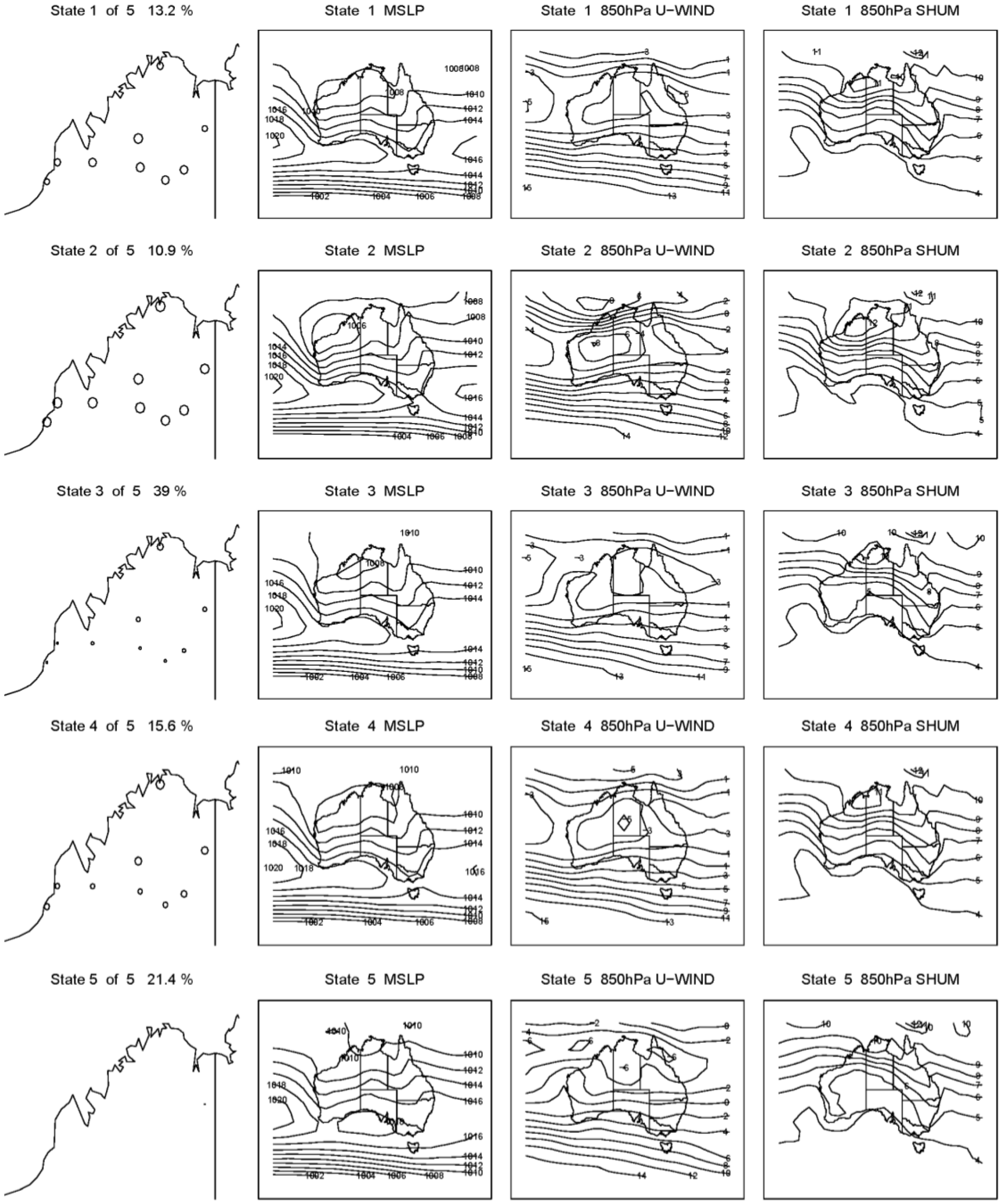


Figure 12 Kimberley November-April NHMM rainfall weather states (diameters of circles proportional to probability of a wet-day) and associated atmospheric predictor fields.

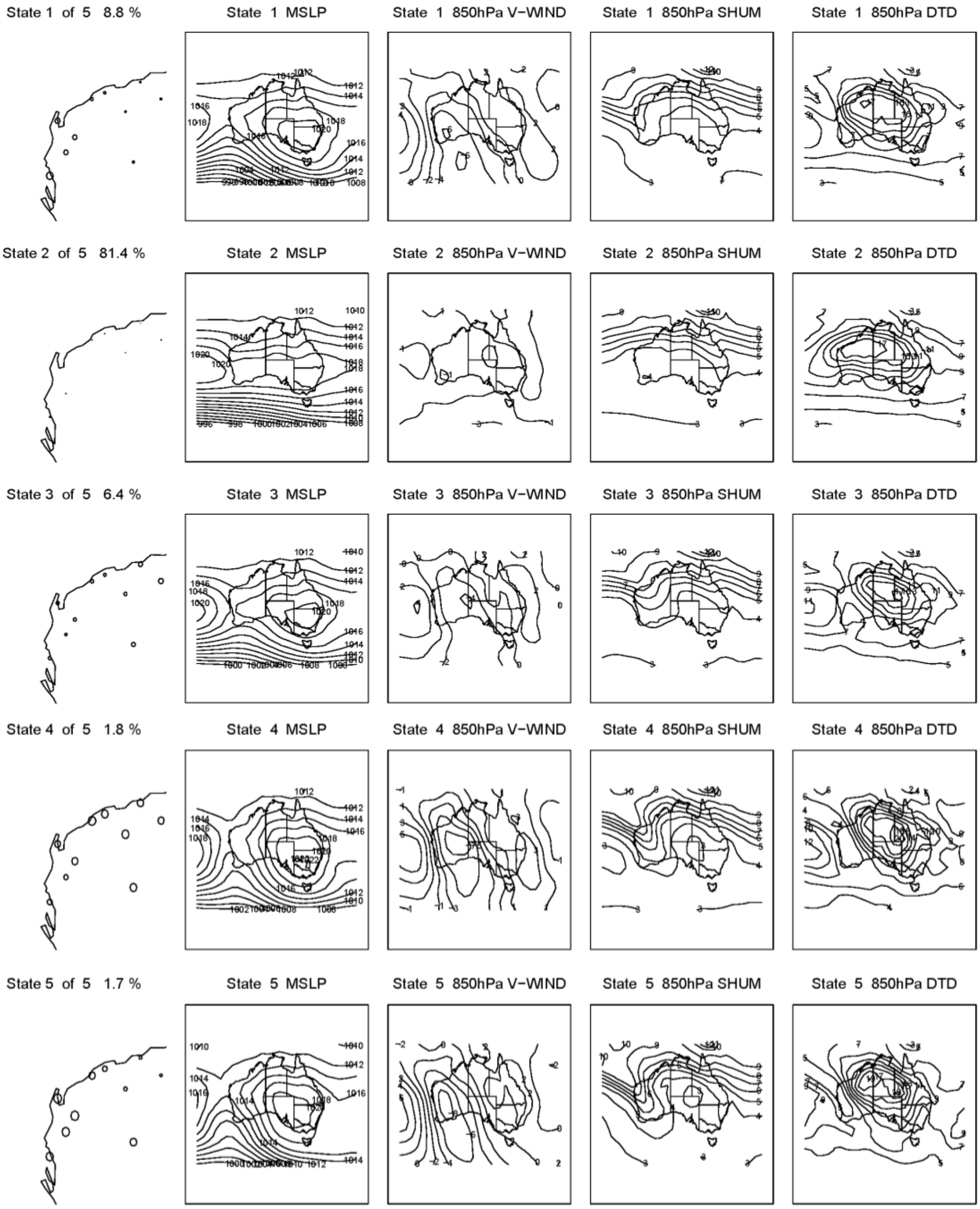


Figure 13 Pilbara May-October NHMM rainfall weather states (diameters of circles proportional to probability of a wet-day) and associated atmospheric predictor fields.

