South Eastern Australian Climate initiative

Final report for Project 1.3.4

Calibration of Statistical Downscaling Models

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Abstract
Statistical downscaling allows us to bridge the gap between the coarse spatial scales of GCMs and the regional and local scales where climate impacts are experienced and analysed. Within SEACI, the Nonhomogeneous Hidden Markov Model (NHMM) statistical downscaling model will be used in a range of projects investigating the historical relationships between regional rainfall and synoptic scale circulation, assessing the ability of GCMs to reproduce key atmospheric processes at the synoptic scale, and using GCM projections to produce regional precipitation projections suitable for use in impacts assessment (such as hydrological models). Confidence in NHMM performance for current and future climates is founded on obtaining parsimonious NHMMs through rigorous calibration and assessment, as undertaken here. The selected NHMMs are shown to perform well, reproducing key properties of observed multi-site daily rainfall, and thus providing a physically realistic linkage between atmospheric processes at the synoptic scale and regional rainfall patterns.

Significant research highlights, breakthroughs and snapshots

- NHMMs were successfully fitted (1986 – 2005) and validated (1958 – 1984) for a 30 station network for summer (November-March) and winter (April-October).
- The selected models simulate the full range of natural climate variability experienced during the 1958 to 2005 period.
- The selected models produce physically consistent and plausible weather state (i.e. multi-site rainfall occurrence) patterns.

Statement of results, their interpretation, and practical significance against each objective

Objective 1: Calibrate Nonhomogeneous Hidden Markov Models (NHMMs) for the south-east Murray Darling Basin (MDB).

The statistical downscaling technique employed relates multi-site, daily rainfall patterns to synoptic-scale atmospheric predictors (Hughes *et al.* 1999; Charles *et al.* 1999). The model (nonhomogeneous hidden Markov model, NHMM) selects a small set of atmospheric predictors that relate to a discrete set of “weather states” associated with particular multi-site daily precipitation occurrence patterns (e.g., wet everywhere, wet in the north and dry in the south, etc.). The sequence of daily transitions from state to state is a function of the selected atmospheric predictors. Characteristics of these states are examined by constructing composite plots of their precipitation occurrence patterns and associated atmospheric predictor fields.

NHMMs were successfully fitted and validated for a 30 station network, shown in Figure 1 and Table 1. Fitting was on an approximately half year basis, with summer defined as November-March and winter as April-October. This season demarcation was selected based on the relationship between atmospheric predictors and multi-site rainfall as determined in the precursor Project 1.3.3 ‘*Atmospheric Predictor Selection for Statistical Downscaling*’.

The fitting period used was 1986 to 2005, with the earlier 1958 to 1984 data reserved for out-of-sample validation. It was not possible to investigate earlier periods due to the unavailability of sufficient quality atmospheric data prior to 1958. The daily rainfall data for the selected 30 station network is of very high quality for the fitting period, as previously determined in Project 1.3.2 ‘*Station Networks and Data for Statistical Downscaling*’. However, for the earlier validation period data quality degrades for some stations due to missing periods of record or an increased incidence of untagged accumulations. This may bias the validation of the NHMM performance for this period.

Objective 2: Determine the performance of the selected NHMMs in terms of reproduction of key statistics of daily multi-site rainfall occurrence and amounts.

The selected downscaling models produce physically consistent and plausible weather state patterns. The summer model has 6 weather states (see Figure 2) and 3 predictors: mean sea level pressure (MSLP), 700 hPa dew-point temperature depression (DT_d), and East – West 500 hPa geopotential height (GPH) gradient. The winter model has 5 weather states (see Figure 3) and 4 predictors: North – South MSLP gradient, 700 hPa and 850 hPa DT_d, and North – South 700 hPa GPH gradient. Brief descriptions of these weather states and their mean frequencies are presented in Tables 3 and 5, for summer and winter respectively. The probabilities of the daily transitions between weather states are presented in Tables 4 and 6, for summer and winter respectively.

Figures 5 to 7 (for Summer) and 8 to 10 (for Winter) evaluate the reproduction of mean seasonal precipitation probabilities, log-odds ratios (measures the correlation in binary series, i.e. daily rainfall occurrence as '1' wet or '0' dry, for all station pairs), and Spearman rank correlations for calibration and validation periods. These confirm that the calibrated NHMMs can reproduce, in turn, the correct frequency of wet days, inter-site correlations in rainfall occurrence, and inter-site correlation in rainfall amounts. For the out-of-sample validation period, there is evidence of increased bias however the previously noted degradation in observed precipitation quality for this period may mean that the observed statistics are biased.

At-site spell lengths and amounts distributions were also well reproduced for the validation period (not shown for reasons of space, available on request). Overall the selected models appear to perform well across the full range of natural climate variability experienced during the 1958 to 2005 period.

Objective 3: Identifying deficiencies requiring further research and development.

