COOPERATIVE RESEARCH CENTRE FOR

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MODELLING VICTORIAN ANNUAL RAINFALL DATA

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SUMMARY

Annual rainfall data from twenty stations with long records were analysed with regard to wet and dry spells and long-term persistence. Small changes in the means and standard deviations over time were observed from the time series plots of the data. The Hidden State Markov (HSM) model was fitted to the data and the results indicated the absence of two state persistence in the data. One hundred replicates of annual rainfall data were generated using the HSM and the widely used first order autoregressive model. The autoregressive model preserved the moments of the data better than the HSM model as these were directly input to the model. The low rainfall sums were satisfactorily reproduced by both models. A further study is in progress using a number of stations selected across Australia and carrying out the HSM calibration with different starting months.

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1. INTRODUCTION

The modelling of annual rainfall data serves two purposes. Firstly, it enables the understanding of the stochastic nature of the data and its implications for long periods of low rainfall. This understanding is necessary to manage water supply systems during low rainfall periods. Secondly, any stochastic data should be able to maintain their statistical characteristics at different time scales and a good annual model allows one to disaggregate annual data into monthly data. In this case, the annual data becomes the input to various disaggregation schemes.

The review (Srikanthan and McMahon, 2000) carried out as part of Project 5.2 of the Climate Variability program recommended an autoregressive time series model or the Hidden State Markov (HSM) model to generate annual rainfall data. In this report, these two models are applied to a number of rainfall stations in Victoria. The parameter uncertainty is not considered in this report, as the aim of the report is to compare the performance of the models. Once a model is chosen, the parameter uncertainty can be later incorporated into the model and the way to carry out this will be described in a later report.

2. DATA ANALYSIS

Twenty rainfall stations with long records were selected. The locations of the selected rainfall stations are shown in Figure 1. The details of annual rainfall data are given in Table 1. The spatial variation of mean annual rainfall and coefficient of variation of annual rainfalls (C_v) are shown in Figures 2 and 3 respectively. The north-west part of the state receives much less rainfall than the south-east part of the state. Of the 20 sites selected, Irymple has the lowest annual mean and Warburton the highest annual mean rainfall. The variation of C_v is the reverse. The sites with low rainfall have high C_v and vice versa.

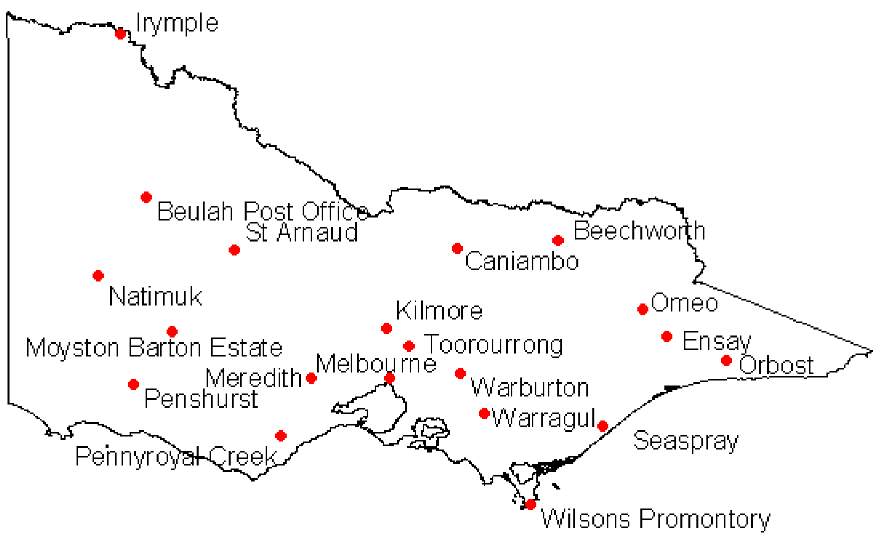

Figure 1. Location of rainfall stations

Table 1. Details of annual rainfall data

Number	Station number	Station name	Latitude (° S)	Longitude (° E)	Data length (years)	Mean (mm)	C_V
1	76015	Irymple	-34.23	142.15	92	279	0.375
2	77004	Beulah Post Office	-35.94	142.42	99	377	0.248
3	79036	Natimuk	-36.75	141.93	93	445	0.205
4	79050	Moyston Barton Estate	-37.32	142.70	94	643	0.199
5	80009	St Arnaud	-36.48	143.35	113	443	0.257
6	81007	Caniambo	-36.45	145.66	96	525	0.271
7	82001	Beechworth	-36.37	146.71	124	962	0.243
8	83025	Omeo	-37.10	147.60	121	681	0.203
9	84015	Ensay	-37.38	147.84	90	709	0.243
10	84030	Orbost	-37.63	148.46	117	852	0.234
11	85073	Seaspray	-38.32	147.18	102	599	0.216
12	85093	Waragul VCH	-38.18	145.93	112	1035	0.150
13	85096	Wilsons Promontory	-39.13	146.42	127	1054	0.159
14	86071	Melbourne RO	-37.81	144.97	145	657	0.183
15	86117	Toorourrong	-37.48	145.15	108	803	0.195
16	86121	Warburton	-37.76	145.69	121	1344	0.156
17	87043	Meredith	-37.82	144.15	125	683	0.184
18	88034	Kilmore	-37.30	144.94	117	726	0.230
19	90061	Pennyroyal Creek	-38.42	143.83	119	793	0.172
20	90063	Penshurst	-37.88	142.29	118	721	0.169

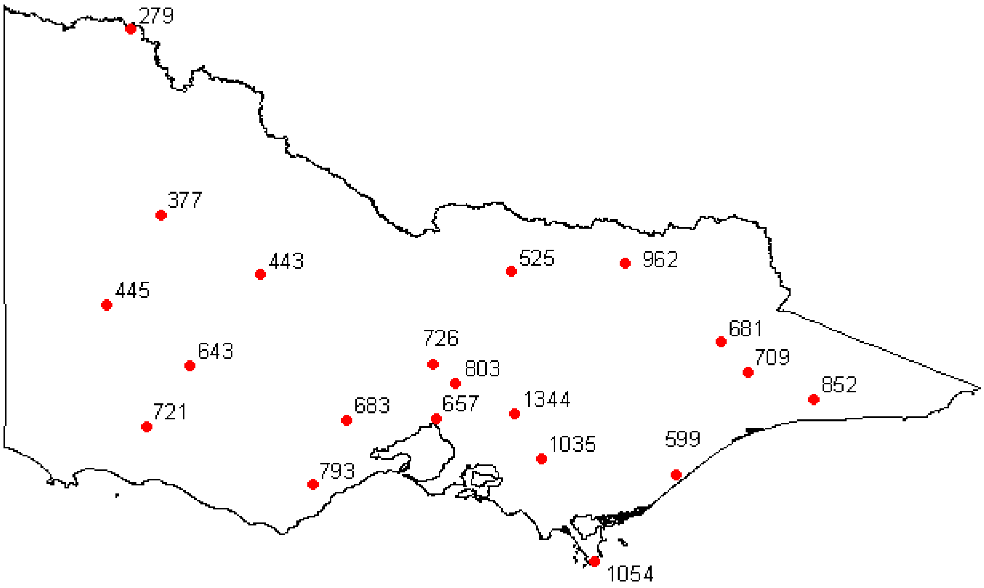

Figure 2. The spatial distribution of the mean annual rainfall

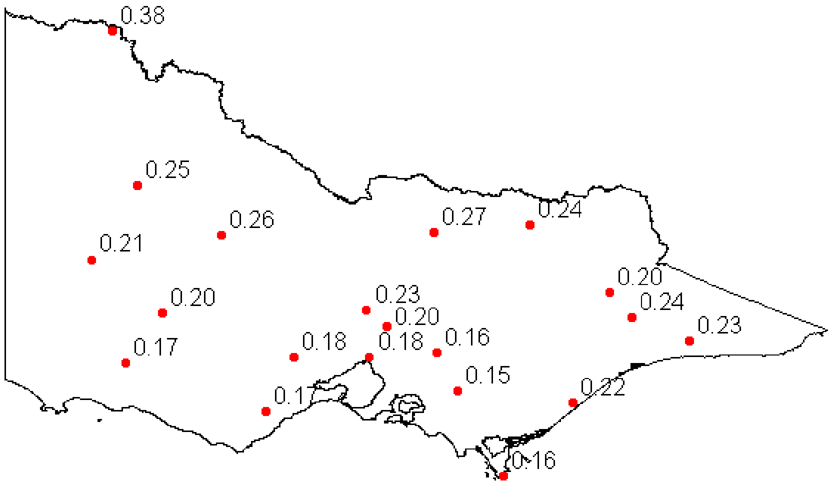

Figure 3. The spatial distribution of the coefficient of variation

A study by Srikanthan and McMahon (2000) looked at the rainfall totals from July to June rather than the calendar year. The same annual series are used in the present study. The annual rainfall data along with five-year moving average, residual mass curves and mean, standard deviation and coefficient of variation for a 20 year moving window are plotted in Figures A1 – A40. A 20-year period was considered to be sufficiently long enough to obtain estimates of mean and variance and at the same short enough to look at the temporal variation in the estimates. The mean value plotted in the figures are the long term means.

Irymple: The time series plot for Irymple (Figure A1) shows that the annual rainfall was less variable in 1930 to 1970 compared to the pre-1930 and post-1970 periods. The residual mass curve also shows a dry period from about 1925 to mid-1940s, average for the period mid-1940s to 1970 and a wet period there after. The 20-year mean decreased up to mid 1940s, increased up to 1970, remained relatively constant and decreased towards the long-term mean towards the end of the record (Figure A2). The standard deviation and the coefficient of variation show distinct periods of low and high variability as noted above. Only a handfull of the 20-year means are outside the 95% confidence limits while a considerable number of 20-year standard deviations are outside the 95% confidence limits.

Beulah Post Office: The annual rainfall for Beulah Post Office appears to be more variable in the early part of the record compared to the latter part (Figure A3). The plots of the 20-year standard deviation and coefficient of variation also show this (Figure A4). The residual mass curve remained below zero all the time suggesting less rainfall during the early part of the record compared to the latter part. The variation in the mean value is within the 95% confidence limits while some of the variation in the standard deviation is outside the 95% confidence limits.

Natimuk: The residual mass curve (Figure A5) shows that the annual rainfall was about the mean value for Natimuk up to 1940. Higher rainfall occurred in the 1940s and a sharp decrease in 1990s. The standard deviation was fairly constant for the whole period (Figure A6). The 20-year mean also indicates a wet period in the middle part of the record. Except for one value for the mean, both the 20-year means and standard deviations are within the 95% confidence limits.

Moyston Barton Estate: The record starts with low rainfall initially, stayed about average until early 1930s and decreased from late 1930s to early 1940s. The 20-year mean plot (Figure A8) shows that higher rainfall occurred from mid-1940s to about 1960 and remained above average most of the time thereafter. The variability of the annual rainfall appears to decrease towards the latter part of the record. Except for one value for mean, both the 20-year means and standard deviations are within the 95% confidence limits.

St Arnaud: The residual mass curve (Figure A9) shows that except for a few years at the beginning of the record, rainfall was below average until 1950 and above average afterwards. The standard deviation and coefficient of variation were low during the middle part of the record (Figure A10). Except for a few values for mean and standard deviation, both the 20-year means and standard deviations are within the 95% confidence limits.

Caniambo: The annual rainfall was more variable during the early part of the record compared to the latter part. Only short wet and dry spells were observed from the residual mass curve (Figure A11). The plots of 20-year standard deviation and coefficient of variation show the decrease in variability with time (Figure A12). The 20-year means are well within the 95% confidence limits. A considerable number of 20-year standard deviations are outside the 95% confidence limits early in the record but are within the 95% confidence limits during more recent times.

Beechworth: The annual rainfall appears to increase steadily. The residual mass curve is entirely below the zero line all the time (Figure A13). Higher rainfalls occurred in the 1910s and the variability decreased towards the end of the record (Figure A14). A considerable number of values of 20-year means and standard deviations are outside the 95% confidence limits.

Omeo: The rainfall was high during the pre-1900 period, followed by low rainfall until 1950 and high thereafter (Figure A15). The 20-year mean also shows this pattern (Figure A16). The standard deviation is fairly stable while the coefficient of variation fluctuates considerably. Except for a few values of the mean, both the 20-year means and standard deviations are within the 95% confidence limits.

Ensay: The rainfall is less variable towards the end of the record (Figure A17). The 20-year mean stayed fairly constant throughout the record period (Figure A18). Both the 20-year means and standard deviations are within the 95% confidence limits

Orbost: The rainfall is low from 1900 to 1930 and high 1950 onwards (Figure A19). Except for a last few values for mean and standard deviation both the 20-year means and standard deviations are within the 95% confidence limits

Seaspray: The record for Seaspray is similar to Beechworth. The rainfall is steadily increasing (Figure A21) and is less variable towards the end of the record (Figure A22). A considerable number of values of 20-year means are outside the 95% confidence limits. The 20-year standard deviations are within the 95% confidence limits.

Warragul: The rainfall is high and more variable during the middle part of the record (Figure A23). The variability decreased towards the end of the record (Figure A24). Except for a few values, both the 20-year means and standard deviations are within the 95% confidence limits.

Wilson's Promontory: The rainfall is low in the middle part of the record (Figure A25) and has low variability initially (Figure A26).). Except for a few values, both the 20-year means and standard deviations are within the 95% confidence limits.

Melbourne: The rainfall is low and less variable in the 1890 to 1910 period and more variable afterwards until 1940 (Figures A27 and A28). The 20-year mean values are within the 95% confidence limits. Except for a few values, 20-year standard deviations are also within the 95% confidence limits.

Toorourrong: The rainfall is low and more variable up to 1950 (Figures A29 and A30). The standard deviation and coefficient of variation show two distinct patterns. Except for a few values for standard deviations, both the 20-year means and standard deviations are within the 95% confidence limits.

Warburton: The rainfall is low and more variable in the period 1910 to 1940 (Figure A31). The variability decreased towards the end of the record (Figure A32). The 20-year mean is well within the 95% confidence limits. The 20-year standard deviations are mainly within the 95% confidence limits.

Meredith: The rainfall is less variable at the beginning of the record (Figures A33 and A34). The middle part of the record shows less rainfall compared to the early and later parts of the record. Except for a few values, both the 20-year means and standard deviations are within the 95% confidence limits.

Kilmore: The rainfall appears to increase gradually with time (Figure A35). It is less variable at the beginning of the record. Except for a few values for standard deviations, both the 20-year means and standard deviations are within the 95% confidence limits.

Pennyroyal Creek: The rainfall is low in the pre-1900 period. It is less variable in the initial part of the record (Figures A37 and A38). Except for a few values, both the 20-year means and standard deviations are within the 95% confidence limits.

Penshurst: The rainfall is low up to 1940 (Figure A39). It is more variable in the middle part of the record (Figure A40). Except for a few values, both the 20-year means and standard deviations are within the 95% confidence limits.

It can be concluded from the above that the mean and standard deviation of rainfall have high and low periods in the past. Most records indicated low variability early in the record and some towards the end of the record as well. A good stochastic model should be able to reproduce these types of variability in the generated data.

3. HIDDEN STATE MARKOV (HSM) MODEL

The HSM model (Figure 4) assumes the climate is in one of two states: wet (W) or dry (D). The wet state refers to high rainfall and dry refers to low rainfall. Each state has an independent rainfall distribution, assumed to be Gaussian. The time spent in each state is governed by the state transition probabilities. This provides an explicit mechanism to replicate the variable length of wet and dry cycles.

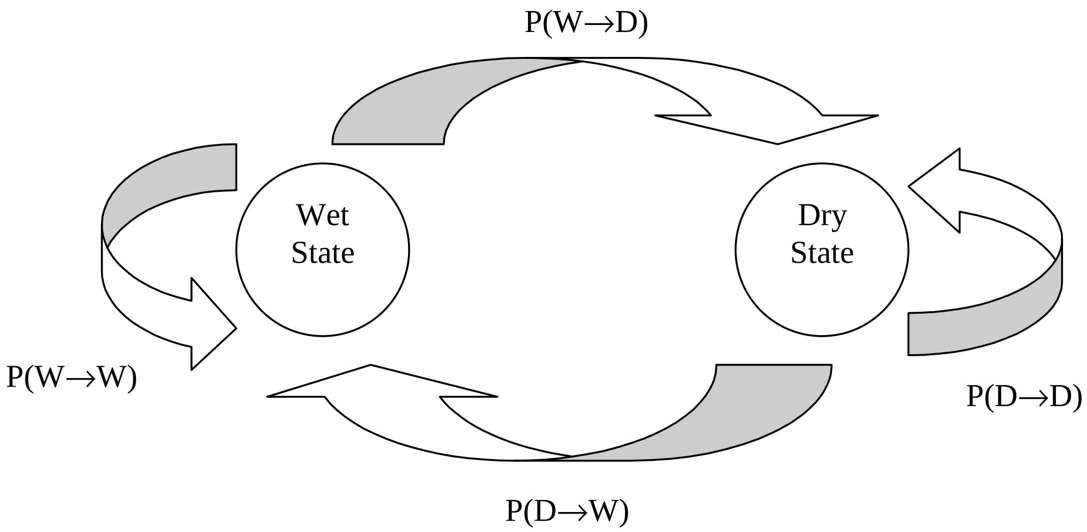

Figure 4. Schematic representation of the HSM model

The simulation of annual rainfall time series is a two-step process. In the first step the climate state at year t, s_t, is simulated by a Markovian process:

$$s_t \mid s_{t-1} \sim \text{Markov}(\mathbf{P}) \tag{1}$$

where **P** is a (2x2) state transition probability matrix whose elements are:

$$p_{ij} = \Pr(s_t = j \mid s_{t-1} = i) \qquad i, j = W, D \tag{2}$$

Once the state for year *t* is known, the rainfall is simulated using:

$$y_t \sim \begin{cases} N(\mu_W, \sigma_W^2) & \text{if } s_t = W \\ N(\mu_D, \sigma_D^2) & \text{if } s_t = D \end{cases} \tag{3}$$

where $N(\mu, \sigma^2)$ denotes a Gaussian distribution with mean μ and variance σ^2. Therefore the vector of unknown parameters for the HSM model, $\boldsymbol{\theta}$, is composed of the rainfall distribution parameters for each state, the transition probabilities, and the hidden state time series, $S_N = \{s_1, s_2, \ldots s_N\}$, where:

$$\boldsymbol{\theta}' = (\mu_W, \sigma_W, \mu_D, \sigma_D, \mathbf{P}, S_N) \tag{4}$$

Prior to model calibration the hidden state time series is unknown. Thus it is included as a model parameter to be estimated during the calibration process.

3.1 Model Calibration - Gibbs Sampler

For model calibration a Bayesian framework is used to infer the distribution of the model parameters, $\boldsymbol{\theta}$, for the given time series data, Y_N. This distribution is referred to as the posterior distribution of the model parameters, $p\left(\boldsymbol{\theta} \mid Y_N\right)$. For the HSM model it is not possible to derive an analytical expression for the posterior distribution. Thus Markov Chain Monte Carlo (MCMC) simulation methods are employed to draw samples from the posterior distribution. The basic idea of MCMC methods is to simulate a Markov chain iterative sequence, where at each iteration a sample of the model parameters, $\boldsymbol{\theta}$, is generated. Given certain conditions the distribution of these samples converges to a stationary distribution which is the posterior distribution, $p\left(\boldsymbol{\theta} \mid Y_N\right)$. To calibrate the HSM model, the MCMC method known as the Gibbs sampler is applied. The details of the calibration process are given in Thyer and Kuzcera (2000).

3.2 Application of HSM model

The HSM model was calibrated for the 20 Victorian rainfall stations using the program ULTIMO_PERSISTO. The annual totals were formed from July to June. The wet state frequency time series and the probability density function of the difference between the wet and dry state means are shown in Figures B1 to B40 in Appendix B. None of the wet state frequency time series indicated persistence in wet and dry states. Most of the series had a tendency to remain in the dry state except Seaspray. This site has a strange behaviour in the sense that it stayed in the dry state in the early part of the record and then switched to wet state and remained there. The probability density function of the difference between the wet and dry state means included zero for all the sites, even though for some sites (Irymple, Warburton and Kilmore), the area enclosed by the probability density function to the left of zero is quite small. The results do not indicate persistence in dry and wet states for the sites examined.

The six model parameters and the state stability (SSI) index are given in Table 2. The state stability index (SSI) is defined as follows:

$$\mathrm{SSI} = \frac{\sum \left|\mathrm{P(W)} - 0.5\right|}{\mathrm{N}} \tag{5}$$

where P(W) is the probability of wet state and N the number of years of data.

Values of SSI close to zero indicate that the wet and dry states are hard to identify. As SSI $\rightarrow$ 0.5, states are well identified. Values of SSI around 0.3 generally indicates persistence, but this needs to be confirmed with a visual inspection of a plot of {P(W)-0.5} versus year.

The SSI values varied from about 0.084 to 0.312. The spatial distribution of SSI is shown in Figure 5. Figures 6 and 7 respectively shows the distribution of P(W$\rightarrow$W) and (D$\rightarrow$W). The difference {P(W$\rightarrow$W) - (D$\rightarrow$W)} gives a measure of persistence. The spatial distribution of persistence is shown in Figure 8. Eight stations show either negative or small persistence. Others indicate some persistence.

Table 2. The parameters of HSM model

Station name	SSI	P(W→D)	P(D→W)	Wet state		Dry state	
				Mean (mm)	Std dev (mm)	Mean (mm)	Std dev (mm)
Irymple	0.312	0.62	0.26	365.2	139.7	247.3	65.2
Beulah Post Office	0.318	0.62	0.18	459.9	141.8	355.4	76.8
Natimuk	0.103	0.51	0.51	478.4	93.6	417.3	81.0
Moyston Barton Estate	0.132	0.57	0.51	696.7	136.2	600.7	106.7
St Arnaud	0.203	0.51	0.29	511.4	123.6	411.8	95.4
Caniambo	0.213	0.54	0.34	606.7	172.4	487.2	103.4
Beechworth	0.294	0.53	0.18	1177.3	308.2	916.6	193.0
Omeo	0.084	0.47	0.44	728.9	144.5	642.3	129.6
Ensay	0.203	0.53	0.31	822.1	184.6	660.5	143.9
Orbost	0.172	0.63	0.40	961.8	230.6	804.3	168.8
Seaspray	0.233	0.26	0.24	656.4	123.4	536.7	110.9
Warragul VCH	0.163	0.50	0.37	1112.2	177.5	991.5	122.7
Wilsons Promontory	0.116	0.49	0.42	1126.8	163.9	1012.3	152.1
Melbourne RO	0.151	0.52	0.44	707.8	133.5	620.5	91.6
Toorourrong	0.150	0.60	0.46	873.1	169.9	758.6	130.1
Warburton	0.327	0.66	0.21	1555.0	253.4	1288.0	153.0
Meredith	0.212	0.51	0.38	759.8	125.7	633.5	94.1
Kilmore	0.272	0.55	0.31	858.3	184.7	663.9	113.4
Pennyroyal Creek	0.274	0.74	0.30	901.5	187.3	769.7	105.1
Penshurst	0.171	0.50	0.39	783.3	127.4	677.0	94.0

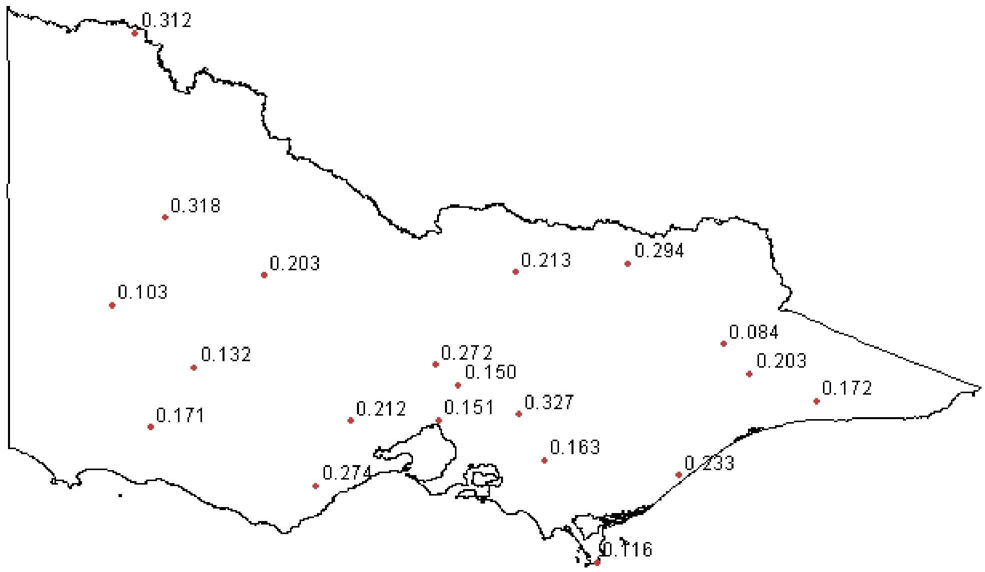

Figure 5. The spatial distribution of SSI

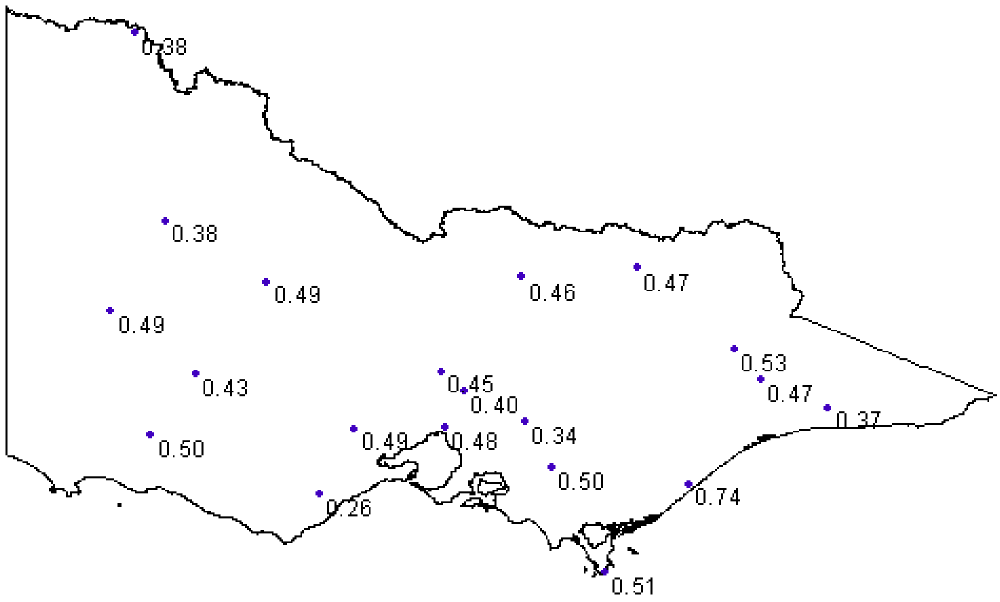

Figure 6. The spatial distribution of P(W→W)