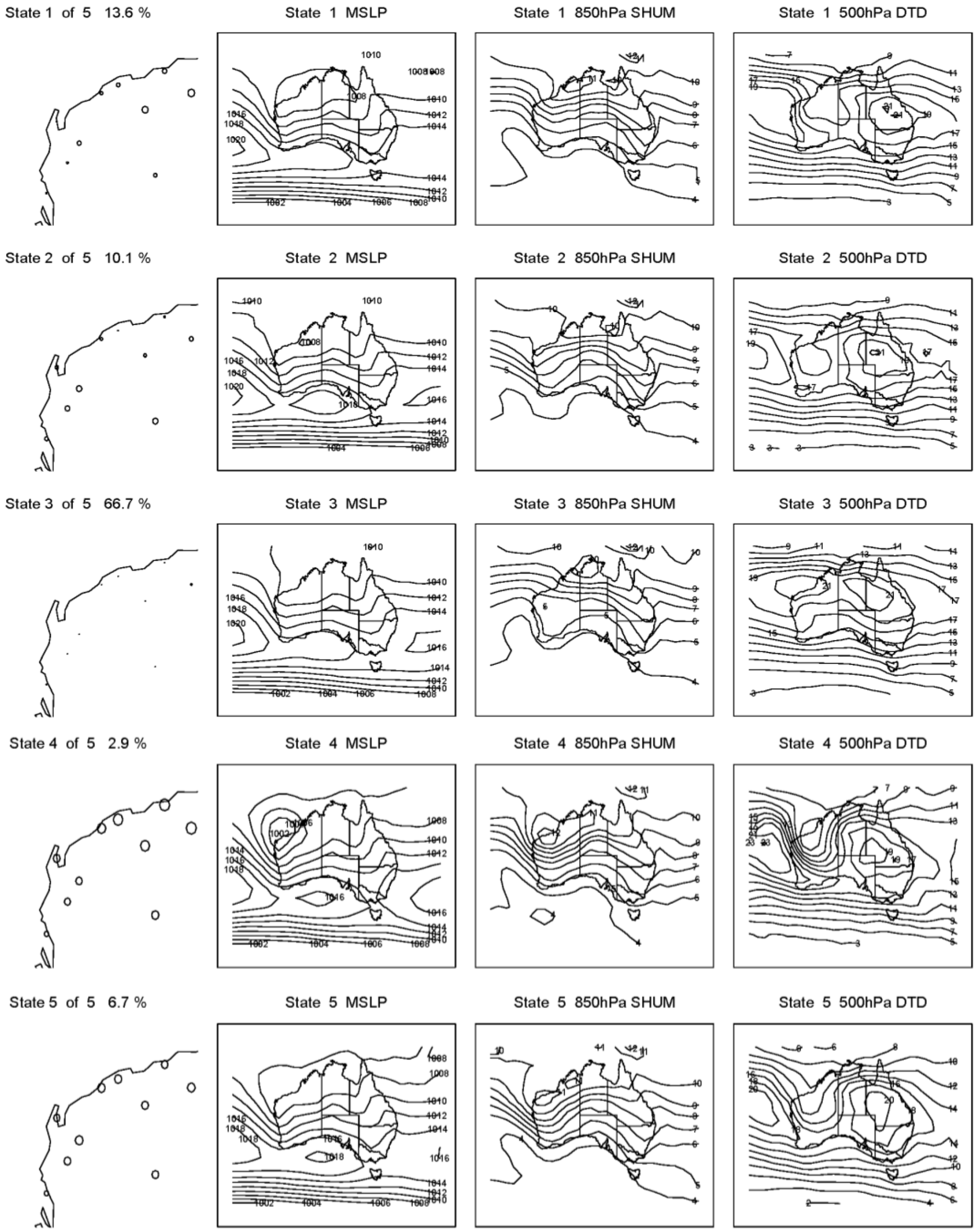


Figure 14 Pilbara November-April NHMM rainfall weather states (diameters of circles proportional to probability of a wet-day) and associated atmospheric predictor fields.

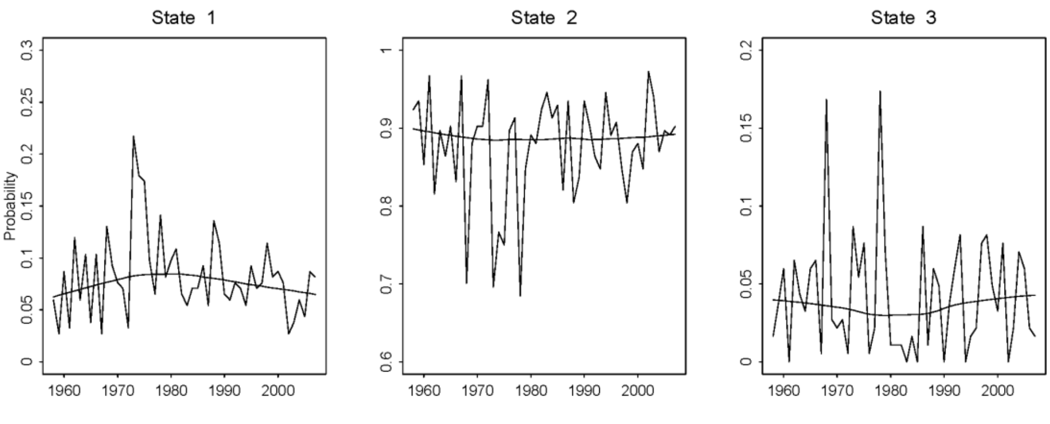


Figure 15 Annual time-series of the Kimberley May-October NHMM weather state probabilities.

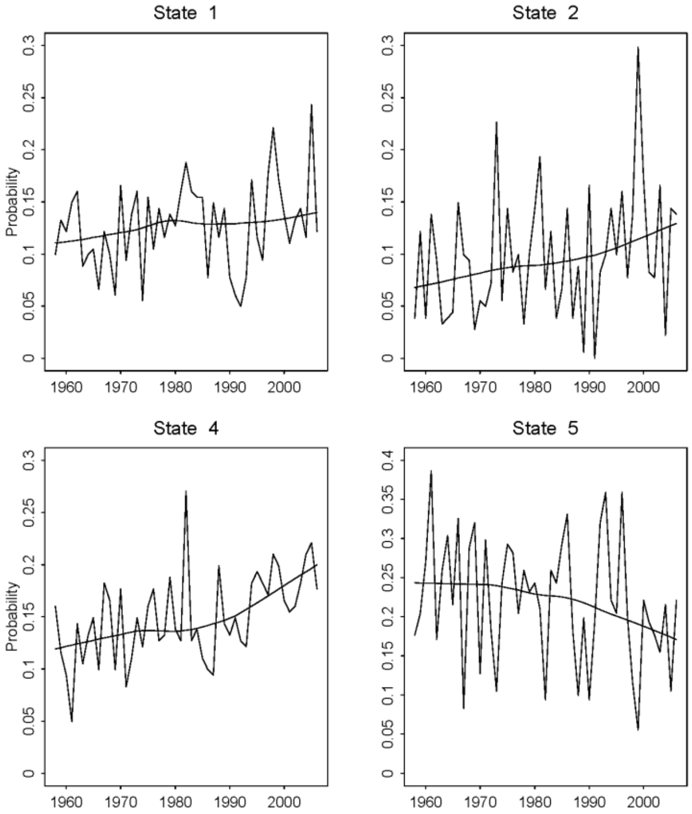


Figure 16

Annual time-series of the Kimberley November-April NHMM weather state probabilities.