One area of relatively deficient performance is poor reproduction of long dry spells in summer for some stations (not shown for reasons of space, available on request). Other NHMM parameterisations will be investigated in the subsequent Project 1.3.5 '*Further development of statistical downscaling methodology*' to determine whether these limitations can be improved upon.

Summary of methods and modifications (with reasons)

- A network of 30 high quality rainfall stations was selected, encompassing the majority of the catchments of the south-east MDB. This station network is not definitive, as future research and client needs can modify the extent of the network. This initial calibration will provide a baseline to which any future NHMMs that use different (potentially lower quality) rainfall station networks can be compared to.
- NHMMs have been calibrated for the selected station network for two seasons ('summer' November to March and 'winter' April to October).
- For each season, a unique NHMM (in terms of number of weather states and atmospheric predictor set used) has been selected based on calibration criteria.

- The performance of these selected NHMMs has been quantified, by assessing reproduction of key statistics of daily multi-site rainfall occurrence and amounts, for calibration and validation periods.

Summary of links to other projects

Project 1.4.3 '*Comparison of Observed and Reanalyses Downscaled Synoptics and Precipitation*' will use the NHMMs selected here to investigate the weather state time-series properties and relate these to the time-series of the atmospheric predictors and observed seasonal rainfall. The ability to reproduce observed properties will provide confidence in using these downscaling models to produce climate change projections in Project 2.1.3 '*Drive Statistical Downscaling Models with GCM Predictor Sets*'. Evaluation of the downscaled rainfall simulations suitability for use in hydrological models will be a key component of these next stage projects.

Publications arising from this project

None to date.

Acknowledgement

The NHMM was originally developed by Professor Jim Hughes, University of Washington, Seattle, USA. His assistance is gratefully acknowledged.

Recommendations for changes to work plan from your original table

None.

References

Charles SP, Bates BC, Hughes JP. 1999. *A spatio-temporal model for downscaling precipitation occurrence and amounts*. Journal of Geophysical Research 104: 31657-31669.

Hughes JP, Guttorp P, Charles SP. 1999. *A non-homogeneous hidden Markov model for precipitation occurrence*. Applied Statistics 48: 15-30.

Project Milestone Reporting Table

To be completed prior to commencing the project				Completed at each Milestone date	
Milestone description[1] (brief) (up to 33% of project activity)	Performance indicators[2] (1- 3 dot points)	Completion date[3] xx/xx/xxxx	Budget[4] for Milestone ($) (SEACI contribution)	Progress[5] (1- 3 dot points)	Recommended changes to workplan[6] (1- 3 dot points)
1. Develop calibration data sets	30 station network selected Seasons for NHMM calibration selected NHMM input files created	1/3/2007	10	Completed	None
2. Calibrate NHMMs	NHMMs calibrated Occurrence NHMMs selected Amounts models calibrated	1/5/2007	15	Completed	None
3. Assess calibrated NHMMs	Occurrence and amounts statistics assessed for calibration period Assessment repeated for validation period Report on final model selection (4-6 pages)	30/6/2007	15	Completed. This report is the report on final model selection.	None

Table 1. *Stations shown in Figure 1.*

Number	BoM No.	BoM Name	Latitude (°S)	Longitude (°E)
1	49048	BALRANALD (TILLARA)	-34.64	143.05
2	70014	CANBERRA AIRPORT	-35.3	149.2
3	70028	YASS (DERRINGULLEN)	-34.74	148.89
4	70054	COOMA (KIAORA)	-36.2	149.06
5	72019	HOLBROOK (GLENFALLOCH)	-35.66	147.56
6	72023	HUME RESERVOIR	-36.1	147.03
7	72150	WAGGA WAGGA AMO	-35.16	147.46
8	73007	BURRINJUCK DAM	-35	148.6
9	73051	MURRINGO (WINDERMERE)	-34.21	148.55
10	74008	GRONG GRONG (BEREMBED)	-34.86	146.82
11	74025	BURRUMBUTTOCK (HOLYROOD)	-35.85	146.78
12	74087	URANA (NOWRANIE)	-35.33	146.03
13	75012	WAKOOL (CALIMO)	-35.42	144.6
14	75049	MAUDE (NAP NAP)	-34.45	144.17
15	75054	CONARGO (PUCKAWIDGEE)	-35.28	145.21
16	75067	CARRATHOOL (UARDRY)	-34.47	145.3
17	76044	NYAH	-35.18	143.37
18	77001	QUAMBATOOK (BARRAPORT NORTH)	-35.98	143.65
19	80044	PATHO WEST	-36	144.42
20	80053	TANDARRA	-36.43	144.25
21	81019	NAGAMBIE (GOULBURN WEIR)	-36.72	145.17
22	82002	BENALLA (SHADFORTH STREET)	-36.55	145.97
23	82018	UPLANDS (GIBBO RIVER PARK)	-36.77	147.69
24	82127	PEECHELBA EAST	-36.14	146.25
25	83010	EUROBIN	-36.64	146.86
26	83038	TAWONGA	-36.66	147.13
27	88011	CAMPBELLTOWN	-37.22	143.96
28	88042	MALMSBURY RESERVOIR	-37.2	144.37
29	88060	KINGLAKE WEST (WALLABY CREEK)	-37.45	145.21
30	88131	NARBETHONG	-37.5	145.68