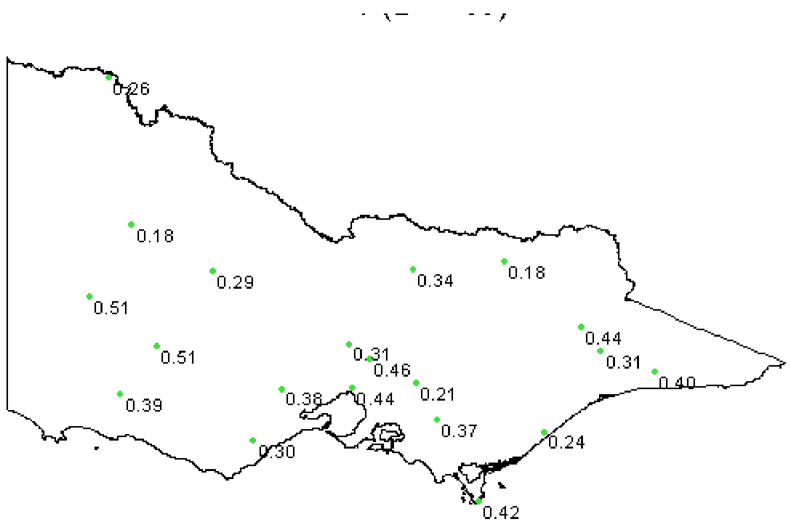

Figure 7. **The spatial distribution of P(D→W)**

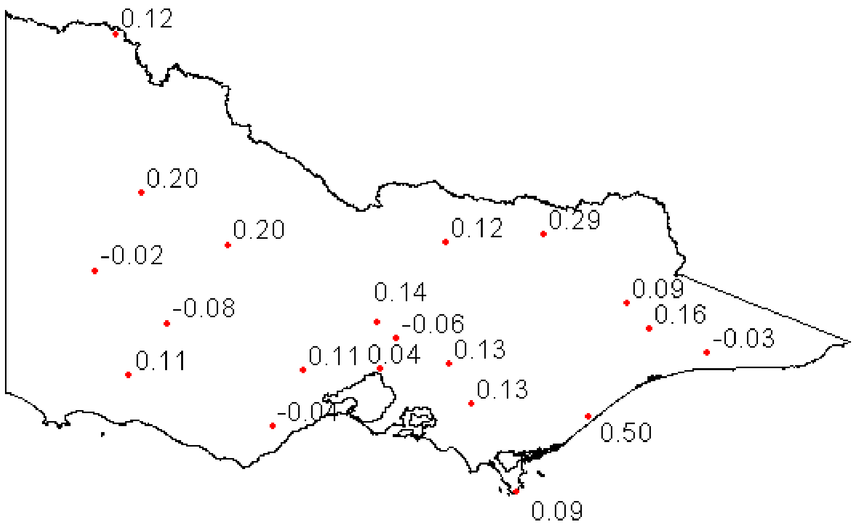

Figure 8. **The spatial distribution of persistence {P(W → W) – P(D → W)**

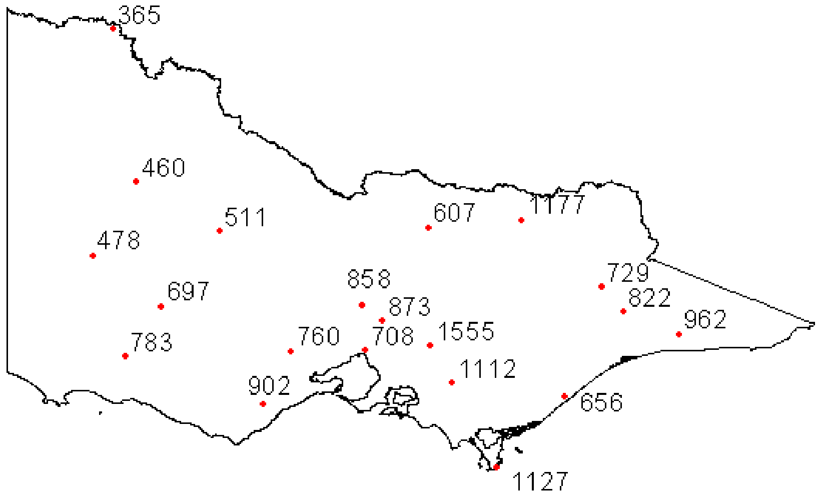

Figure 9. The spatial distribution of wet state mean

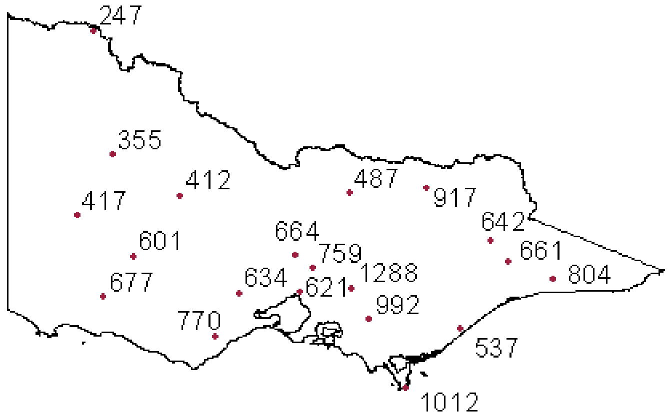

Figure 10. The spatial distribution of dry state mean

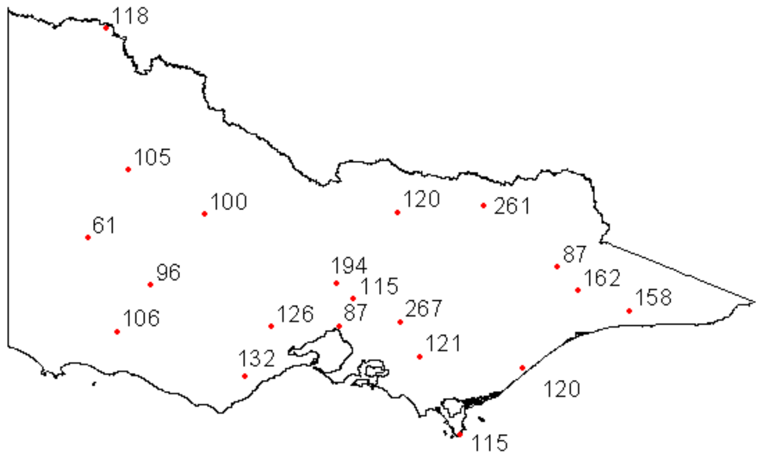

Figure 11. The spatial distribution of the difference between the means of wet and dry states

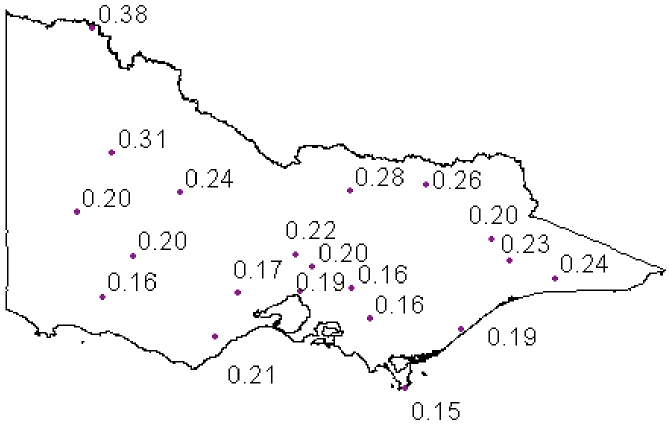

Figure 12. The spatial distribution of wet state C_v

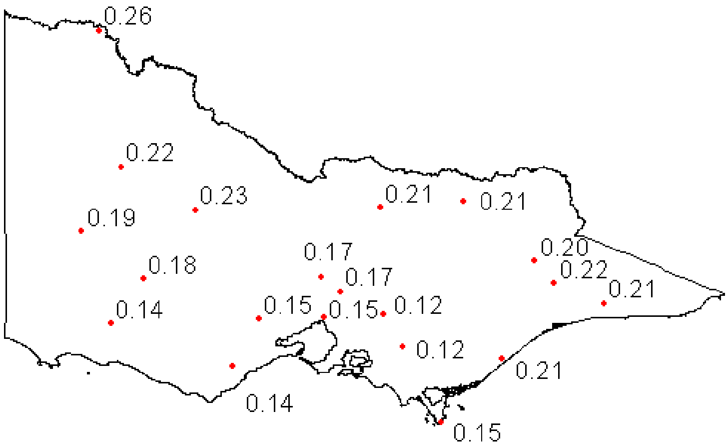

Figure 13. The spatial distribution of dry state C_v

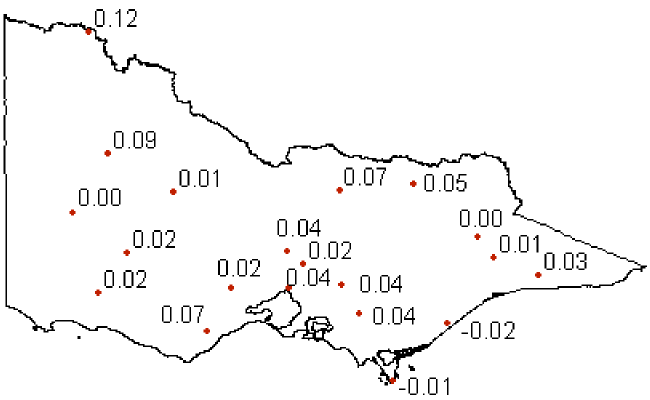

Figure 14. The spatial distribution of the difference between the C_v of wet and states

The spatial distribution of the means for the wet and dry state are shown in Figures 9 and 10 respectively. Figure 11 shows the distribution of the difference between the means of wet and dry states. The difference varies from about 60 to 260 mm. The C_v for the wet and dry states are shown in Figures 12 and 13 respectively. The wet state C_v is slightly larger than the dry state C_v for all the sites except three sites. The differences between the C_v of wet and dry states, shown in Figure 14, are about 0.1 or less.

Thyer (2001) defined a wet and dry separation index (WADSI) to determine objectively whether or not the wet and dry states are significantly different.

$$\mathrm{WADSI} = \frac{\mu_W - \mu_D}{\sqrt{\left(\sigma_W^2 + \sigma_D^2\right)}} \tag{6}$$

A value of 1.645 or larger for WADSI indicates that the wet and dry states are significantly different at 5% level. The values of WADSI for the 20 stations are given in Table 4.

Table 4. The estimates of WADSI

Station name	**WADSI**	**Station name**	**WADSI**
Irymple	0.765	Seaspray	0.721
Beulah Post Office	0.648	Waragul VCH	0.559
Natimuk	0.494	Wilsons Promontory	0.512
Moyston Barton Estate	0.555	Melbourne RO	0.539
St Arnaud	0.638	Toorourrong	0.535
Caniambo	0.594	Warburton	0.902
Beechworth	0.717	Meredith	0.804
Omeo	0.446	Kilmore	0.897
Ensay	0.690	Pennyroyal Creek	0.614
Orbost	0.551	Penshurst	0.671

The numbers in Table 4 clearly shows that the two states are not statistically distinct. Thyer and Kuczera (2000) found that the wet and dry spells were more prominent by choosing the year appropriately. In this study, the year was fixed from July to June and this aspect of starting the year in different months should be considered before making conclusions of no prolonged wet and dry spells in the Victorian data.

Even though the results did not justify the HSM model, it was used to investigate the effect of using two slightly different means and standard deviations in the generation of annual rainfall data. One hundred replicates, each of length equal to the historic data, were generated. The evaluation of the model is described in Chapter 5.

4. TIME SERIES MODEL USING THE AUTOREGRESSIVE MODEL (AR(1))

The parameters of the annual data for the twenty sites are given in Table 4. The coefficients of skewness, which are significantly different from zero, are shown in bold. Thirteen sites have skewed data. None of the lag one autocorrelation coefficients is significantly different from zero. The autocorrelation functions and partial autocorrelation functions were calculated and are presented in Table C1 in Appendix C. Based on this statistical significance, either a random Gaussian or a random Gamma model is adequate to model the annual rainfall data. However, Gaussian distribution was assumed for only one site Wilson's Promontory. Likewise, independence was assumed only when the lag one autocorrelation coefficient was smaller than 0.05. The models selected are also given in Table 4. An AR(1) model was used to model the dependence in the annual data.

The AR(1) model is of the form

$$X_t = rX_{t-1} + (1 - r^2)^{1/2} \eta_t \qquad (7)$$

where X_t standardised rainfall in year t
η_t normally distributed random component with zero mean and unit variance
r lag one autocorrelation coefficient

The annual rainfall amount is obtained from:

$$x_t = \bar{x} + s X_t \qquad (8)$$

If the annual data are skewed, the skewness in the data can be modelled through the Wilson-Hilferty transformation.

$$\varepsilon_t = \frac{2}{g_\varepsilon}\left\{\left(1 + \frac{g_\varepsilon \eta_t}{6} - \frac{g_\varepsilon^2}{36}\right)^3 - 1\right\} \qquad (9)$$

where g_ε is the skewness of ε_t which is related to the skewness of annual data (g) through

$$g_\varepsilon = \frac{(1 - r^3)}{(1 - r^2)^{3/2}} g \qquad (10)$$

For independent data, the variable r in the above equations is set to zero.

One hundred replicates, each of length equal to the historic data, were generated. The evaluation of the model is described in Chapter 5.

Table 4. The parameters of the annual rainfall data and the selected time series model.

Station name	Mean	Std Dev	CV	Skew	Corr	Model
Irymple	278.7	104.5	0.375	**1.243**	0.081	Dependent Gamma
Beulah Post Office	377.2	93.4	0.248	**0.995**	-0.010	Independent Gamma
Natimuk	445.4	91.3	0.205	0.339	0.023	Independent Gamma
Moyston Barton Estate	643.0	128.0	0.199	0.460	0.045	Independent Gamma
St Arnaud	442.6	114.0	0.257	**0.499**	0.133	Dependent Gamma
Caniambo	524.7	142.3	0.271	**0.771**	-0.035	Independent Gamma
Beechworth	961.6	233.6	0.243	**0.712**	0.182	Dependent Gamma
Omeo	681.1	138.0	0.203	0.357	-0.028	Independent Gamma
Ensay	709.0	172.1	0.243	0.462	0.039	Independent Gamma
Orbost	852.1	199.6	0.234	**0.644**	-0.117	Dependent Gamma
Seaspray	598.8	129.5	0.216	0.249	0.176	Dependent Gamma
Warragul VCH	1035.1	155.5	0.150	**0.616**	0.021	Independent Gamma
Wilsons Promontory	1053.9	167.9	0.159	-0.083	0.064	Independent Gaussian
Melbourne RO	657.0	120.4	0.183	**0.474**	0.076	Dependent Gamma
Toorourrong	802.6	156.2	0.195	0.429	-0.027	Independent Gamma
Warburton	1343.9	210.0	0.156	**0.905**	0.021	Independent Gamma
Meredith	683.3	125.6	0.184	**0.475**	0.109	Dependent Gamma
Kilmore	726.1	167.2	0.230	**0.804**	0.119	Dependent Gamma
Pennyroyal Creek	792.8	136.0	0.172	**1.058**	0.172	Dependent Gamma
Penshurst	720.5	122.0	0.169	**0.523**	0.087	Dependent Gamma

5. COMPARISON OF RESULTS

The performance of the data generation models is evaluated using a number of statistics. These include:

1. Mean
2. Standard deviation
3. Coefficient of skewness
4. Lag one autocorrelation coefficient
5. Extreme values: maximum and minimum
6. Range of residual mass curve
7. Low rainfall sums of 2, 3, 5, 7 and 10-year duration

In addition to the above statistics, three replicates were selected at random and compared visually with the observed data in Figures D1 – D20. The figures show that the generated data and the observed data look very similar and show variations in mean and standard deviation with time. The residual mass curves plotted for these replicates were also compared with those of the observed data in Figures D21 –D40. In a few cases, the selected replicates did not produce the most severe deficit, but in general the generated sequences were able to have the residual mass curves similar to the observed one. The range of the residual mass curves are compared further to assess the adequacy of the generated data.

The above statistics were calculated for each of the 100 replicates. The average values of the statistics are given in Table 5. The extreme values, range and the low rainfall sums were standardised by dividing by the annual mean. The range of the statistics (minimum, 25th percentile, mean, 75th percentile and maximum) from the 100 replicates are shown in Figures E1 – E11.

The mean and standard deviation are well reproduced by both the models. The HSM model produced a larger range for the mean and standard deviation than the autoregressive model. However, a small positive bias is evident in the average value of the mean and standard deviation of the generated data from the HSM model (Figures E1(b) and E2(b)). The skewness of the generated data from both models is smaller than the corresponding historical value. The autoregressive model (ARM) performed slightly better than the HSM model. This is to be expected as the ARM explicitly took account of the skewness while the HSM model assumed normal distribution for both the wet and dry state distributions. For both the historical as well as the generated data the correlation coefficient was small and not significantly different from zero.

The maximum rainfalls were well reproduced by both the models for all the sites except three (Irymple, Beulah and Pennyroyal Creek). The ARM has slightly larger range of maximum values than the HSM model (Figure E4(a) and E4(b)). For Irymple, Beulah and Pennyroyal Creek, the average of the maximum from the 100 replicates was considerably smaller than the corresponding historical values (Table 5). However, the range of maximum rainfall obtained from the 100 replicates included the observed maximum rainfall and hence the model performance is considered adequate. The average of the minimum rainfalls from the 100 replicates was not well reproduced by both the models. It can be observed that there is a tendency for the HSM model to produce smaller and ARM larger values than the corresponding historical values. The HSM model produced more severe rainfall than the ARM. However, except for one case, the range of minimum rainfalls obtained from the 100 replicates included the observed minimum values. The only exception is that the ARM did not perform well for Irymple as all the estimates from the 100 replicates were larger than the historical value Figure E5(a) and E5(b)).

The range was reproduced well by both the models for all the sites except seven when the averages of the range estimates from the 100 replicates were compared with the corresponding historical values. These are shaded in Table 5. For these seven sites, the models underestimated the range. The performance of the ARM is marginally better than the HSM model. However, the observed values of the range lie within the range of values obtained from the 100 replicates (Figure E6).

When the average value of the low rainfall sums from the 100 replicates were compared with the corresponding historical values, the low rainfall sums were reproduced well by the HSM model for all the sites for all the durations (Table 5). The ARM did not reproduce the low rainfall sums for durations up to five years for Irymple and Beulah. However, it did preserve the sums for these sites for longer durations and for the other sites for all durations. Here again, Figures E7 to E11 show the range of low rainfall sums obtained from the 100 replicates in which the observed low rainfall sums lie within the range of values obtained from the 100 replicates.

6. CONCLUSIONS

Annual rainfall data from 20 sites from Victoria were analysed with regard to prolonged wet and dry spells and long term persistence. Small changes in the means and standard deviations over time were observed from the time series plots of the data. The Hidden State Markov (HSM) model was fitted to the data and the results indicated the absence of two-state persistence in the data. One hundred replicates of annual rainfall data were generated using the HSM and the widely used first order autoregressive model. The autoregressive model preserved the moments of the data better than the HSM model as these were directly input to the model. The low rainfall sums were satisfactorily reproduced by both models. A further study is in progress using a number of stations selected across Australia and carrying out the HSM calibration with different starting months. This will enable us to come up with an appropriate annual model for different parts of the country.

Table 5. Comparison of the statistics estimated from the historical and generated data. HSM – Hidden State Markov model, ARM – Autoregressive model

Station name		Mean	Std Dev	CV	Skew	Corr	Max	Min	Range	2-year	3-year	5-year	7-year	10-year
Irymple	His	278.7	104.5	0.375	1.243	0.081	2.567	0.304	5.010	0.943	1.588	3.171	5.076	7.782
	HSM	283.3	106.9	0.377	0.999	0.029	2.269	0.266	4.316	0.947	1.690	3.339	5.068	7.748
	ARM	278.6	102.9	0.369	1.130	0.078	2.313	0.457	4.492	1.072	1.783	3.374	5.070	7.729
Beulah Post Office	His	377.2	93.4	0.248	0.995	-0.010	2.069	0.538	2.514	1.276	2.258	4.004	5.927	8.707
	HSM	379.3	104.7	0.276	0.726	0.031	1.921	0.409	3.318	1.166	1.983	3.727	5.504	8.261
	ARM	377.4	92.2	0.244	0.901	-0.006	1.827	0.598	2.868	1.355	2.185	3.931	5.737	8.543
Natimuk	His	445.4	91.3	0.205	0.339	0.023	1.519	0.581	2.052	1.416	2.373	4.195	6.169	9.123
	HSM	448.4	92.2	0.206	0.106	-0.016	1.527	0.514	2.228	1.320	2.178	3.986	5.844	8.678
	ARM	445.4	90.4	0.203	0.313	-0.003	1.562	0.559	2.310	1.362	2.221	4.029	5.876	8.735
Moyston Barton	His	643.0	128.0	0.199	0.460	0.045	1.511	0.581	2.505	1.281	2.073	3.910	6.134	8.570
Estate	HSM	646.9	129.8	0.201	0.203	-0.007	1.527	0.536	2.237	1.344	2.197	4.002	5.842	8.701
	ARM	642.9	126.8	0.197	0.451	-0.004	1.578	0.596	2.239	1.406	2.269	4.068	5.926	8.794
St Arnaud	His	442.6	114.0	0.257	0.499	0.133	1.727	0.518	5.260	1.121	2.098	3.501	5.347	8.047
	HSM	447.0	115.6	0.259	0.263	0.034	1.720	0.393	3.287	1.139	1.949	3.685	5.468	8.251
	ARM	442.9	113.0	0.255	0.456	0.126	1.760	0.475	3.534	1.175	1.958	3.646	5.416	8.201
Caniambo	His	524.7	142.3	0.271	0.771	-0.035	1.879	0.479	1.896	1.178	1.924	3.822	5.918	8.688
	HSM	534.8	145.6	0.272	0.545	0.018	1.811	0.418	3.244	1.181	2.005	3.768	5.558	8.321
	ARM	524.6	140.8	0.268	0.711	-0.002	1.862	0.513	3.100	1.243	2.057	3.774	5.562	8.332
Beechworth	His	961.6	233.6	0.243	0.712	0.182	1.854	0.557	5.001	1.271	1.931	3.385	5.018	7.781
	HSM	984.2	252.4	0.256	0.576	0.058	1.816	0.428	3.408	1.184	2.004	3.732	5.525	8.278
	ARM	962.9	232.1	0.241	0.659	0.177	1.781	0.538	3.707	1.233	2.012	3.700	5.444	8.193
Omeo	His	681.1	138.0	0.203	0.357	-0.028	1.715	0.620	3.120	1.350	2.189	3.930	5.959	8.536
	HSM	683.5	143.2	0.210	0.111	0.020	1.565	0.480	2.747	1.265	2.100	3.897	5.751	8.600
	ARM	681.8	137.0	0.201	0.324	-0.004	1.581	0.557	2.581	1.347	2.202	3.985	5.816	8.664
Ensay	His	709.0	172.1	0.243	0.462	0.039	1.594	0.509	1.959	1.279	2.161	4.037	5.851	8.465
	HSM	722.4	177.8	0.246	0.273	0.028	1.664	0.451	2.834	1.194	2.020	3.771	5.594	8.398
	ARM	709.4	170.3	0.240	0.431	-0.005	1.694	0.509	2.674	1.276	2.116	3.887	5.692	8.520
Orbost	His	852.1	199.6	0.234	0.644	-0.117	1.759	0.540	3.703	1.322	2.156	4.087	5.857	8.470
	HSM	866.2	210.3	0.243	0.317	-0.003	1.683	0.440	2.992	1.198	2.017	3.762	5.562	8.385
	ARM	852.3	198.3	0.233	0.595	-0.113	1.725	0.545	2.711	1.351	2.198	3.977	5.796	8.631