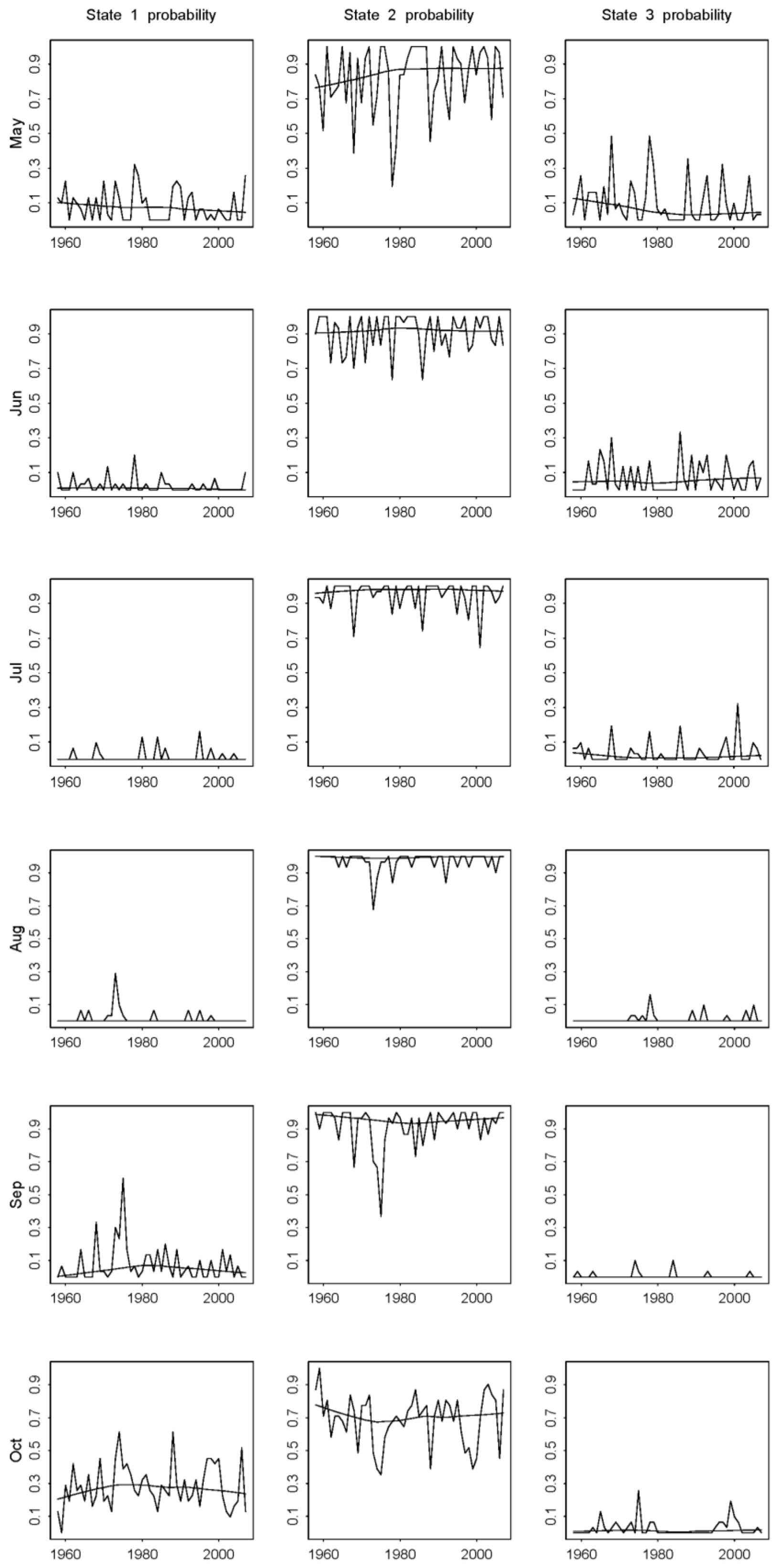


Figure 17

Monthly time-series of the Kimberley May-October NHMM weather state probabilities.

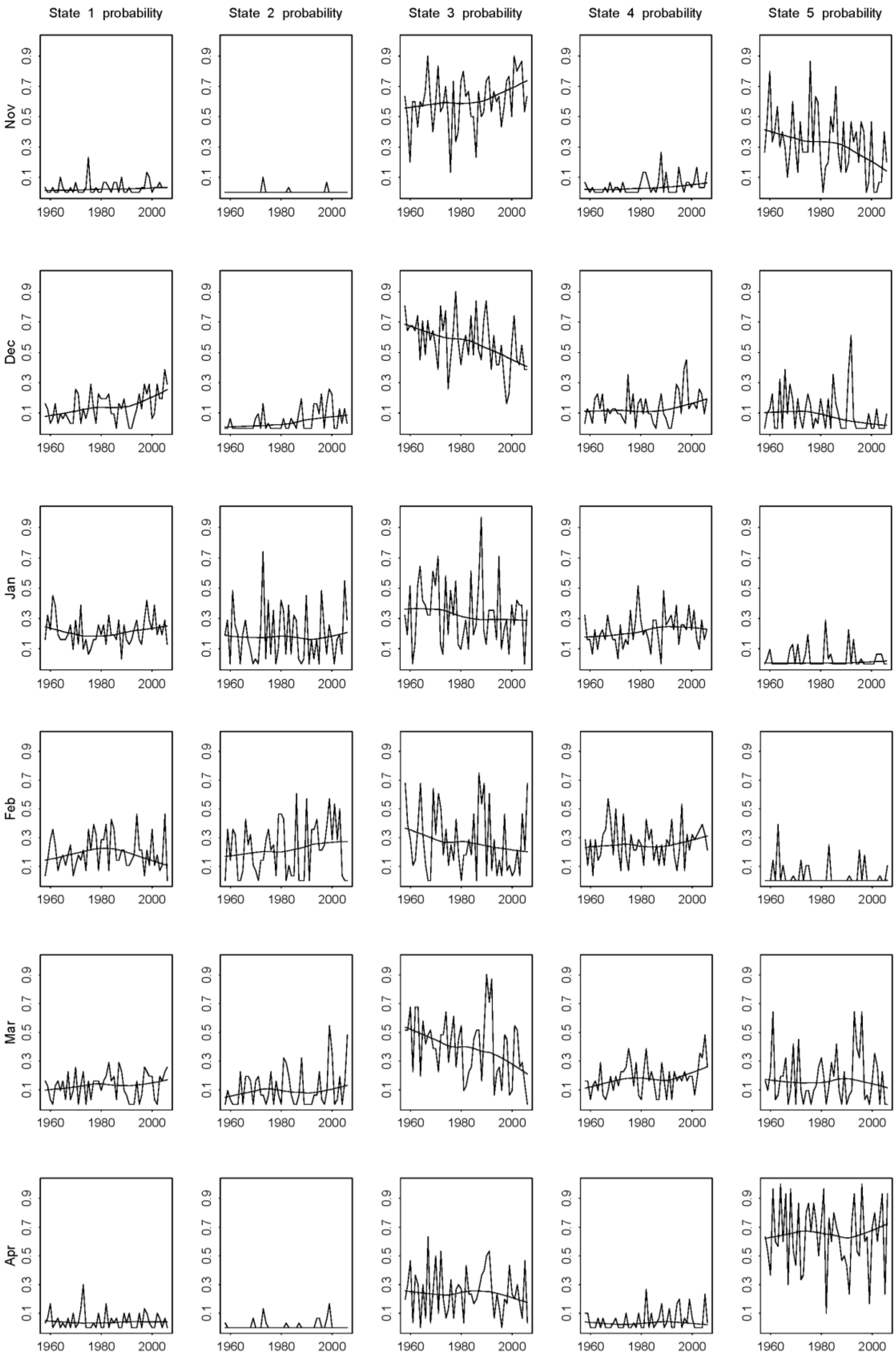


Figure 18 Monthly time-series of the Kimberley November-April NHMM weather state probabilities.