Table 2. *Selected atmospheric predictor sets.*

Atmospheric predictor	NCEP/NCAR Reanalysis Grids (refer to Figure 2)
Summer *MSLP* DT_d^{700} East – West GPH^{500}	 (B2+B3+B4+C2+C3+C4)/6 (C2+C3+C4+D2+D3+D4)/6 (C3+C4+D3+D4)-(E3+E4+F3+F4)/4
Winter North – South *MSLP* DT_d^{700} DT_d^{850} North–South GPH^{700}	 (A5+B5+C5+D5)-(A4+B4+C4+D4)/4 (B2+B3+B4+C2+C3+C4+D2+D3+D4)/9 (A3+A4+B3+B4+C3+C4)/6 (A5+B5+C5)-(A4+B4+C4)/4

Table 3. *Summary of Summer weather state patterns*

State		Description
No.	%Freq.	
1	58	Rainfall: dry everywhere Synoptics: high pressure centred over SE Australia; warm, dry continental airflow
2	5	Rainfall: wet only in the most southerly stations Synoptics: high moving into the Australian Bight; southerly moist maritime airflow
3	6	Rainfall: wet everywhere Synoptics: low trough over SE Australia; southerly moist maritime airflow
4	15	Rainfall: wet in the northeast Synoptics: weak low trough over SE Australia.
5	11	Rainfall: moderately wet everywhere Synoptics: low trough over SE Australia; southerly moist maritime airflow
6	5	Rainfall: north (dry) to south (wet) rainfall gradient Synoptics: moderate low trough over SE Australia; southerly moist maritime airflow

Table 4. *Weather state TPM[#] for Summer NHMM.*

	1	2	3	4	5	6
1	0.76	0.04	0.02	0.09	0.04	0.04
2	0.48	0.22	0.03	0.06	0.11	0.10
3	0.15	0.03	0.25	0.20	0.33	0.04
4	0.46	0.02	0.04	0.34	0.11	0.04
5	0.26	0.04	0.16	0.24	0.26	0.05
6	0.20	0.06	0.16	0.11	0.24	0.22

[#] Transition Probability Matrix. * e.g., 4% probability of being state 2 today if previous day was state 1.

Table 5. *Summary of Winter weather state patterns*

State		Description
No.	%Freq.	
1	48	Rainfall: dry everywhere Synoptics: high pressure centred over region; dry continental air
2	12	Rainfall: wet everywhere Synoptics: low pressure trough; moist southerly maritime airflow
3	10	Rainfall: moderately wet everywhere Synoptics: weak low pressure trough; moist system over region
4	18	Rainfall: wet in the south predominantly Synoptics: weak low pressure trough; moist southerly maritime airflow
5	12	Rainfall: wet everywhere, moderate in northwest Synoptics: low pressure trough further east than in State 2; moist southerly maritime airflow

Table 6. *Weather state TPM[#] for Winter NHMM.*

	1	2	3	4	5
1	0.72	0.04	0.07	0.13	0.04
2	0.09	0.27	0.13	0.21	0.30
3	0.30	0.22	0.31	0.11	0.07
4	0.36	0.12	0.06	0.30	0.15
5	0.22	0.17	0.05	0.29	0.27

[#] Transition Probability Matrix. * e.g., 22% probability of being state 2 today if previous day was state 3.