Table 5. (Cont)

Station name		Mean	Std Dev	CV	Skew	Corr	Max	Min	Range	2-year	3-year	5-year	7-year	10-year
Seaspray	His	598.8	129.5	0.216	0.249	0.176	1.575	0.580	4.969	1.177	1.862	3.393	5.248	7.529
	HSM	594.3	130.2	0.219	0.114	0.100	1.567	0.480	3.028	1.243	2.070	3.800	5.578	8.368
	ARM	599.4	128.5	0.215	0.229	0.166	1.583	0.516	2.898	1.248	2.064	3.801	5.613	8.416
Warragul VCH	His	1035.1	155.5	0.150	0.616	0.021	1.523	0.678	2.445	1.539	2.432	4.446	6.356	9.136
	HSM	1041.3	158.0	0.152	0.368	0.000	1.442	0.648	1.880	1.502	2.401	4.250	6.115	9.012
	ARM	1035.3	154.3	0.149	0.573	-0.003	1.466	0.708	1.885	1.553	2.447	4.288	6.163	9.045
Wilsons	His	1053.9	167.9	0.159	-0.083	0.064	1.374	0.524	3.090	1.360	2.369	4.290	6.036	8.766
Promontory	HSM	1064.0	166.8	0.157	0.058	0.000	1.419	0.603	2.032	1.437	2.332	4.157	6.040	8.900
	ARM	1054.7	167.1	0.158	0.009	-0.001	1.408	0.600	2.106	1.439	2.321	4.154	6.024	8.912
Melbourne RO	His	657.0	120.4	0.183	0.474	0.076	1.524	0.577	2.170	1.387	2.314	4.125	6.063	9.041
	HSM	660.3	119.8	0.181	0.372	0.004	1.556	0.569	2.490	1.379	2.248	4.060	5.930	8.745
	ARM	657.4	120.3	0.183	0.449	0.075	1.561	0.610	2.814	1.393	2.243	4.028	5.852	8.666
Toorourrong	His	802.6	156.2	0.195	0.429	-0.027	1.534	0.570	2.357	1.314	2.106	3.866	5.933	8.726
	HSM	809.4	159.5	0.197	0.231	-0.018	1.542	0.538	2.337	1.348	2.210	4.029	5.881	8.741
	ARM	802.6	155.3	0.193	0.404	-0.008	1.567	0.594	2.396	1.400	2.264	4.065	5.911	8.779
Warburton	His	1343.9	210.0	0.156	0.905	0.021	1.498	0.715	1.701	1.620	2.547	4.246	6.212	9.102
	HSM	1351.8	214.3	0.158	0.747	0.038	1.528	0.663	2.108	1.512	2.402	4.239	6.120	8.980
	ARM	1344.7	208.0	0.155	0.819	-0.003	1.527	0.731	1.993	1.571	2.454	4.279	6.149	9.020
Meredith	His	683.3	125.6	0.184	0.475	0.109	1.523	0.652	3.008	1.396	2.205	3.913	5.869	8.404
	HSM	685.7	124.8	0.182	0.357	0.023	1.517	0.591	2.385	1.406	2.272	4.089	5.955	8.792
	ARM	684.0	125.0	0.183	0.437	0.104	1.548	0.614	2.601	1.399	2.244	4.030	5.854	8.684
Kilmore	His	726.1	167.2	0.230	0.804	0.119	1.690	0.589	3.056	1.240	2.106	3.863	5.773	8.645
	HSM	735.3	171.8	0.234	0.656	0.048	1.708	0.517	3.004	1.289	2.105	3.839	5.654	8.450
	ARM	726.3	166.0	0.229	0.741	0.116	1.748	0.585	3.236	1.316	2.125	3.842	5.619	8.406
Pennyroyal Creek	His	792.8	136.0	0.172	1.058	0.172	1.779	0.657	2.942	1.453	2.167	3.988	5.620	8.383
	HSM	807.9	146.6	0.181	0.629	-0.016	1.597	0.582	2.294	1.413	2.296	4.130	5.992	8.835
	ARM	793.3	134.5	0.169	0.953	0.164	1.594	0.722	2.486	1.519	2.366	4.144	5.981	8.807
Penshurst	His	720.5	122.0	0.169	0.523	0.087	1.482	0.651	3.513	1.361	2.342	4.091	5.963	8.599
	HSM	724.4	121.5	0.168	0.349	0.007	1.482	0.615	2.100	1.457	2.335	4.164	6.041	8.910
	ARM	720.9	121.1	0.168	0.485	0.082	1.512	0.653	2.304	1.457	2.323	4.134	5.983	8.847

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APPENDIX A

PLOTS OF OBSERVED DATA

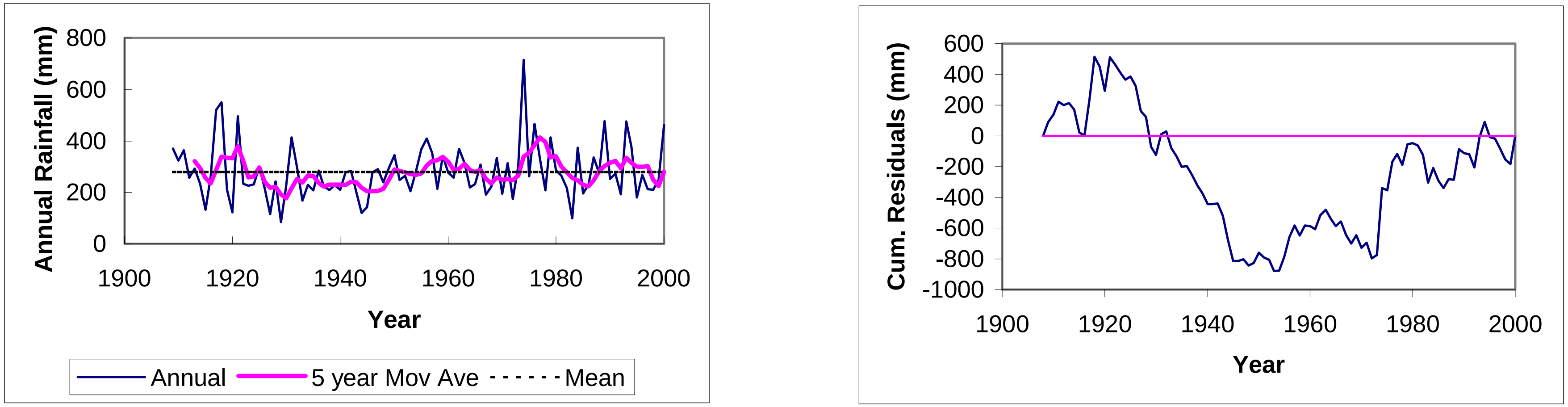


Figure A1. **Time series plot and residual mass curve for Irymple (076015).**

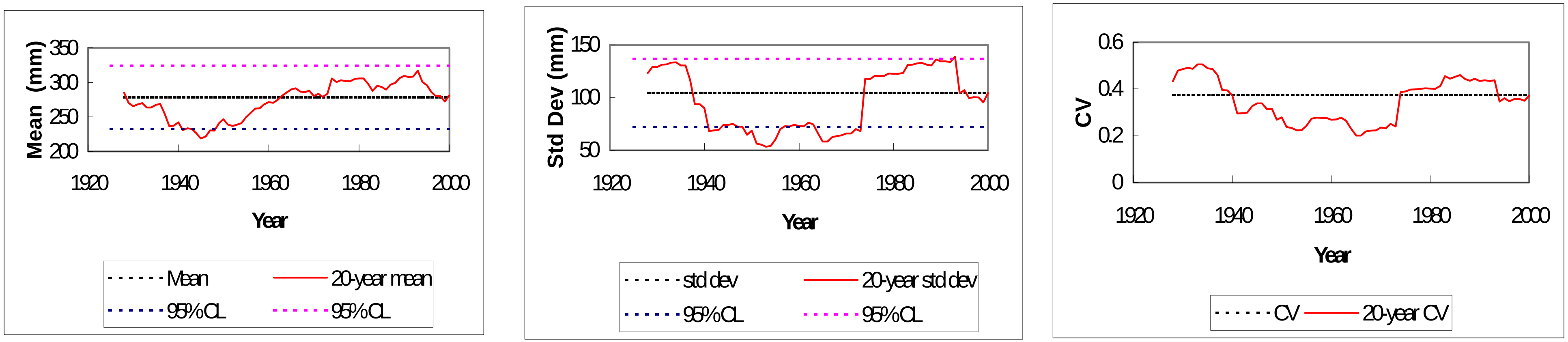


Figure A2. **Mean, standard deviation and coefficient of variation of annual rainfall for Irymple (076015).**

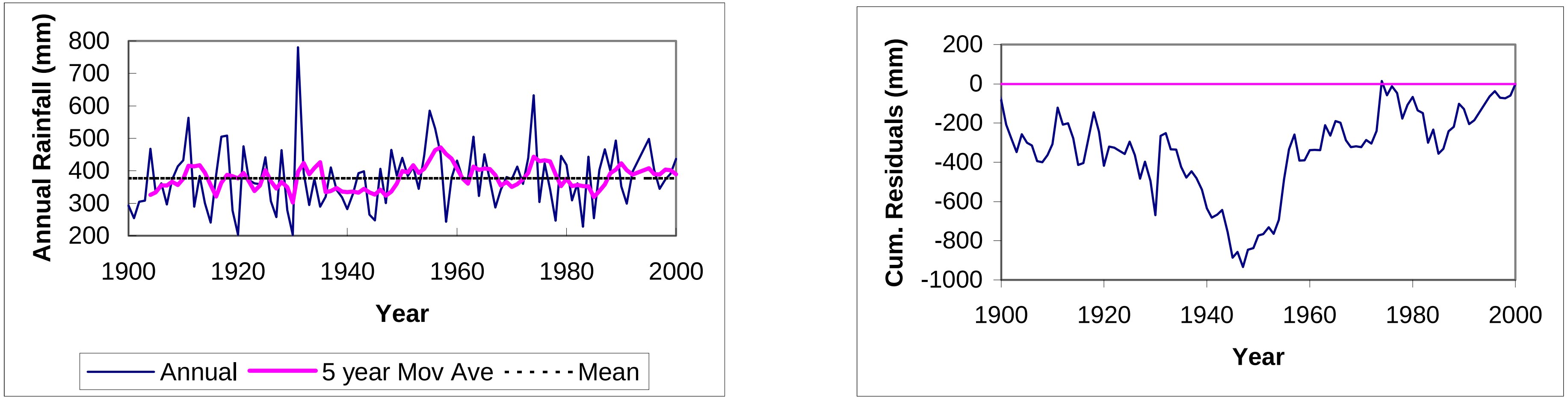


Figure A3. **Time series plot and residual mass curve for Beulah Post Office (077004).**

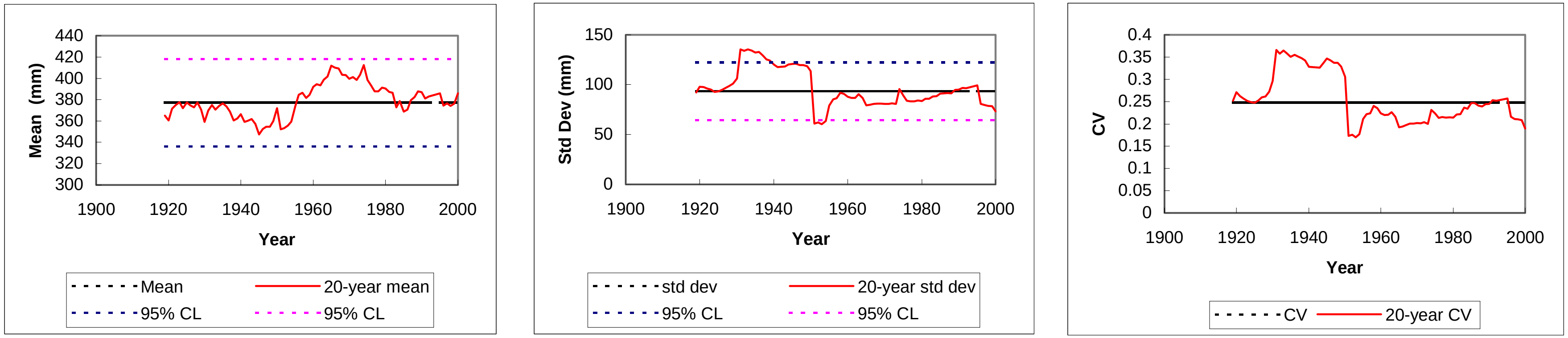
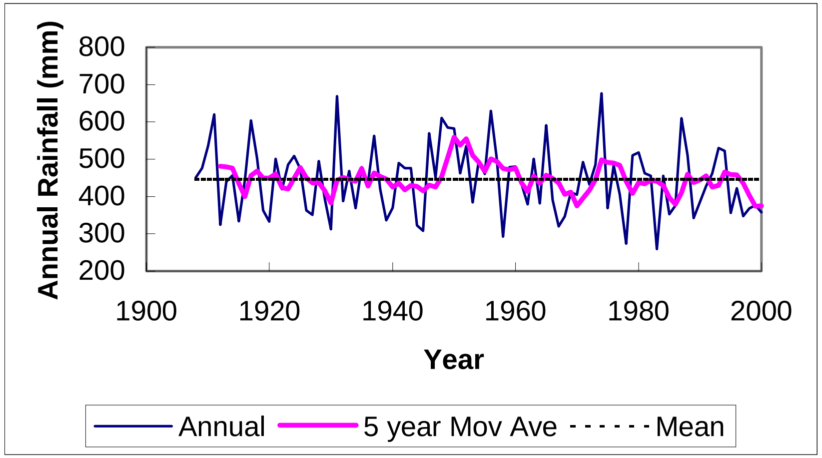


Figure A4. **Mean, standard deviation and coefficient of variation of annual rainfall for Beulah Post Office (077004).**



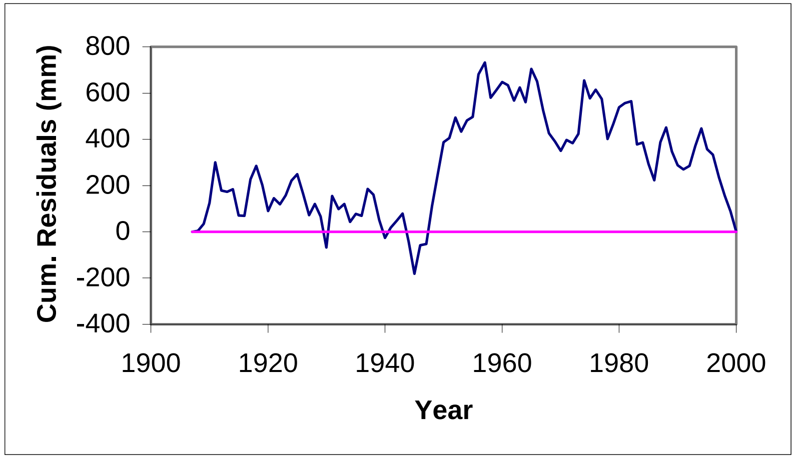
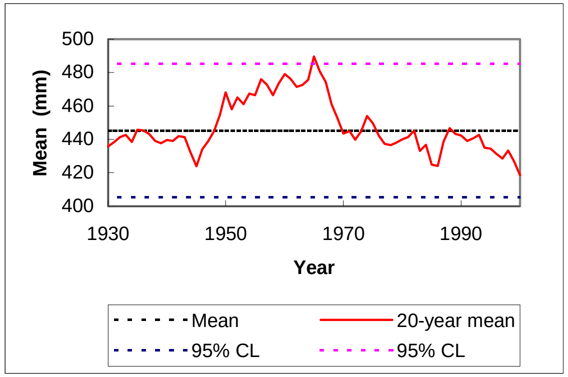
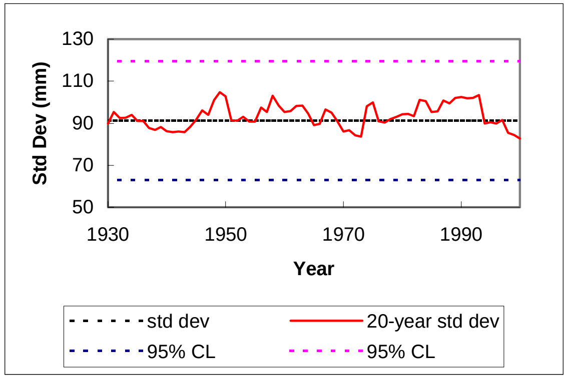


Figure A5. Time series plot and residual mass curve for Natimuk (079036).





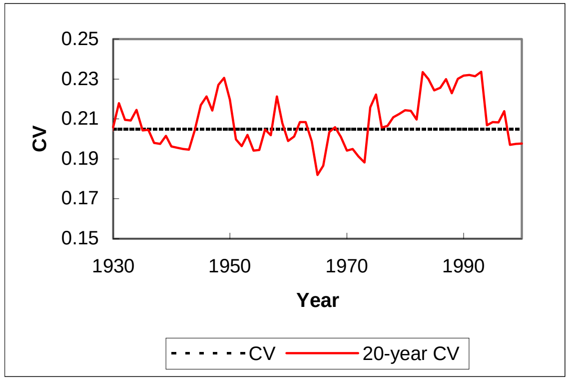
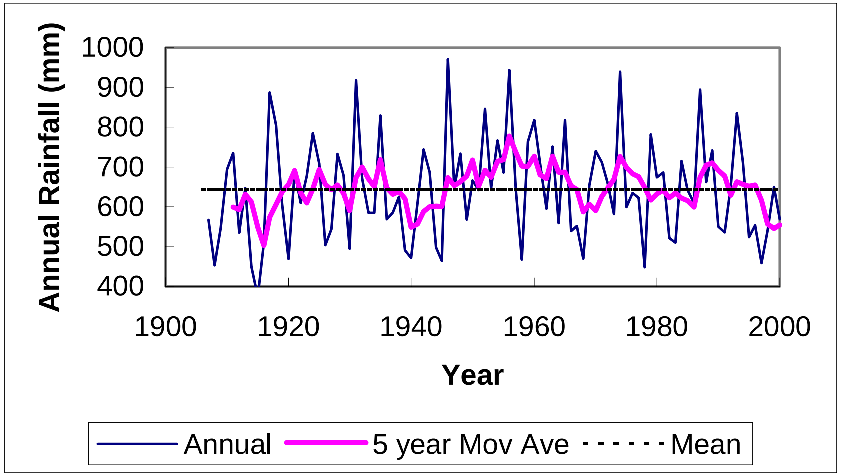


Figure A6. Mean, standard deviation and coefficient of variation of annual rainfall for Natimuk (079036).



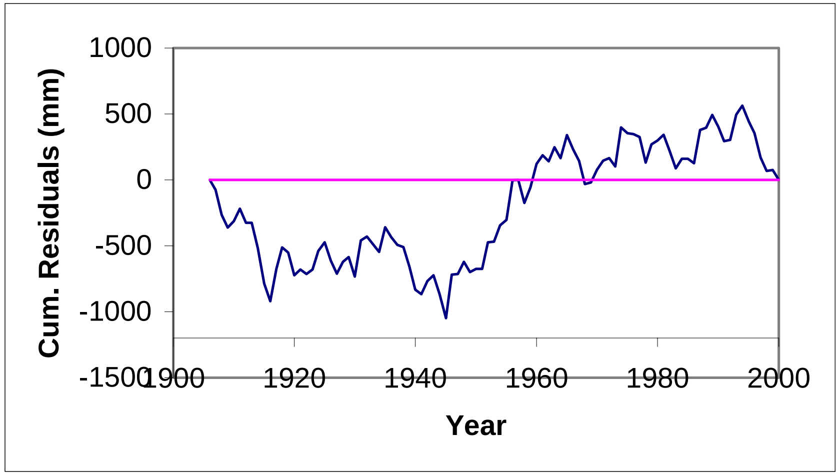
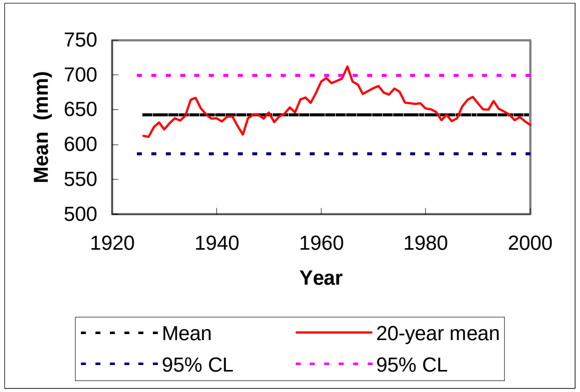
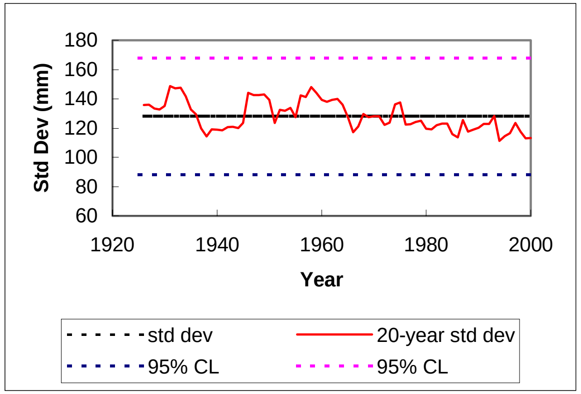


Figure A7. **Time series plot and residual mass curve for Moyston Barton Estate (79050).**





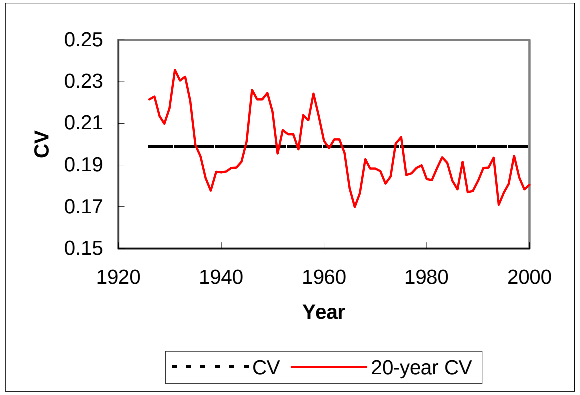


Figure A8. **Mean, standard deviation and coefficient of variation of annual rainfall for Moyston Barton Estate (79050).**

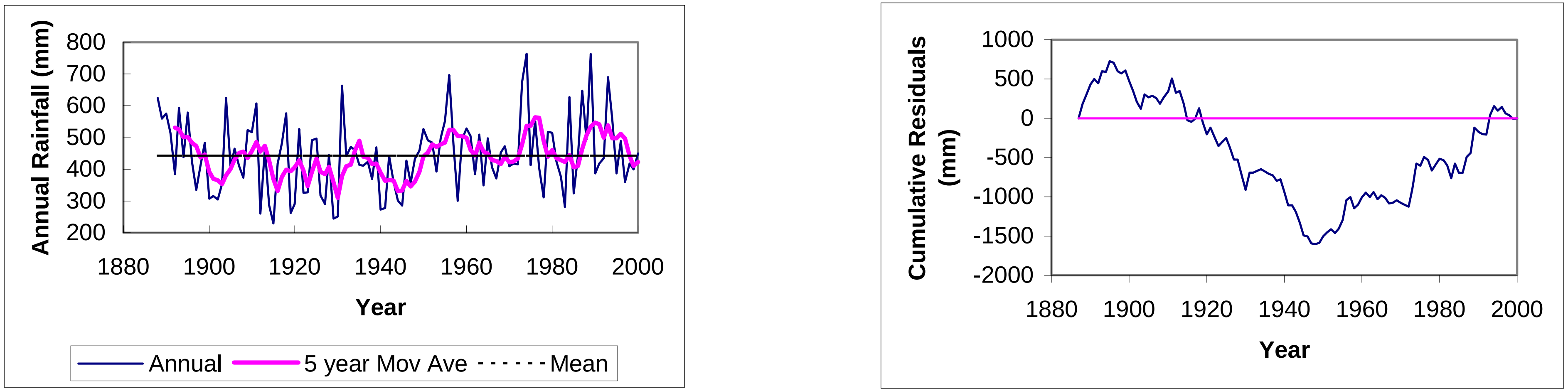


Figure A9. Time series plot and residual mass curve for St Arnaud (080009).