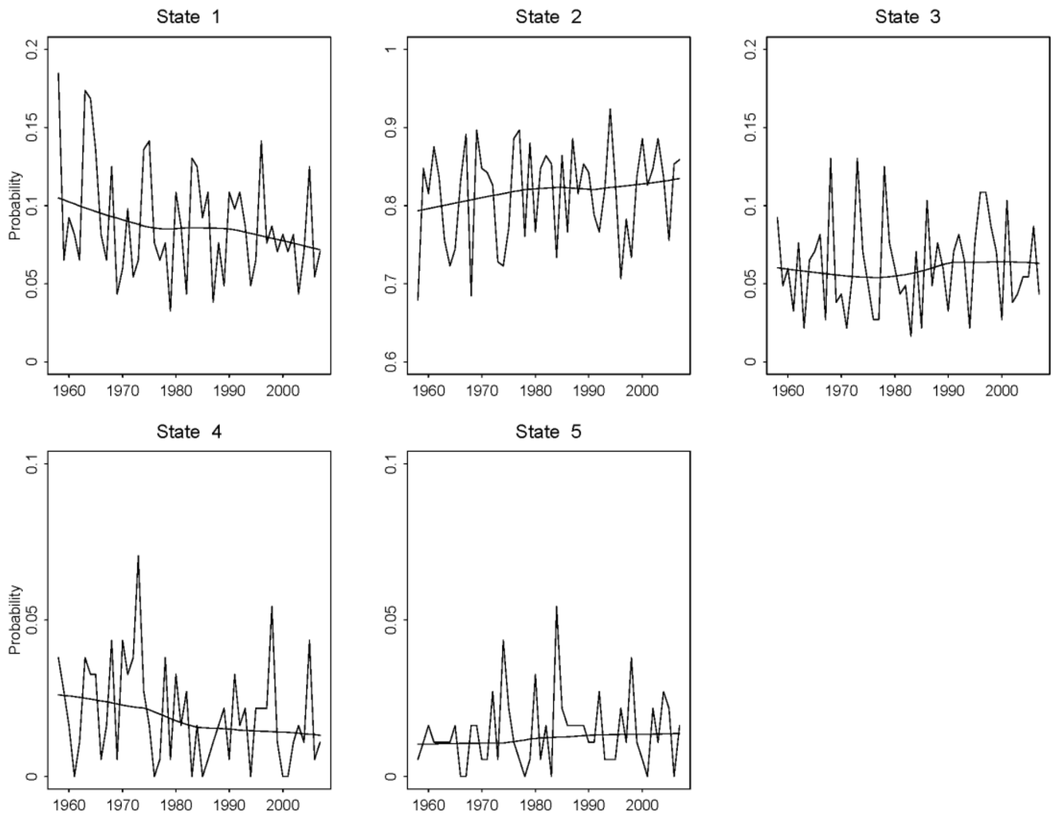


Figure 19 Annual time-series of the Pilbara May-October NHMM weather state probabilities.

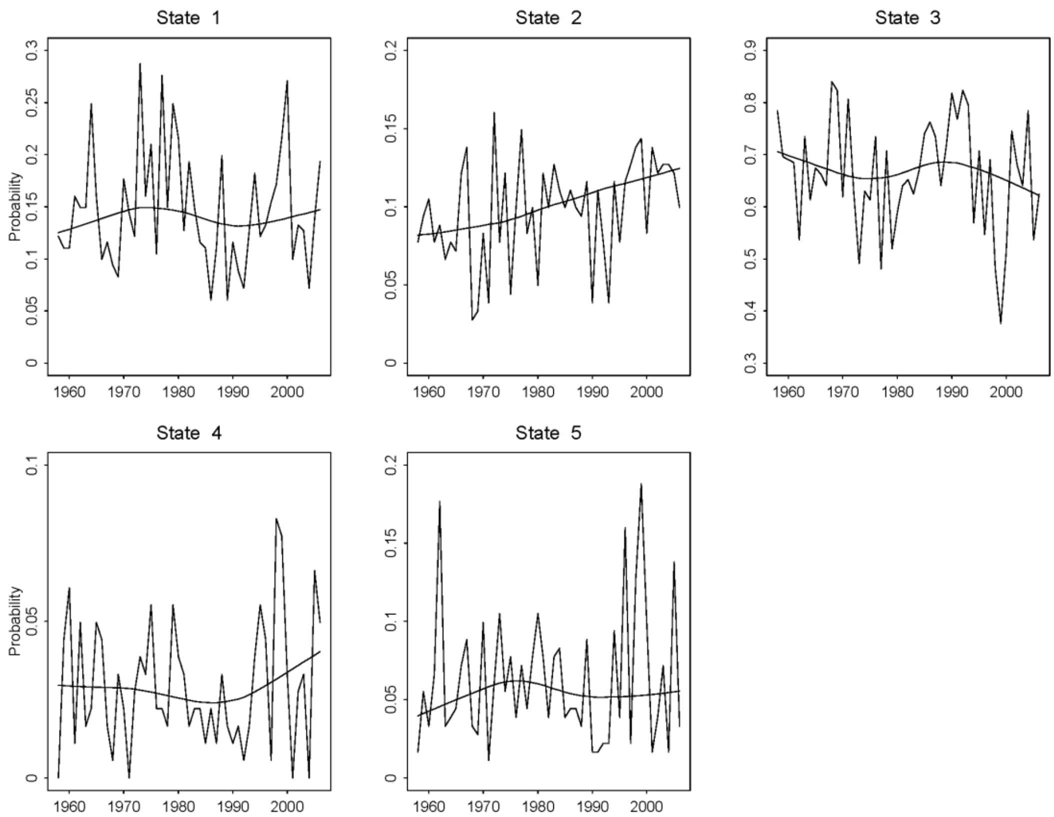


Figure 20 Annual time-series of the Pilbara November-April NHMM weather state probabilities.

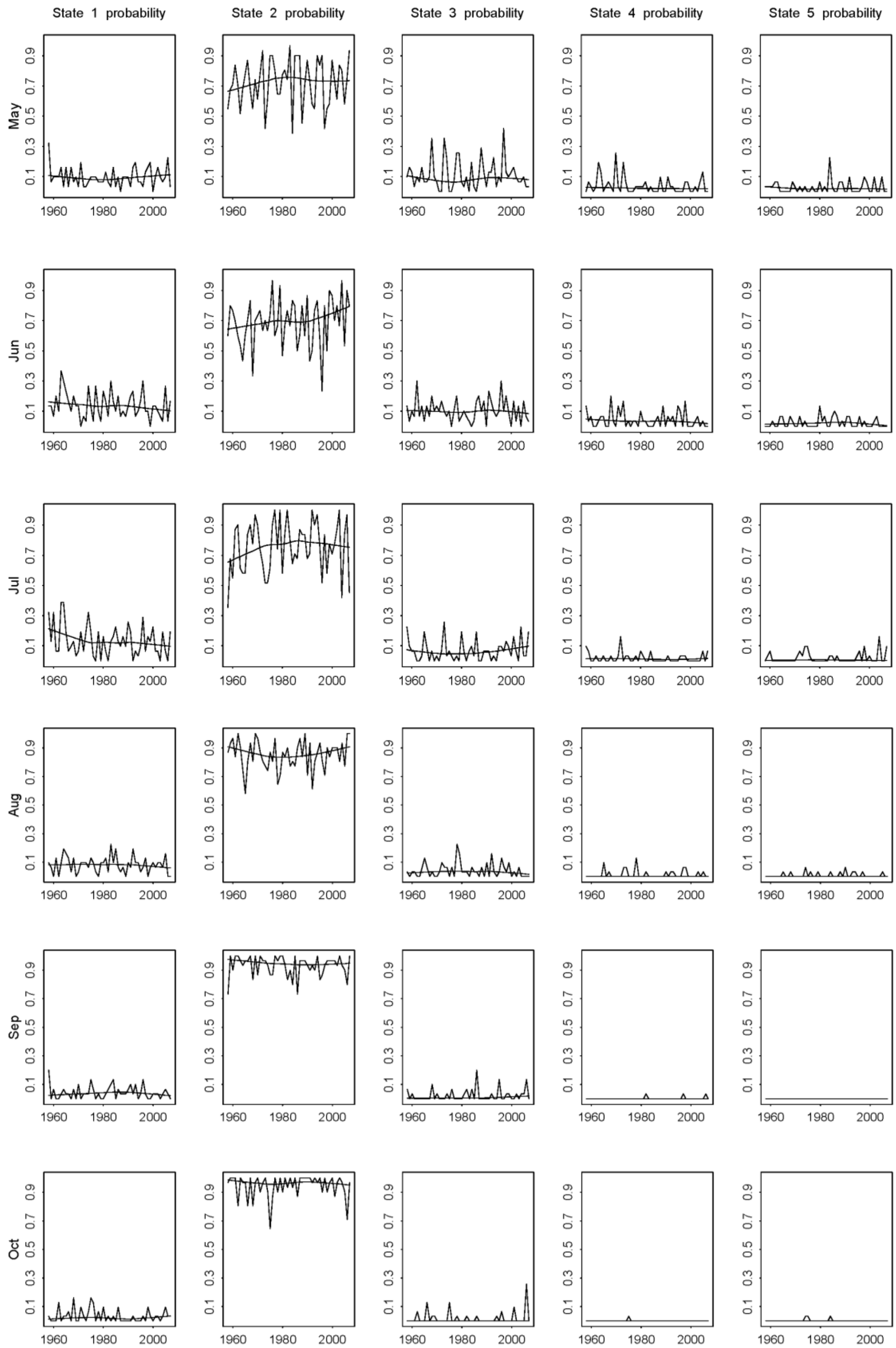


Figure 21 Monthly time-series of the Pilbara May-October NHMM weather state probabilities.