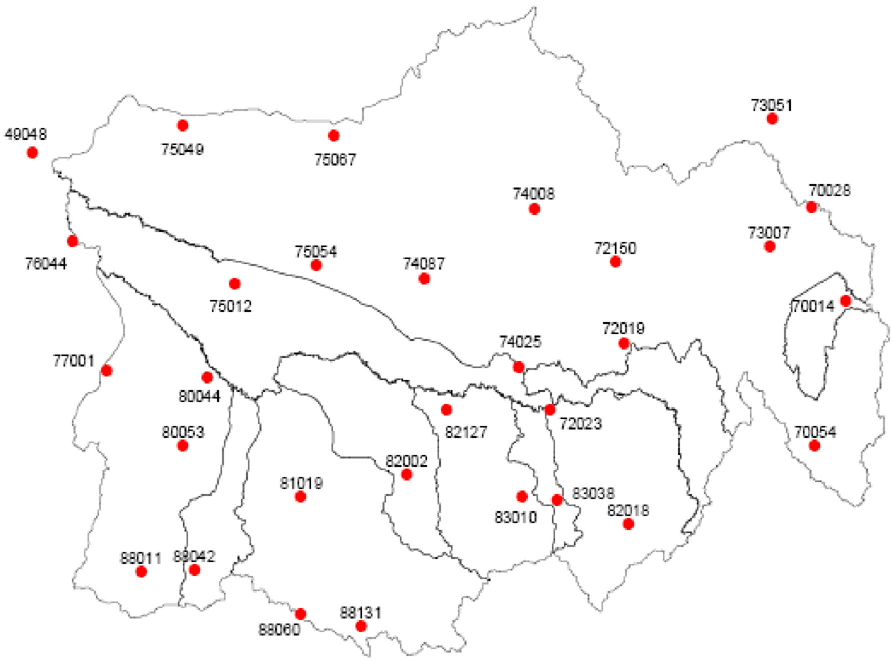

Figure 1. Location of 30 stations in Table 1.

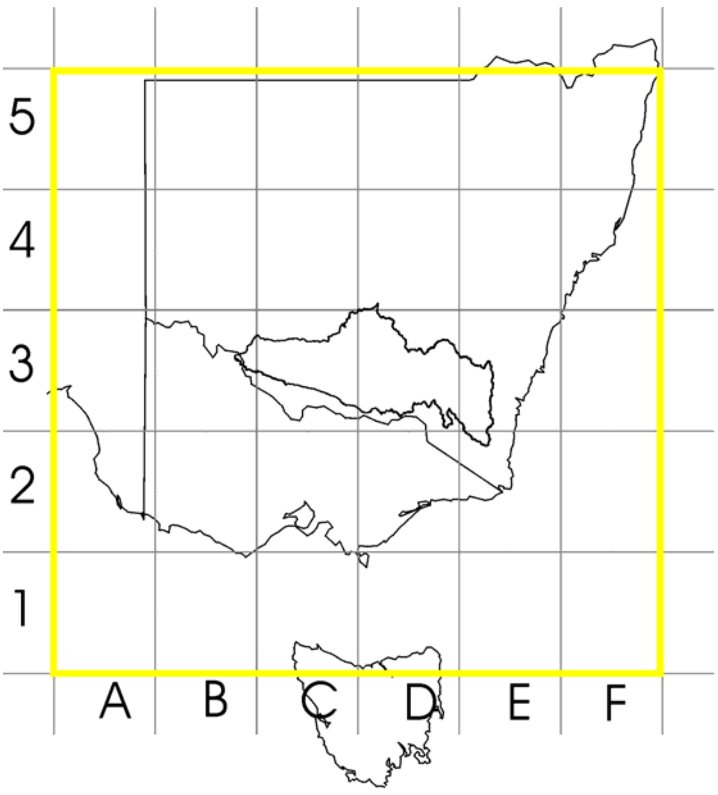

Figure 2. Reanalysis atmospheric data grid, showing coordinates (A to F, 1 to 5) used in Table 2. (outline of Murrumbidgee shown for reference).