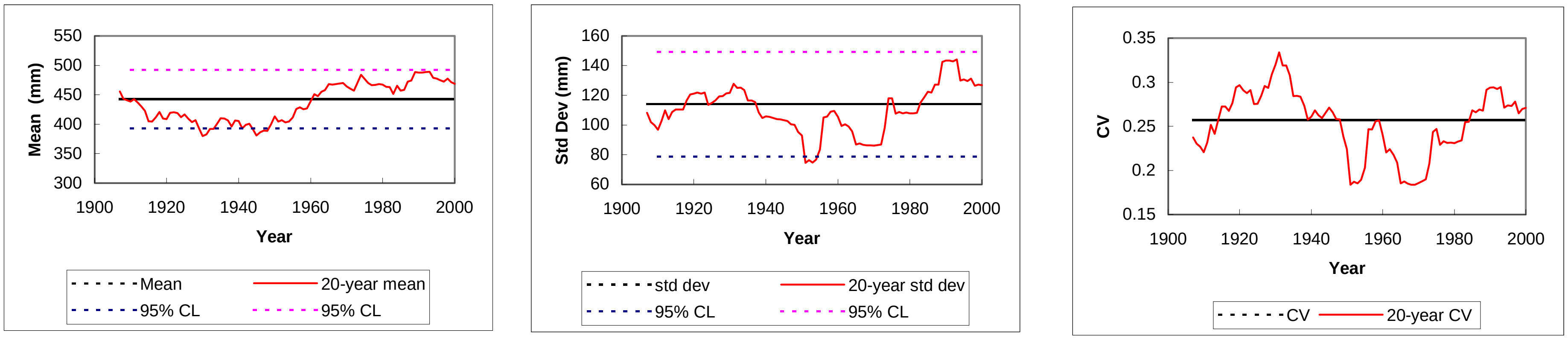


Figure A10. Mean, standard deviation and coefficient of variation of annual rainfall for St Arnaud (080009).

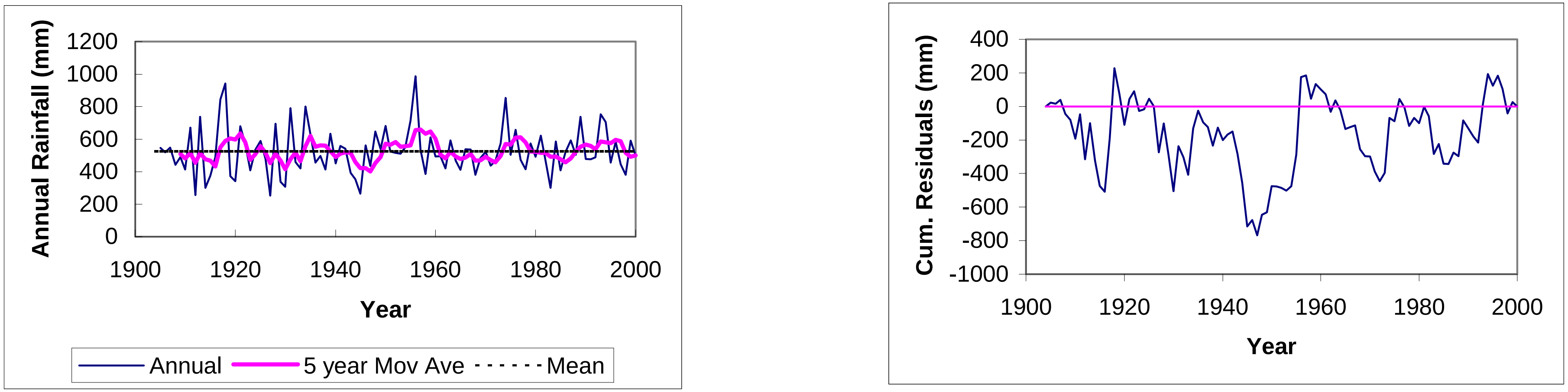


Figure A11. Time series plot and residual mass curve for Caniambo (081007).

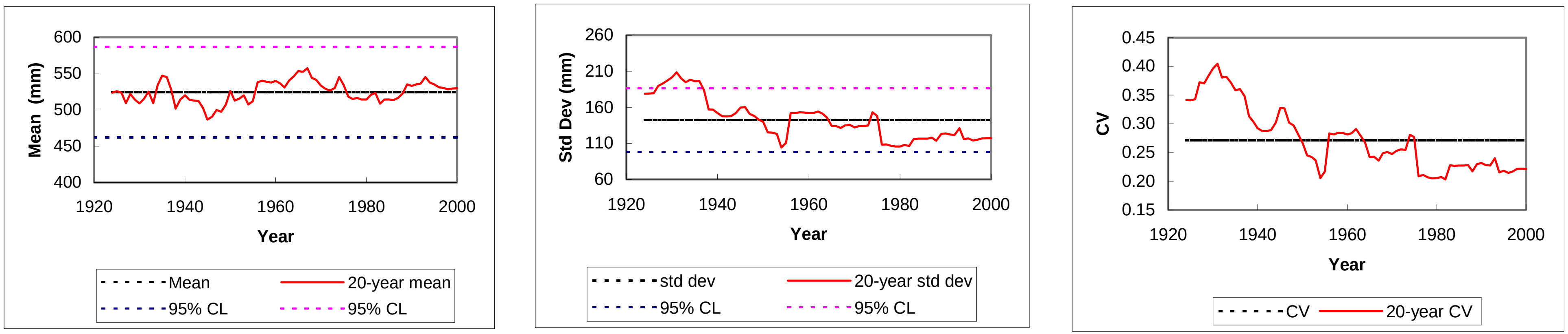


Figure A12 Mean, standard deviation and coefficient of variation of annual rainfall for Caniambo (081007).

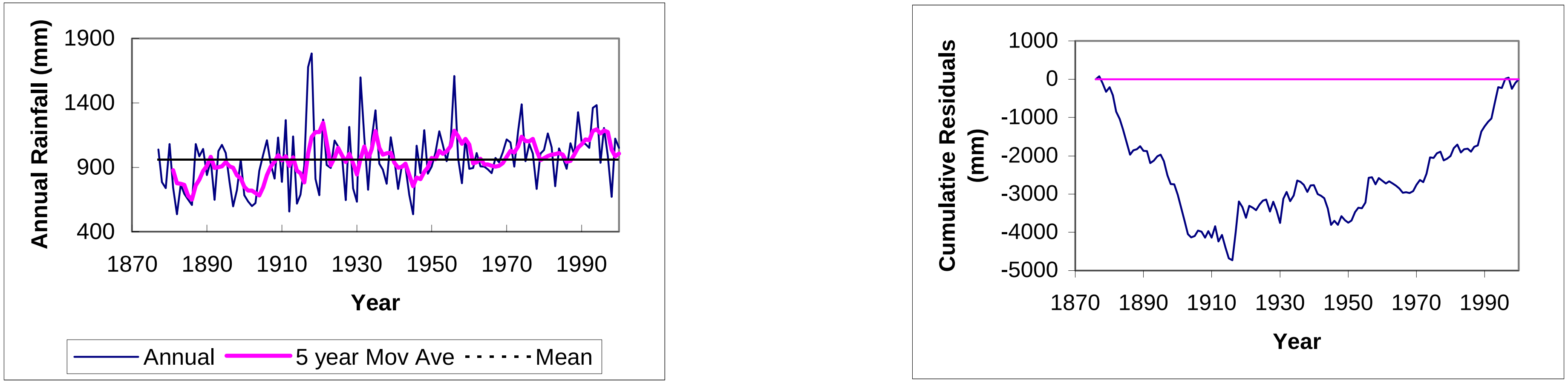


Figure A13. **Time series plot and residual mass curve for Beechworth (082001).**

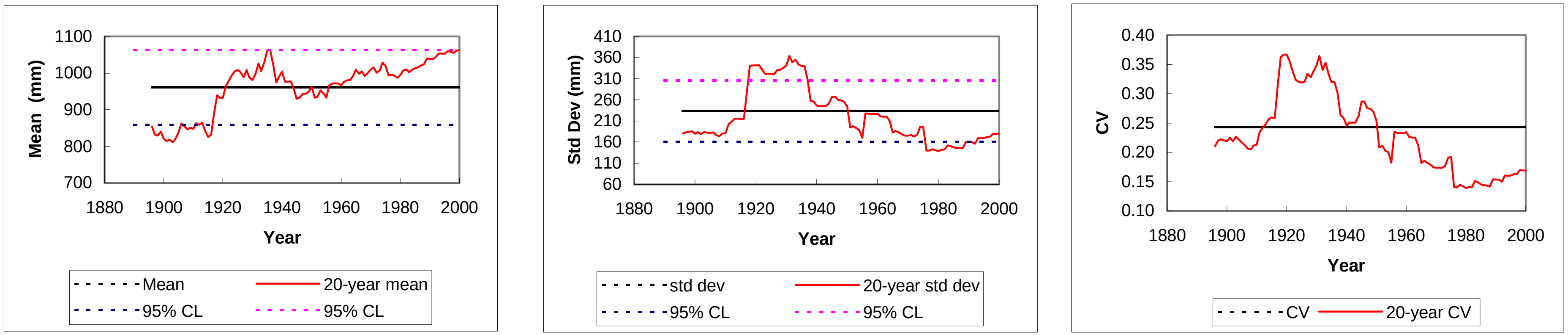


Figure A14. **Mean, standard deviation and coefficient of variation of annual rainfall for Beechworth (082001).**

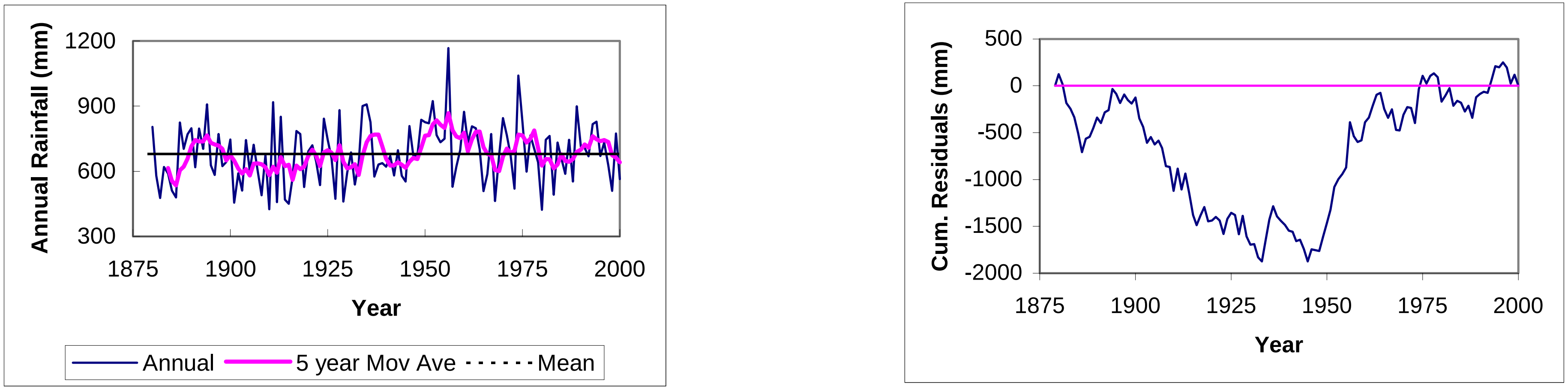


Figure A15. Time series plot and residual mass curve for Omeo (083025).

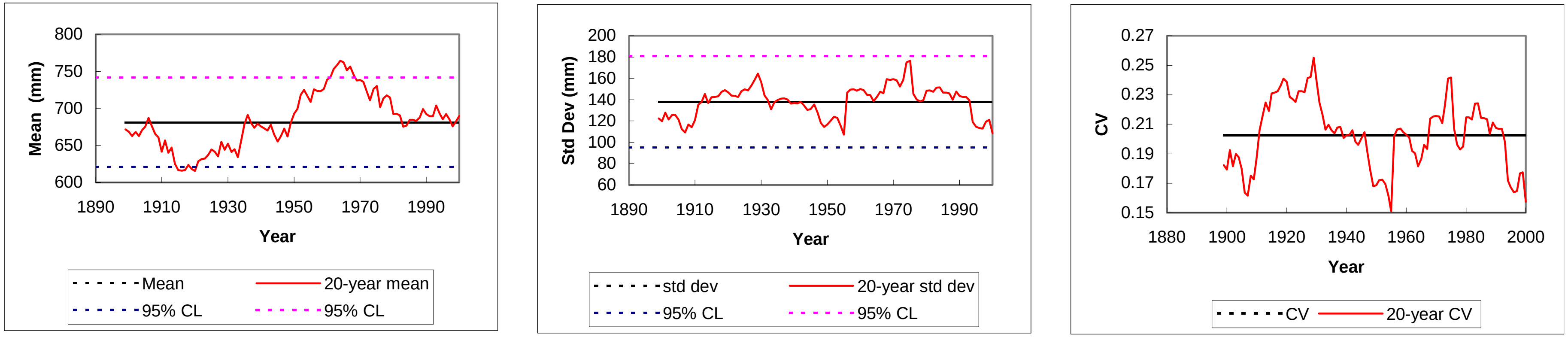
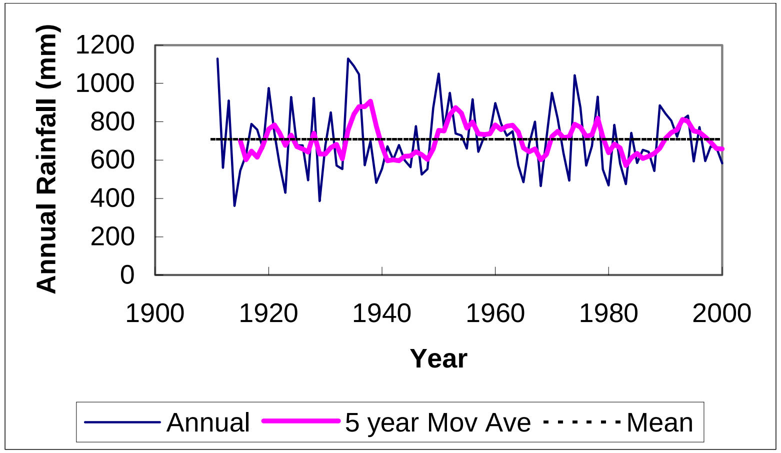


Figure A16. Mean, standard deviation and coefficient of variation of annual rainfall for Omeo (083025).



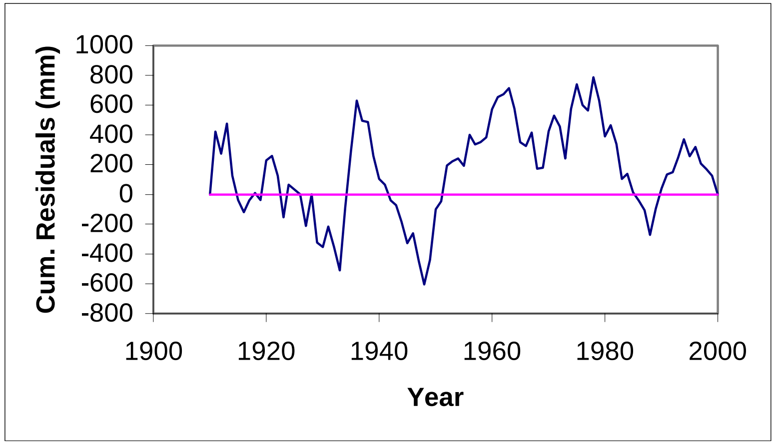


Figure A17. Time series plot and residual mass curve for Ensay (84015).

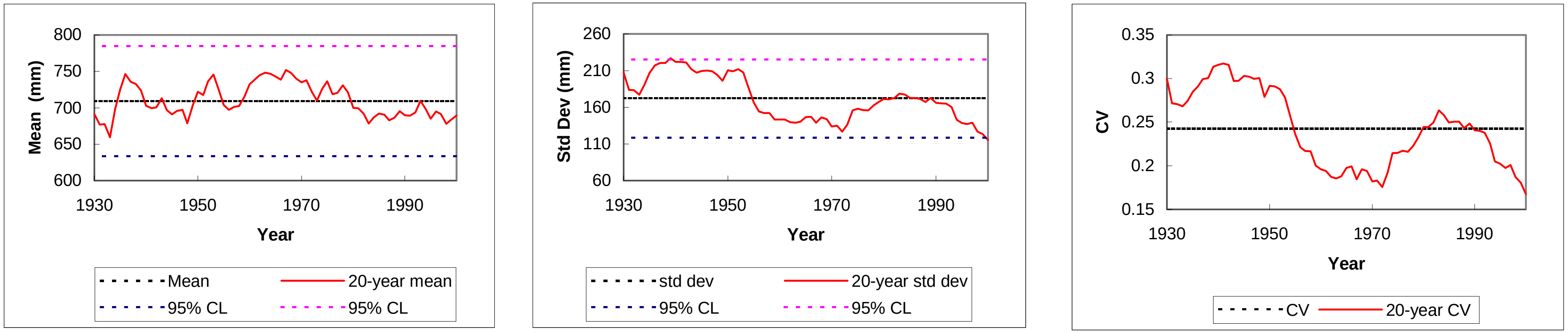


Figure A18. Mean, standard deviation and coefficient of variation of annual rainfall for Ensay (84015).

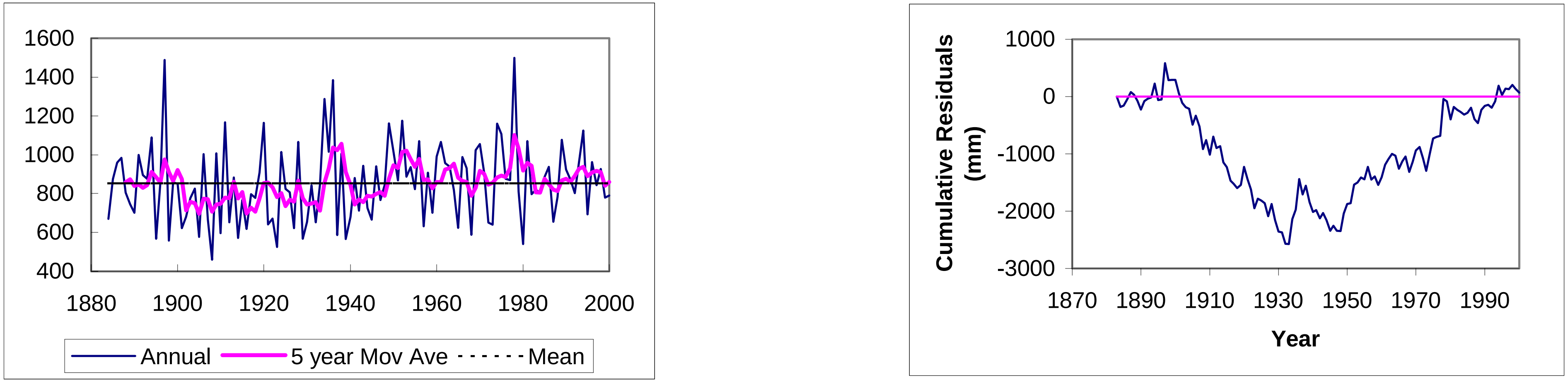


Figure A19. Time series plot and residual mass curve for Orbost (084030).

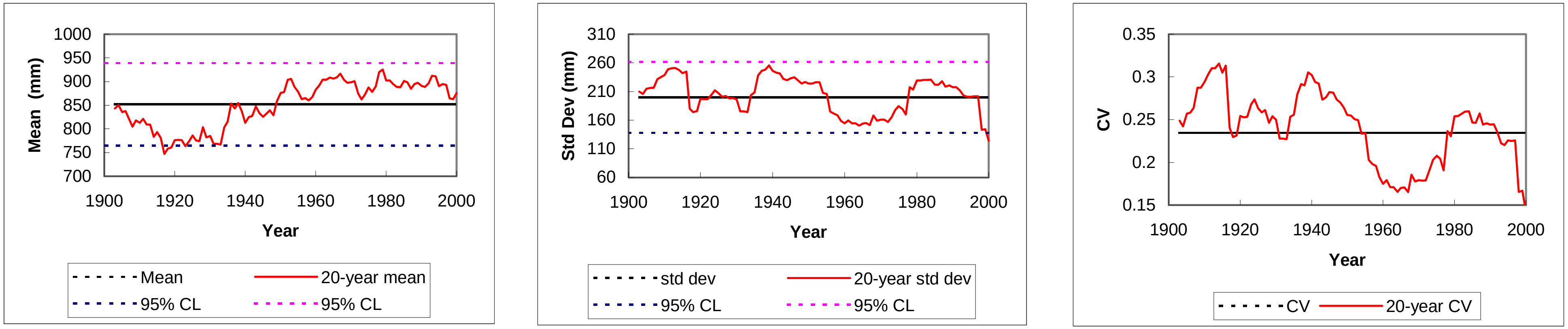


Figure A20. Mean, standard deviation and coefficient of variation of annual rainfall for Orbost (084030).

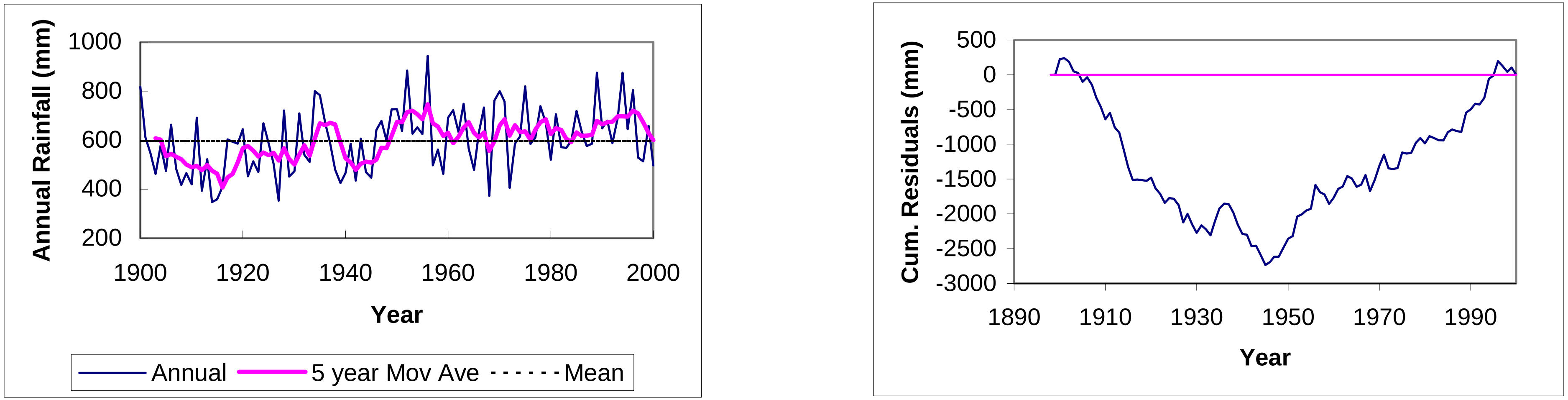


Figure A21 Time series plot and residual mass curve for Seaspray (085073).

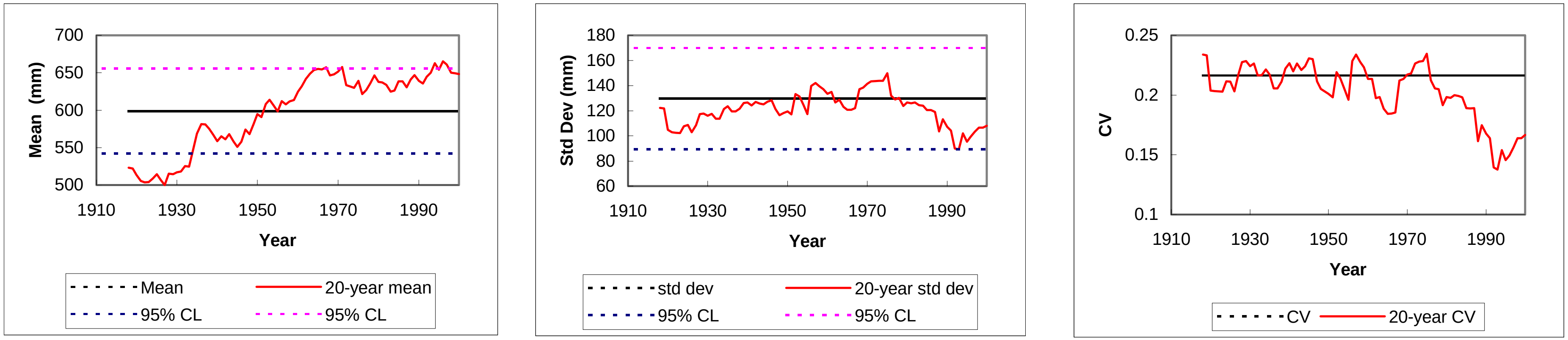
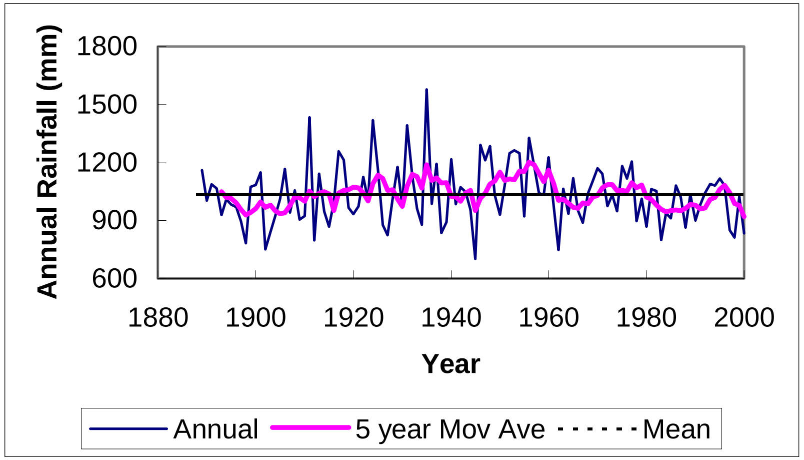


Figure A22. Mean, standard deviation and coefficient of variation of annual rainfall for Seaspray (085073).