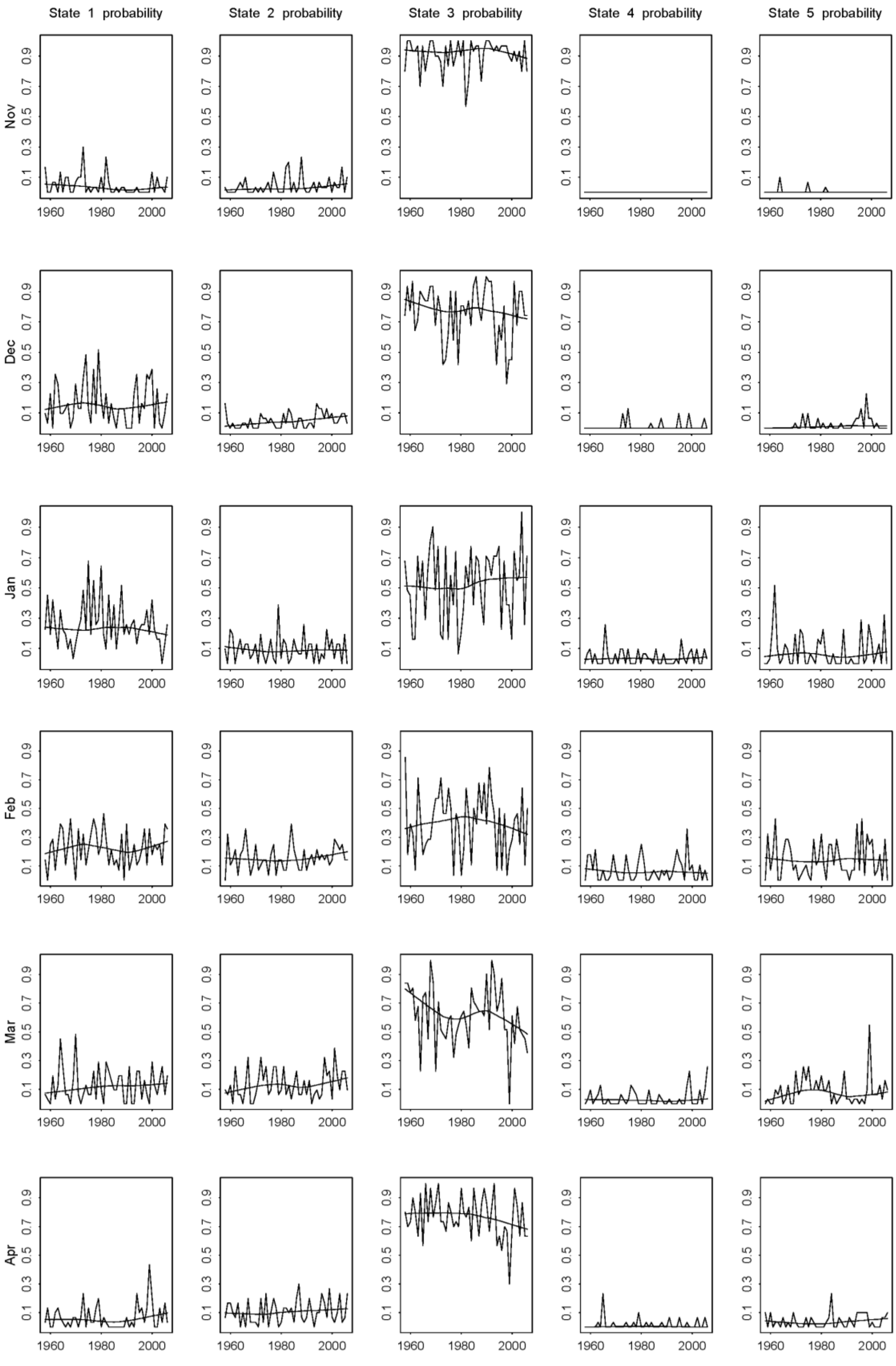


Figure 22 Monthly time-series of the Pilbara November-April NHMM weather state probabilities.

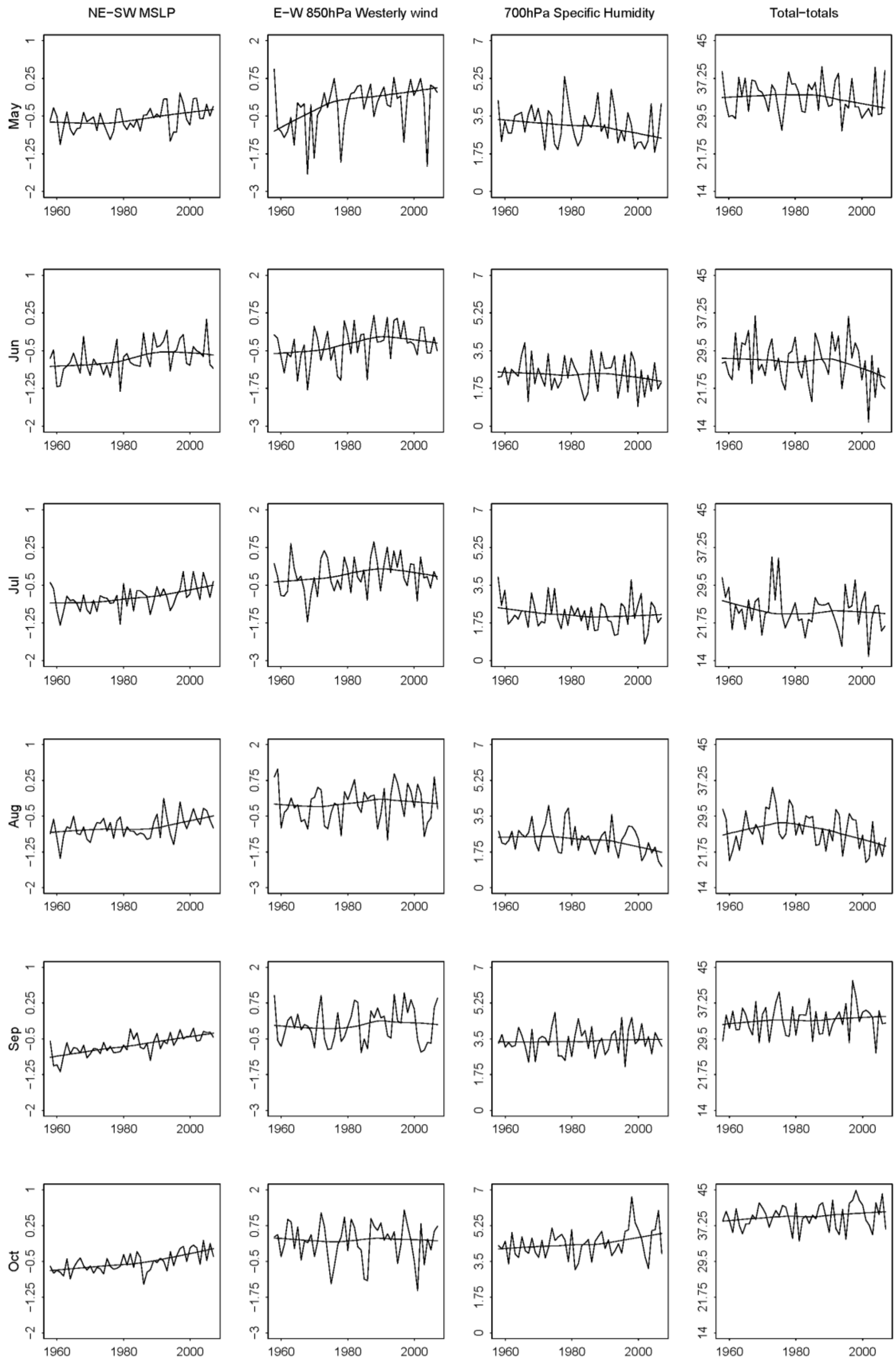


Figure 23 Monthly time-series of the Kimberley May-October NHMM atmospheric predictors. Units are hPa for MSLP, m/s for wind, g/kg for specific humidity. Total-totals in an index combining temperature and dew-point temperature as a measure of atmospheric instability.