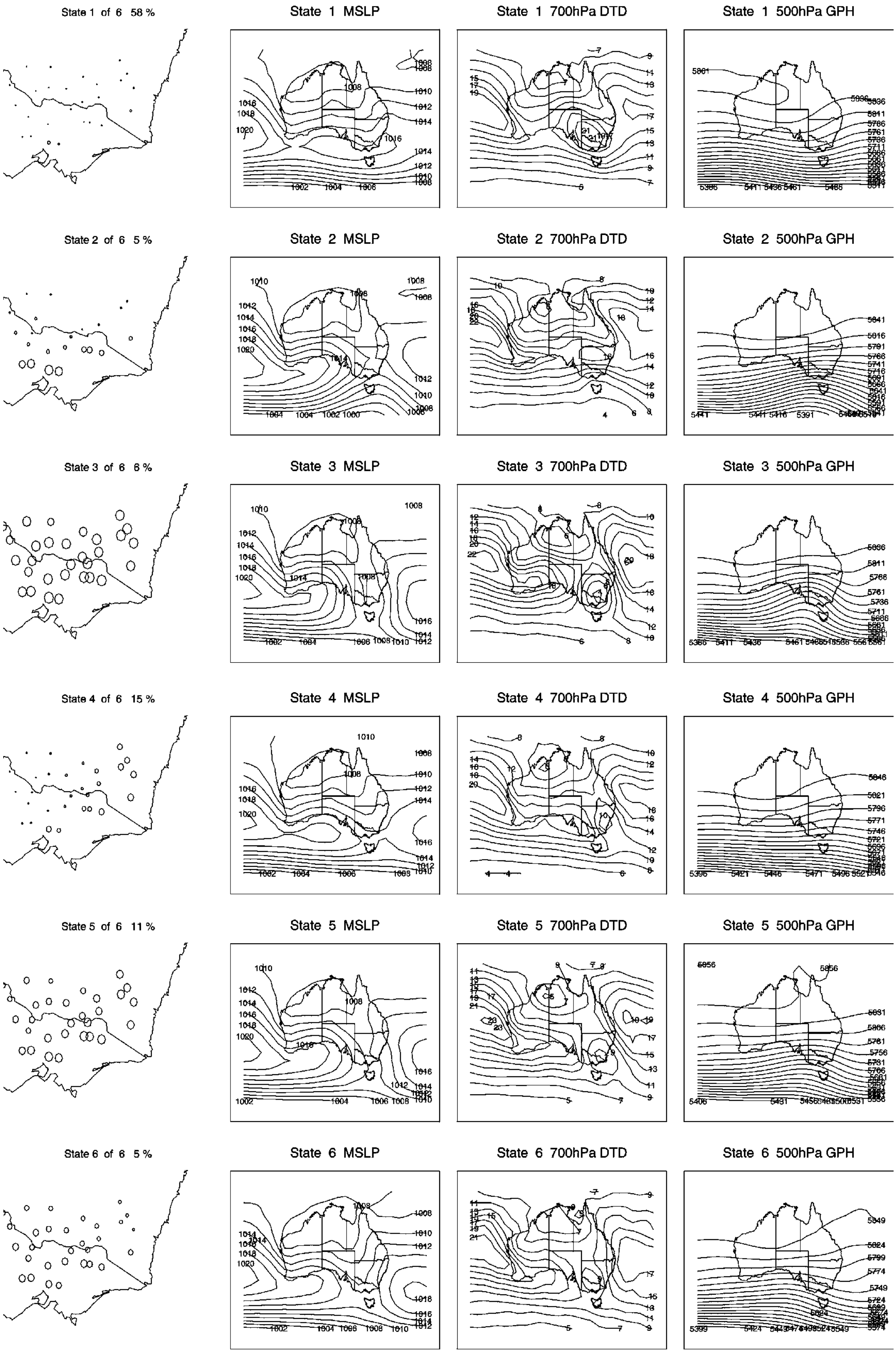

Figure 3: Weather states of the summer NHMM: precipitation occurrence probabilities, diameters of circles proportional to probability of a wet-day with the largest circle 1.0; composite MSLP (hPa); 700 hPa DTd (K); 500 hPa GPH (m).