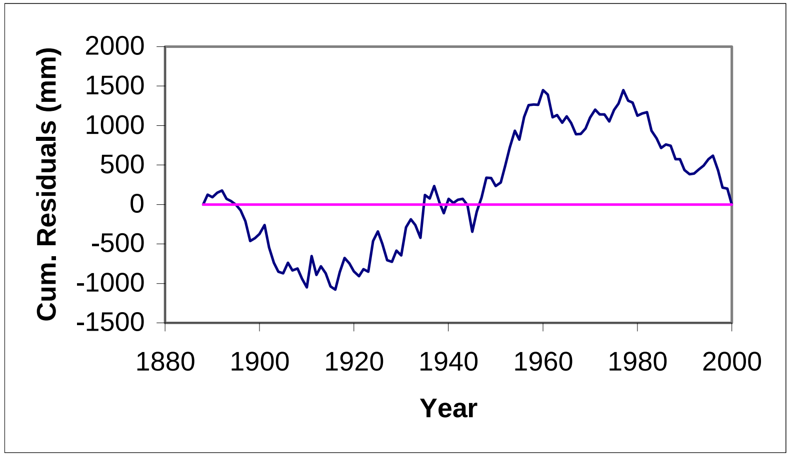
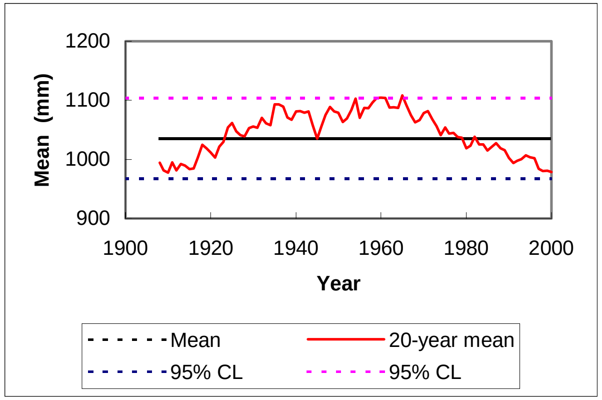
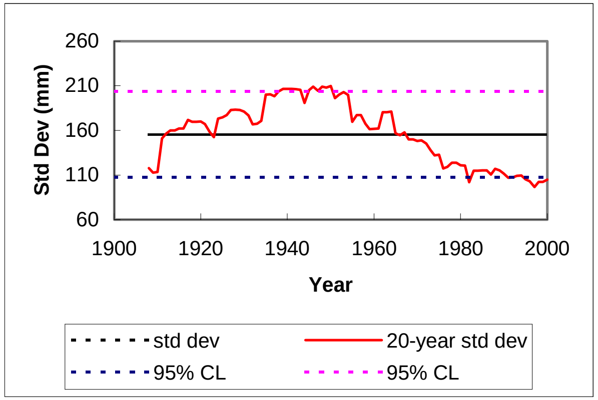


Figure A23. Time series plot and residual mass curve for Warragul (085093).





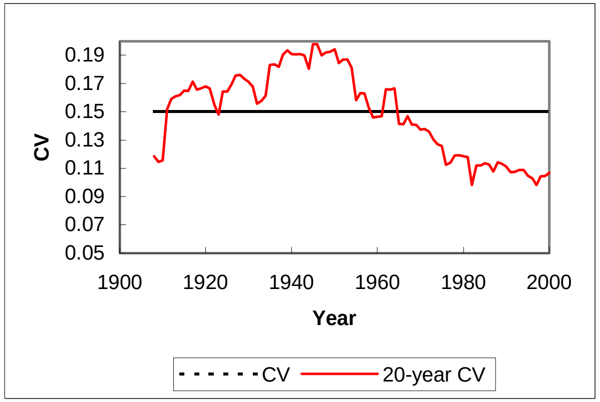
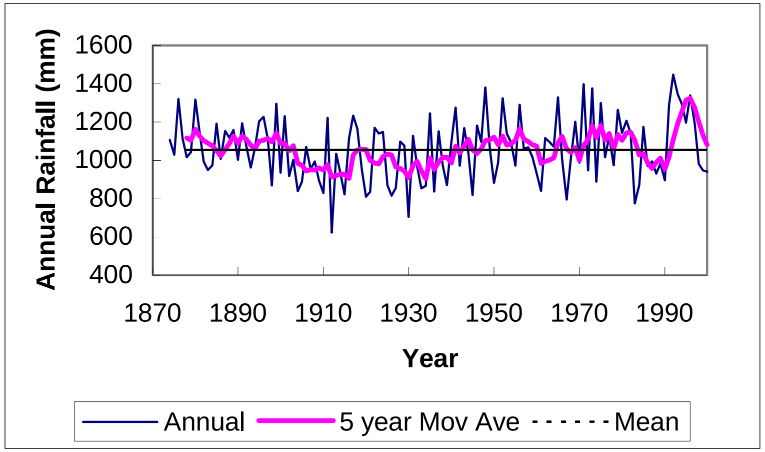


Figure A24. Mean, standard deviation and coefficient of variation of annual rainfall for Warragul (085093).



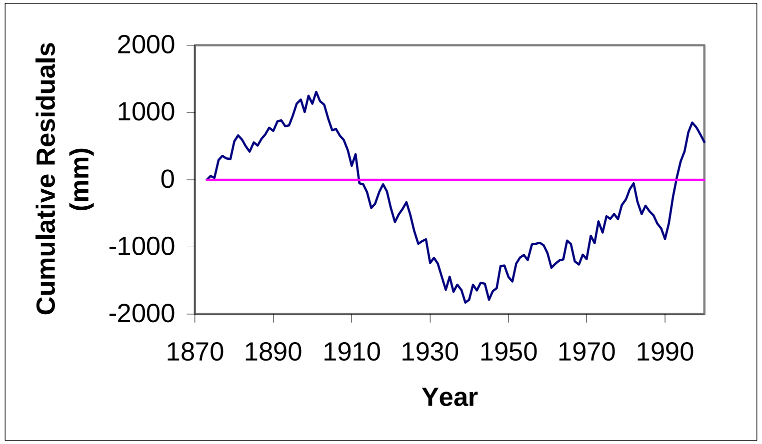
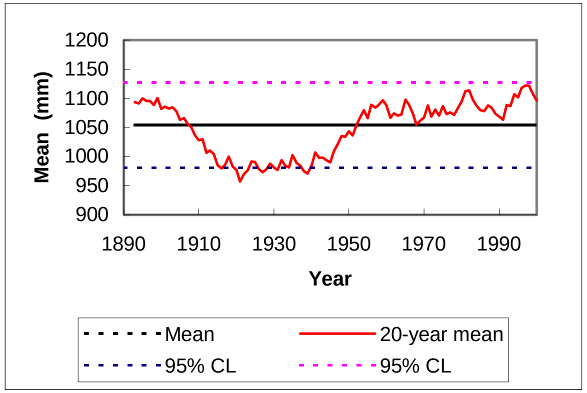
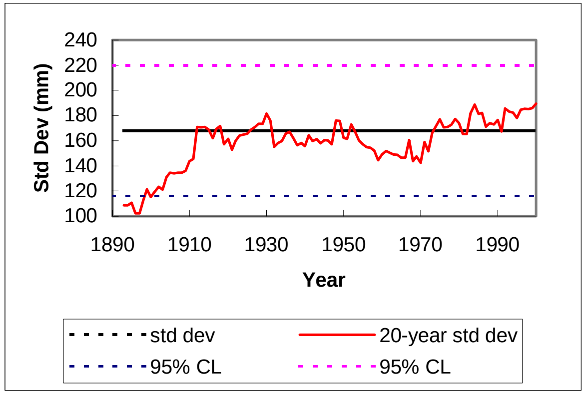


Figure A25. Time series plot and residual mass curve for Wilson's Promontory (085096).





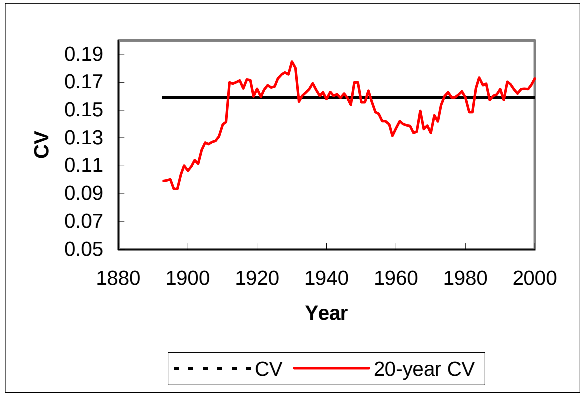


Figure A26. Mean, standard deviation and coefficient of variation of annual rainfall for Wilson's Promontory (085096).

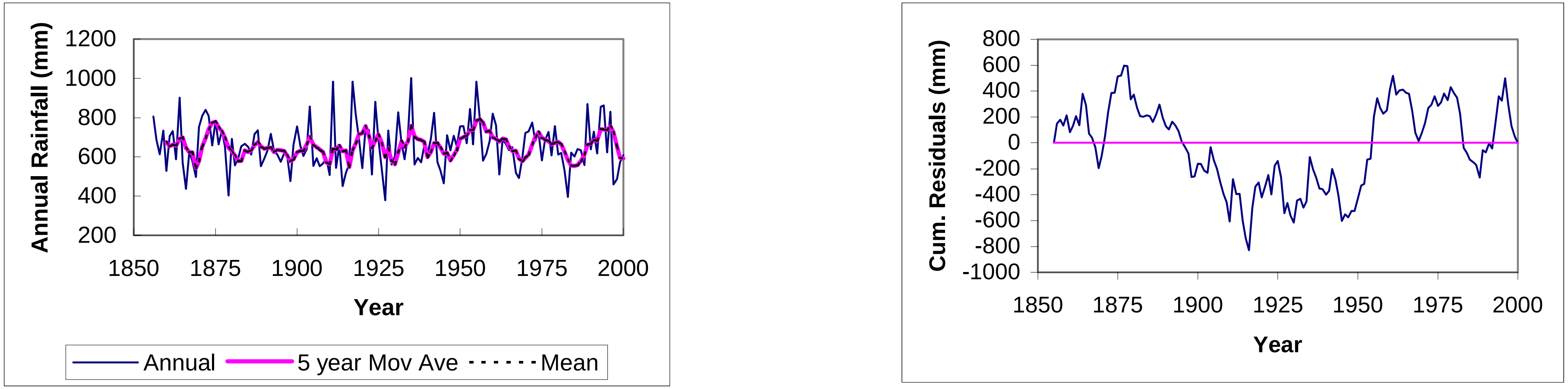


Figure A27. **Time series plot and residual mass curve for Melbourne (086071).**

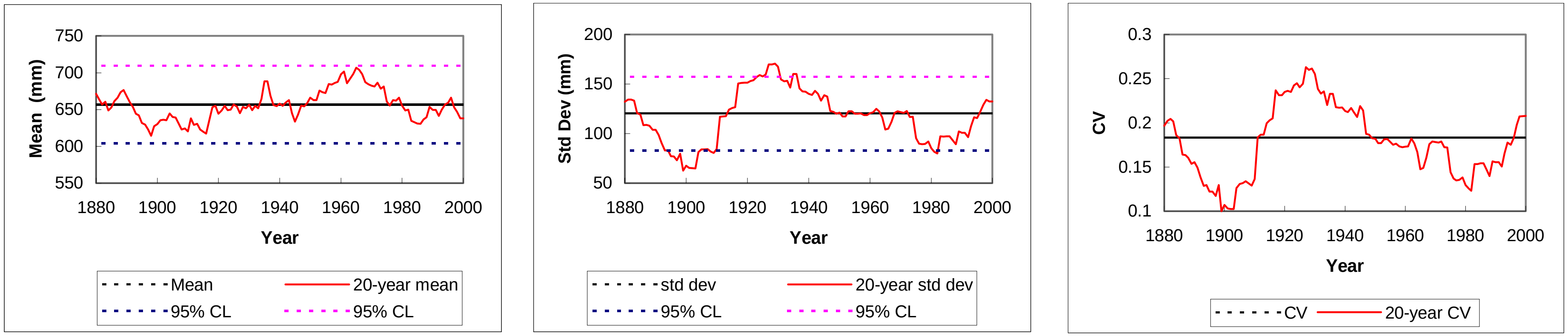
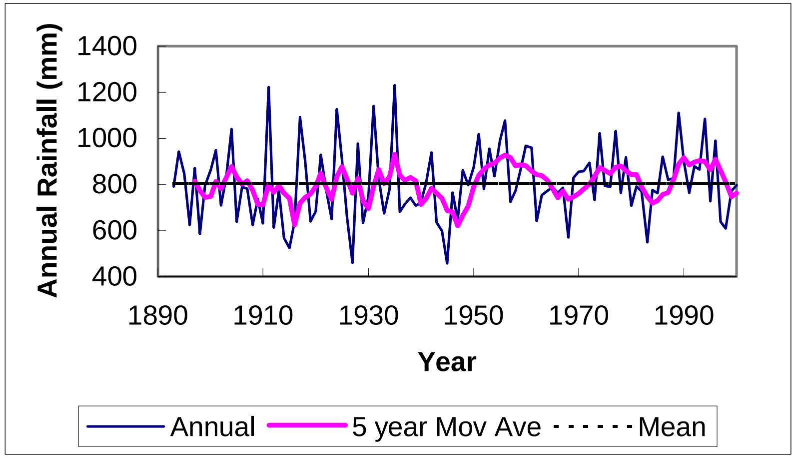


Figure A28. **Mean, standard deviation and coefficient of variation of annual rainfall for Melbourne (086071).**



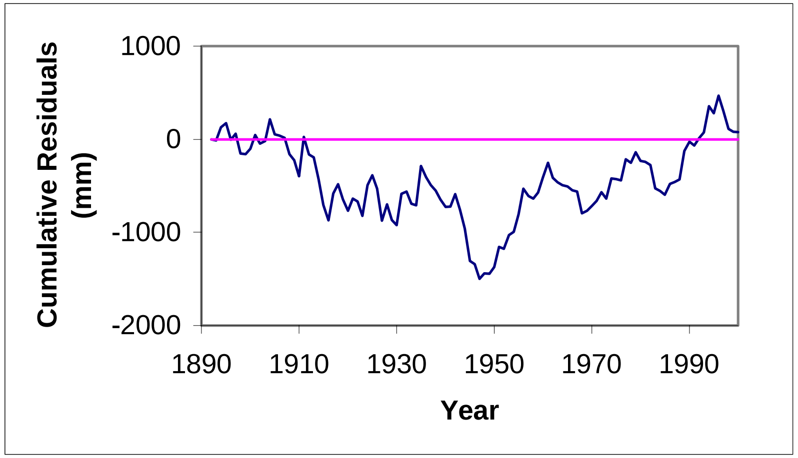
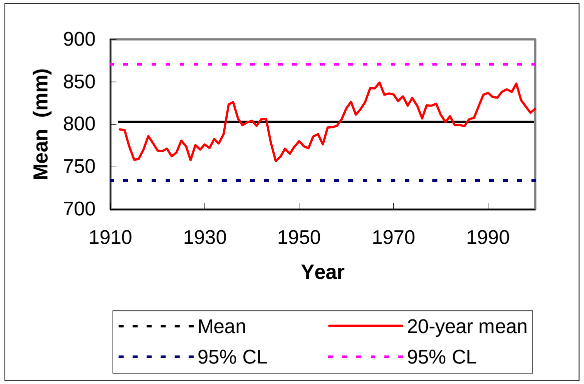
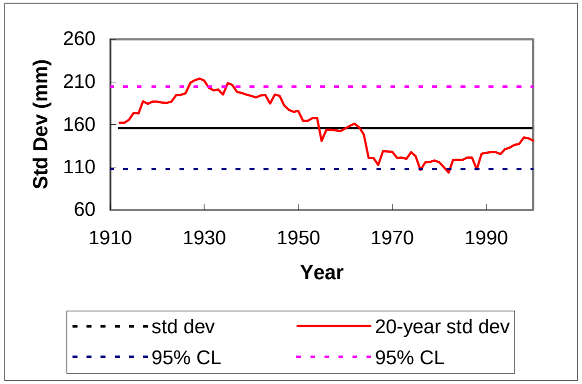


Figure A29. Time series plot and residual mass curve for Toorourrong (086117).





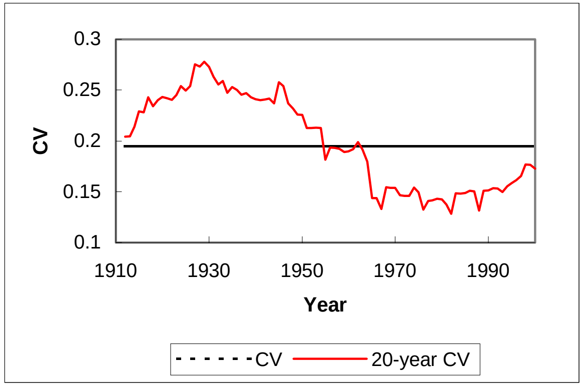
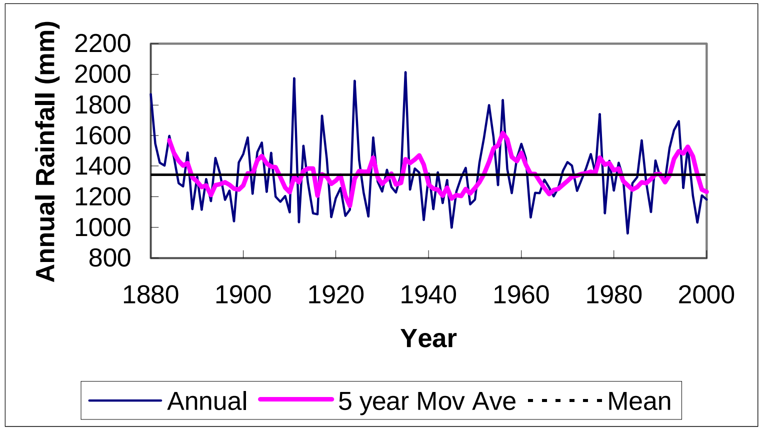


Figure A30. Mean, standard deviation and coefficient of variation of annual rainfall for Toorourrong (086117).



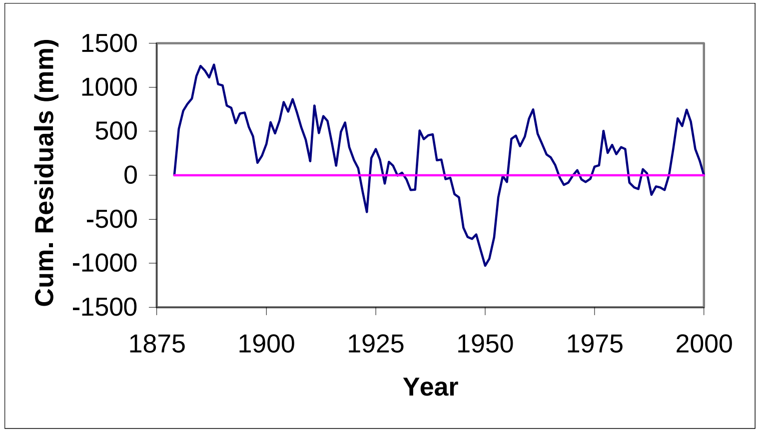
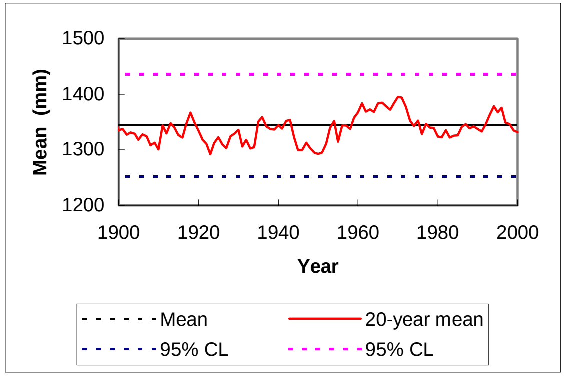
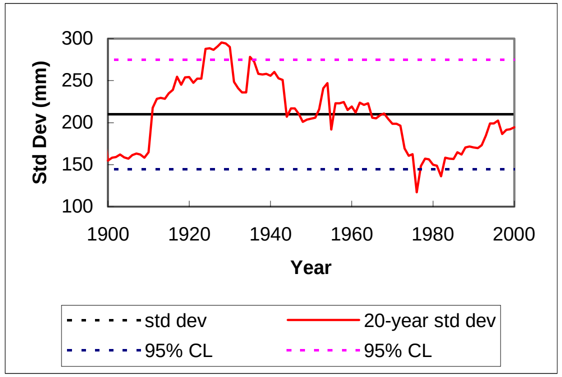


Figure A31. Time series plot and residual mass curve for Warburton (086121).





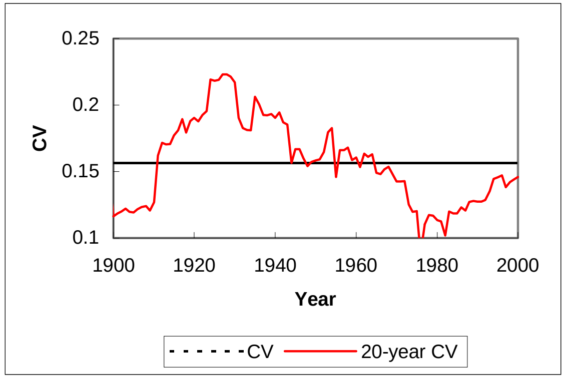


Figure A32. Mean, standard deviation and coefficient of variation of annual rainfall for Warburton (086121).

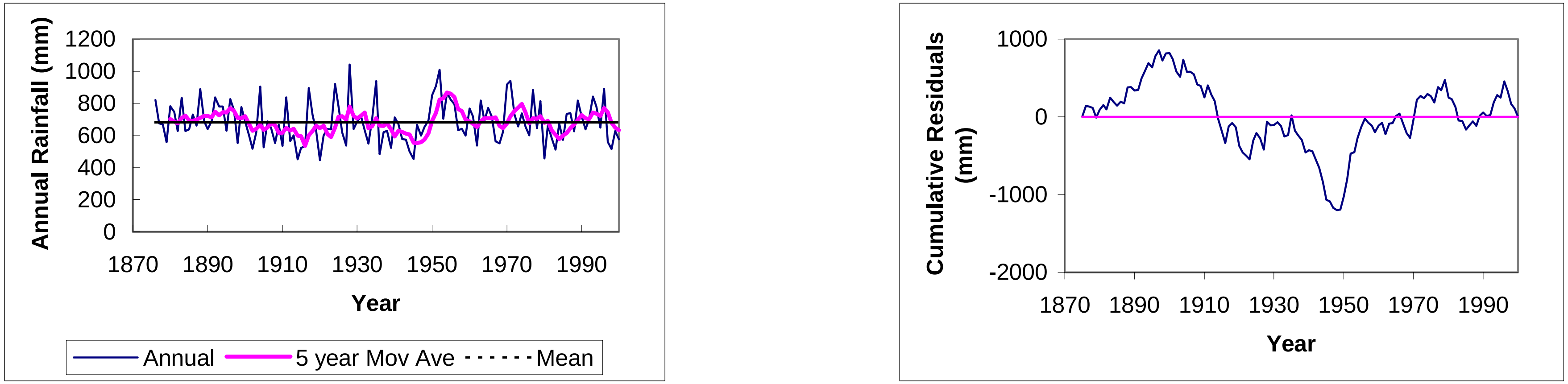


Figure A33. Time series plot and residual mass curve for Meredith (087043).

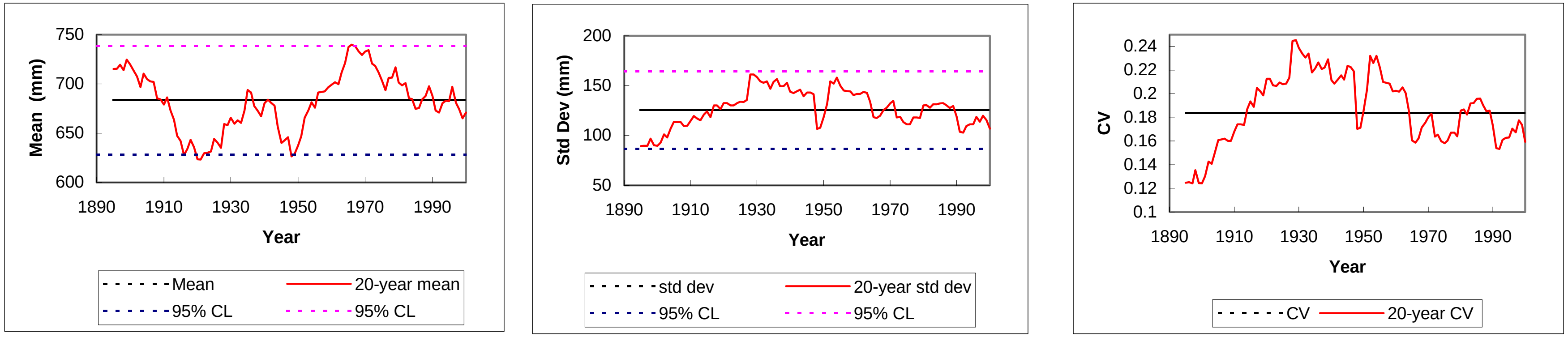
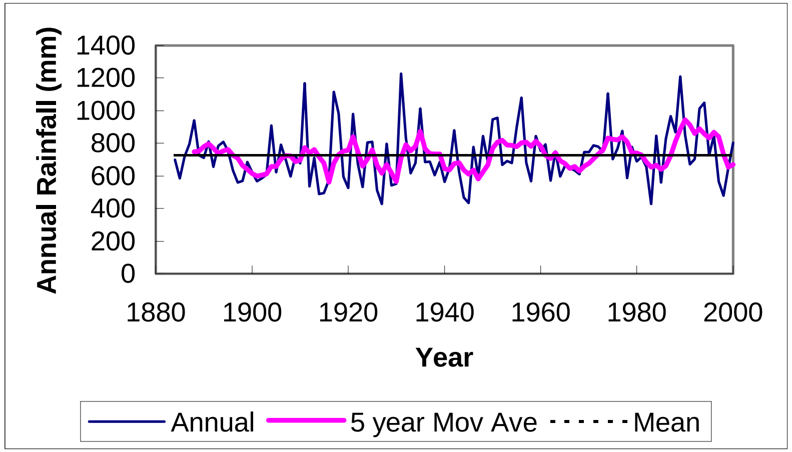


Figure A34. Mean, standard deviation and coefficient of variation of annual rainfall for Meredith (087043).



