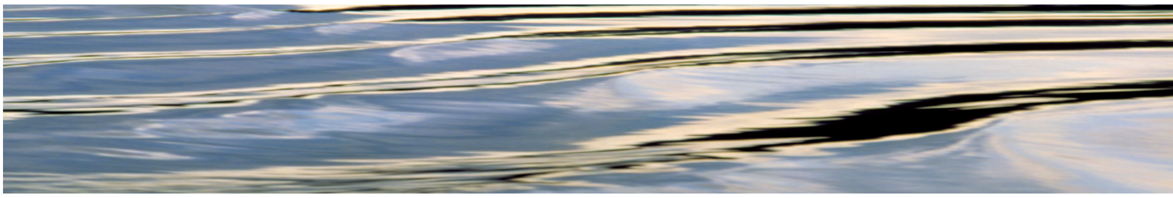
COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

STOCHASTIC GENERATION OF MONTHLY RAINFALL DATA

TECHNICAL REPORT
Report 02/8
September 2002

Ratnasingham Srikanthan / Thomas A. McMahon / Ashish Sharma



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CATCHMENT HYDROLOGY

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Stochastic Generation of Monthly Rainfall Data

Bibliography
ISBN 1 876006 89 7

1. Rain and rainfall - Australia - Mathematical models. I. McMahon, T. A. (Thomas Aquinas). II. Sharma, A. (Ashish), 968- . III. Cooperative Research Centre for Catchment Hydrology. IV. Title. (Series: Report (Cooperative Research Centre for Catchment Hydrology); 02/8)

551.5770724

Keywords
Precipitation (Atmospheric)
Rain
Modelling (Hydrological)
Modelling (Stochastic)
Nonparametric Model
Method of Fragments
Calibration
Stream Flow
Water Data

Stochastic Generation of Monthly Rainfall Data

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Preface

One of the goals of the Climate Variability Program in the CRC for Catchment Hydrology is to provide water managers and researchers with computer programs to generate stochastic climate data. The stochastic data are needed at time scales from less than one hour to a year and for point sites to large catchments like the Murrumbidgee and Fitzroy.

The first report in this series, 'Stochastic Generation of Climate Data: A Review' (CRC Technical Report 00/16), reviewed methods of stochastic generation of climate data and recommended the testing of a number of techniques. The second report, Stochastic Generation of Annual Rainfall Data' (CRC Technical Report 02/6), compared the first order autoregressive and hidden state Markov models for the generation of annual rainfall data. This third report, 'Stochastic Generation of Monthly rainfall Data', tests the method of fragments and a nonparametric model for the generation of monthly rainfall data at ten sites across Australia.

Dr Francis Chiew
Program Leader
Climate Variability Program

Summary

This report describes a new method for the generation of monthly rainfall data. The method of fragments was recommended (Srikanthan and McMahon, 1985) for the generation of monthly rainfall data. It has some limitations and modifications were made to overcome these for the generation of streamflow data. However, these are not suitable as the rainfall data has a number of months of no rainfall. Sharma and O'Neill (2001) proposed a nonparametric model for the generation of monthly streamflow data. This recent method was applied to generate rainfall data for 10 rainfall stations located in various parts of Australia. The results from this model are compared with those from the method of fragments. The comparison shows that the nonparametric model is marginally better than the method of fragments.

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1. Introduction

Monthly rainfall data are generally needed in the simulation of water resources systems to produce monthly flows for the estimation of water yield from large catchments. But monthly rainfall models do not work for sites which have significant number of months of no rainfall. In an earlier study, Srikanthan and McMahon (1985) recommended the method of fragments to disaggregate the annual rainfall data generated by a first order autoregressive model. The main drawbacks of this approach are the inability to preserve the monthly correlation between the first month of a year and last month of the previous year and the occurrence of similar patterns from a short length of historic data. Using streamflow as the example, Maheepala and Perera (1996) proposed a modification to the selection of fragments that preserves the year-end monthly correlation to improve on the first drawback. Porter and Pink (1991) used synthetic fragments from a Thomas-Fiering monthly (streamflow) model to overcome the second drawback. For sites with considerable number of zero rainfall months, there will be problems with the application of the Thomas-Fiering monthly model.

Recently, Sharma and O'Neill (2001) developed a nonparametric approach to model the inter-annual dependence in monthly streamflows. In this report, this recent method is applied to generate rainfall data for 10 rainfall stations located in various parts of Australia. The results from this model are compared with those from the method of fragments.

2. Rainfall Data

Ten rainfall stations were selected to cover the Australian continent. The locations of the selected rainfall stations are shown in Figure 1 and details of the sites are given in Table 1. The number of months of no rainfall varies from 0 to 90 %. The large percentage of no rainfall months renders the application of the Thomas-Fiering model to be very difficult.

Table 1. Details of the rainfall stations selected

Number	Name	Latitude	Longitude	State	Length of Record (yrs)	Annual Mean (mm)
006036	Meeedo	-25.66	114.62	WA	95	216
009034	Perth	-31.95	115.84	WA	116	868
014902	Katherine Council	-14.46	132.26	NT	112	974
015540	Alice Springs Post Office	-23.71	133.87	NT	113	280
023000	Adelaide	-34.93	138.58	SA	140	530
028004	Palmerville	-16.00	144.08	QLD	110	1034
040214	Brisbane	-27.48	153.03	QLD	134	1154
066062	Sydney	-33.86	151.20	NSW	141	1226
086071	Melbourne	-37.81	144.97	VIC	140	657
094061	Sandford (Maydena)	-42.93	147.52	TAS	112	578

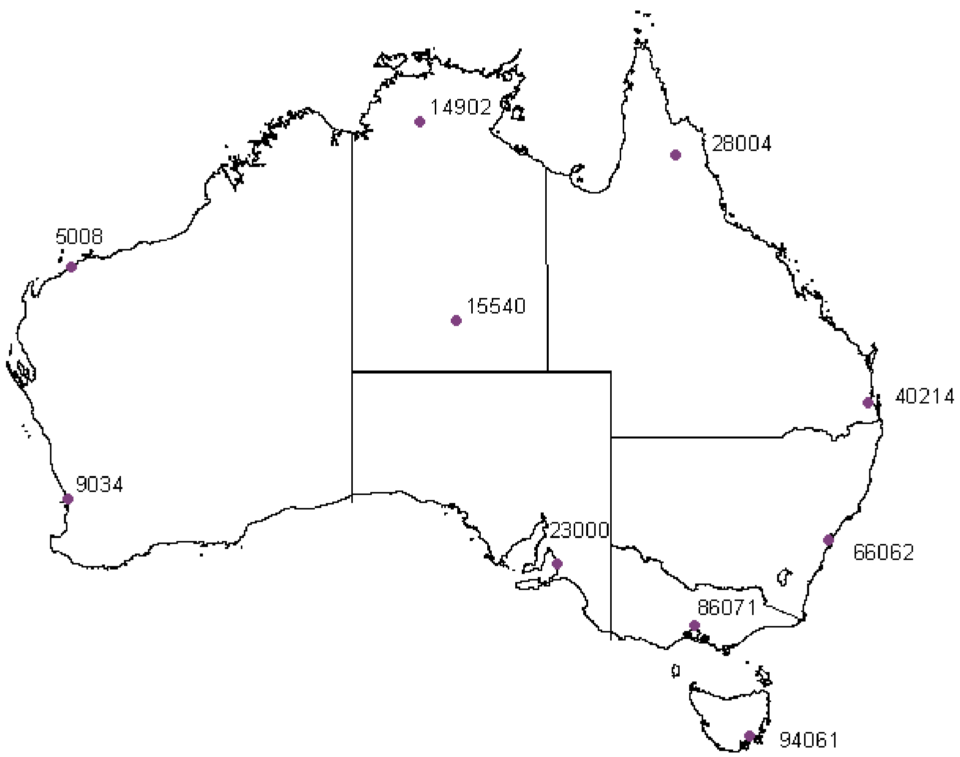


Figure 1. Location of the rainfall stations selected

3. Nonparametric Model

The nonparametric model (NP2) preserves both the short term (month to month) as well as the inter-annual (month to year, year to year) dependencies in simulated rainfalls. The model adopted in this study uses only the dependence on the previous month and the previous 12 months rainfall total. The generation of monthly rainfall data proceeds from the following conditional probability density:

$$f(X_t \mid X_{t-1}, Z_t) = \frac{f(X_t, X_{t-1}, Z_t)}{f_m(X_{t-1}, Z_t)} \qquad (1)$$

where X_t rainfall for month t

Z_t previous 12 months rainfall $(= X_{t-1} + X_{t-2} + \dots + X_{t-12})$

f_m marginal probability density of X_{t-1} and Z_t

Using a Gaussian kernel function, the above conditional probability density is estimated as (Sharma and O'Neill, 2001):

$$\hat{f}(X_t \mid X_{t-1}, Z_t) = \sum_{i=1}^{n} \frac{1}{\sqrt{2\pi\lambda^2 S'}} w_i \exp\left(-\frac{(x_i - b_i)^2}{2\lambda^2 S'}\right) \qquad (2)$$

where λ a smoothing parameter, known as the "band width" of the known density estimate S' a measure of spread of the conditional probability density, expressed as:

$$S' = S_{11} - \begin{bmatrix} S_{12} \\ S_{1z} \end{bmatrix}^T \begin{bmatrix} S_{22} & S_{2z} \\ S_{2z} & S_{zz} \end{bmatrix} \begin{bmatrix} S_{12} \\ S_{1z} \end{bmatrix}$$

where the covariance matrix of the variable set (X_t, X_{t-1}, Z_t) is written as

$$Cov(X_t, X_{t-1}, Z_t) = \begin{bmatrix} S_{11} & S_{12} & S_{1z} \\ S_{12} & S_{22} & S_{2z} \\ S_{1z} & S_{2z} & S_{zz} \end{bmatrix}$$

w_i is the weight associated with each kernel that constitutes the conditional probability density:

$$w_i = \frac{\exp\left\{-\frac{1}{2\lambda^2}\begin{bmatrix} X_{t-1} - x_{i-1} \\ Z_t - z_i \end{bmatrix}^T \begin{bmatrix} S_{22} & S_{2z} \\ S_{2z} & S_{zz} \end{bmatrix}^{-1} \begin{bmatrix} X_{t-1} - x_{i-1} \\ Z_t - z_i \end{bmatrix}\right\}}{\sum_{j=1}^{n} \exp\left\{-\frac{1}{2\lambda^2}\begin{bmatrix} X_{t-1} - x_{j-1} \\ Z_t - z_j \end{bmatrix}^T \begin{bmatrix} S_{22} S_{2z} \\ S_{2z} S_{zz} \end{bmatrix}^{-1} \begin{bmatrix} X_{t-1} - x_{j-1} \\ Z_t - z_j \end{bmatrix}\right\}}$$

b_i is the conditional mean associated with each kernel:

$$b_i = x_i + \begin{bmatrix} S_{12} \\ S_{1z} \end{bmatrix}^T \begin{bmatrix} S_{22} & S_{2z} \\ S_{2z} & S_{zz} \end{bmatrix}^{-1} \begin{bmatrix} X_{t-1} - x_{i-1} \\ Z_t - z_i \end{bmatrix}$$

x_t and z_t represent the rainfall for month t and the sum of the prior 12 monthly rainfalls respectively.

The conditional probability density estimate in Equation (2) can be viewed as consisting of n kernels having relative areas equal to weight w_i, centred at b_i, and having a spread proportional to S'. Each of these is a slice of the trivariate kernels that constitute the joint probability density of (X_t, X_{t-1}, Z_t), along the conditioning plane specified by (X_{t-1}, Z_t). The weight w_i depends directly on how far the kernel is from the conditioning plane. A small weight implies that the kernel is far from the conditioning plane and does not make up a significant portion of the conditional density estimate. On the other hand, a large w_i implies the kernel is close to the conditioning plane and constitutes a significant portion of the conditional density estimate. Consequently, data generation will proceed with more emphasis given to the observed data points lying closer to the conditioning plane and less emphasis given to the data points that lie further away.

Monthly rainfall is generated by following the steps below:

Step 1. Select the band width and estimate the covariances S_{11}, S_{12}, S_{1z}, S_{22}, S_{2z}, S_{zz}.

Step2. Start the data generation by arbitrarily assigning values to X_{t-1} and Z_t.

Step 3. Given X_{t-1} and Z_t, estimate the weight w_i associated with each kernel.

Step 4. Pick a data point with probability w_i.

Step 5. The new value of X_t can be obtained as $X_t = b_i + \lambda(S')^{1/2} W_i$, where W_i is a Gaussian random variable with zero mean and unit standard deviation.

Step 6. Repeat steps 3 to 5 until the required length of data is generated.

The first few generated values are discarded to reduce the effect of the arbitrary initialisation used. In this study, the first 16 years of generated data are discarded.

To overcome the problem of generating negative rainfall, a variable kernel (Scott, 1992) has been used for data points close to the zero rainfall boundary. The band width of the conditional kernel used for generating a new rainfall in step 5 is reduced depending on the distance of its centre (b_i) from the zero rainfall boundary. The modified step 5 is as follows:

Step 5a. Estimate a transformed band width λ' such that

$$\lambda = \lambda \quad \textbf{if } F_{N(bi,\lambda^2 S')}(X_t \le 0) \le \alpha$$

$$= \lambda' \quad \textbf{if } F_{N(bi,\lambda^2 S')}(X_t \le 0) > \alpha$$

where $F_{N(bi,\lambda^2 S')}(X_t \le 0) = \alpha$ and $F_{N(\mu,\sigma^2)}$ is the cumulative probability of a Gaussian distribution with mean μ and variance σ^2, with the bandwidth being transformed to λ' if for the selected Gaussian kernel, the probability of the rainfall X_t being less than or equal to zero, is estimated to be greater than a specified threshold α.

Step 5b. Generate a new value of X_t using as $X_t = b_i + \lambda'(S')^{1/2} W_i$, where W_i is a Gaussian random variate with zero mean and unit variance.

Step 5c. Repeat step 5b if the generated value of X_t is less than zero, until a positive value results.

4. Method of Fragments

In the method of fragments (MFM), the observed monthly rainfalls are standardised year by year so that the sum of the monthly rainfall in any equals to unity. This is carried out by dividing the monthly rainfall in a year by the corresponding annual rainfall. By doing so, from a record of n years, one will have n sets of fragments of monthly rainfalls. The appropriate monthly fragments for a given year, k, is selected by considering the closeness of the generated annual rainfall data and the monthly rainfall for the last month of the previous year of the already disaggregated data to the corresponding historical values (Maheepala and Perera, 1996). This is achieved by selecting the monthly fragments of a year, i, in the generated monthly series that produces a minimum value for α_i, which is defined below:

$$\alpha_i = \left(\frac{x'_k - x_i}{s_x}\right)^2 + \left(\frac{y'_{k-1} - y_{i-1}}{s_y}\right)^2 \qquad (3)$$

where x'_k = generated annual rainfall for year k

x_i = historical annual rainfall for year i

s_x = standard deviation of the annual rainfall

y'_{k-1} = disaggregated monthly rainfall for the last month of year k-1

y_{i-1} = historical monthly rainfall for the last month of year i-1

s_y = standard deviation of the monthly rainfall for the last month of a year

The generated annual rainfalls are disaggregated by multiplying the generated rainfall by each of the twelve fragments to give twelve generated monthly rainfalls. In this study, the generated annual rainfall is obtained from a first order autoregressive model with parameter uncertainty (Srikanthan *et al.*, 2002).

5. Model Evaluation

The model evaluation is carried out at annual and monthly time periods. The parameters used to evaluate the annual level are the annual mean, standard deviation, coefficient of skewness, lag one autocorrelation coefficient, extreme events, adjusted range and low rainfall sums. The maximum and minimum rainfall depth occurring in the historic record or in each of the generated sequences are taken as the extreme events. Rank one 2-, 3-, 5-, 7- and 10-year low rainfall sums are used. The adjusted range (R) is obtained from

$$R = \max \{D_k\} - \min \{D_k\} \qquad k = 1, 2, \ldots, n \quad (4)$$

where $D_k = \sum_{t=1}^{k} (x_t - \bar{x})$ and $\bar{x} = \frac{1}{n}\sum_{t=1}^{n} x_t$

The extreme events, low rainfall sums and the adjusted range are standardised by dividing them by the mean annual rainfall.