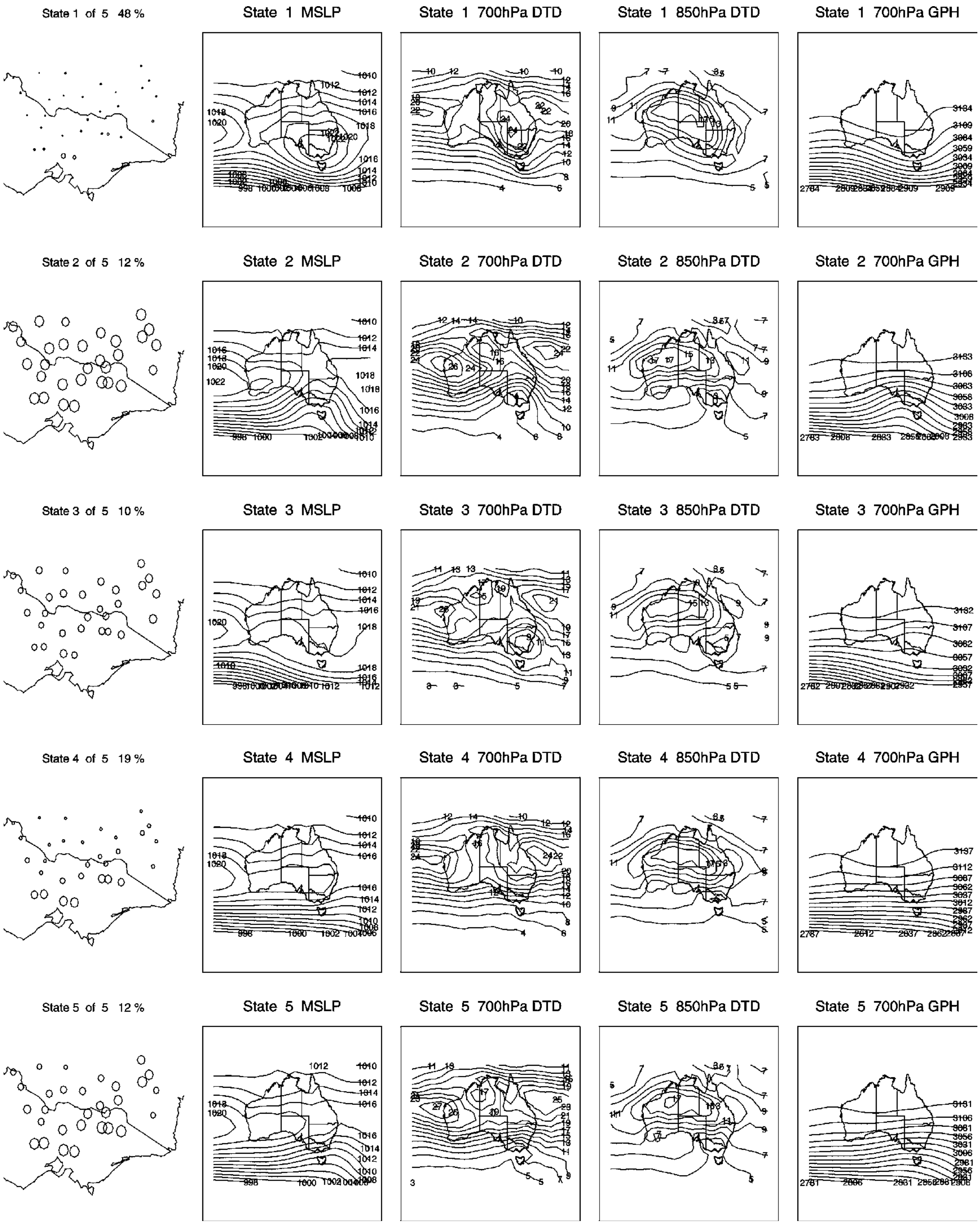

Figure 4: Weather states of the winter NHMM: precipitation occurrence probabilities, diameters of circles proportional to probability of a wet-day with the largest circle 1.0; composite MSLP (hPa); 700 hPa DTd (K); 850 hPa DTd (K); 700 hPa GPH (m).

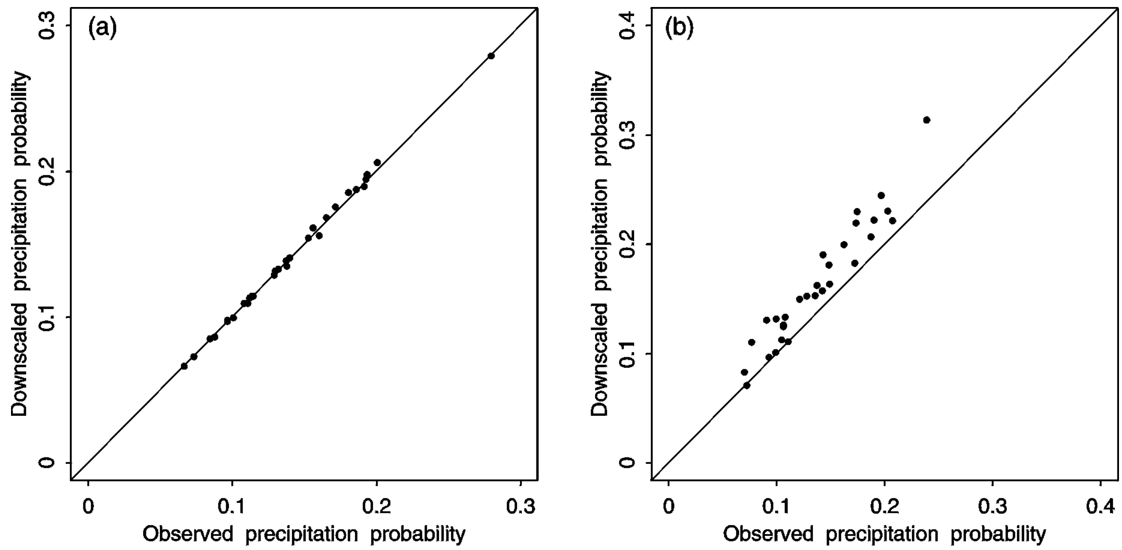

Figure 5: Summer NHMM precipitation probabilities (a) fitting period verification and (b) out-of-sample validation.