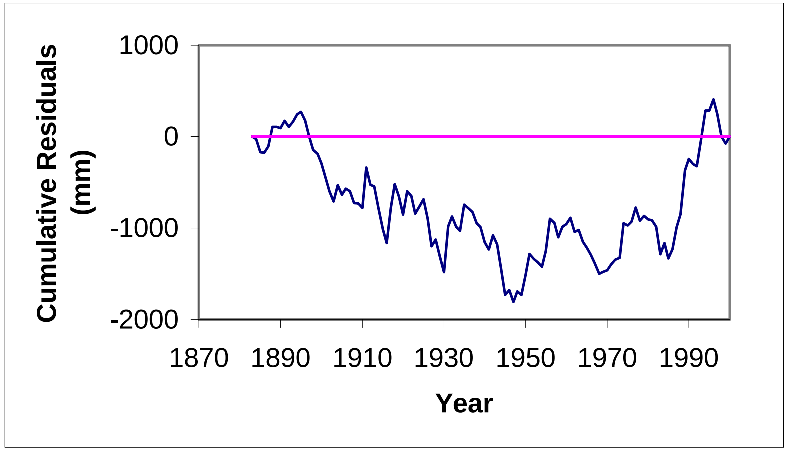
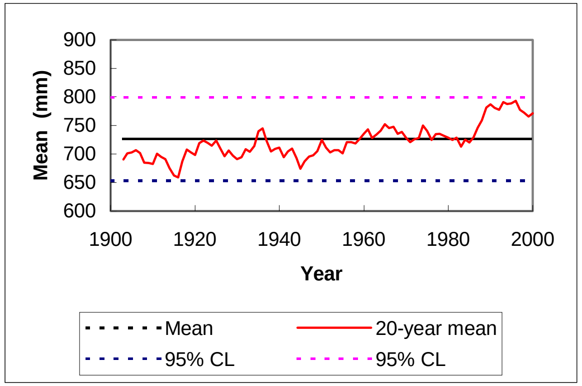
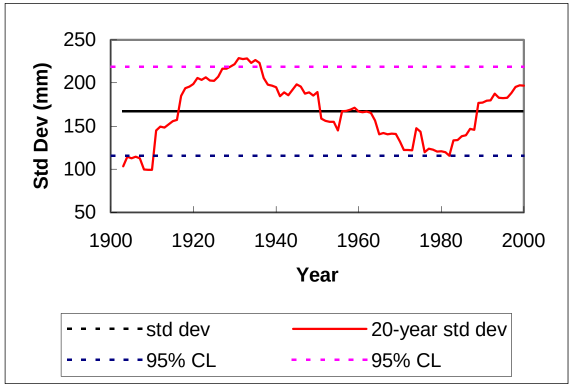


Figure A35. Time series plot and residual mass curve for Kilmore (088034).





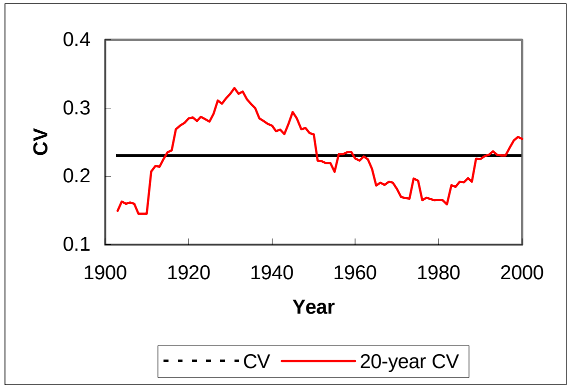


Figure A36. Mean, standard deviation and coefficient of variation of annual rainfall for Kilmore (088034).

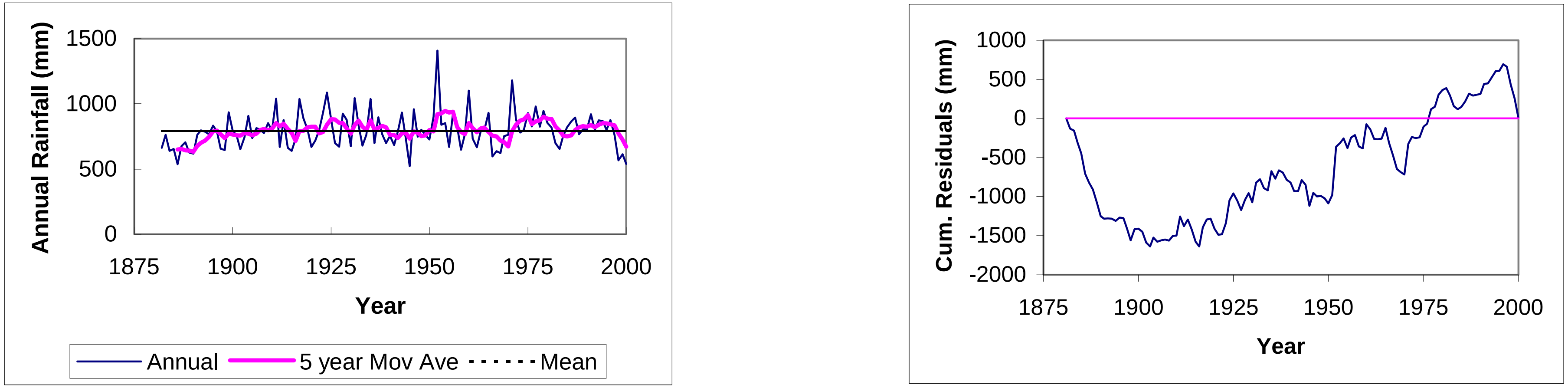


Figure A37. Time series plot and residual mass curve for Pennyroyal Creek (90061).

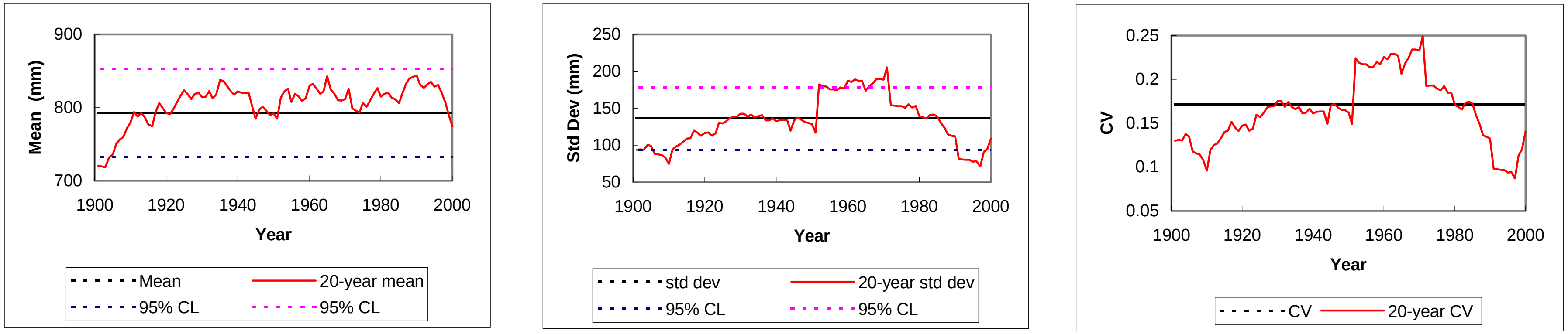
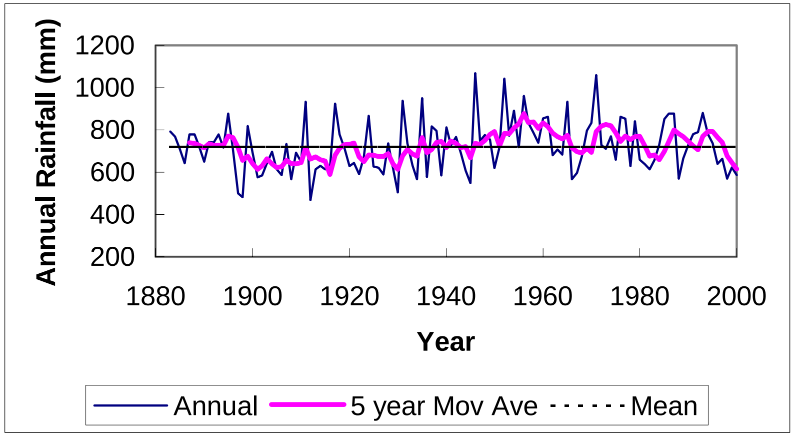


Figure A38. Mean, standard deviation and coefficient of variation of annual rainfall for Pennyroyal Creek (90061).



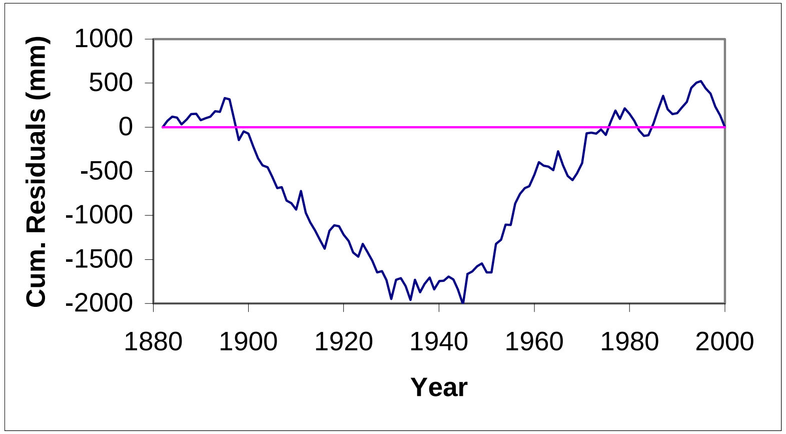
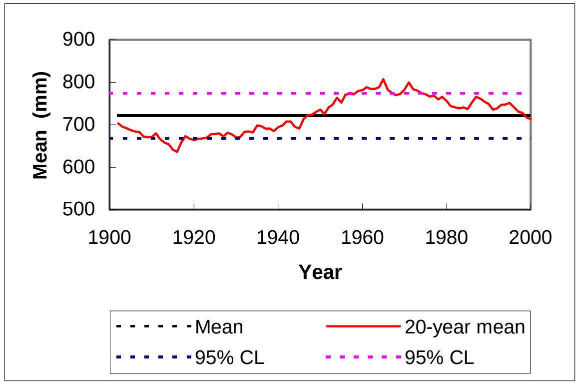
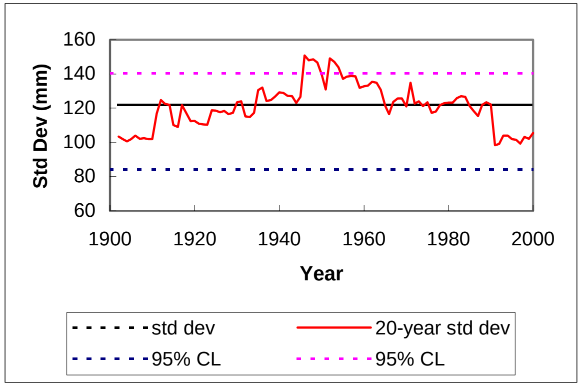


Figure A39. Time series plot and residual mass curve for Penshurst (090063).





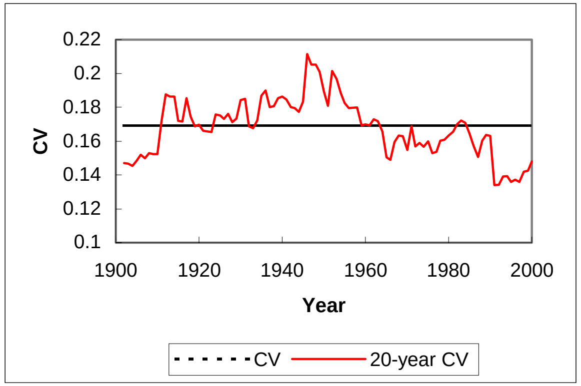


Figure A40. Mean, standard deviation and coefficient of variation of annual rainfall for Penshurst (09006

APPENDIX B

HSM MODEL CALIBRATION PLOTS

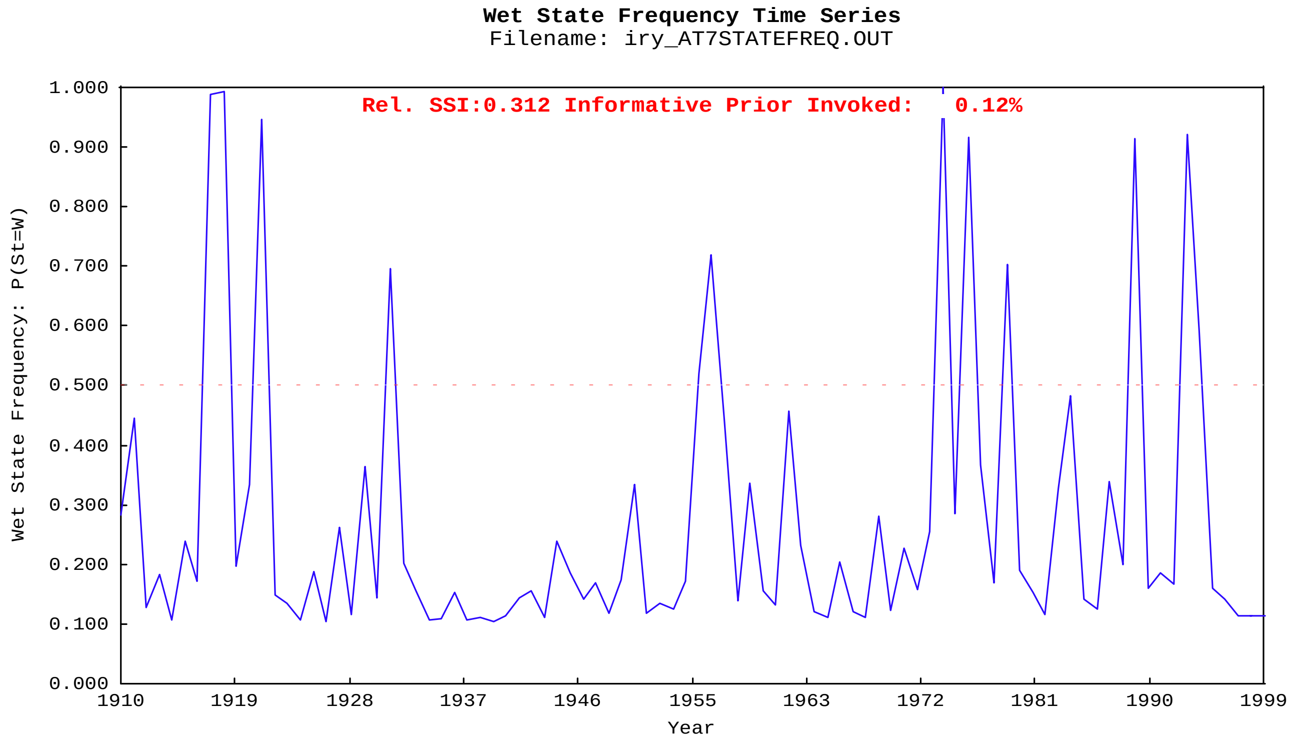


Figure B1. The wet state frequency time series for Irymple.

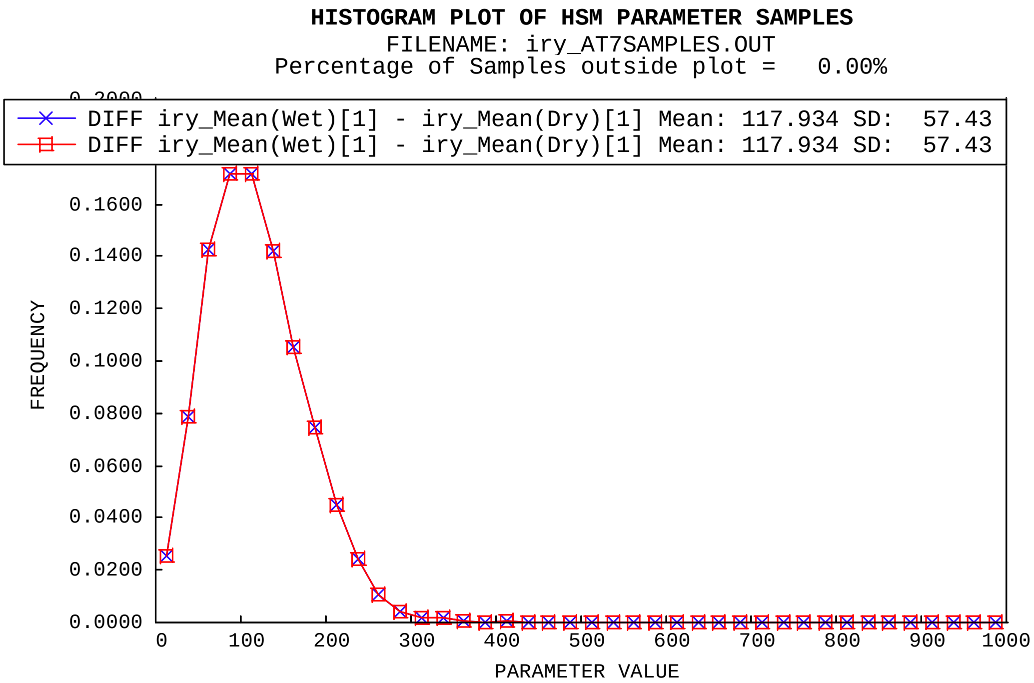


Figure B2. The probability distribution of the difference between the wet and dry state means for Irymple.

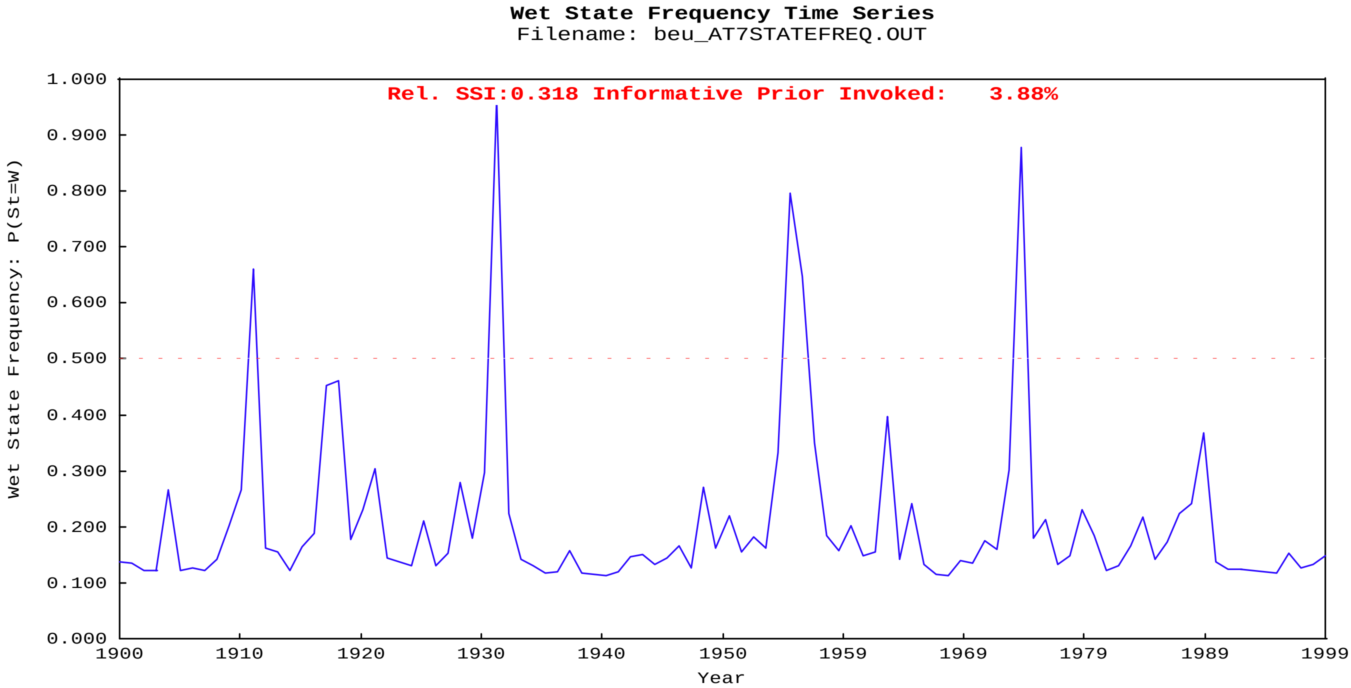


Figure B3. The wet state frequency time series for Beulah.

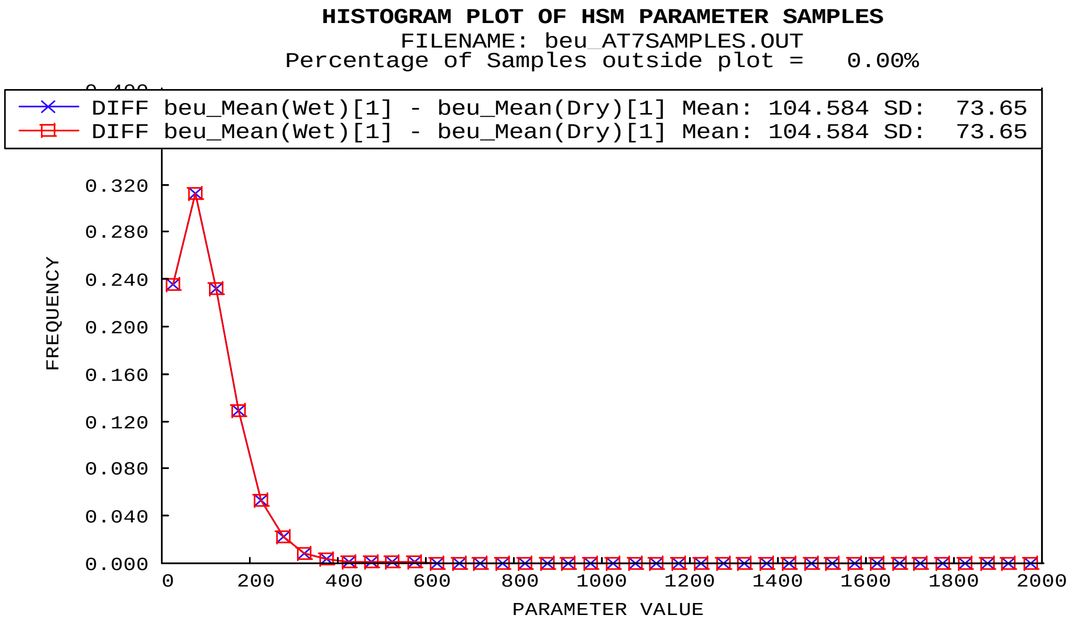


Figure B4. The probability distribution of the difference between the wet and dry state means for Beulah.

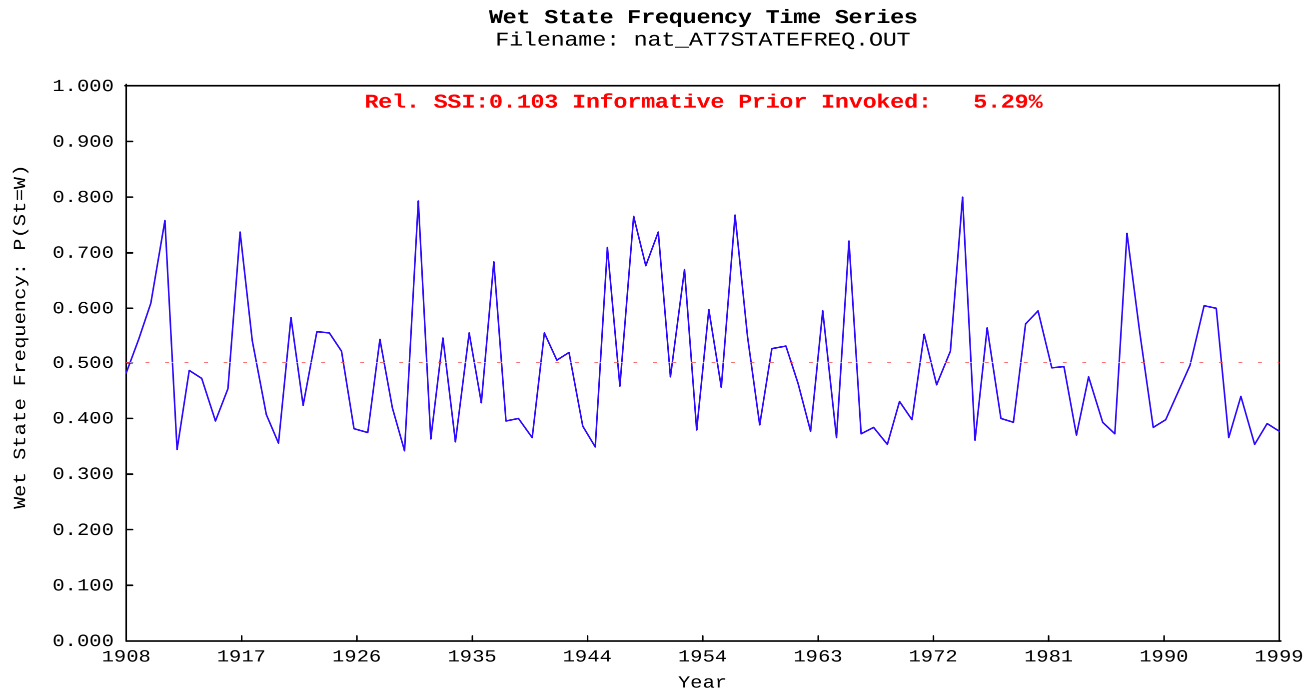


Figure B5. The wet state frequency time series for Natimuk.