At the monthly level, the following seven parameters are used:

1. monthly mean
2. monthly standard deviation
3. monthly coefficients of skewness,
4. serial correlation coefficients between successive months
5. maximum monthly rainfall
6. minimum monthly rainfall
7. relative frequency of no rainfall months

The serial correlation coefficient corresponding to month t is the correlation between the t and (t-1) monthly pairs. The extreme events are divided by the overall monthly mean (i.e. annual mean divided by 12).

6. Discussion of Results

6.1 Annual Parameters

Because the annual rainfall data generated by a first order autoregressive model was evaluated in Srikanthan *et al.* (2002), only the average values of the annual parameters from the replicates are presented (Tables 2-4). However, for the nonparametric model, a complete set of results is presented (Figures 2-5).

It can be seen from Table 2 that the annual mean, standard deviation, skewness and lag one autocorrelation were satisfactorily preserved with one or two exceptions. In the case of MFM the standard deviation was higher for Katherine and Brisbane and for NP2 it was higher for Katherine. The lag one autocorrelation was higher for Meedo from MFM and it was lower for Alice Springs from NP2.

Table 2. Comparison of annual mean, standard deviation, skewness and lag one autocorrelation coefficient

	Mean (mm)			Std Dev (mm)			Skewness			Lag one autocorrelation		
Station	Hist	MFM	NP2	Hist	MFM	NP2	Hist	MFM	NP2	Hist	MFM	NP2
Meedo	214	220	216	102	96	102	1.105	0.878	0.873	-0.032	0.258	0.059
Perth	868	874	876	162	164	168	0.103	0.639	0.210	-0.051	-0.019	0.030
Katherine	975	973	983	251	261	275	0.046	0.153	0.219	0.069	0.084	0.066
Alice Springs	282	285	279	145	146	144	1.498	1.401	1.182	0.289	0.230	0.068
Adelaide	530	531	532	108	107	115	0.057	0.610	0.232	-0.010	0.076	0.045
Palmerville	1035	1043	1041	302	327	321	0.661	0.681	0.474	0.070	0.062	0.057
Brisbane	1154	1161	1162	358	384	356	0.592	0.953	0.659	0.016	0.054	0.106
Sydney	1225	1223	1230	331	342	347	0.607	0.825	0.524	0.101	0.129	0.070
Melbourne	659	657	660	127	125	132	0.001	0.571	0.257	0.012	0.104	-0.064
Sandford	576	578	583	131	130	130	0.432	0.748	0.404	0.011	0.105	0.037

The maximum and minimum events were reproduced satisfactorily for both the models (Table 3). A small downward bias in the ranges is observed for Perth, Katherine, Alice Springs, Brisbane and Sydney. The low rainfall sums of durations 2-, 3-, 5-, 7- and 10-year are satisfactorily reproduced by both the models.

The box plots in Figures 2-5 represent the variability in the parameters estimated from the 100 replicates each of length equal to the corresponding historical record. In these figures, a box represents the 25th and 75th percentiles, a horizontal line represents the median and the whiskers extend to the 2.5th and 97.5th percentile of the generated parameters. The annual mean, standard deviation and skewness are preserved (Figure 2). The annual lag one correlation is reproduced for all the stations except Alice Springs (Figure 3). Figure 3 also shows that the extreme events are reproduced. The adjusted range and the low rainfall sums are also reproduced (Figures 4 and 5).

Table 3. Comparison of maximum, minimum and adjusted range of annual rainfall

	Maximum			Minimum			Range		
Station	**Hist**	**MFM**	**NP2**	**Hist**	**MFM**	**NP2**	**Hist**	**MFM**	**NP2**
Meedo	2.619	2.513	2.560	0.305	0.263	0.220	5.817	6.233	5.740
Perth	1.542	1.620	1.533	0.586	0.630	0.561	3.571	2.386	2.478
Katherine	1.615	1.717	1.771	0.451	0.373	0.355	4.344	3.549	3.715
Alice Springs	3.207	3.131	2.838	0.191	0.257	0.170	8.205	7.723	6.754
Adelaide	1.485	1.673	1.628	0.487	0.592	0.506	2.275	3.000	3.148
Palmerville	2.027	2.031	1.923	0.433	0.401	0.369	3.595	3.998	3.855
Brisbane	1.944	2.247	1.969	0.357	0.414	0.389	6.490	4.786	4.599
Sydney	1.790	1.992	1.874	0.476	0.473	0.421	5.785	4.332	4.164
Melbourne	1.468	1.632	1.545	0.504	0.599	0.544	2.239	2.840	2.628
Sandford	1.603	1.759	1.657	0.566	0.576	0.537	2.846	3.061	2.986

Table 4. Comparison of low rainfall sums of 2-, 3-, 5-, 7- and 10-year durations standardised by the mean annual rainfall

Station	**2-year**			**3-year**			**5-year**			**7-year**			**10-year**		
	Hist	**MFM**	**NP2**	**Hist**	**MFM**	**NP2**	**Hist**	**MFM**	**NP2**	**Hist**	**MFM**	**NP2**	**Hist**	**MFM**	**NP2**
Meedo	0.772	0.751	0.739	1.419	1.374	1.351	2.797	2.813	2.817	4.665	4.425	4.455	7.515	7.061	7.061
Perth	1.439	1.449	1.371	2.305	2.316	2.226	4.012	4.124	4.043	5.962	5.995	5.917	8.803	8.849	8.748
Katherine	1.173	1.053	0.995	1.927	1.828	1.774	3.605	3.544	3.459	5.516	5.328	5.289	8.232	8.038	8.041
Alice	0.716	0.705	0.628	1.130	1.257	1.288	2.446	2.584	2.742	3.628	4.082	4.346	6.320	6.535	6.868
Adelaide	1.389	1.367	1.296	2.066	2.202	2.127	4.020	3.958	3.878	5.872	5.771	5.688	8.369	8.559	8.483
Palmerville	1.259	1.075	1.033	1.854	1.840	1.778	3.389	3.500	3.438	5.107	5.252	5.178	7.590	7.987	7.914
Brisbane	0.976	1.066	1.072	1.851	1.817	1.815	3.607	3.422	3.443	5.231	5.148	5.157	7.732	7.829	7.866
Sydney	1.262	1.142	1.139	2.033	1.897	1.940	3.650	3.534	3.585	5.234	5.251	5.359	7.945	7.909	8.086
Melbourne	1.313	1.376	1.320	2.166	2.216	2.193	4.107	3.962	4.008	6.107	5.784	5.868	8.899	8.603	8.688
Sandford	1.323	1.323	1.361	2.179	2.142	2.193	3.912	3.893	3.947	5.759	5.700	5.757	8.730	8.470	8.591

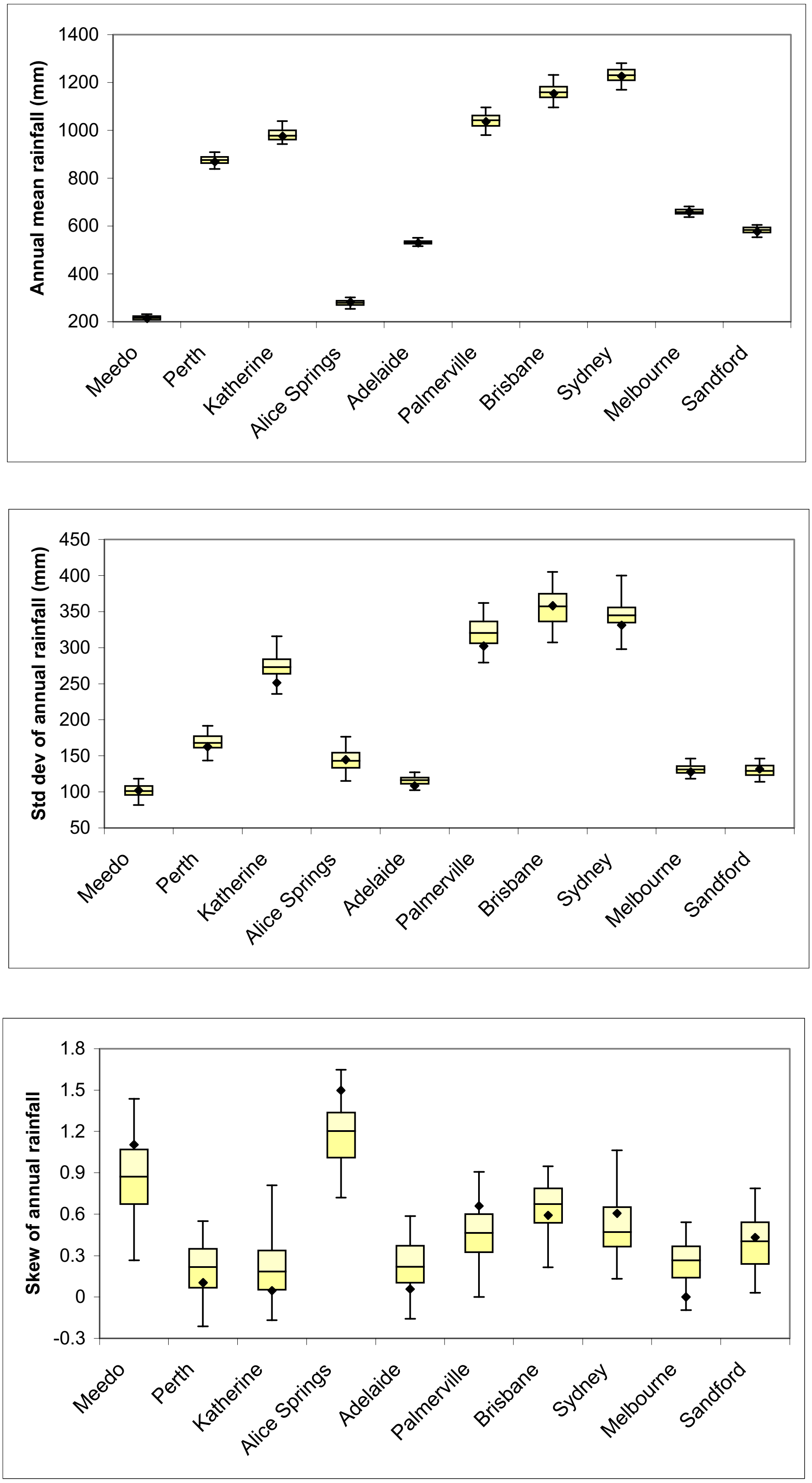


Figure 2. Comparison of annual mean, standard deviation and skewness for the nonparametric model

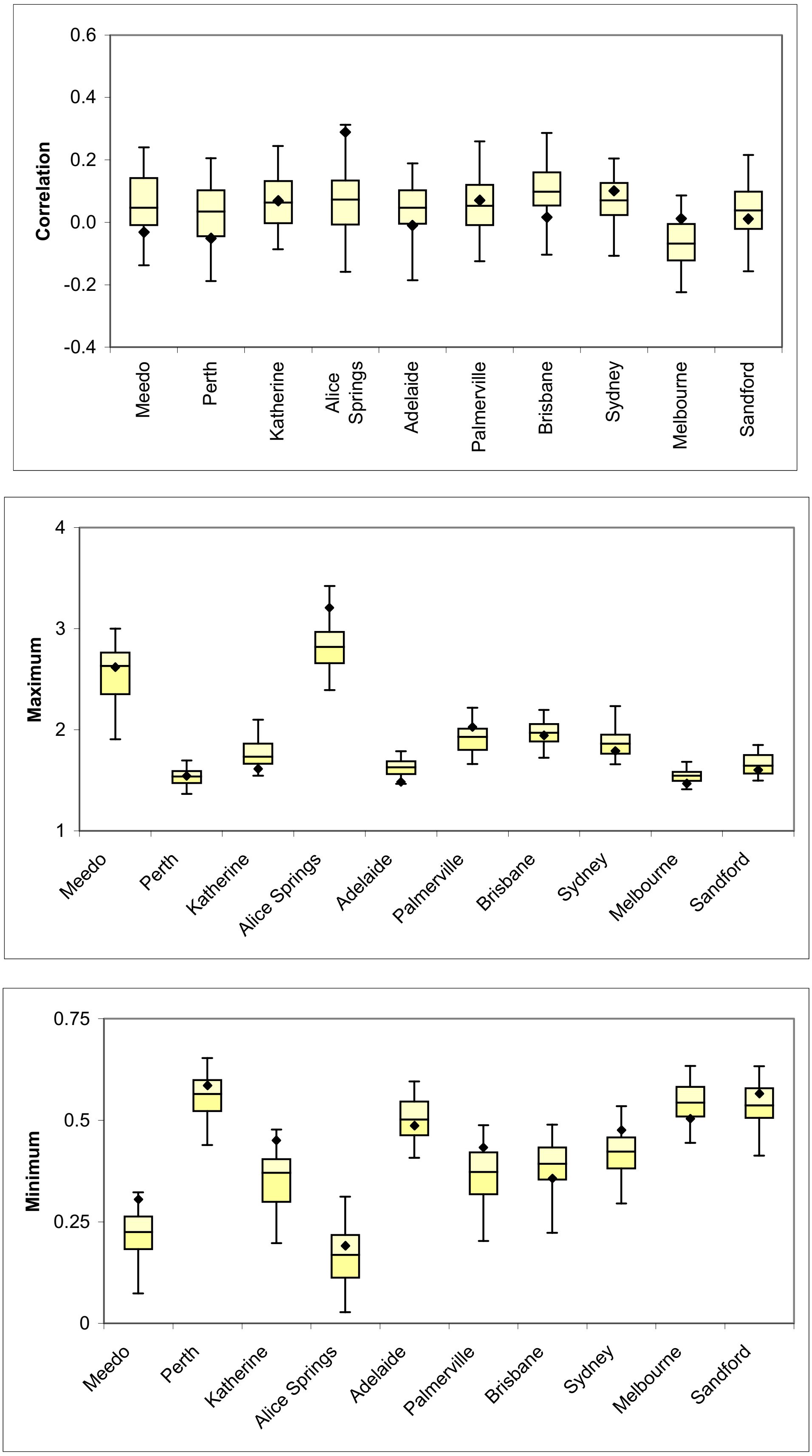


Figure 3. Comparison of annual correlation, maximum and minimum rainfall standardised by the mean annual rainfall for the nonparametric model

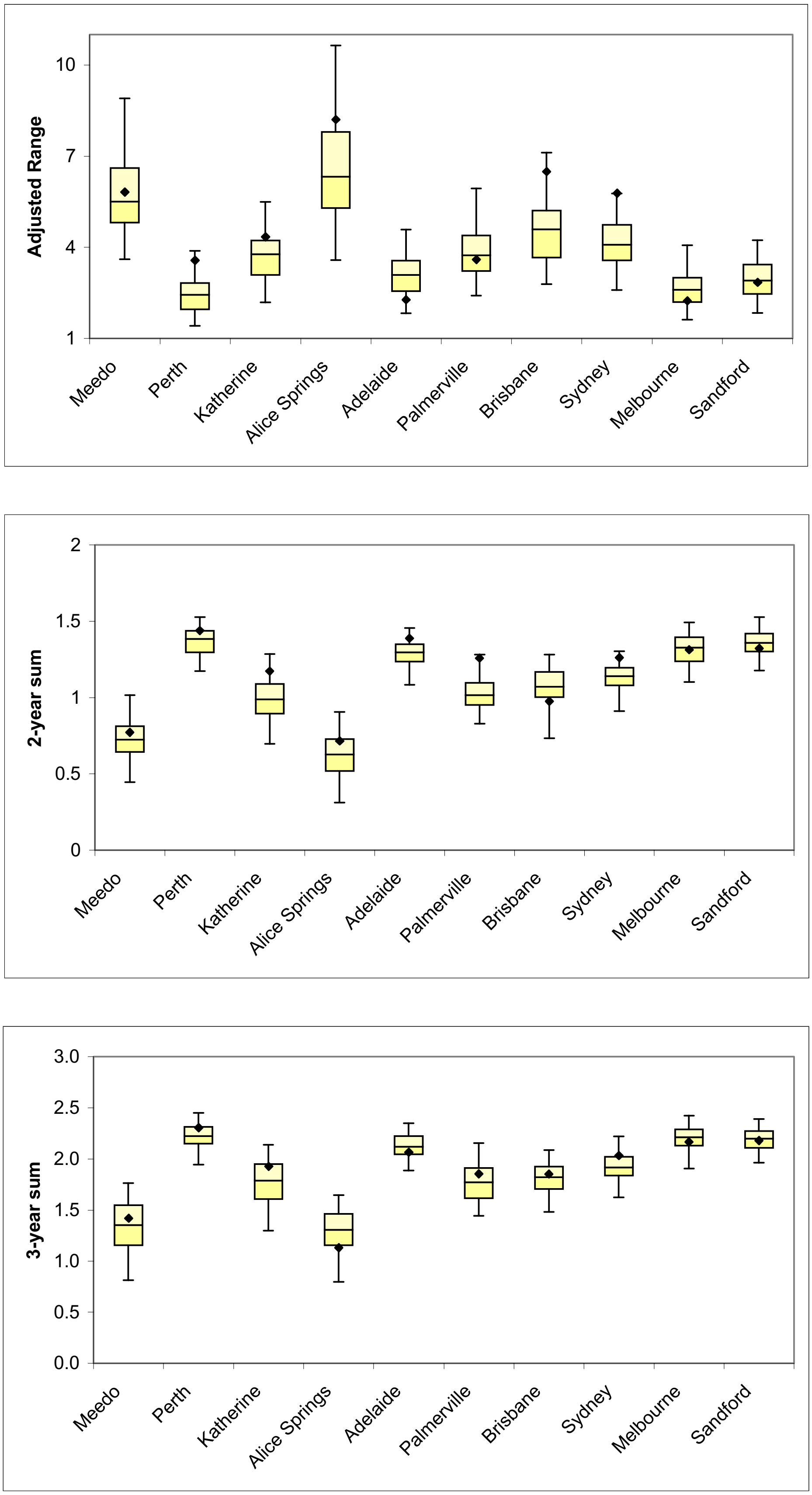


Figure 4. Comparison of adjusted range, 2-, and 3-year low rainfall sums standardised by the mean annual rainfall for the nonparametric model