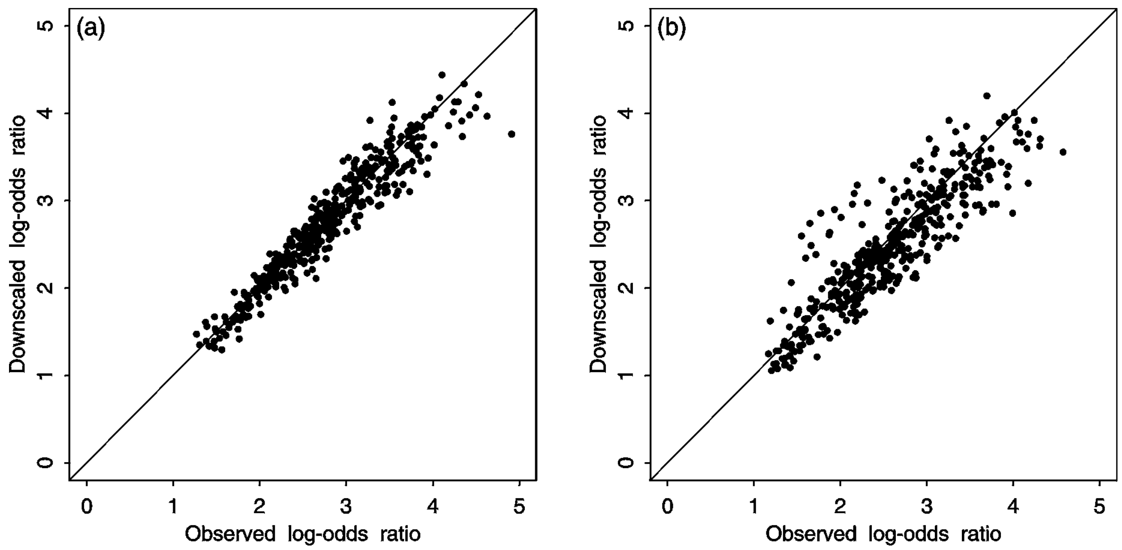

Figure 6: Summer NHMM log-odds ratios (a) fitting period verification and (b) out-of-sample validation.

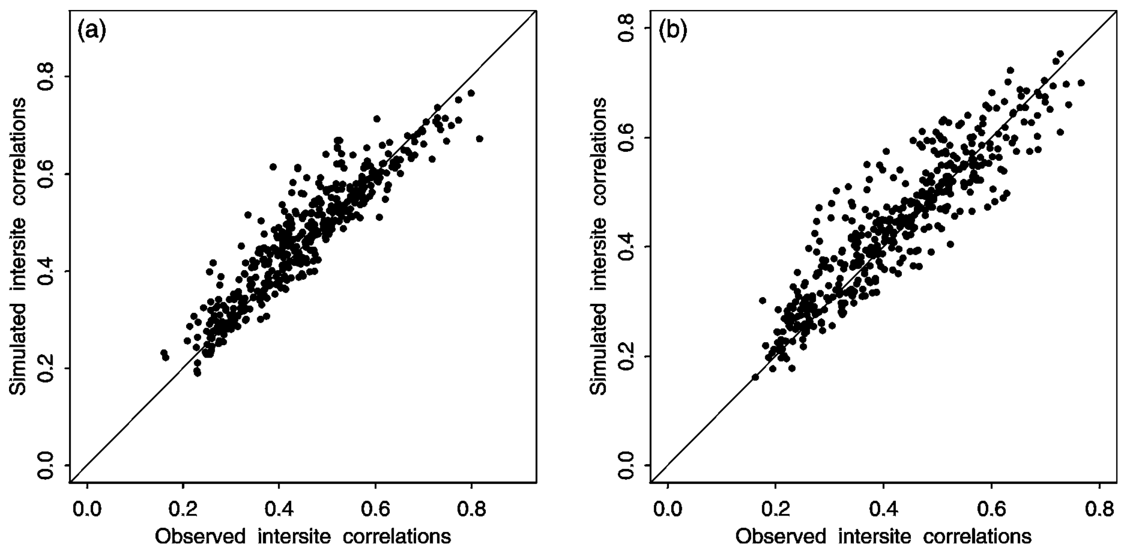

Figure 7: Summer NHMM amounts Spearman rank correlation (a) fitting period verification and (b) out-of-sample validation.

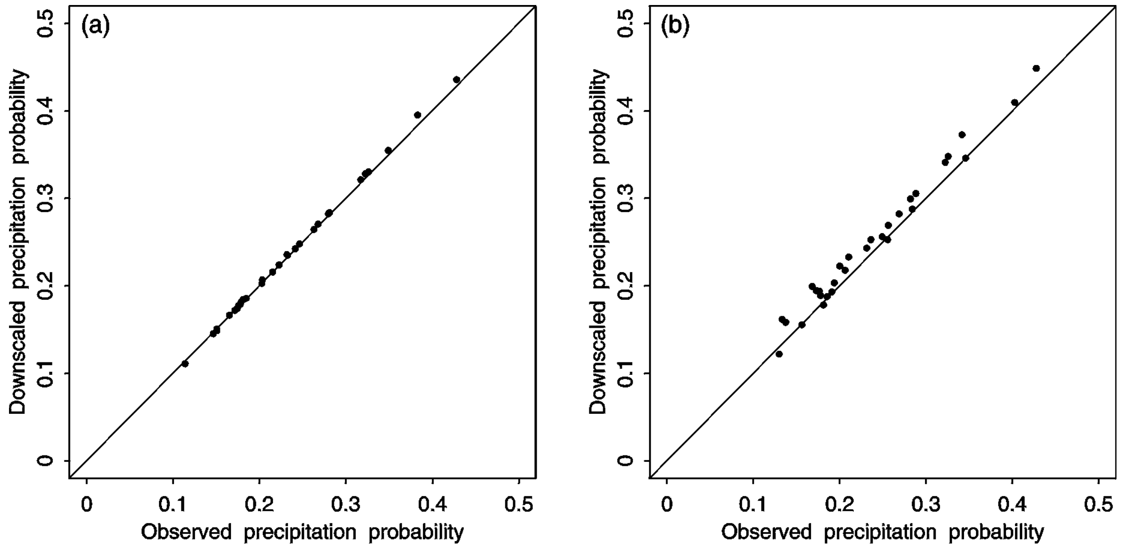

Figure 8: Winter NHMM precipitation probabilities (a) fitting period verification and (b) out-of-sample validation.