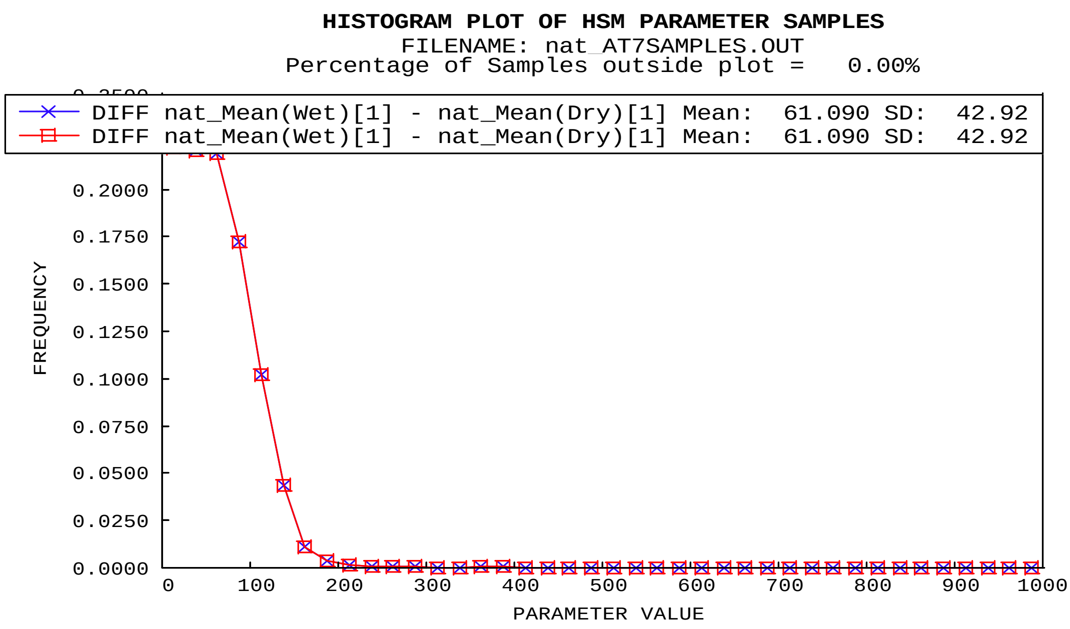


Figure B6. The probability distribution of the difference between the wet and dry state means for Natimuk.

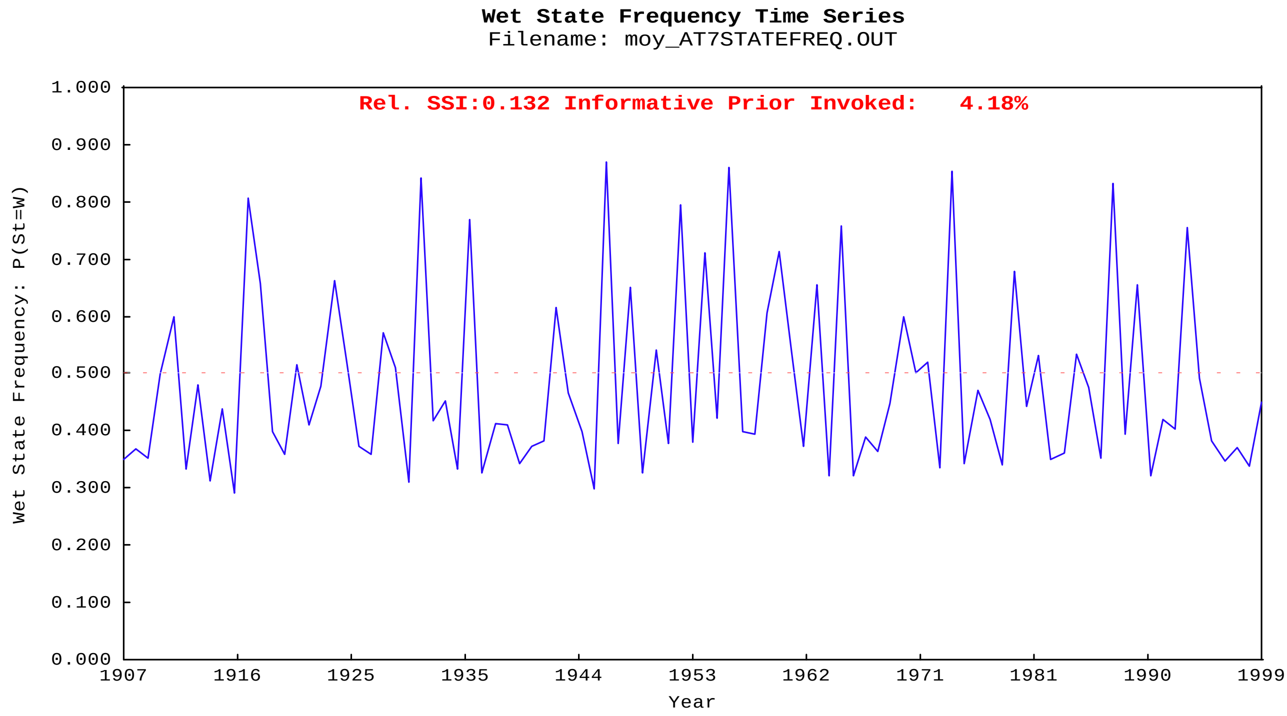


Figure B7. The wet state frequency time series for Moyston Barton Estate.

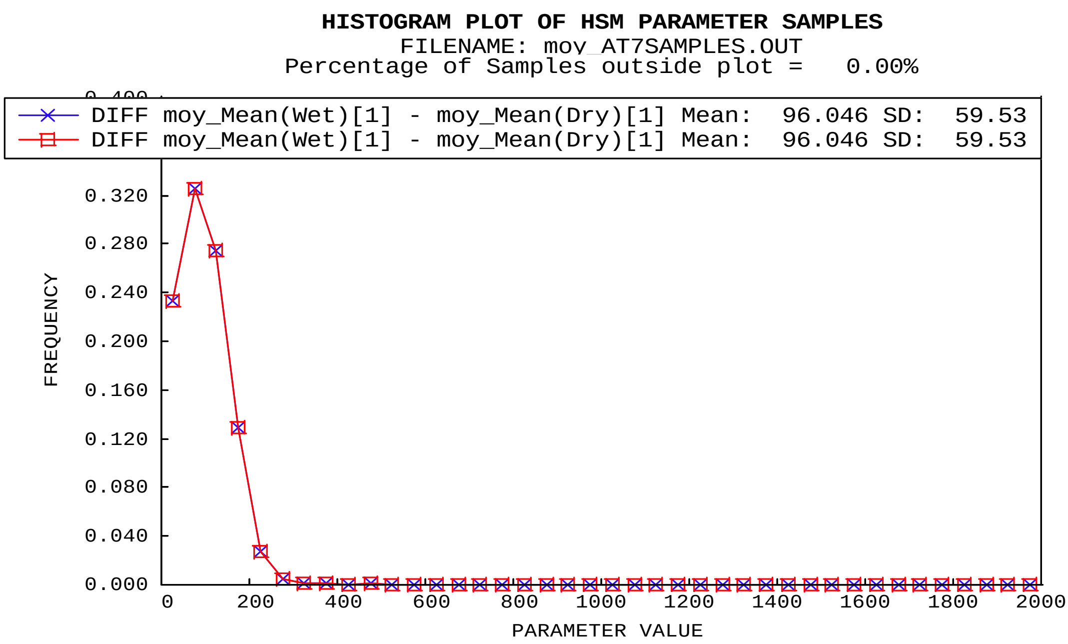


Figure B8. **The probability distribution of the difference between the wet and dry state means for Moyston Barton Estate.**

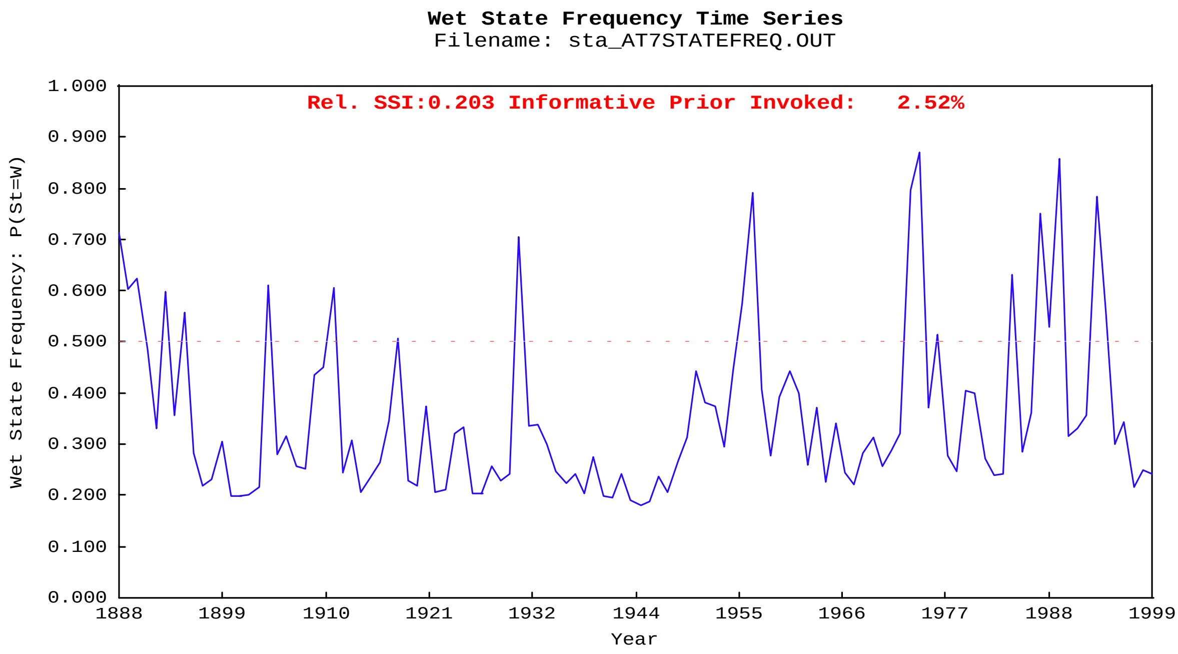


Figure B9. The wet state frequency time series for St Arnaud.

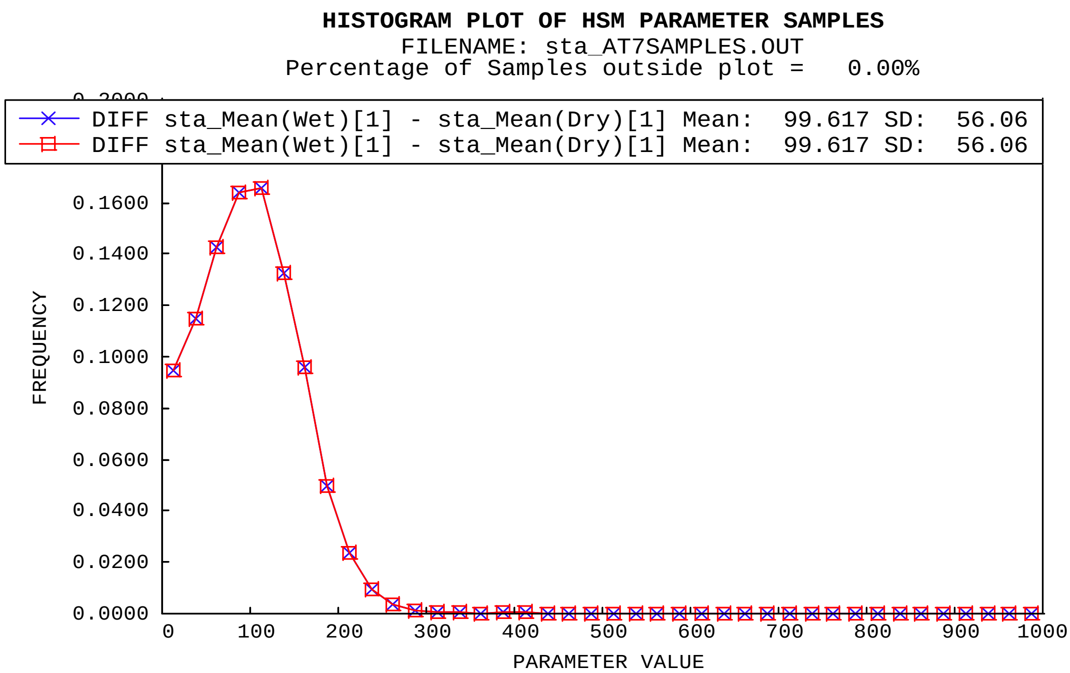


Figure B10. The probability distribution of the difference between the wet and dry state means for St Arnaud.

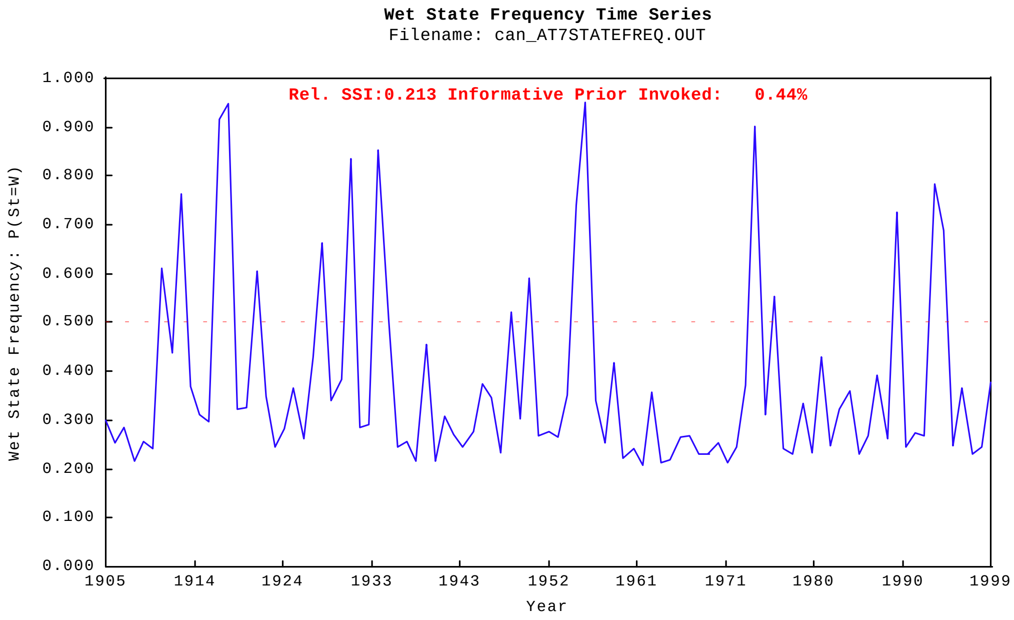


Figure B11. The wet state frequency time series for Caniambo.

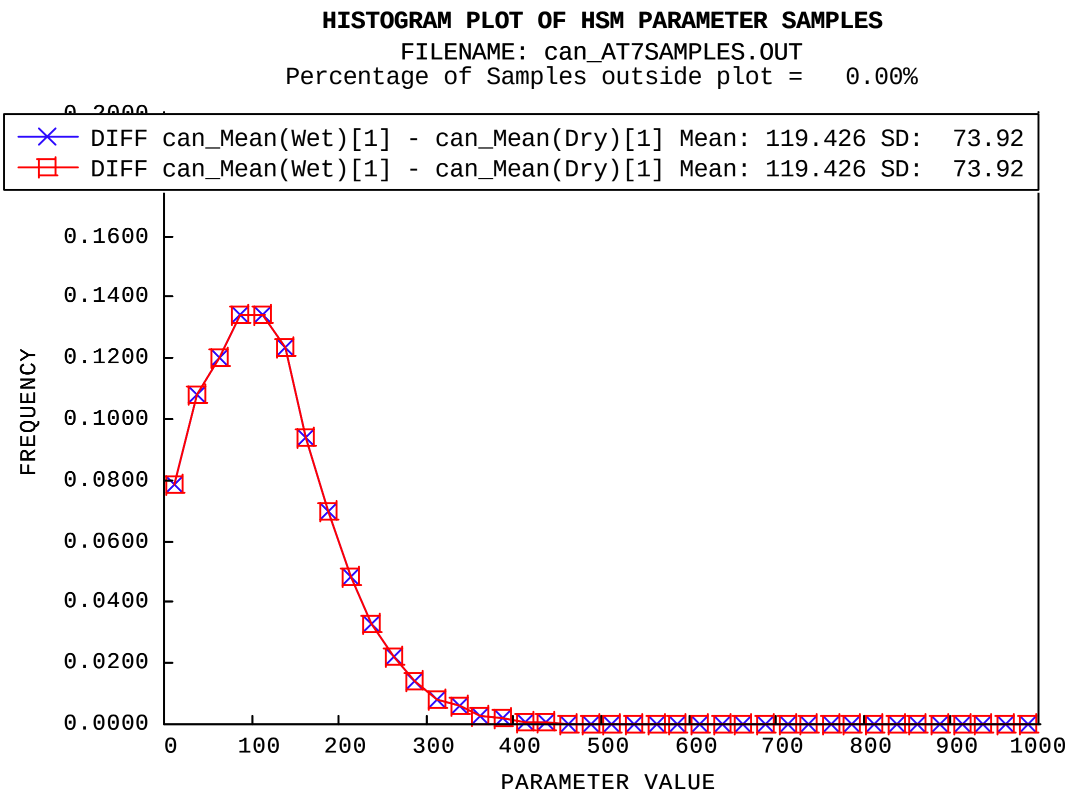


Figure B12. The probability distribution of the difference between the wet and dry state means for Caniambo.

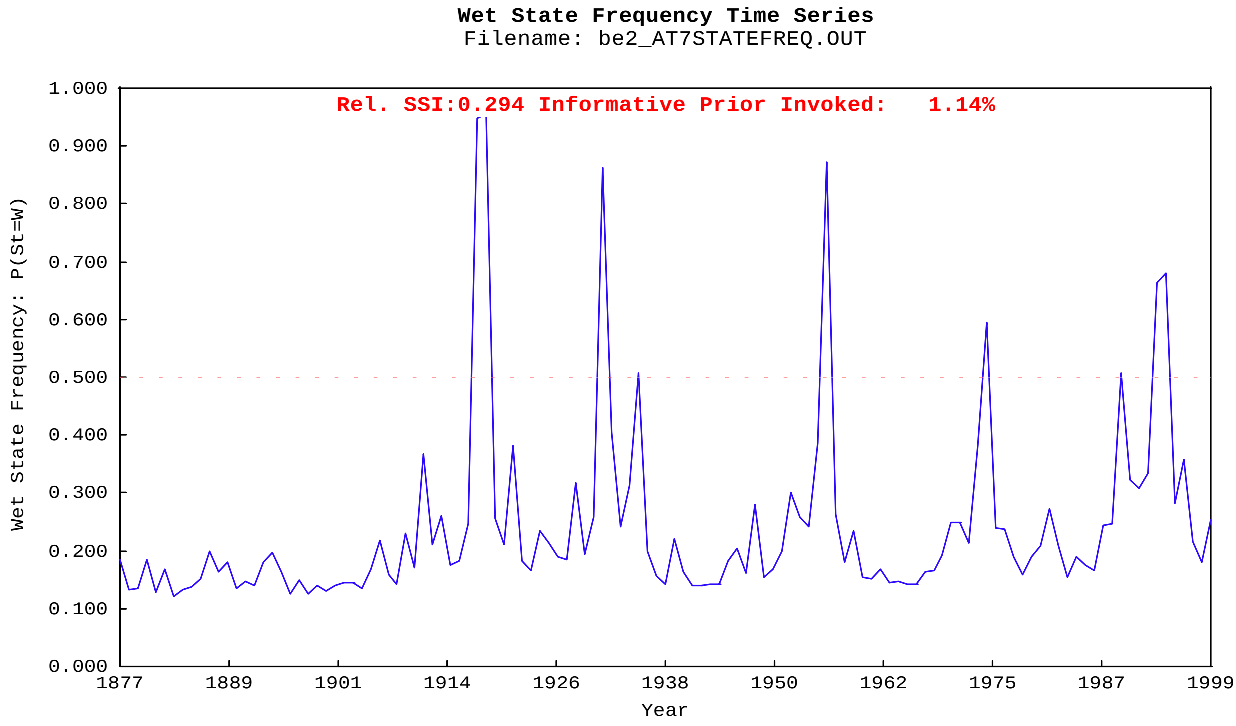


Figure B13. The wet state frequency time series for Beechworth.

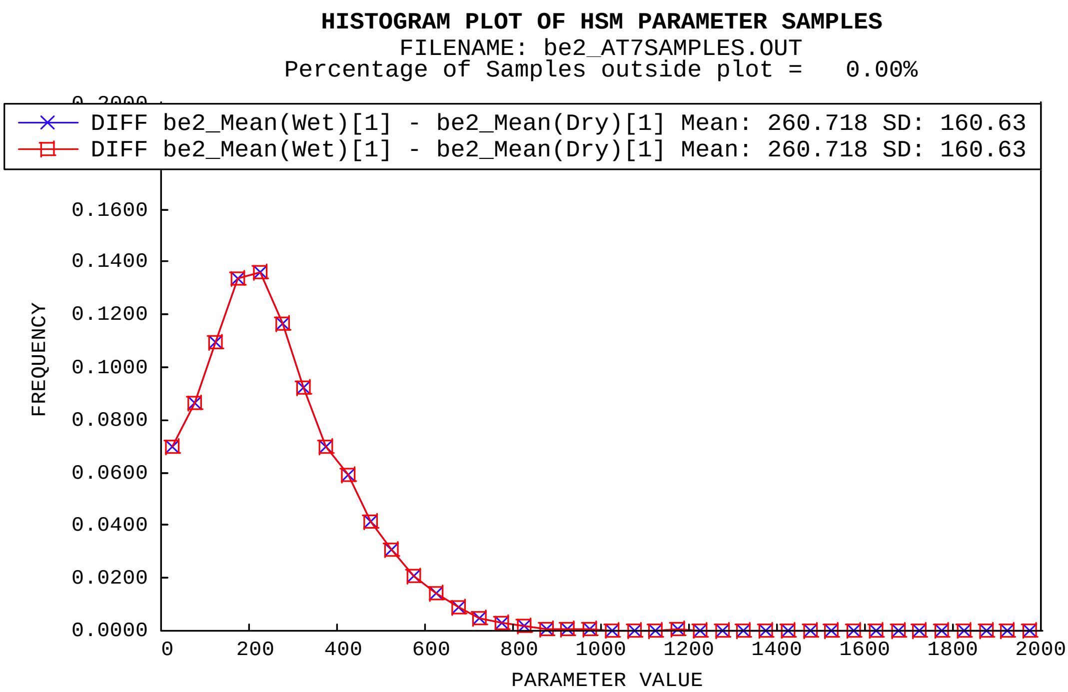


Figure B14. The probability distribution of the difference between the wet and dry state means for Beechworth.

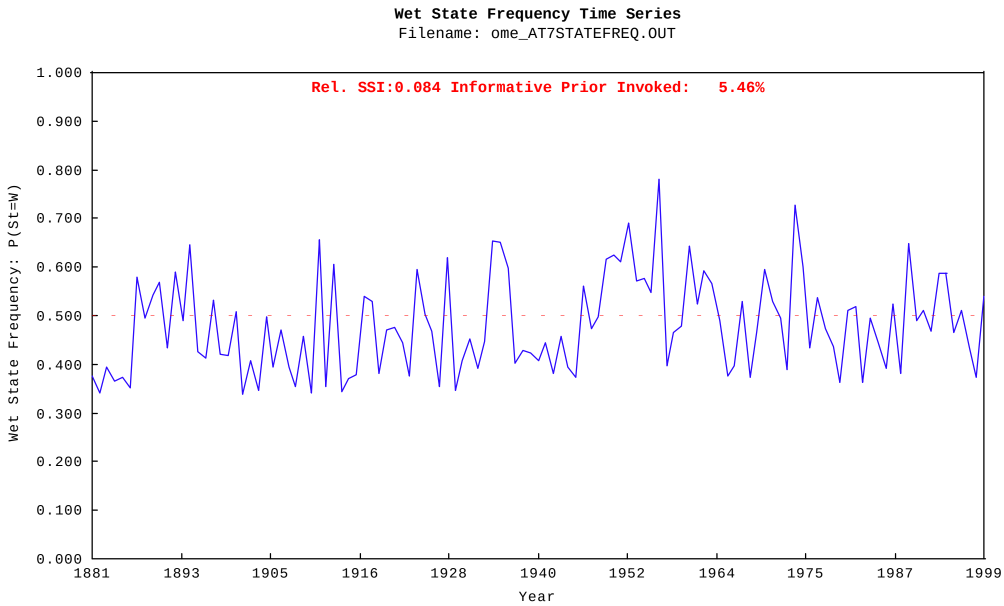


Figure B15. The wet state frequency time series for Omeo.