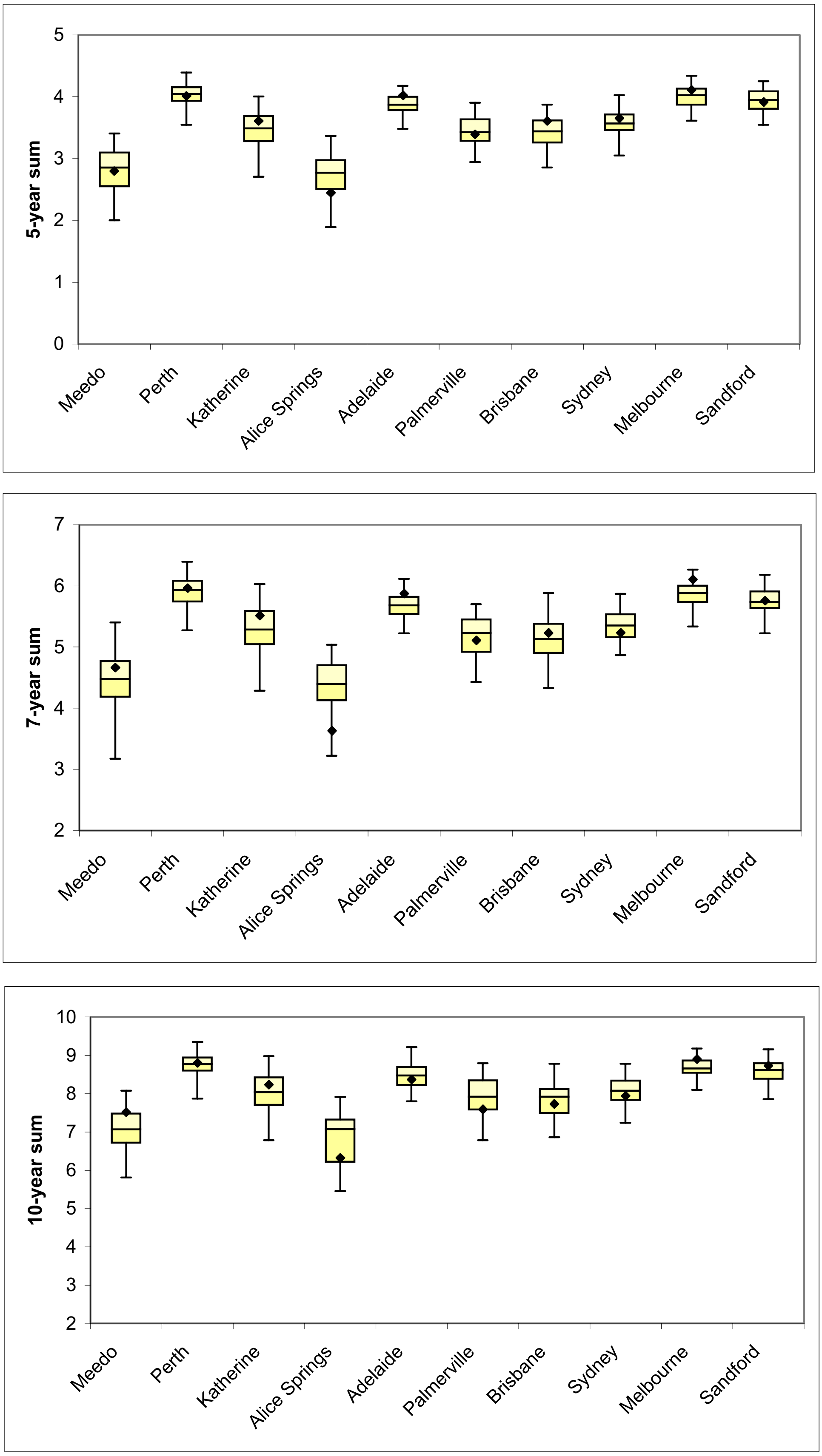


Figure 5. Comparison of 5-, 7- and 10-year low rainfall sums standardised by the mean annual rainfall for the nonparametric model

6.2 Monthly Parameters

The monthly parameters listed in Section 5 were estimated from each of the 100 replicates for both the models. For each parameter, the mean, median, 2.5-, 25-, 75- and 97.5- percentile values are obtained for comparison. The mean estimated from the 100 replicates for the monthly parameters are given in Tables A1 to A7 in Appendix A. Both models reproduced the monthly mean (Table A1), standard deviation (Table A2), skewness (Table A3) and correlation (Table A4) well. Both models preserved the extreme events and the relative frequency of no rainfall months (Tables A5-A7).

The percentile values of the parameters from the generated data and the historical parameters are shown in Figures A1-A7 for both the models. For the first five parameters, the historical values are all within the 95% confidence limits (Figures A1-A5). For months of low rainfall the method of fragments produced more extreme rainfall totals than the historical minimum rainfalls (Figure A6). The nonparametric model performs better than the method of fragments with regard to minimum rainfall. Both models satisfactorily reproduced the relative frequency of no rainfall months.

7. Conclusions

The method of fragments and the nonparametric model, developed by Sharma and O'Neill (2001), were compared using monthly rainfall data from ten rainfall stations located in different parts of Australia. The comparison was carried out at the monthly level. Both models were found to preserve the annual and monthly characteristics adequately. However, the nonparametric model has the following advantages over the method of fragments:

1. It eliminates the need for choosing a starting month for forming annual totals as it uses only the monthly data.
2. It also eliminates the need for a separate model that simulates the annual rainfall values.
3. It does not repeat the same yearly patterns.
4. Minimum rainfalls were generated better.

The annual parameters estimated from the monthly data generated by the nonparametric method were compared with the corresponding values and found to be satisfactory.

Both models preserved the annual and monthly characteristics satisfactorily, with the nonparametric model performing marginally better than the method of fragments.

8. References

Maheepala, S. and Perera, C. J. C., 1996. Monthly hydrologic data generation by disaggregation. J. Hydrol. 178, 277-291.

Porter, J. W. and Pink, B. J., 1991. A method of synthetic fragments for disaggregation in stochastic data generation. Hydrology and Water Resources Symposium, Institution of Engineers, Australia, 187-191.

Scott, D. W., 1992. Multivariate density estimation: Theory, Practice and Visualisation. John Wiley & Sons Inc., New York.

Sharma, A. and O'Neill, R., 2001. A nonparametric approach for representing interannual dependence in monthly streamflow. Submitted to Water Resources Research.

Srikanthan, R. and McMahon, T.A., 1985. Stochastic generation of rainfall and evaporation data. AWRC Technical Paper No. 84, 301pp.

Srikanthan, R., McMahon, T. A., Thyer, M. A. and Kuczera, G., 2002. Stochastic generation of annual rainfall data. CRC for Catchment Hydrology Technical Report 02/6, Melbourne.

Appendix A

Comparison of Monthly Parameters

The average values of monthly parameters from 100 replicates of generated data and the corresponding historical values are presented in Tables A1-A7. The notations used are:

Hist Historical value

MFM Results from the method of fragments

NP2 Results from the nonparametric model

The box plots in Figures A1-A7 show the variability in the estimates of the monthly parameters from the 100 replicates. The sets of figures in the left hand side column refer to the method of fragments and the right hand side figures refer to the nonparametric model.

Table A1. Comparison of historical and generated mean monthly rainfall (mm)

Station		Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
Meedo	Hist	15.6	20.3	18.8	13.6	34.8	42.1	34.0	18.5	5.1	5.8	3.2	3.6
	MFM	19.8	20.6	21.6	12.0	32.7	44.2	34.6	18.7	5.4	4.4	3.1	2.6
	NP2	16.4	21.8	18.4	12.1	34.8	42.2	33.0	18.9	5.2	6.2	3.1	3.8
Perth	Hist	8.8	12.2	19.2	45.7	122.7	181.9	172.9	135.0	79.8	54.5	21.3	13.7
	MFM	9.7	13.1	19.8	46.7	125.5	183.8	170.1	134.3	79.0	55.8	22.3	13.8
	NP2	9.1	12.4	19.8	46.4	123.0	183.7	173.2	136.6	80.6	54.9	22.2	13.9
Katherine	Hist	232.2	215.5	164.6	32.7	5.3	2.3	1.1	0.6	6.4	30.3	86.1	192.7
	MFM	238.3	212.4	170.1	28.0	4.9	1.7	0.8	0.6	6.7	30.8	84.9	193.7
	NP2	236.6	215.9	171.8	31.4	5.1	2.1	1.1	0.5	6.1	30.6	86.6	194.8
Alice Springs	Hist	43.1	43.1	33.7	16.6	16.3	14.0	11.5	10.1	9.6	20.4	25.2	36.5
	MFM	41.2	41.8	39.0	17.1	15.5	15.0	11.9	9.6	9.7	20.7	26.1	37.4
	NP2	42.8	41.0	31.8	16.4	15.7	15.5	15.5	9.3	8.8	19.8	25.8	36.8
Adelaide	Hist	20.0	20.9	24.1	44.3	68.3	71.5	66.2	61.5	50.9	44.6	30.6	26.4
	MFM	20.2	21.4	23.2	46.3	68.8	69.8	64.4	62.5	51.7	45.5	30.7	26.0
	NP2	20.1	21.2	24.0	44.8	68.5	71.9	67.0	61.4	51.3	45.1	30.4	26.7
Palmerville	Hist	260.2	258.8	182.4	49.3	16.0	11.7	5.3	3.5	8.0	19.0	61.6	156.9
	MFM	272.0	261.5	179.2	51.2	14.0	12.2	6.1	2.8	7.1	19.6	58.4	158.3
	NP2	261.2	260.8	184.9	51.2	15.1	12.1	5.4	3.5	7.6	19.2	62.5	157.6
Brisbane	Hist	159.4	164.2	145.5	95.4	74.2	70.4	56.9	44.7	44.9	76.8	97.7	127.7
	MFM	170.8	162.9	140.6	98.5	67.6	70.2	55.3	41.4	45.3	76.2	97.1	134.9
	NP2	158.8	162.9	146.7	94.7	74.1	72.1	58.4	43.1	45.1	77.6	99.2	128.9
Sydney	Hist	103.5	116.7	132.1	127.1	121.9	131.5	99.2	82.8	70.6	76.5	82.9	78.9
	MFM	100.5	115.4	135.4	119.2	122.4	132.9	97.7	86.1	69.8	80.1	86.4	76.6
	NP2	103.5	115.4	134.2	130.1	123.0	128.9	98.7	84.0	69.8	77.4	84.7	80.0
Melbourne	Hist	48.5	47.4	51.8	57.8	57.5	50.0	48.6	50.8	59.1	67.7	60.3	59.6
	MFM	47.6	43.5	53.2	55.2	57.8	50.4	49.3	51.0	58.3	68.2	61.2	61.6
	NP2	48.5	47.4	51.5	57.0	58.1	49.6	48.4	50.9	58.8	67.7	61.5	60.8
Sandford	Hist	46.4	41.6	42.9	54.3	44.0	51.0	47.0	45.2	43.3	55.2	48.0	58.3
	MFM	46.6	43.4	39.6	54.5	45.7	51.7	48.2	42.2	42.7	54.8	48.1	60.2
	NP2	46.2	42.9	43.0	55.8	44.4	51.5	47.3	45.1	43.1	55.4	49.5	58.5

Table A2. Comparison of historical and generated standard deviation of monthly rainfall (mm)

Station		Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
Meedo	Hist	32.4	29.6	27.8	23.1	36.6	31.2	35.0	19.1	6.3	13.1	8.8	10.2
	MFM	38.7	26.6	31.0	16.8	36.3	30.2	32.8	17.5	7.4	10.0	6.6	6.7
	NP2	33.0	30.5	27.8	18.1	37.5	32.2	34.9	19.1	6.5	12.5	7.9	10.1
Perth	Hist	14.0	21.1	22.5	32.7	60.8	69.7	62.1	58.0	40.2	32.3	16.4	14.5
	MFM	13.8	20.5	22.7	34.1	61.3	65.7	57.0	57.2	39.7	34.3	18.1	14.5
	NP2	13.7	20.7	23.2	34.6	67.3	77.8	68.2	64.7	43.8	34.5	17.7	14.6
Katherine	Hist	118.9	106.3	133.2	48.2	12.2	8.4	5.4	2.6	14.2	34.5	59.7	107.4
	MFM	124.8	100.1	139.0	41.5	11.6	6.2	3.6	2.6	13.8	35.4	54.2	104.9
	NP2	132.2	117.8	146.9	46.2	12.3	7.6	5.3	2.2	12.9	33.6	62.3	118.3
Alice Springs	Hist	56.5	56.8	52.6	26.3	24.0	19.6	21.5	22.7	17.2	21.8	26.8	47.4
	MFM	56.7	54.4	60.2	28.1	23.0	20.5	27.0	22.0	17.0	22.7	27.1	48.2
	NP2	56.1	54.4	50.8	25.7	23.5	21.4	35.1	20.6	15.6	21.5	27.0	47.9
Adelaide	Hist	19.6	25.2	24.1	32.3	37.5	39.1	29.1	26.0	25.1	24.3	23.3	21.3
	MFM	19.8	25.4	22.9	33.5	38.0	35.2	29.1	26.3	25.0	25.1	22.7	21.5
	NP2	20.0	25.9	24.3	33.4	39.9	41.4	32.6	28.8	27.4	26.5	23.6	22.1
Palmerville	Hist	135.1	130.0	118.5	58.6	24.1	17.8	10.5	11.2	18.0	20.4	53.1	96.7
	MFM	151.2	133.8	122.5	61.3	21.7	17.7	11.8	8.1	15.4	21.2	54.6	94.3
	NP2	150.0	144.2	128.2	54.8	22.8	17.8	10.8	10.5	17.2	20.3	55.3	103.1
Brisbane	Hist	127.6	147.8	125.5	94.5	76.5	82.9	58.7	57.6	32.5	64.4	68.3	85.4
	MFM	141.5	159.1	120.5	93.4	71.5	87.0	53.6	52.0	30.7	61.0	66.9	88.3
	NP2	126.9	152.4	128.7	95.0	77.3	83.1	60.4	53.0	33.1	66.5	71.5	90.0
Sydney	Hist	77.6	110.5	105.3	114.0	109.0	113.9	84.0	85.3	60.4	65.8	77.3	65.1
	MFM	75.4	110.9	109.6	103.3	105.5	120.6	83.4	85.3	56.0	68.6	76.9	64.9
	NP2	79.0	111.0	110.7	117.0	111.9	113.1	86.5	88.2	60.9	67.6	79.7	66.5
Melbourne	Hist	36.1	44.8	39.0	37.1	27.7	23.8	22.7	20.5	29.4	33.2	37.3	38.9
	MFM	34.8	41.7	41.3	35.8	27.0	23.1	23.4	21.3	28.2	34.4	37.1	39.5
	NP2	37.8	45.2	40.4	37.8	30.0	25.3	24.6	22.6	31.7	36.5	40.4	41.8
Sandford	Hist	33.4	35.5	32.1	40.3	27.4	34.2	26.9	28.6	23.1	30.5	28.6	42.3
	MFM	33.8	35.9	26.5	39.7	27.9	34.6	28.3	25.4	23.4	30.6	29.0	42.6
	NP2	34.3	37.1	32.0	41.6	28.6	36.4	28.5	31.1	24.7	32.1	31.1	44.3