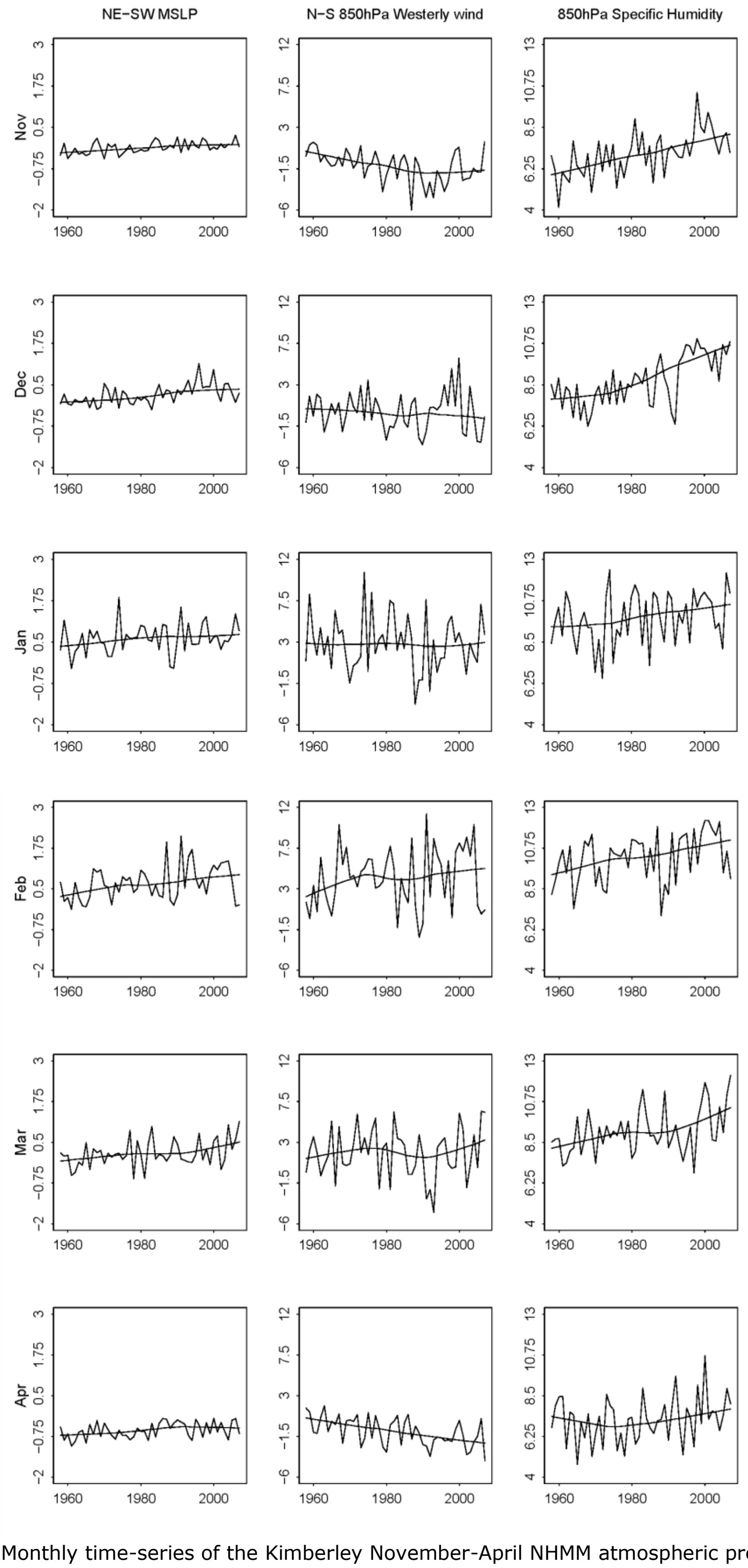


Figure 24
Monthly time-series of the Kimberley November-April NHMM atmospheric predictors. Units are hPa for MSLP, m/s for wind, g/kg for specific humidity.

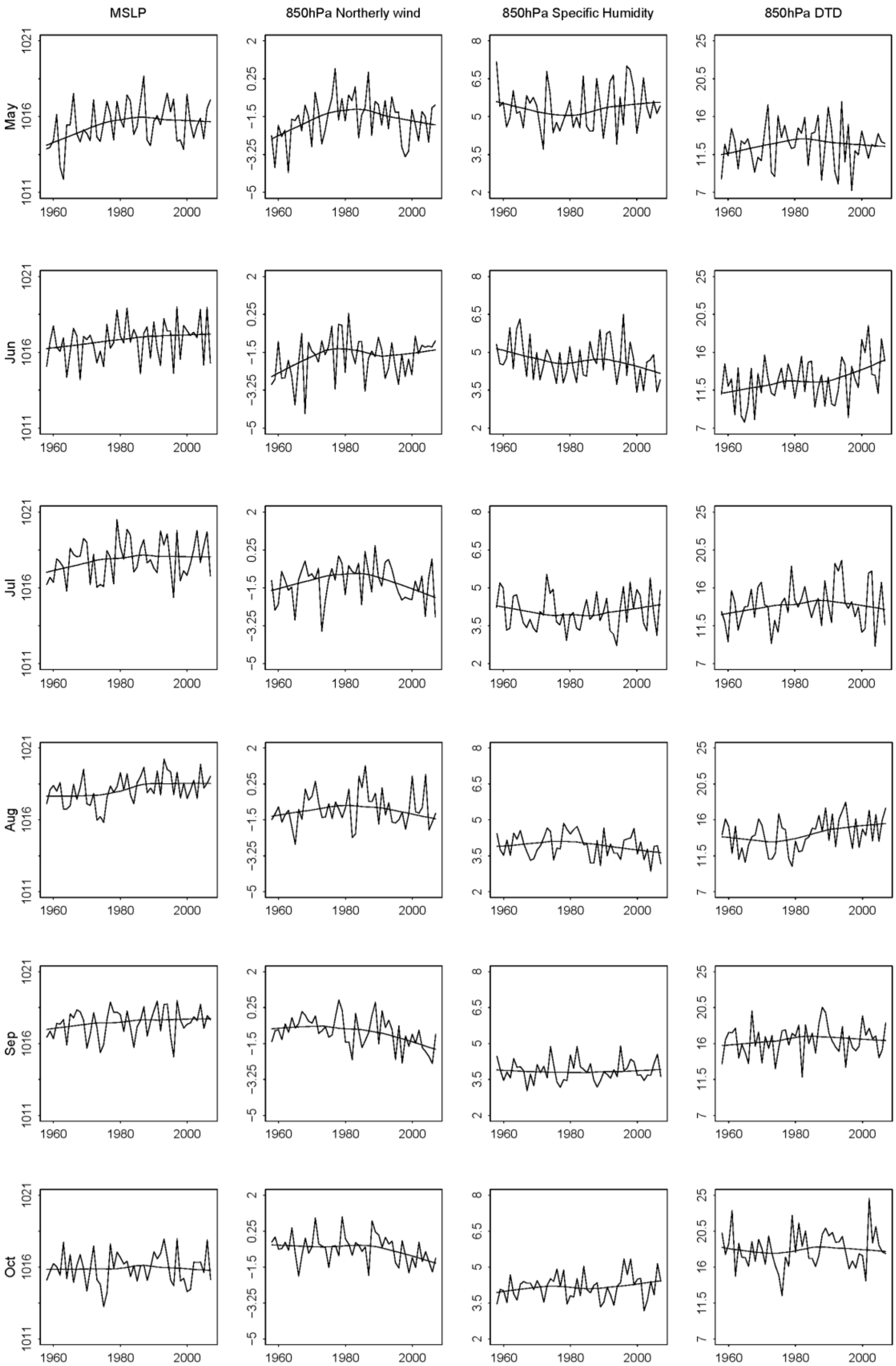


Figure 25 Monthly time-series of the Pilbara May-October NHMM atmospheric predictors. Units are hPa for MSLP, m/s for wind, g/kg for specific humidity and K for DTD (Dewpoint Temperature Depression).