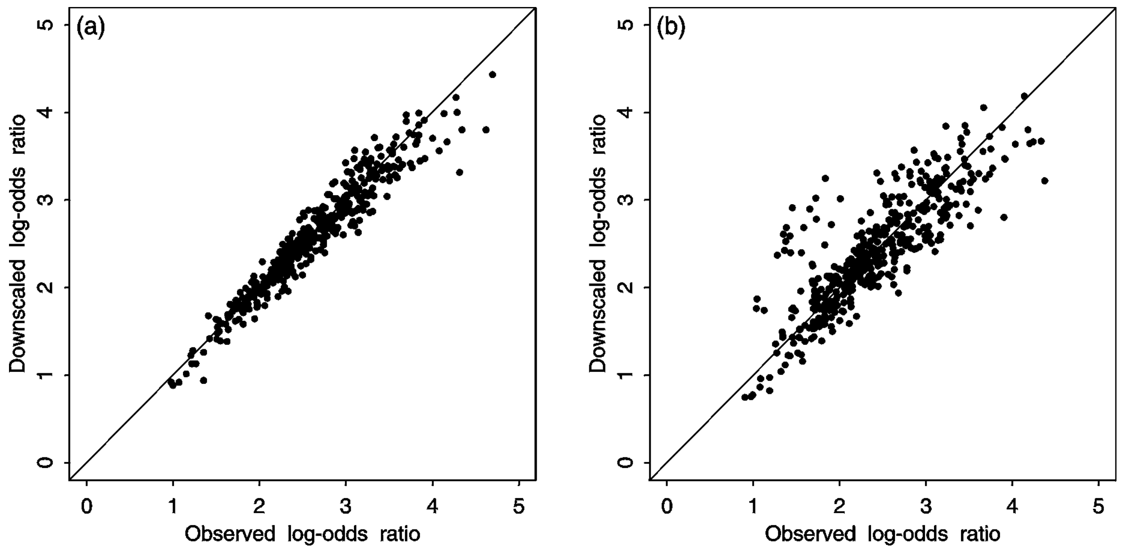

Figure 9: Winter NHMM log-odds ratios (a) fitting period verification and (b) out-of-sample validation.

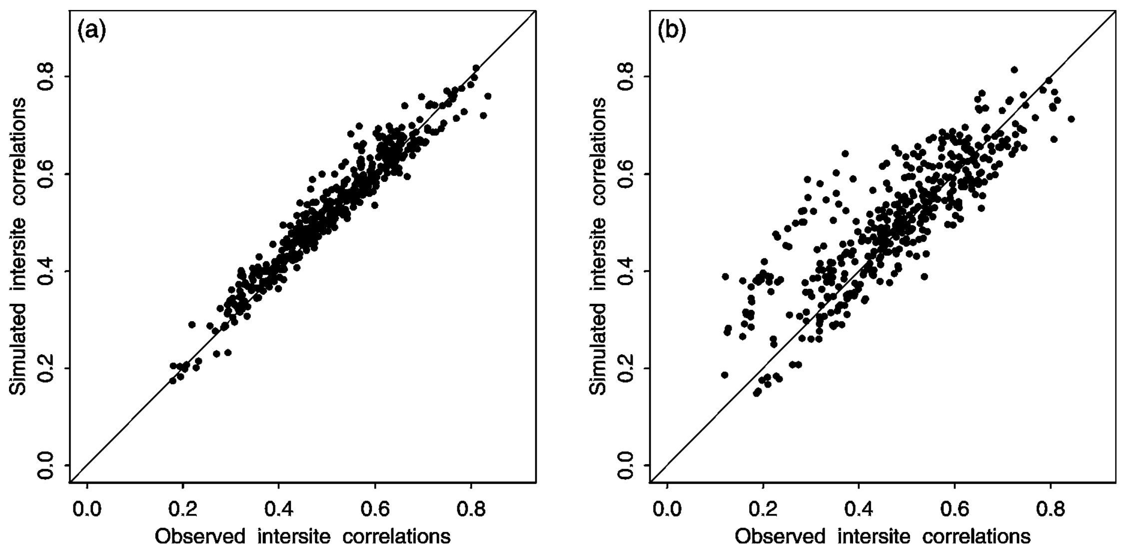

Figure 10: Winter NHMM amounts Spearman rank correlation (a) fitting period verification and (b) out-of-sample validation.