Table A3. Comparison of historical and generated skewness of monthly rainfall

Station		Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
Meedo	Hist	4.009	2.364	2.311	3.533	1.619	0.955	2.097	1.409	1.719	3.702	4.787	5.507
	MFM	3.277	1.774	1.963	2.378	1.627	0.657	1.979	1.314	1.969	4.113	3.704	4.003
	NP2	3.487	2.107	2.202	2.751	1.603	0.905	1.958	1.251	1.640	3.306	4.174	4.187
Perth	Hist	4.608	4.274	2.553	0.769	0.521	0.788	0.842	0.733	0.687	1.403	1.079	2.121
	MFM	2.815	3.360	2.320	0.931	0.667	0.624	0.898	0.690	0.788	1.770	1.114	2.055
	NP2	3.491	3.362	2.276	0.759	0.464	0.430	0.488	0.551	0.594	1.018	1.026	1.841
Katherine	Hist	1.269	0.427	1.506	1.916	2.723	5.053	6.991	5.480	3.374	1.564	1.428	1.670
	MFM	1.055	0.468	1.247	2.088	2.859	5.820	5.823	5.870	2.887	1.601	1.211	1.651
	NP2	0.898	0.414	1.182	1.890	2.762	5.272	6.412	5.738	2.910	1.466	1.158	1.352
Alice Springs	Hist	2.344	1.442	3.439	1.971	1.663	1.698	2.782	3.984	2.548	1.725	1.947	2.502
	MFM	2.387	1.546	3.341	2.032	1.662	1.768	3.876	3.886	2.516	1.797	2.100	2.381
	NP2	2.247	1.471	3.192	1.981	1.670	1.620	4.218	3.654	2.579	1.706	1.813	2.359
Adelaide	Hist	1.427	1.994	1.855	1.215	0.710	1.012	0.336	0.764	0.738	0.684	1.334	1.262
	MFM	1.543	1.693	1.728	1.162	0.872	0.846	0.363	0.867	0.708	0.777	1.339	1.360
	NP2	1.363	1.859	1.683	1.113	0.601	0.849	0.274	0.544	0.542	0.595	1.106	1.162
Palmerville	Hist	1.210	0.576	0.872	3.969	3.374	2.250	2.997	6.319	3.253	1.195	1.700	0.717
	MFM	1.444	0.541	0.986	3.280	3.349	2.034	2.761	5.479	3.156	1.238	1.975	0.723
	NP2	0.859	0.514	0.807	2.333	3.212	2.035	3.001	5.596	3.308	1.176	1.503	0.669
Brisbane	Hist	2.646	2.380	2.165	2.052	2.045	3.341	1.766	3.396	0.749	2.390	1.348	1.224
	MFM	2.521	2.610	1.859	1.985	2.372	2.808	1.575	3.623	0.633	1.740	1.264	0.960
	NP2	2.000	2.022	1.783	1.807	1.926	2.547	1.635	3.090	0.713	1.829	1.216	1.020
Sydney	Hist	1.317	2.092	1.429	1.733	1.726	1.450	1.016	2.160	1.684	1.605	2.859	1.790
	MFM	1.311	2.003	1.406	1.715	1.567	1.667	1.156	2.002	1.421	1.614	2.458	1.800
	NP2	1.164	1.937	1.332	1.507	1.599	1.358	0.977	1.992	1.535	1.434	2.410	1.541
Melbourne	Hist	1.177	1.662	1.229	1.030	0.500	0.745	1.790	0.526	1.392	0.738	1.144	1.042
	MFM	1.425	1.789	1.283	0.994	0.384	0.780	1.462	0.552	1.307	0.708	1.208	0.917
	NP2	1.074	1.515	1.148	0.955	0.449	0.623	1.255	0.401	1.030	0.629	0.887	0.889
Sandford	Hist	1.050	1.660	2.264	1.653	0.907	2.052	1.490	1.361	0.992	1.213	1.203	1.030
	MFM	1.169	1.414	1.584	1.636	0.894	1.649	1.181	1.528	0.881	1.292	1.211	1.026
	NP2	0.921	1.329	1.695	1.429	0.794	1.604	1.142	1.149	0.783	1.010	1.026	0.928

Table A4. Comparison of historical and generated correlation of monthly rainfall

Satation		Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
Meedo	Hist	-0.110	0.128	0.015	0.024	0.056	0.070	-0.032	-0.053	0.032	0.032	0.304	0.038
	MFM	-0.119	0.171	-0.021	0.077	-0.038	0.093	0.082	-0.111	0.059	0.094	-0.021	-0.035
	NP2	-0.126	0.145	0.023	0.026	0.063	0.038	-0.033	-0.060	0.046	0.015	0.132	0.040
Perth	Hist	-0.067	-0.008	-0.078	0.044	0.007	0.139	-0.090	-0.073	-0.003	0.130	-0.091	-0.024
	MFM	-0.130	0.061	-0.111	0.113	-0.014	0.220	-0.057	-0.059	-0.019	0.173	-0.061	-0.097
	NP2	-0.069	0.006	-0.083	0.057	0.003	0.141	-0.056	-0.068	0.001	0.094	-0.058	-0.010
Katherine	Hist	-0.144	-0.053	0.091	-0.124	0.051	0.215	-0.040	-0.048	0.042	0.066	0.033	-0.215
	MFM	-0.164	-0.074	0.047	-0.162	0.077	0.263	-0.038	-0.049	0.016	0.084	0.035	-0.232
	NP2	-0.135	-0.043	0.084	-0.176	0.002	0.262	-0.038	-0.048	0.060	0.134	0.013	-0.221
Alice Springs	Hist	-0.081	0.178	0.064	0.095	-0.054	0.108	0.136	0.306	0.530	0.036	0.023	0.287
	MFM	-0.113	0.162	0.034	0.148	-0.073	0.126	0.191	0.163	0.529	0.016	0.044	0.147
	NP2	-0.087	0.180	0.069	0.095	-0.067	0.139	0.372	0.125	0.440	-0.025	0.042	0.279
Adelaide	Hist	0.001	-0.068	-0.064	-0.009	0.043	0.061	0.083	0.156	0.078	-0.013	-0.003	-0.095
	MFM	0.031	-0.073	-0.083	0.037	0.027	0.092	0.001	0.139	0.080	-0.010	0.021	-0.085
	NP2	0.012	-0.088	-0.029	-0.024	0.019	0.052	0.087	0.163	0.072	-0.023	-0.019	-0.087
Palmerville	Hist	0.129	0.236	0.010	0.260	-0.033	-0.076	0.052	-0.072	0.369	-0.042	0.266	0.147
	MFM	0.043	0.243	0.024	0.322	0.009	-0.093	0.119	-0.018	0.122	-0.054	0.299	0.209
	NP2	0.116	0.227	0.006	0.242	0.005	-0.052	0.060	-0.056	0.305	-0.053	0.251	0.159
Brisbane	Hist	0.155	-0.025	0.048	0.143	0.023	0.055	-0.004	0.134	0.203	-0.025	0.177	0.126
	MFM	0.164	-0.004	0.126	0.153	-0.087	0.059	0.003	0.220	0.139	0.032	0.189	0.213
	NP2	0.171	-0.022	0.049	0.152	-0.004	0.101	-0.017	0.162	0.154	0.002	0.170	0.124
Sydney	Hist	0.130	0.137	0.083	0.010	0.041	0.018	0.043	0.026	0.070	-0.027	0.077	0.089
	MFM	0.172	0.120	0.083	-0.016	0.075	0.022	0.098	0.048	0.097	-0.006	0.099	0.085
	NP2	0.103	0.155	0.066	0.002	0.032	0.022	0.037	0.015	0.106	-0.005	0.069	0.106
Melbourne	Hist	-0.092	-0.023	0.107	-0.026	-0.029	-0.081	0.055	-0.017	0.072	0.181	0.185	0.293
	MFM	-0.101	-0.011	0.095	0.005	-0.076	-0.017	-0.006	-0.014	0.087	0.195	0.126	0.282
	NP2	-0.097	-0.006	0.096	-0.020	-0.044	-0.089	0.065	-0.016	0.082	0.171	0.179	0.284
Sandford	Hist	0.052	0.052	0.027	-0.144	0.057	0.080	0.018	0.101	-0.016	-0.094	0.074	0.117
	MFM	0.172	0.031	0.019	-0.233	0.093	0.152	0.018	0.149	0.016	-0.022	0.033	0.091
	NP2	0.057	0.043	0.042	-0.156	0.053	0.083	0.001	0.112	0.002	-0.094	0.075	0.130

Table A5. Comparison of historical and generated maximum monthly rainfall

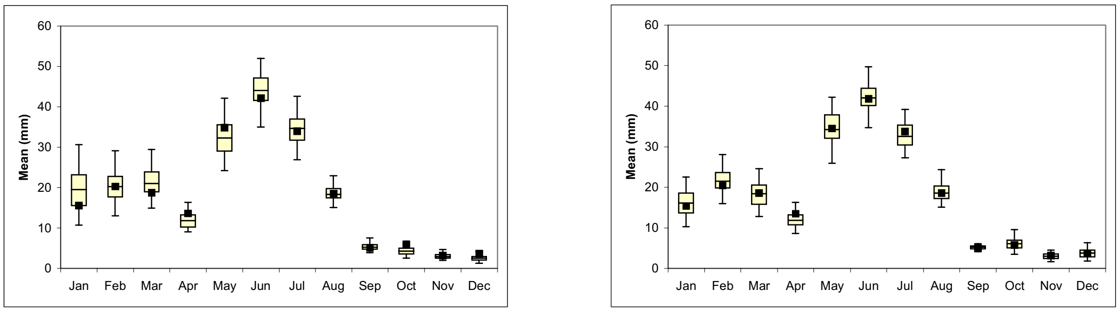
Station		Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
Meedo	Hist	12.139	8.311	8.489	7.522	9.256	7.333	10.200	4.989	1.817	4.172	3.433	4.556
	MFM	11.570	6.962	8.064	5.207	9.191	7.117	9.251	4.481	1.850	3.441	2.242	2.380
	NP2	10.735	7.869	7.813	5.961	9.119	7.667	9.826	4.612	1.684	3.830	2.750	3.454
Perth	Hist	1.590	2.299	2.007	2.057	4.259	6.582	5.877	4.400	2.753	2.764	1.012	1.116
	MFM	1.160	1.847	1.842	2.244	4.305	5.320	5.144	4.309	2.780	2.812	1.017	1.043
	NP2	1.265	1.807	1.864	2.109	4.393	5.950	5.349	4.612	2.911	2.483	1.062	1.075
Katherine	Hist	8.681	6.070	7.974	2.623	0.760	0.667	0.591	0.238	1.120	1.833	4.381	9.266
	MFM	8.636	6.006	7.733	2.522	0.697	0.570	0.349	0.217	0.925	1.850	3.671	8.299
	NP2	8.618	6.561	8.108	2.570	0.703	0.606	0.491	0.192	0.877	1.801	3.963	8.634
Alice Springs	Hist	13.436	10.106	15.553	5.019	4.659	3.411	4.646	6.771	3.844	4.950	5.949	12.351
	MFM	13.451	10.041	15.583	5.112	4.141	3.687	7.378	5.720	3.587	4.971	6.443	11.100
	NP2	12.619	9.453	13.681	4.732	4.275	3.530	9.729	5.522	3.432	4.582	5.914	11.288
Adelaide	Hist	1.902	3.503	2.640	3.503	4.458	4.934	3.136	3.571	3.353	3.016	2.563	2.289
	MFM	1.972	2.861	2.556	3.661	4.441	4.393	3.260	3.488	3.109	2.944	2.395	2.263
	NP2	2.007	3.119	2.674	3.579	4.402	4.888	3.461	3.474	3.151	2.952	2.449	2.345
Palmerville	Hist	9.438	7.530	7.107	5.452	1.983	1.087	0.658	1.076	1.132	0.970	3.679	5.355
	MFM	9.812	7.363	6.881	4.761	1.619	0.984	0.658	0.735	0.985	1.004	3.542	5.142
	NP2	9.054	7.796	7.029	3.810	1.694	0.989	0.674	0.894	1.072	0.955	3.358	5.467
Brisbane	Hist	9.066	10.668	8.992	5.694	4.259	6.732	3.426	3.876	1.434	4.753	4.293	4.586
	MFM	9.174	10.707	7.410	5.187	3.987	5.719	2.800	3.793	1.406	3.652	3.793	4.459
	NP2	8.007	9.408	7.887	5.195	4.068	5.549	3.169	3.600	1.470	4.105	4.080	4.564
Sydney	Hist	3.789	6.172	5.103	6.089	5.726	6.291	3.290	4.724	3.483	2.790	5.062	3.934
	MFM	3.668	5.950	4.915	5.462	5.270	6.351	3.635	4.571	2.857	2.886	4.871	3.563
	NP2	3.803	5.911	5.140	5.769	5.590	5.597	3.524	4.781	3.167	2.979	4.950	3.518
Melbourne	Hist	3.215	4.351	3.483	3.562	2.603	2.133	3.258	2.024	3.682	3.531	3.764	3.605
	MFM	3.223	4.029	3.599	3.393	2.476	2.195	2.915	2.070	3.418	3.323	3.668	3.469
	NP2	3.249	4.154	3.341	3.453	2.691	2.186	2.954	2.132	3.364	3.438	3.599	3.666
Sandford	Hist	3.218	3.978	4.553	4.588	2.653	4.821	3.280	3.006	2.574	3.698	3.336	3.592
	MFM	3.217	3.725	3.222	4.355	2.770	4.097	3.091	2.751	2.414	3.628	3.301	3.756
	NP2	3.059	3.682	3.750	4.356	2.644	4.399	3.174	3.036	2.486	3.516	3.254	3.748

Table A6. Comparison of historical and generated minimum monthly rainfall

Station		Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
Meedo	Hist	0	0	0	0	0	0.072	0	0	0	0	0	0
	MFM	0	0	0	0	0	0.09	0.001	0	0	0	0	0
	NP2	0	0	0	0	0	0.03	0	0	0	0	0	0
Perth	Hist	0	0	0	0	0.195	0.759	0.85	0.163	0.12	0.014	0	0
	MFM	0	0	0	0.001	0.267	0.935	0.958	0.216	0.125	0.076	0.001	0
	NP2	0	0	0	0	0.077	0.33	0.423	0.116	0.067	0.021	0.001	0
Katherine	Hist	0.627	0.124	0	0	0	0	0	0	0	0	0.016	0.435
	MFM	0.592	0.323	0.004	0	0	0	0	0	0	0	0.033	0.401
	NP2	0.187	0.106	0.002	0	0	0	0	0	0	0	0.013	0.134
Alice Springs	Hist	0	0	0	0	0	0	0	0	0	0	0	0
	MFM	0	0	0	0	0	0	0	0	0	0	0	0
	NP2	0	0	0	0	0	0	0	0	0	0	0	0
Adelaide	Hist	0	0	0	0	0.059	0.136	0.229	0.19	0.158	0.023	0.032	0
	MFM	0	0	0	0.005	0.083	0.21	0.243	0.293	0.275	0.072	0.057	0.009
	NP2	0	0	0	0.006	0.038	0.061	0.096	0.091	0.057	0.018	0.012	0.002
Palmerville	Hist	0.029	0.116	0.044	0	0	0	0	0	0	0	0.015	0.029
	MFM	0.288	0.285	0.149	0.001	0	0	0	0	0	0	0.017	0.068
	NP2	0.062	0.079	0.054	0	0	0	0	0	0	0	0.004	0.023
Brisbane	Hist	0.085	0.185	0.029	0.011	0.005	0	0	0	0.002	0.008	0.021	0.093
	MFM	0.164	0.165	0.075	0.014	0.013	0.003	0.005	0	0.004	0.014	0.066	0.101
	NP2	0.036	0.033	0.013	0.005	0.004	0.001	0.001	0	0.002	0.007	0.013	0.024
Sydney	Hist	0.055	0.029	0.082	0.014	0.036	0.04	0.018	0	0.021	0.006	0.019	0.027
	MFM	0.07	0.032	0.104	0.026	0.041	0.042	0.02	0.007	0.033	0.028	0.029	0.028
	NP2	0.017	0.009	0.028	0.011	0.012	0.007	0.005	0.002	0.006	0.008	0.007	0.011
Melbourne	Hist	0.005	0.009	0.068	0.000	0.069	0.146	0.172	0.226	0.245	0.137	0.119	0.031
	MFM	0.017	0.010	0.075	0.005	0.121	0.177	0.184	0.224	0.266	0.170	0.158	0.050
	NP2	0.004	0.002	0.019	0.012	0.043	0.071	0.063	0.088	0.071	0.056	0.03	0.014
Sandford	Hist	0.069	0	0.054	0.029	0	0.066	0.17	0.133	0.158	0.154	0.143	0.033
	MFM	0.083	0.007	0.071	0.077	0.078	0.086	0.202	0.148	0.168	0.221	0.188	0.046
	NP2	0.025	0.004	0.026	0.026	0.017	0.034	0.054	0.033	0.053	0.064	0.056	0.013