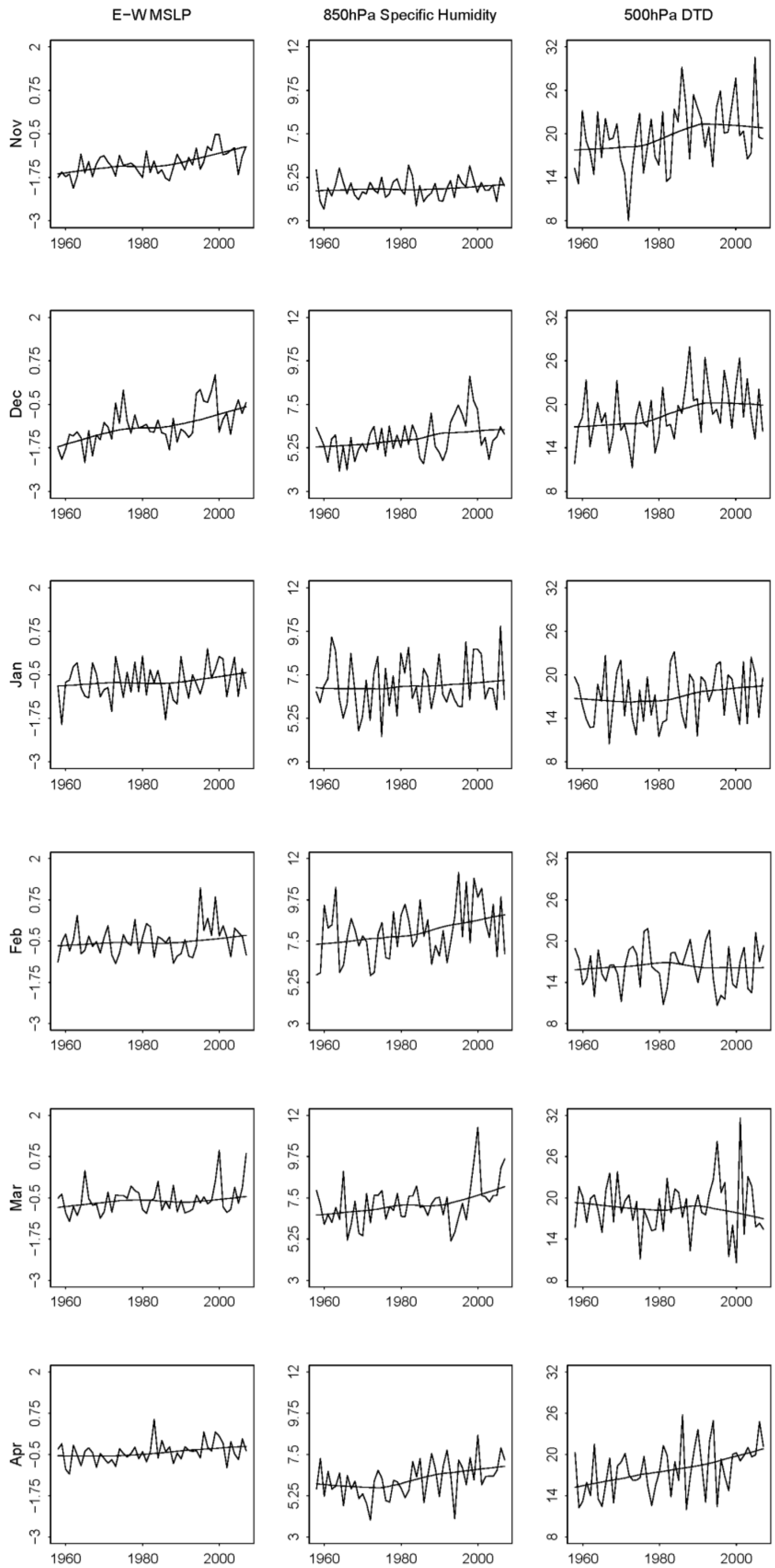


Figure 26 Monthly time-series of the Pilbara November-April NHMM atmospheric predictors. Units are hPa for MSLP, g/kg for specific humidity and K for DTD (Dewpoint Temperature Depression).

Milestone 2.3.4. Assessment of the ability of GCMs to simulate atmospheric predictors required for downscaling

The selection of GCMs based on assessment of their performance over the NW region is on-going, to be completed as part of Milestone 2.3.5 as outlined below. A minimum of five GCMs from the Intergovernmental Panel on Climate Change (IPCC) Assessment Report Four (AR4) are being investigated. These five are the GFDL 2.0 and 2.1, MIROC-medres, CSIRO Mk3.5, and MPI-ECHAM5 GCMs. The rationale on choosing these five was based on their performance in other assessment studies (e.g. see Milestone 3.1 report) and the availability of dynamically downscaled results from these GCMs using CSIRO's CCAM stretched-grid atmospheric global model (run at approximately 60km resolution over Australia). This will allow direct comparison between the NHMM statistically downscaled and CCAM dynamically downscaled projections.

The atmospheric predictors required by the Kimberley and Pilbara May-October and November-April NHMMs have been extracted from the five GCMs for the calibration period, and their distributions are compared to the NNR predictors in Figure 27 to Figure 30. Overall the reproduction of the majority of the required predictors by the majority of these GCMs appears reasonable. The next step is to assess their performance driving the NNR calibrated NHMMs in terms of reproducing weather state and rain gauge statistics of the calibration period (Milestone 2.3.5). Seasonal and monthly bias correction of means and variances will be assessed to determine how best to correct for the GCM biases seen in Figure 27 to Figure 30.

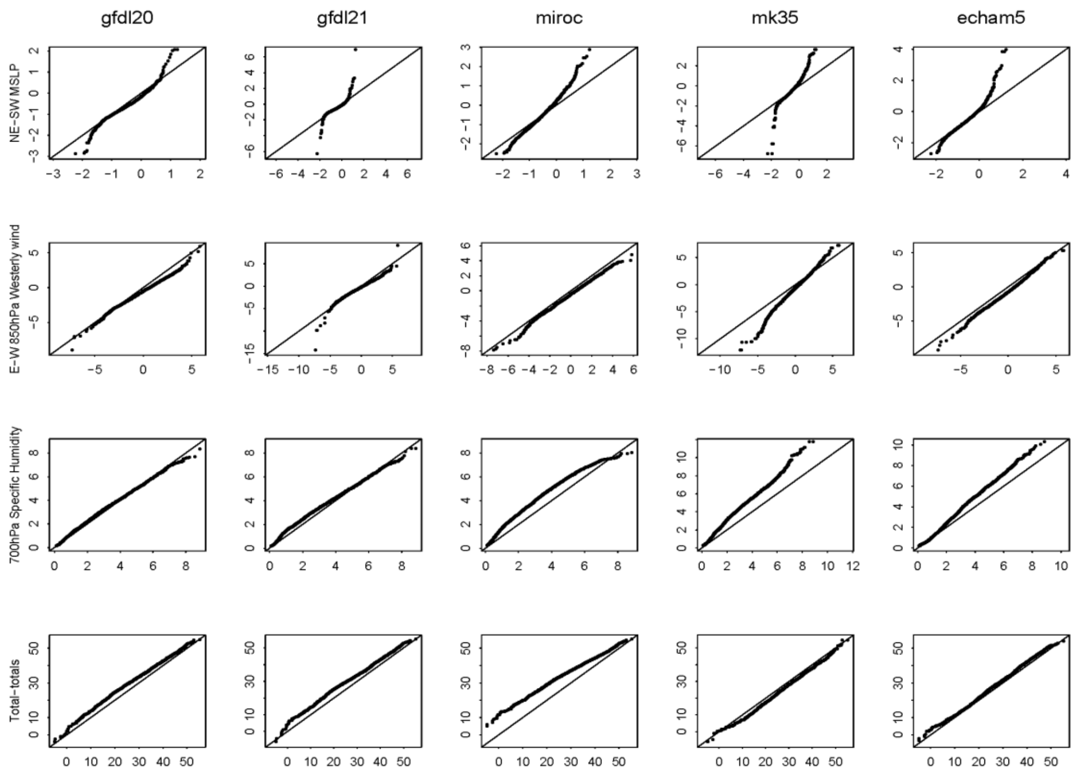


Figure 27 Quantile-quantile plots (i.e. the distributions of two series plotted against each other) for NNR (x-axis) versus GCM (y-axis) atmospheric predictors of the Kimberley May-October NHMM.