Table A7. Comparison of historical and generated number of months of no rainfall

Station		Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
Meedo	Hist	35.1	28.7	36.2	33.0	10.6	0	5.3	10.6	35.1	41.5	63.8	68.1
	MFM	35.8	28.6	35.5	32.9	13.2	0	5.5	7.1	37.7	40.6	58.8	69.0
	NP2	37.2	29.4	38.6	32.6	11.3	0.2	5.7	10.8	33.9	42.1	65.6	68.6
Perth	Hist	7.8	11.3	4.3	2.6	0	0	0	0	0	0	0.9	2.6
	MFM	9.3	11.8	2.9	2.2	0	0	0	0	0	0	1.9	2.5
	NP2	8.3	14.4	4.6	2.8	0.0	0.0	0.0	0.0	0.0	0.1	1.2	3.4
Katherine	Hist	0	0	0.9	32.4	63.1	77.5	90.1	89.2	57.7	8.1	0	0
	MFM	0	0	2.6	33.7	63.6	79.2	89.3	92.4	56.2	9.5	0	0
	NP2	0.0	0.0	1.1	33.2	65.8	80.1	90.1	90.1	59.3	9.0	0.0	0.0
Alice Springs	Hist	11.6	22.3	19.6	38.4	36.6	32.1	45.5	39.3	38.4	15.2	6.3	10.7
	MFM	13.3	20.7	16.8	40.0	36.6	28.7	47.0	42.2	36.5	17.7	5.4	8.9
	NP2	11.6	22.5	21.2	38.8	38.2	31.8	45.2	40.7	41.0	16.2	7.1	11.0
Adelaide	Hist	4.3	5.0	2.2	0.7	0	0	0	0	0	0	0	0.7
	MFM	4.0	5.3	2.3	1.3	0	0	0	0	0	0	0	0.9
	NP2	4.3	6.5	2.9	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.1	1.0
Palmerville	Hist	0	0	0	3.7	11.9	25.7	49.5	56.9	47.7	17.4	0	0
	MFM	0	0	0	4.2	13.4	25.7	47.5	60.0	46.9	17.1	0	0
	NP2	0.0	0.1	0.0	3.8	12.9	26.2	50.0	55.1	49.0	18.0	0.2	0.1
Brisbane	Hist	0	0	0	0	0	0.8	0.8	3.8	0	0	0	0
	MFM	0	0	0	0	0	1.0	0.3	4.7	0	0	0	0
	NP2	0.0	0.0	0.1	0.2	0.2	1.2	0.8	4.3	0.3	0.1	0.1	0.0
Sydney	Hist	0	0	0	0	0	0	0	0.7	0	0	0	0
	MFM	0	0	0	0	0	0	0	0.6	0	0	0	0
	NP2	0.0	0.1	0.0	0.0	0.0	0.1	0.2	0.8	0.1	0.1	0.1	0.1
Melbourne	Hist	0	0	0	0.7	0	0	0	0	0	0	0	0
	MFM	0	0	0	2.2	0	0	0	0	0	0	0	0
	NP2	0.3	0.5	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Sandford	Hist	0	0.9	0	0	0.9	0	0	0	0	0	0	0
	MFM	0	1.1	0	0	0.2	0	0	0	0	0	0	0
	NP2	0.0	0.9	0.0	0.1	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.1



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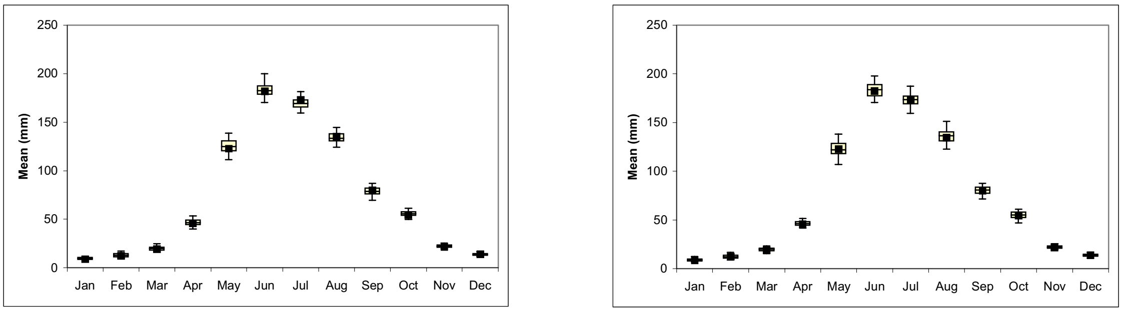
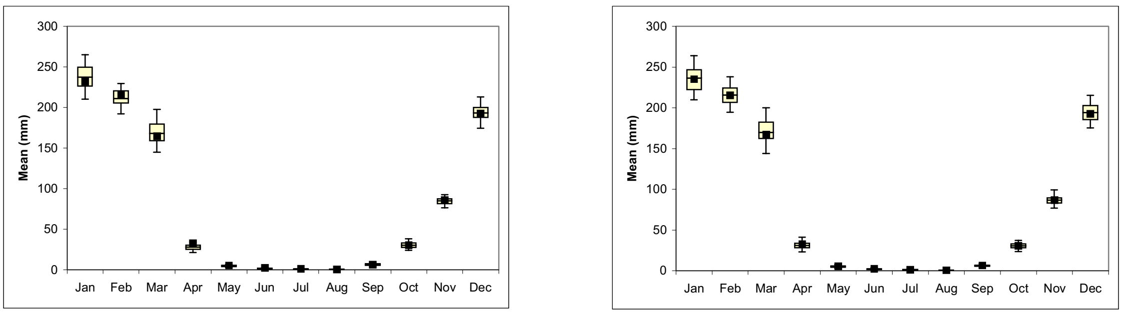
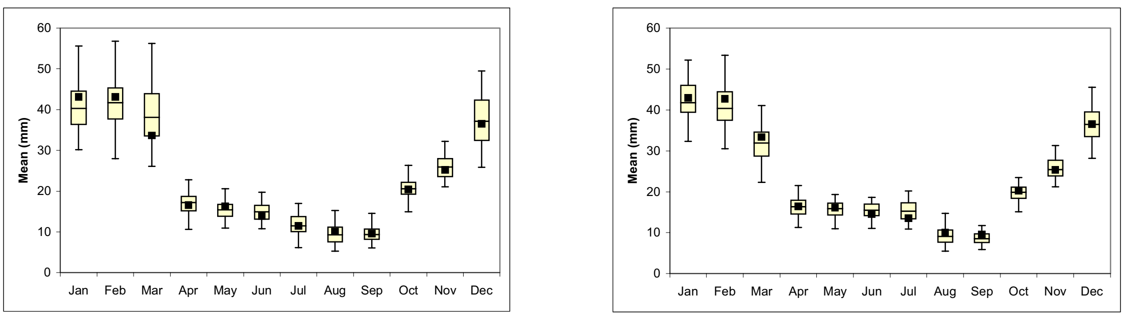


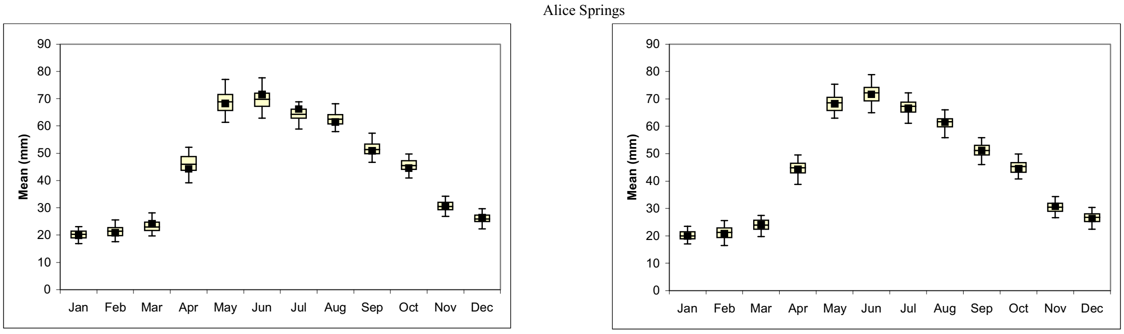
Perth



Katherine



Alice Springs

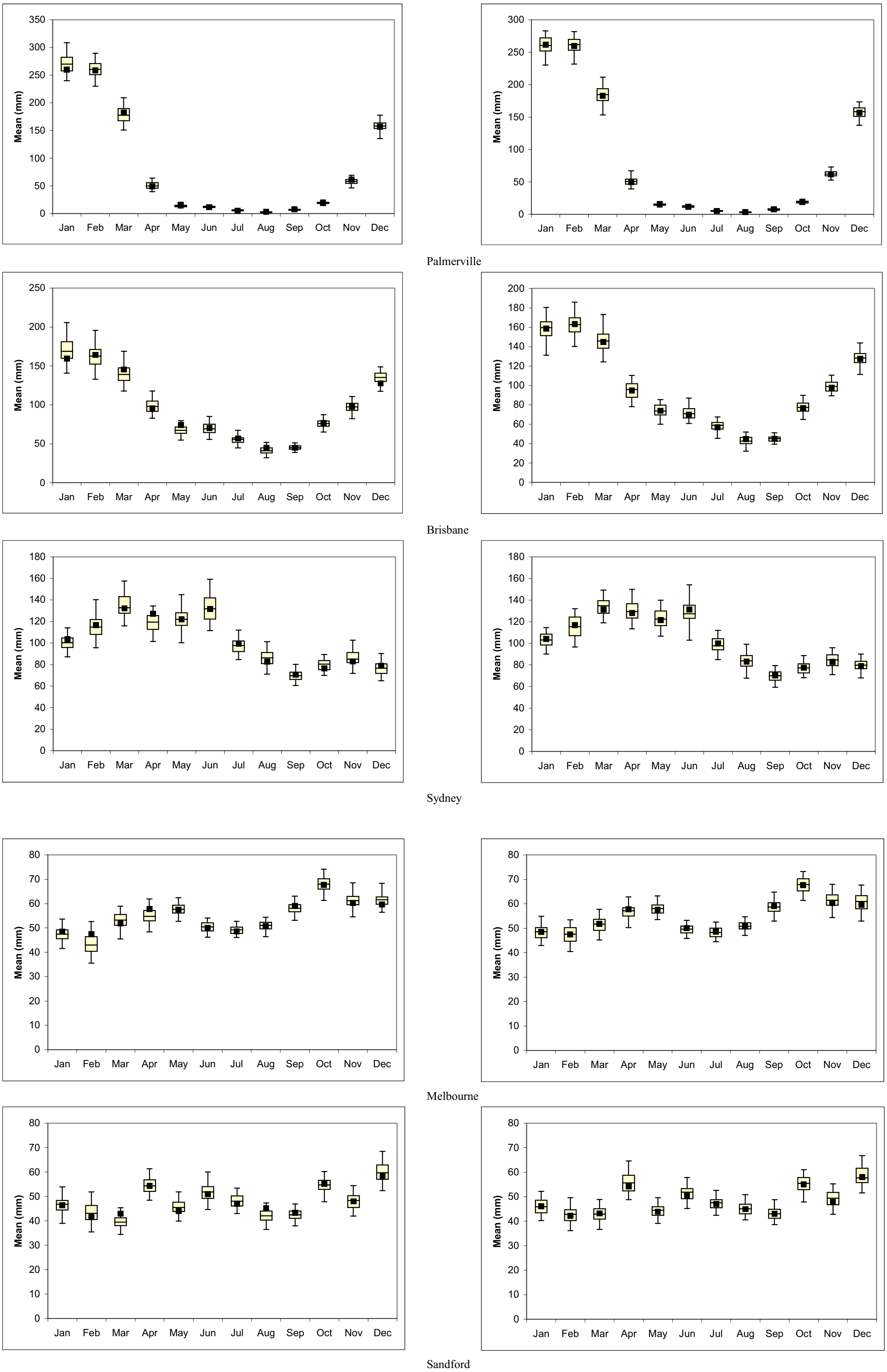


Adelaide

Method of fragments

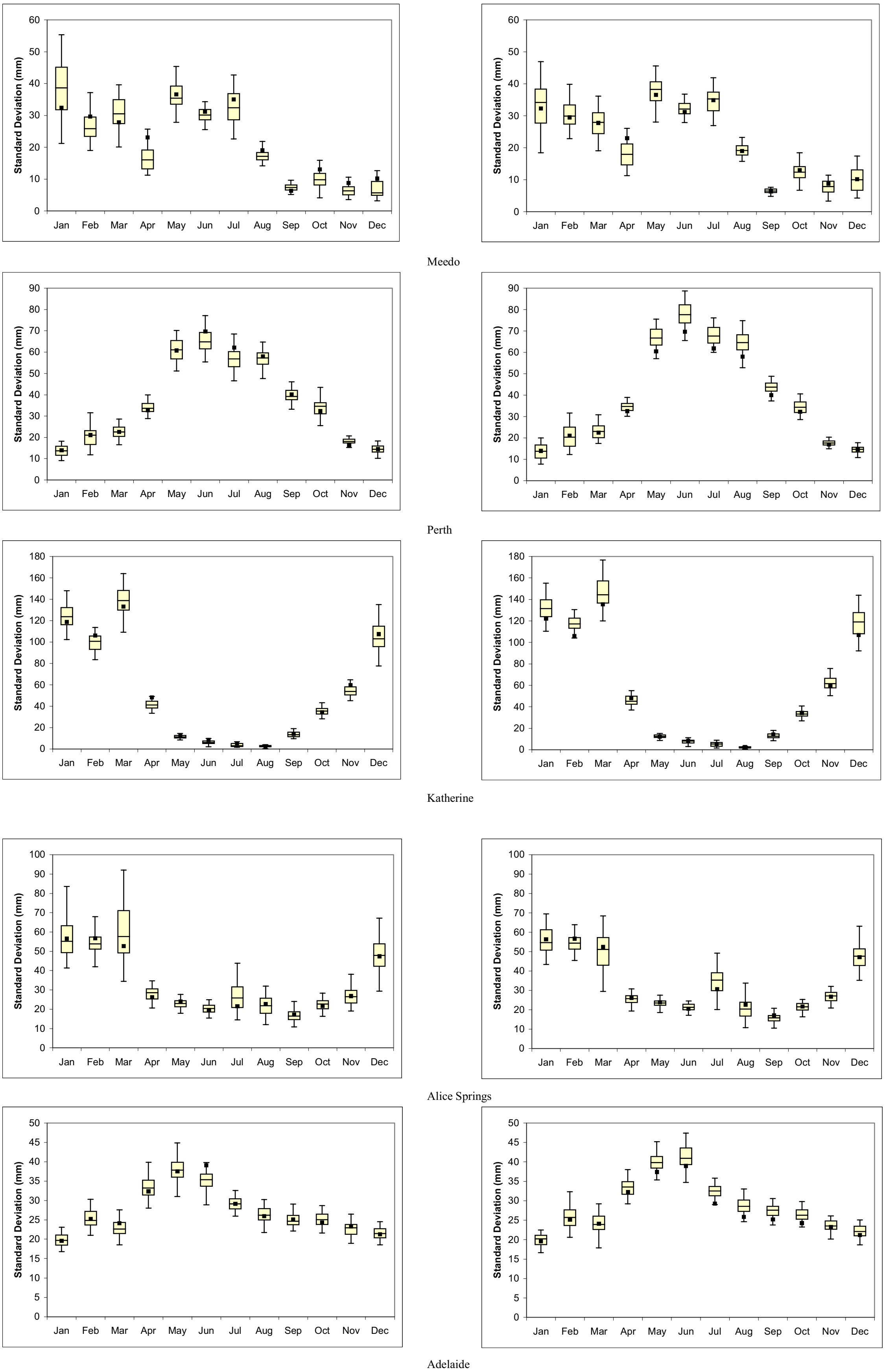
Nonparametric model

Figure A1. Comparison of historical and generated monthly mean (mm)



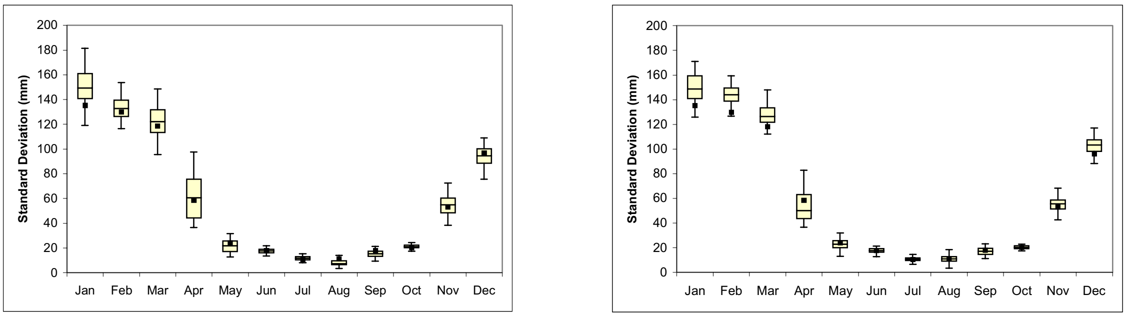
Method of fragments | Nonparametric model

Figure A1. (Cont)

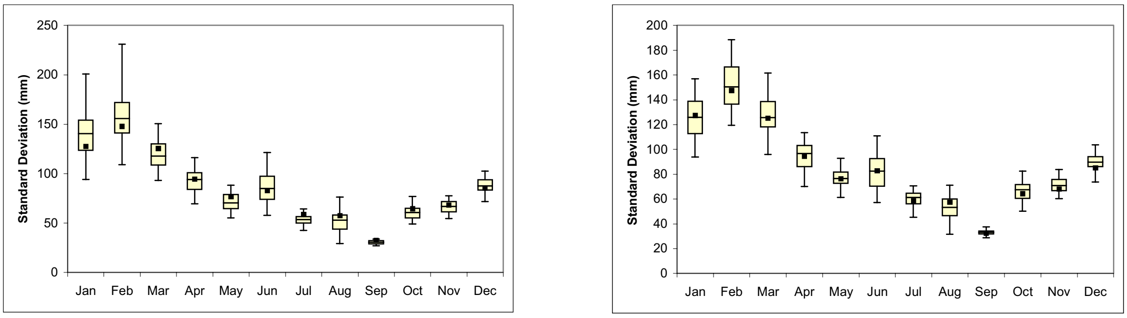


Method of fragments   Nonparametric model

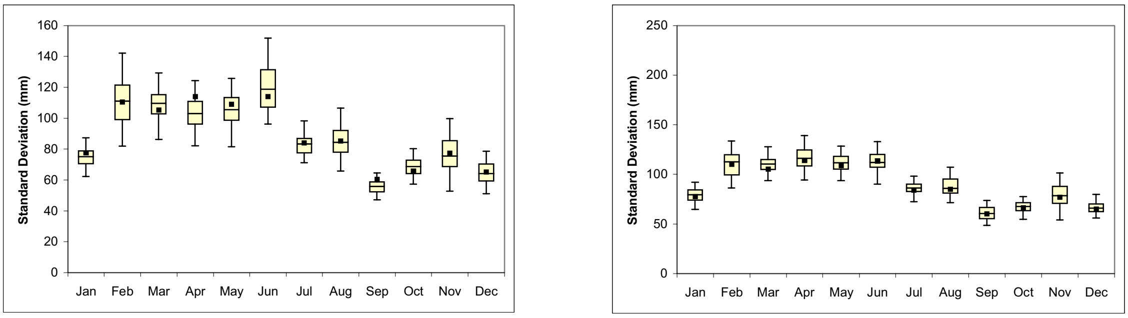
Figure A2. Comparison of historical and generated standard deviation of monthly rainfall



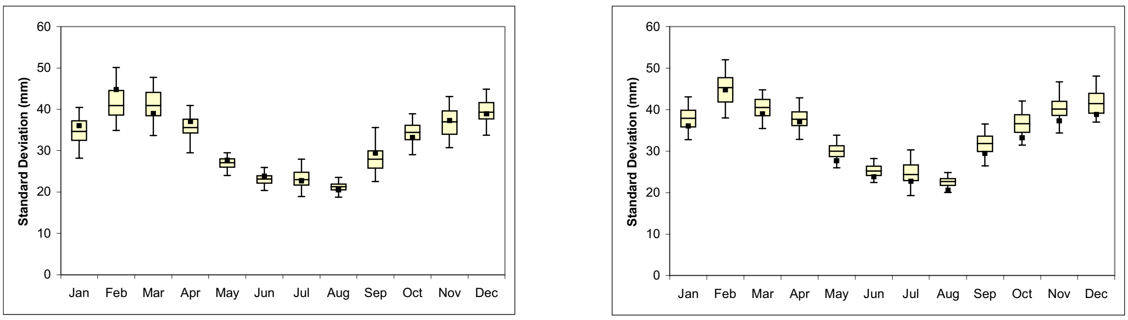
Palmerville



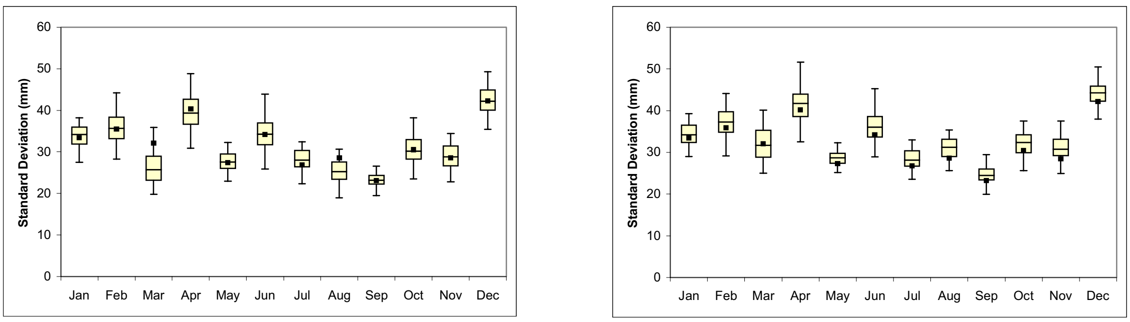
Brisbane



Sydney



Melbourne



Sandford

Method of fragments   Nonparametric model

Figure A2. (Cont)

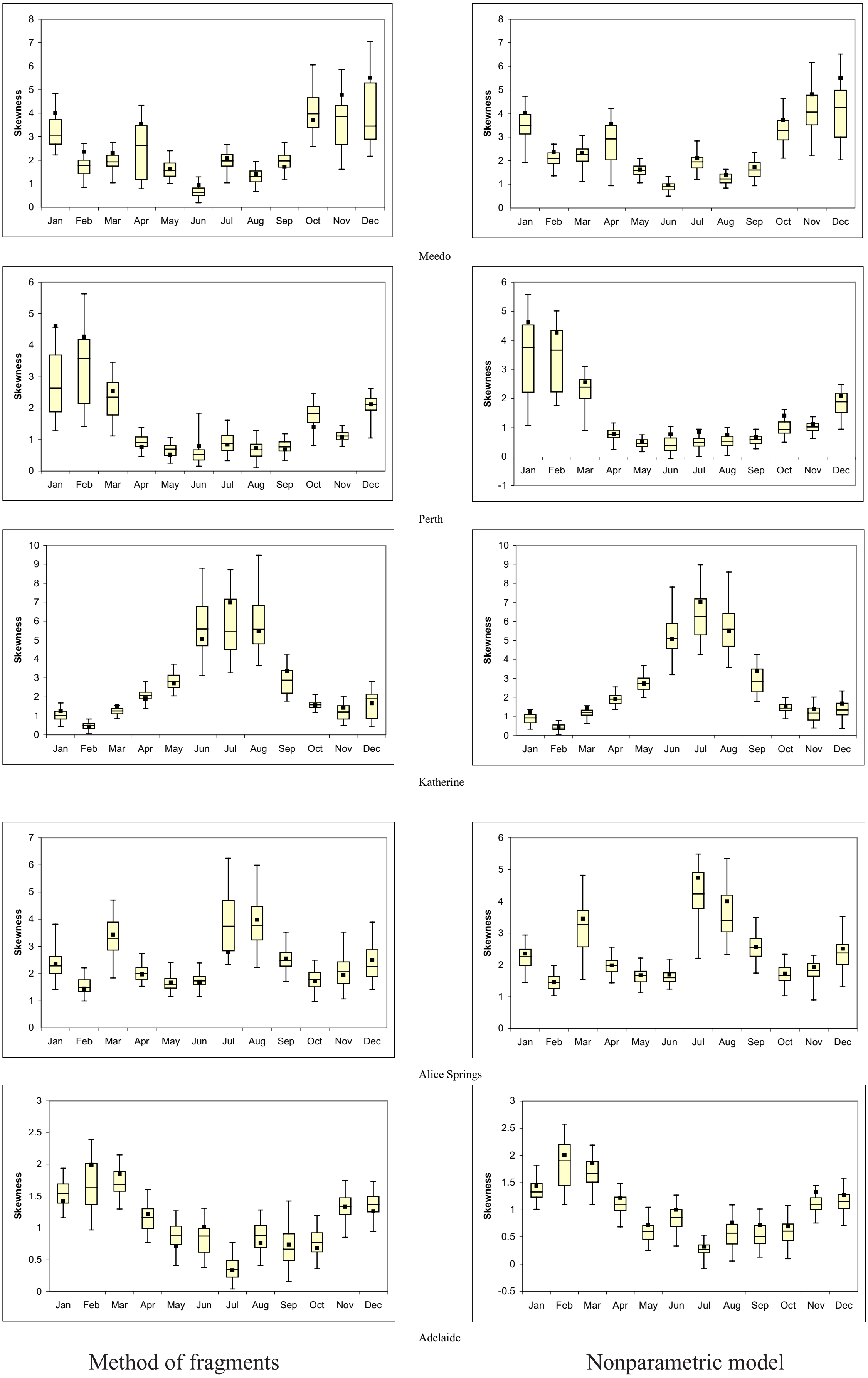


Figure A3. Comparison of historical and generated skewness of monthly rainfall

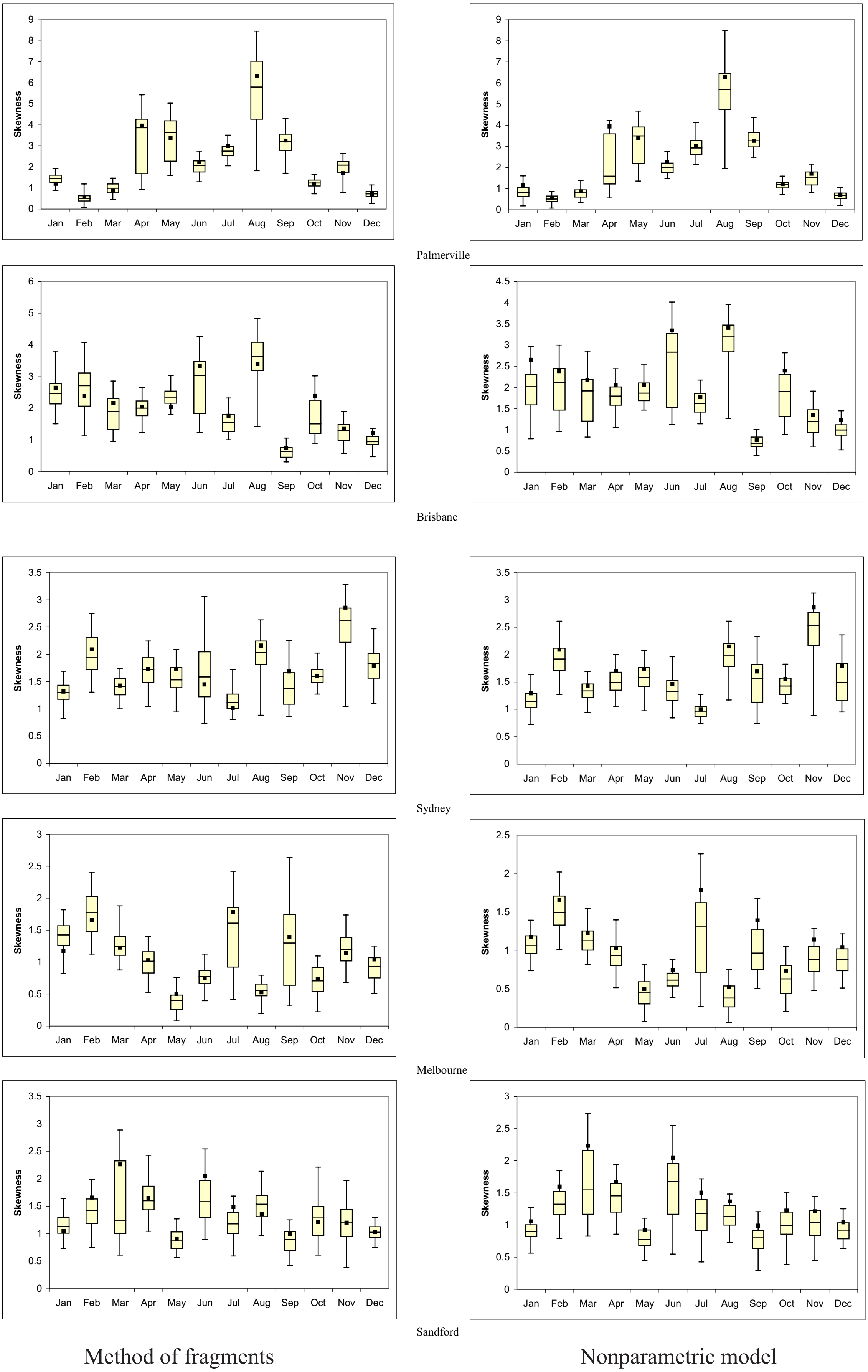
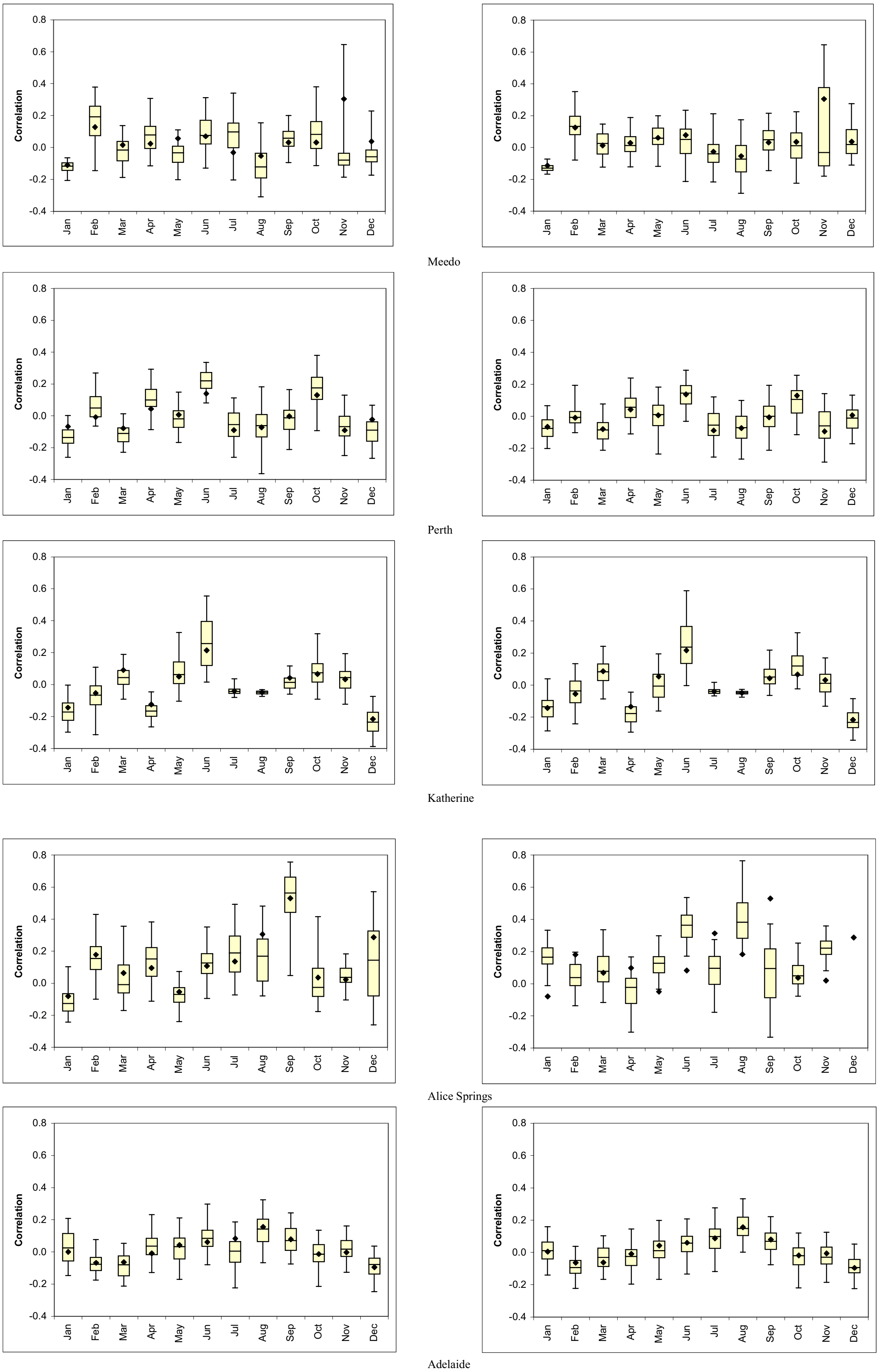