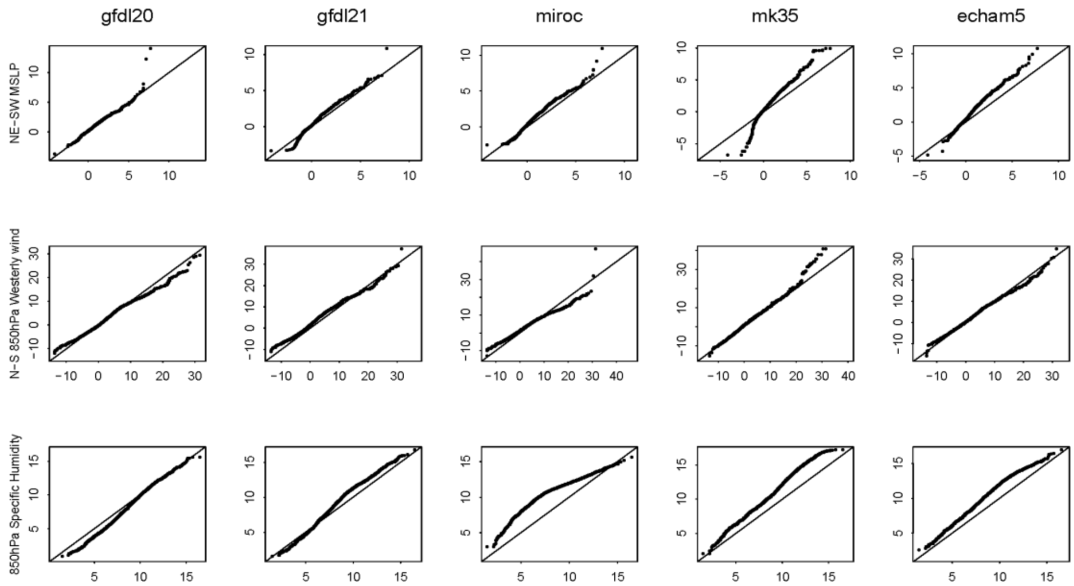


Figure 28 Quantile-quantile plots (i.e. the distributions of two series plotted against each other) for NNR (x-axis) versus GCM (y-axis) atmospheric predictors of the Kimberley November-April NHMM.

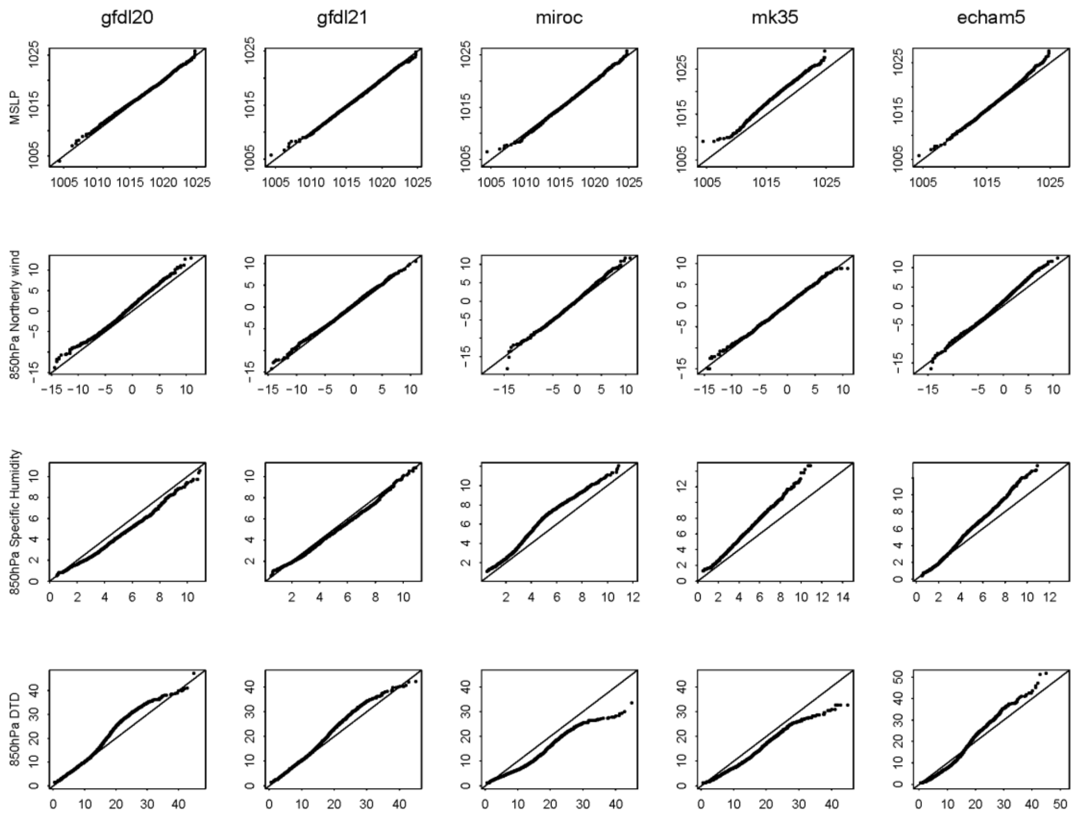


Figure 29 Quantile-quantile plots (i.e. the distributions of two series plotted against each other) for NNR (x-axis) versus GCM (y-axis) atmospheric predictors of the Pilbara May-October NHMM.

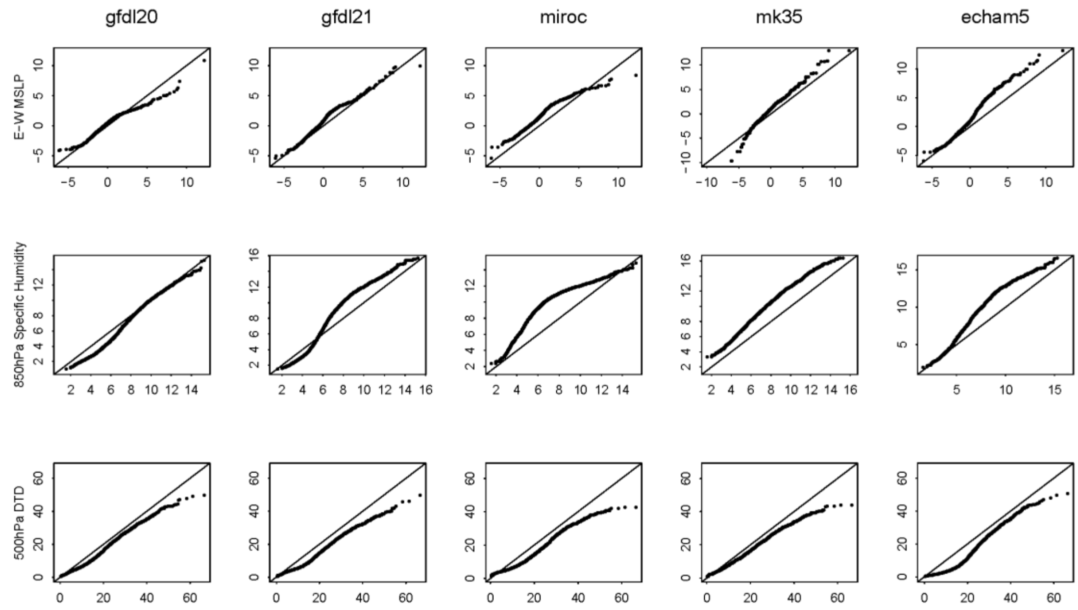


Figure 30 Quantile-quantile plots (i.e. the distributions of two series plotted against each other) for NNR (x-axis) versus GCM (y-axis) atmospheric predictors of the Pilbara November-April NHMM.