Figure A3. (Cont)



Method of fragments   Nonparametric model

Figure A4. Comparison of historical and generated correlation of monthly rainfall

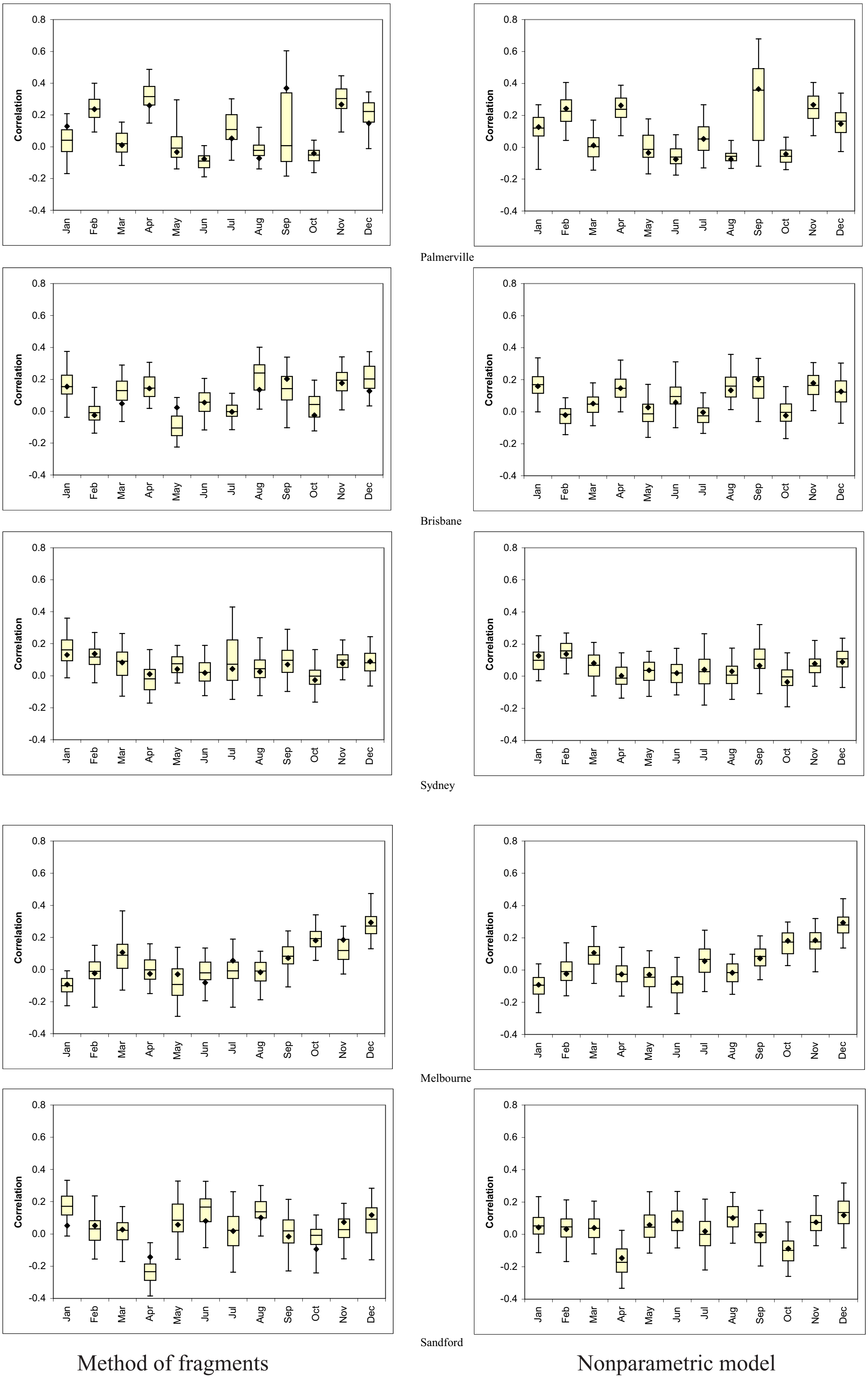
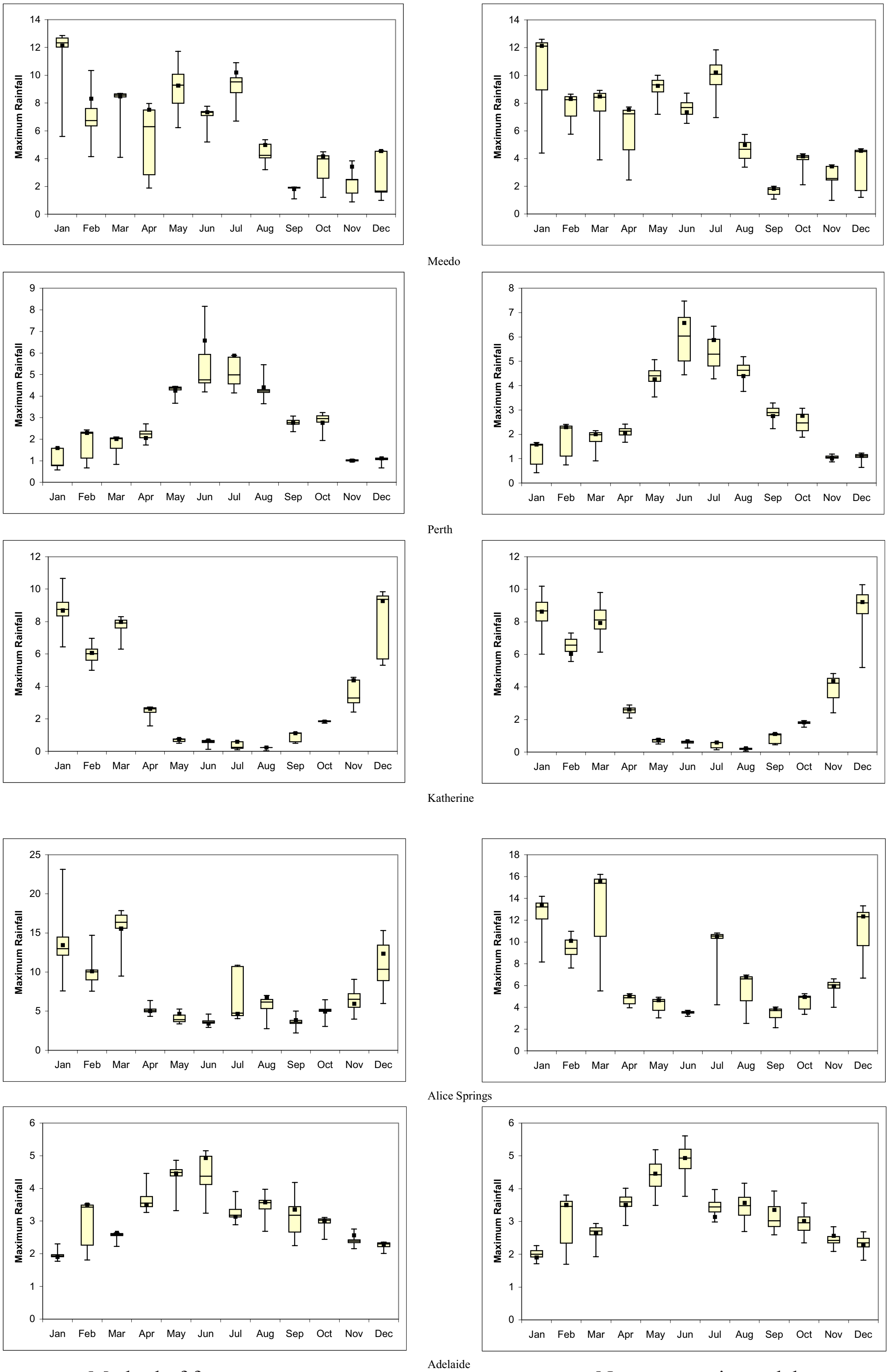


Figure A4. (Cont)



Method of fragments

Nonparametric model

Figure A5. Comparison of historical and generated maximum monthly rainfall

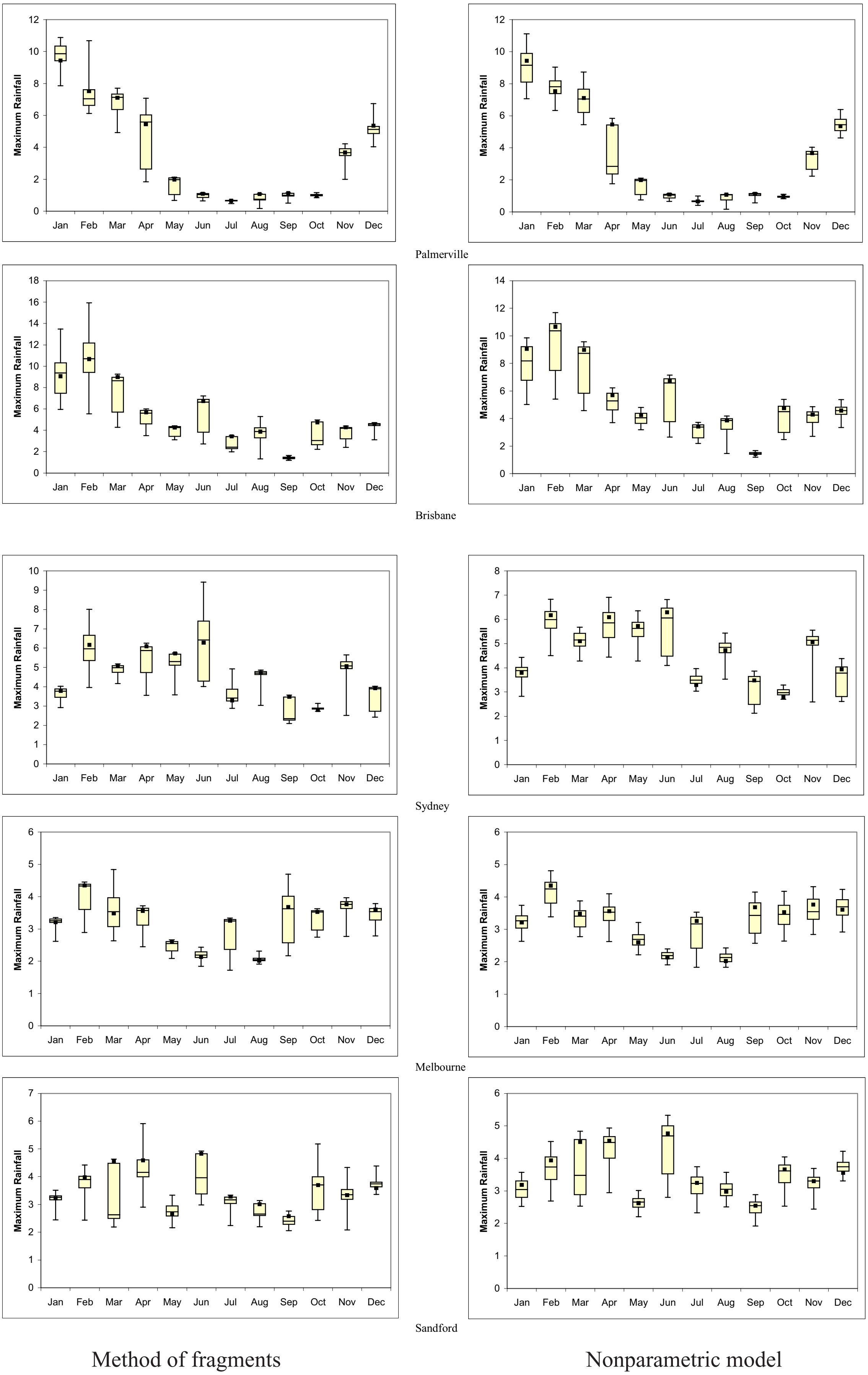


Figure A5. (Cont.)

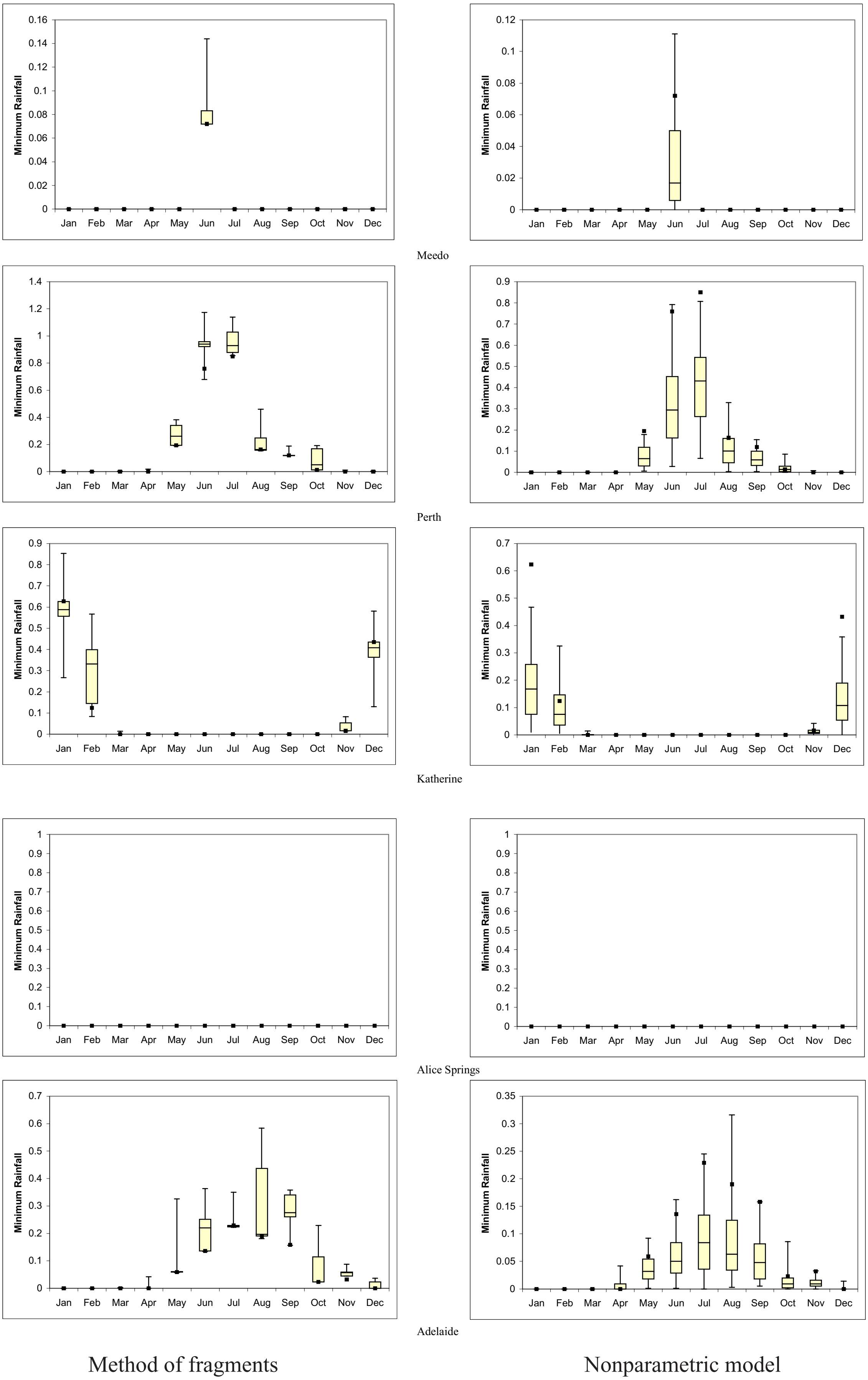


Figure A6. Comparison of historical and generated minimum rainfall

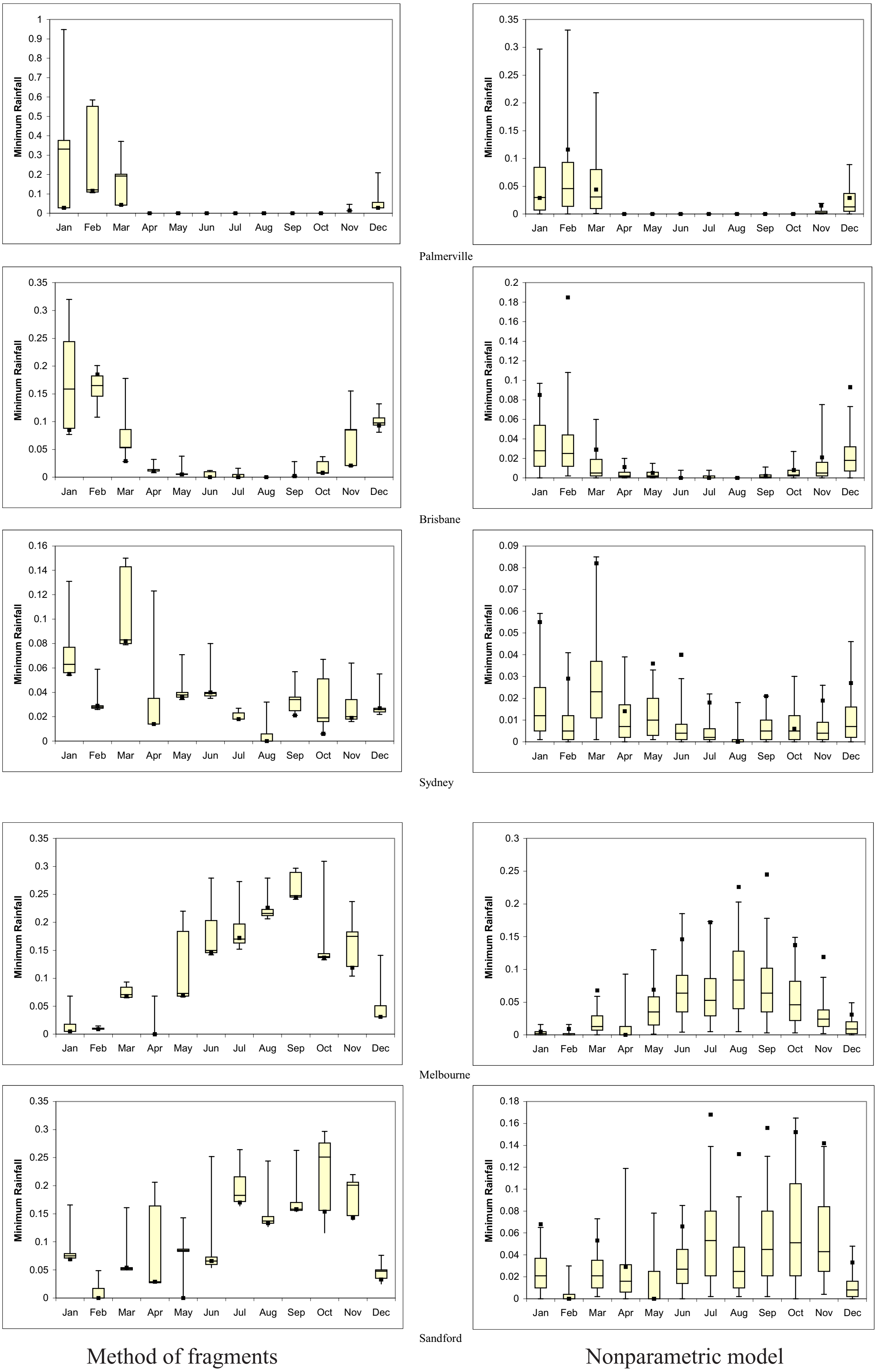


Figure A6. (Cont.)

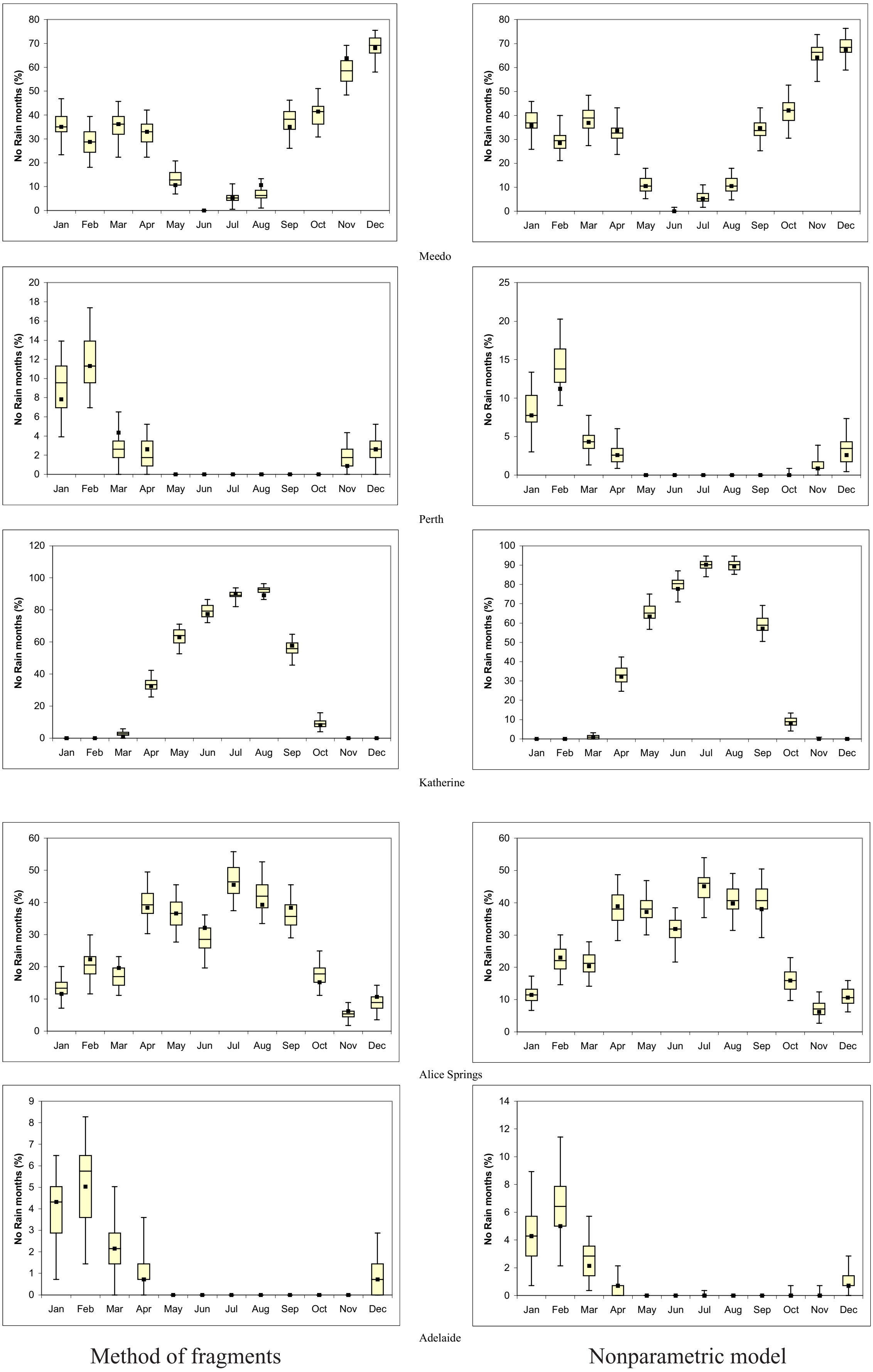
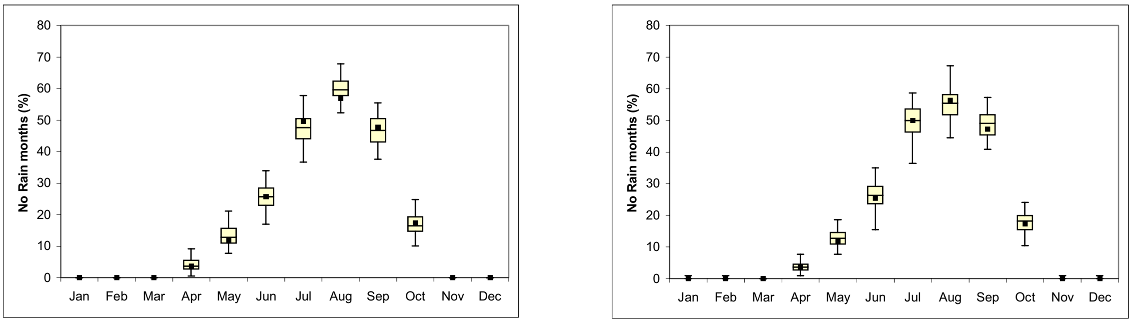
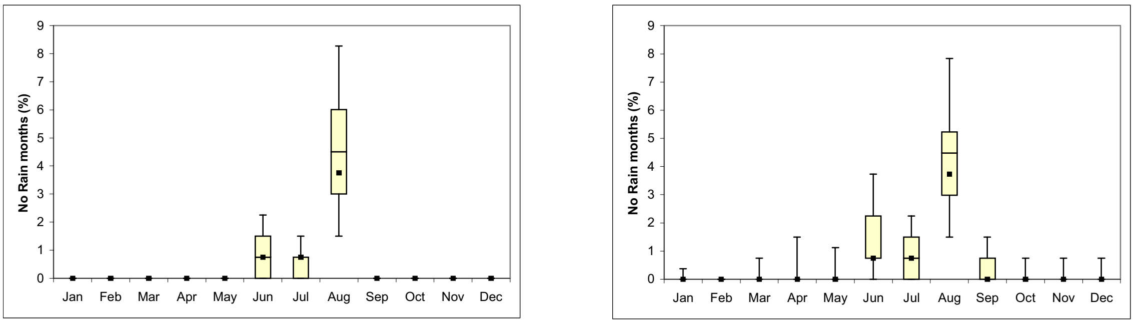


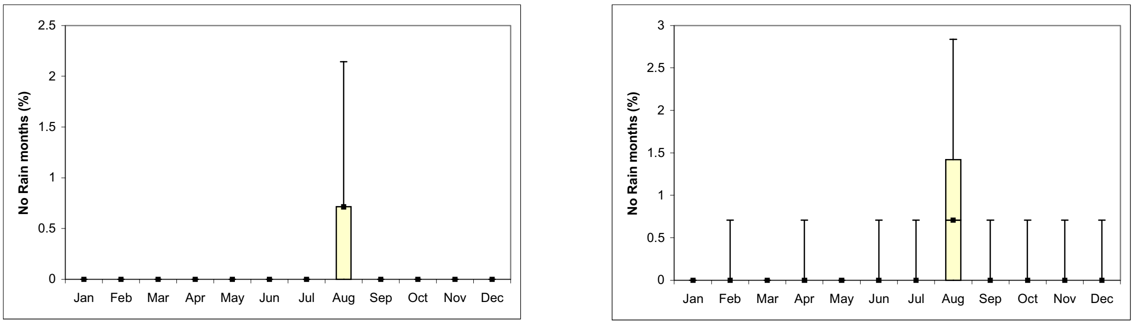
Figure A7. Comparison of historical and generated number of no rainfall months



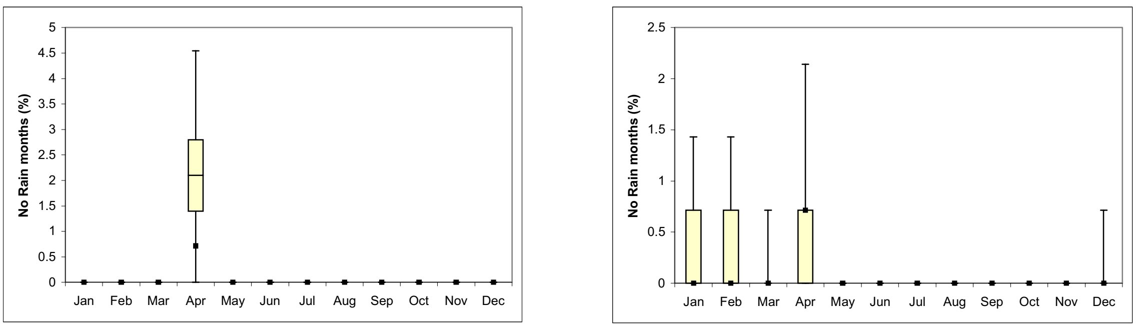
Palmerville



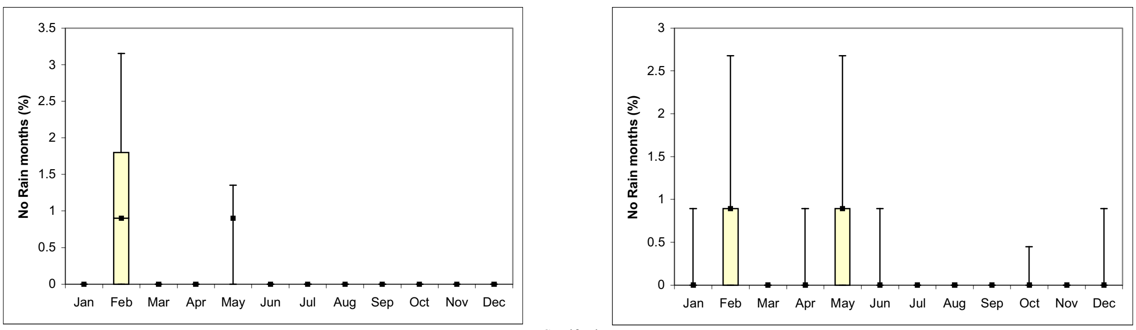
Brisbane



Sydney



Melbourne



Sandford

Method of fragments — Nonparametric model

Figure A7. (Cont.)

COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

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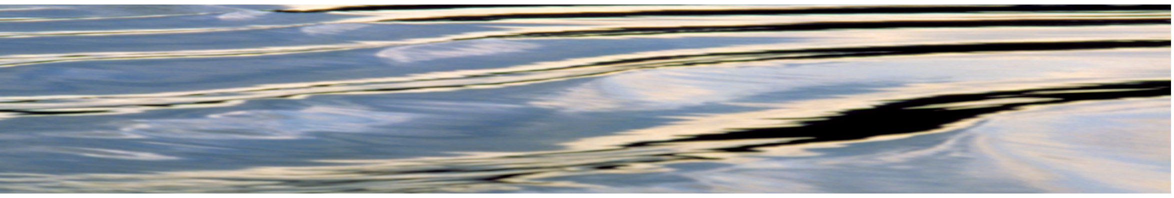

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- Bureau of Meteorology
- CSIRO Land and Water
- Department of Land and Water Conservation, NSW
- Department of Natural Resources and Environment, Vic
- Goulburn-Murray Water
- Griffith University
- Melbourne Water
- Monash University
- Murray-Darling Basin Commission
- Natural Resources and Mines, Qld
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- Wimmera Mallee Water

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