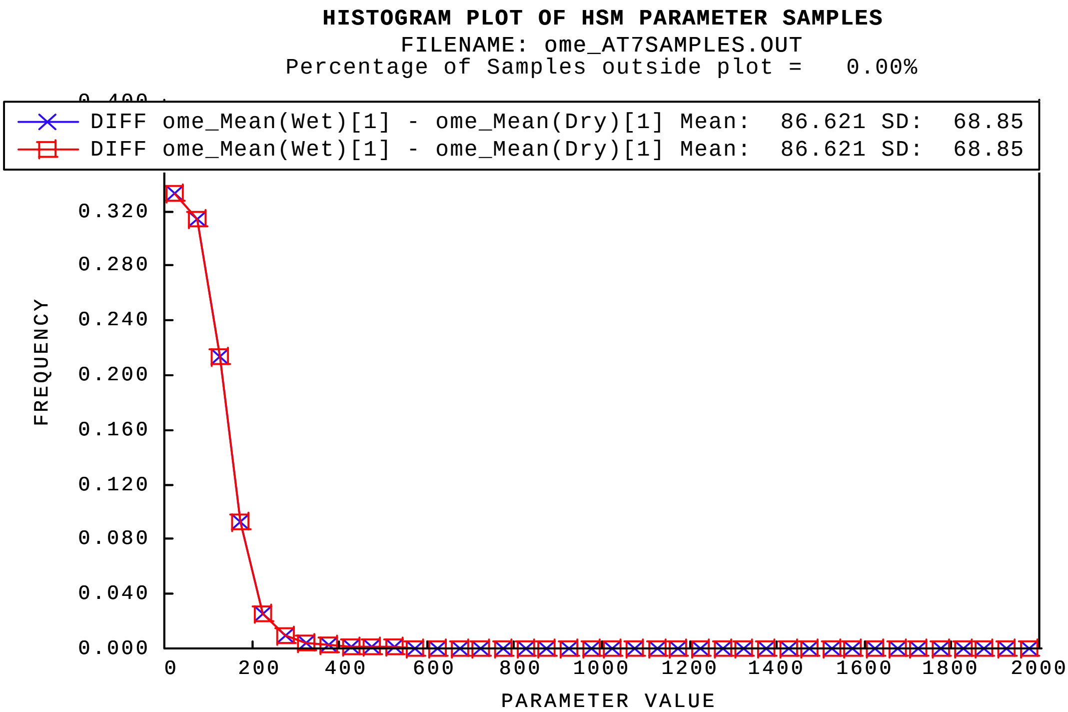


Figure B16. The probability distribution of the difference between the wet and dry state means for Omeo.

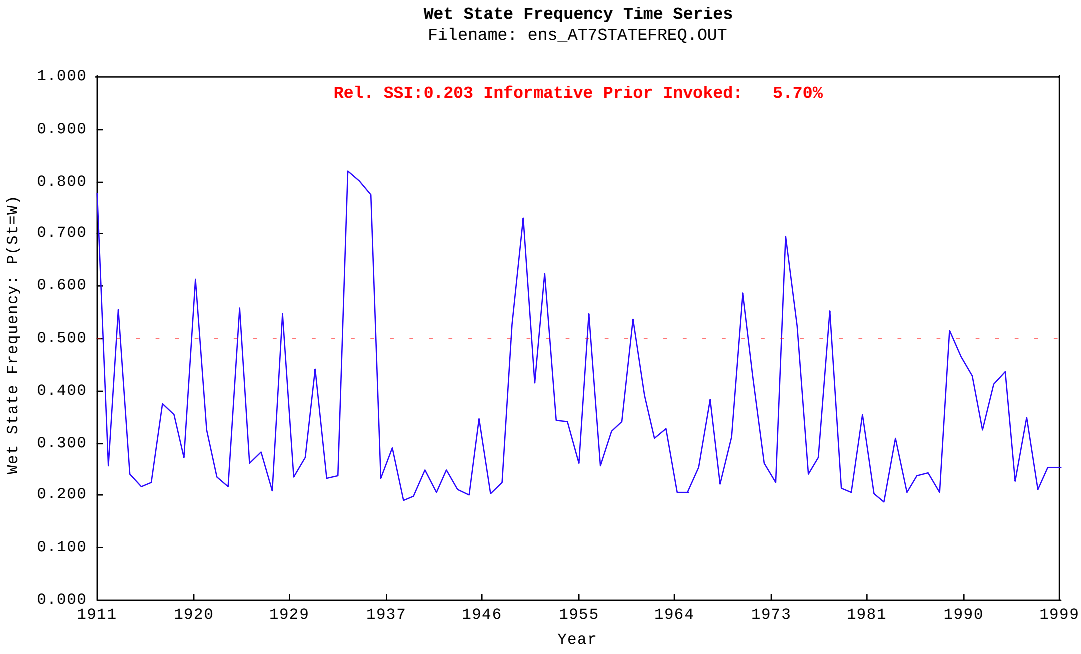


Figure B17. The wet state frequency time series for Ensay.

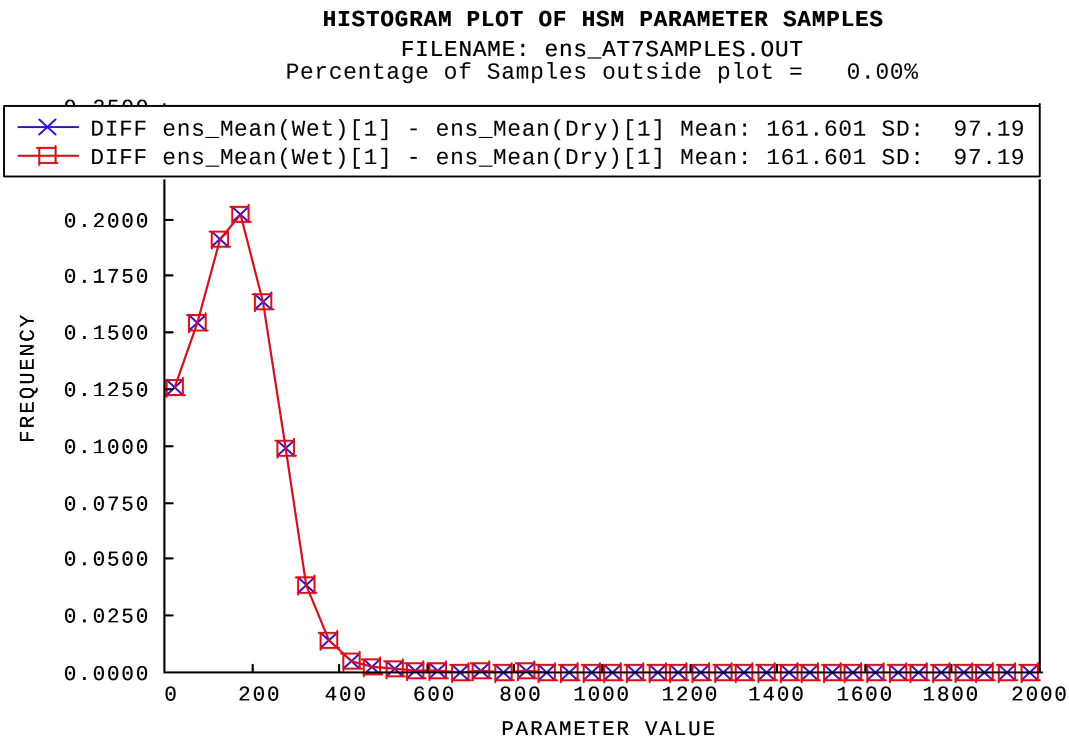


Figure B18. The probability distribution of the difference between the wet and dry state means for Ensay.

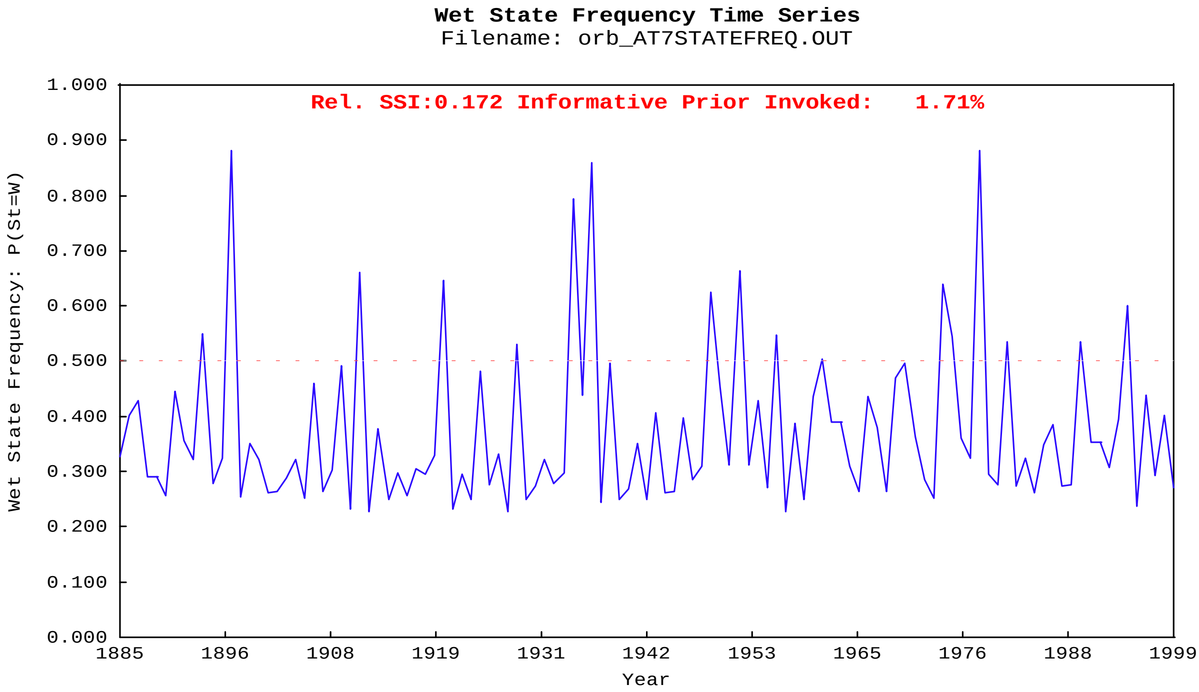


Figure B19. The wet state frequency time series for Orbost.

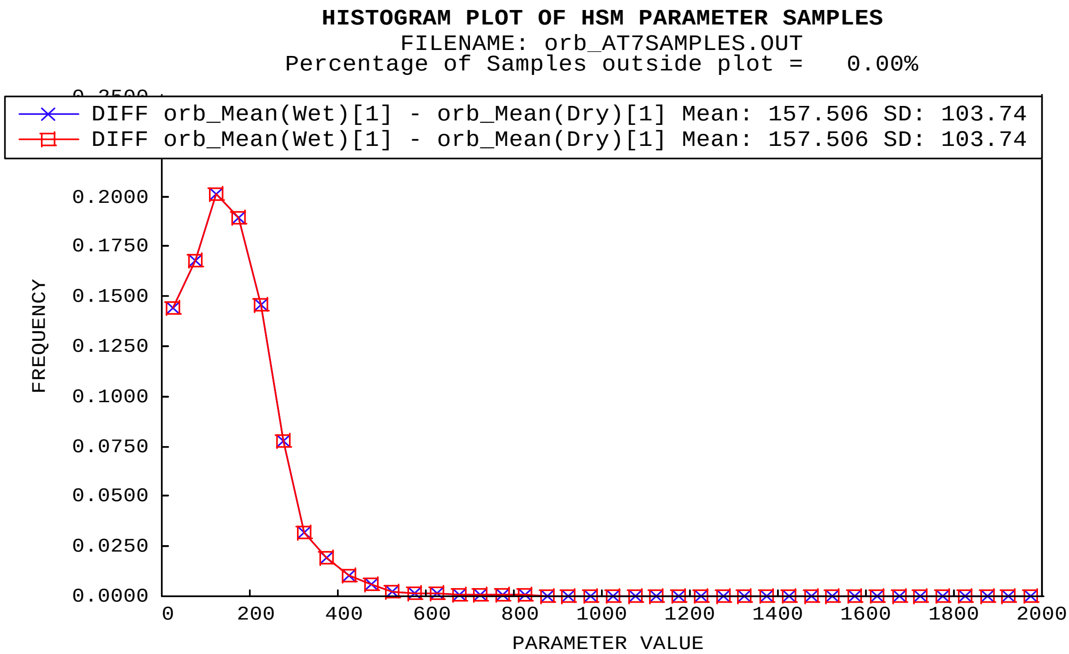


Figure B20. The probability distribution of the difference between the wet and dry state means for Orbost.

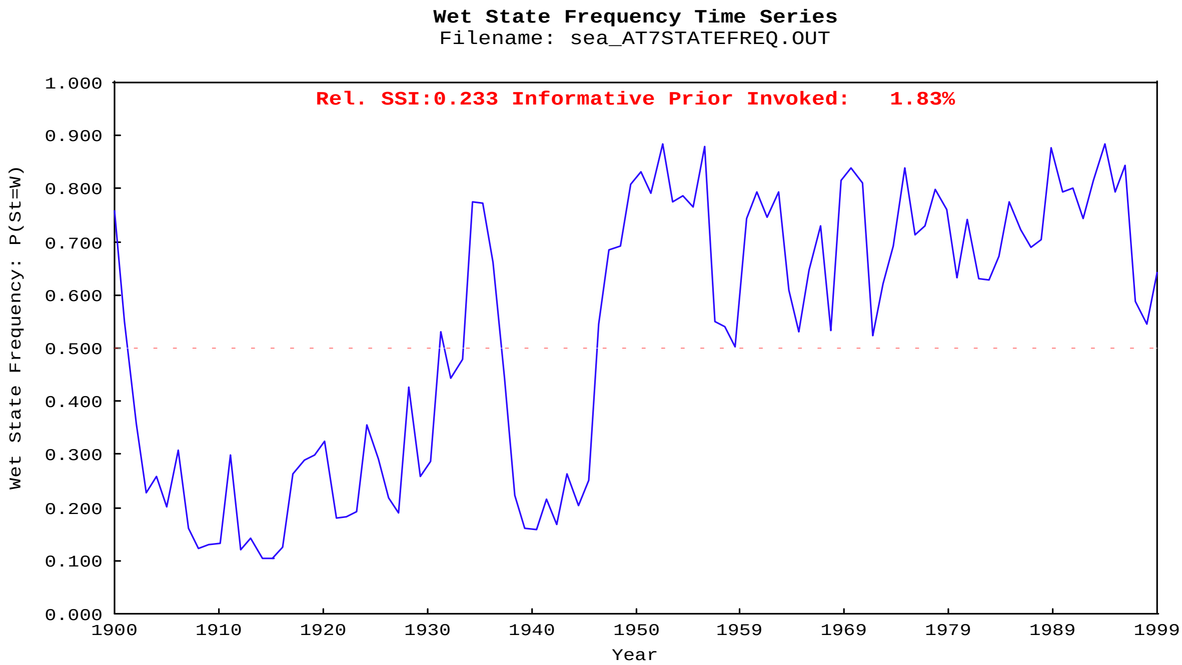


Figure B21. The wet state frequency time series for Seaspray.

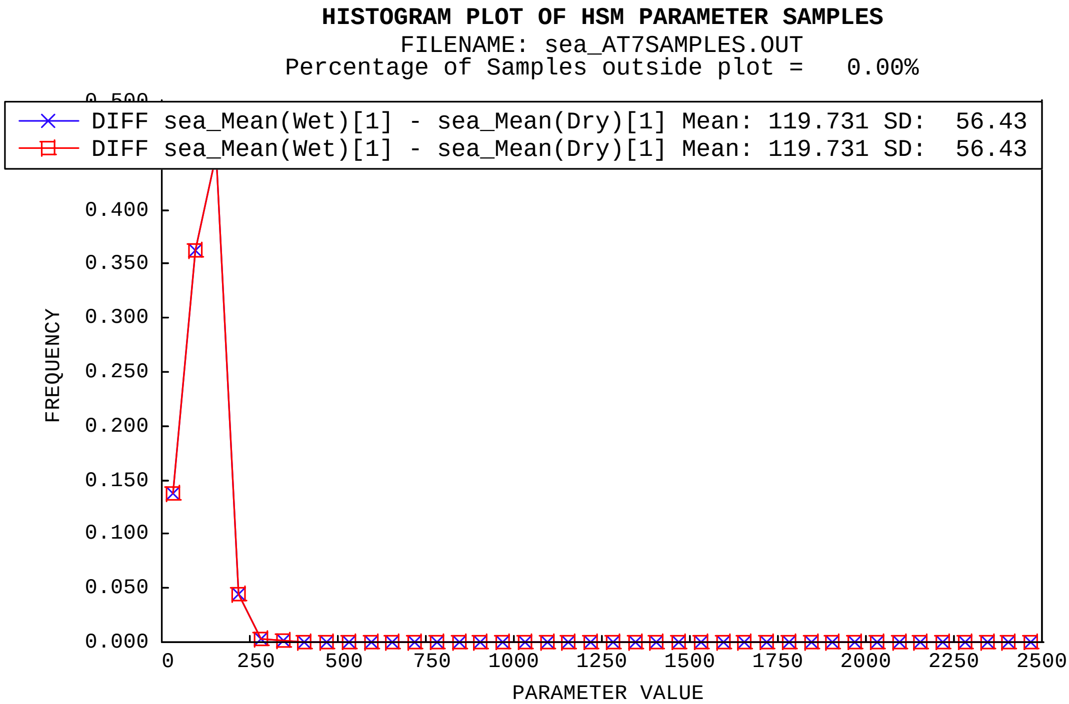


Figure B22. The probability distribution of the difference between the wet and dry state means for Seaspray.

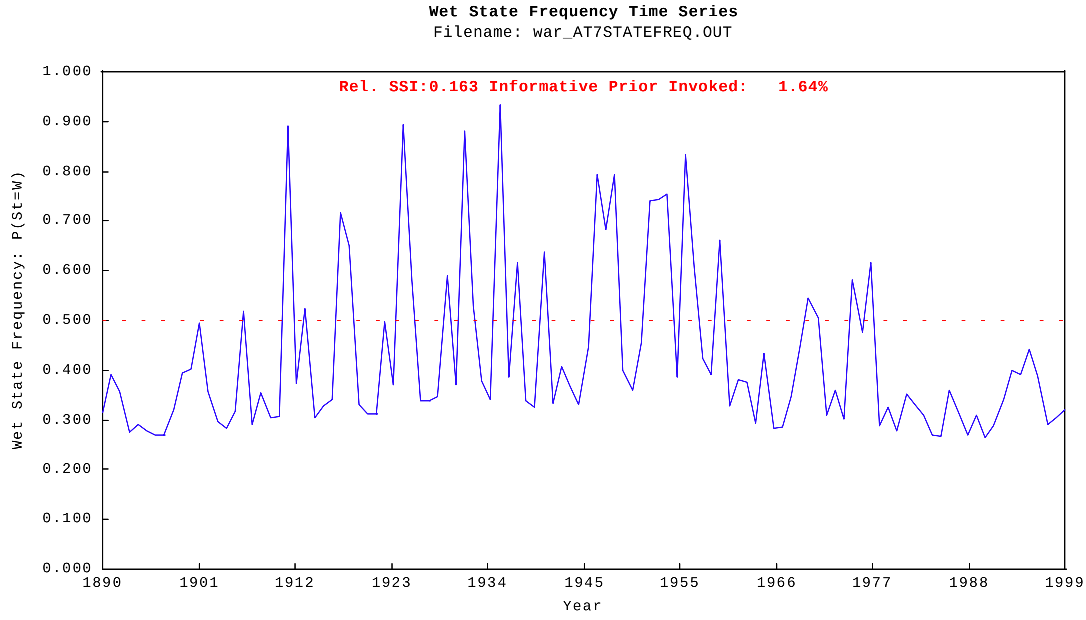


Figure B23. The wet state frequency time series for Warragul.

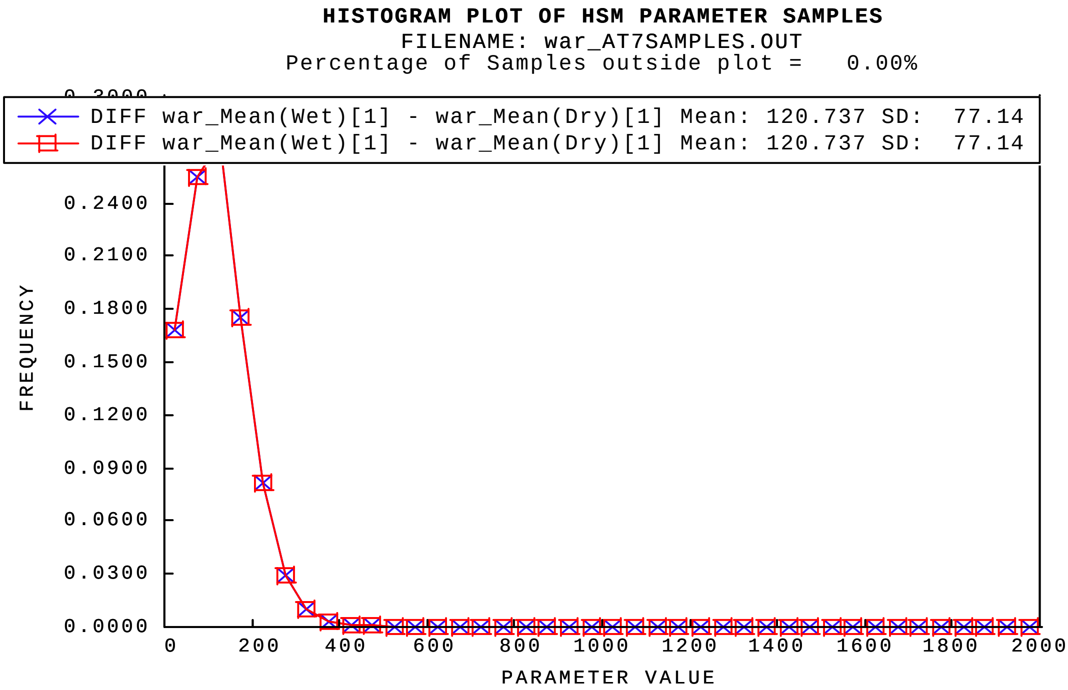


Figure B24. The probability distribution of the difference between the wet and dry state means for Warragul.

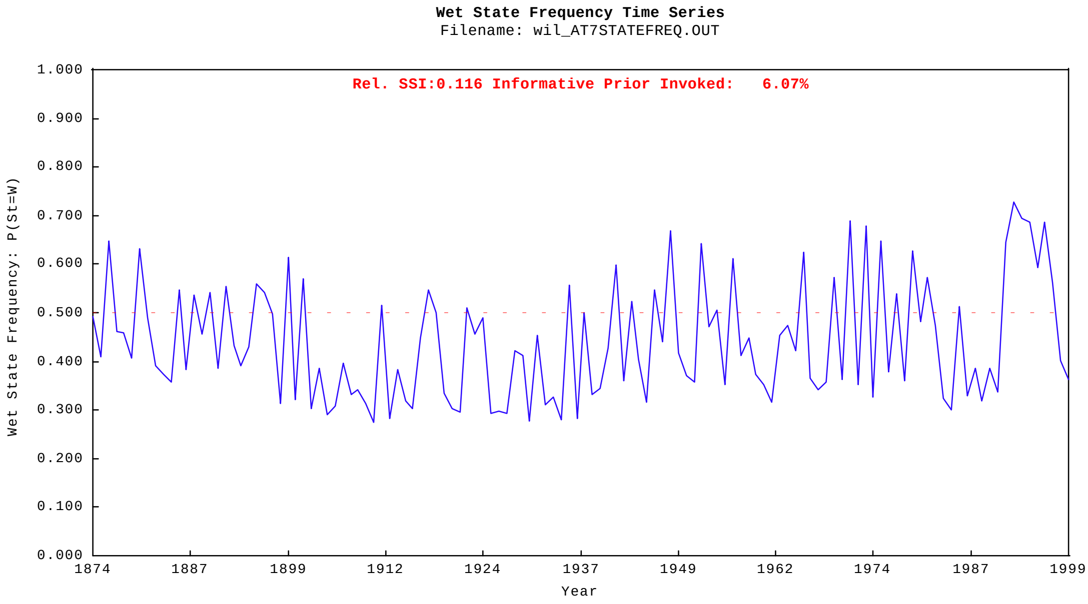


Figure B25. The wet state frequency time series for Wilson's Promontory.

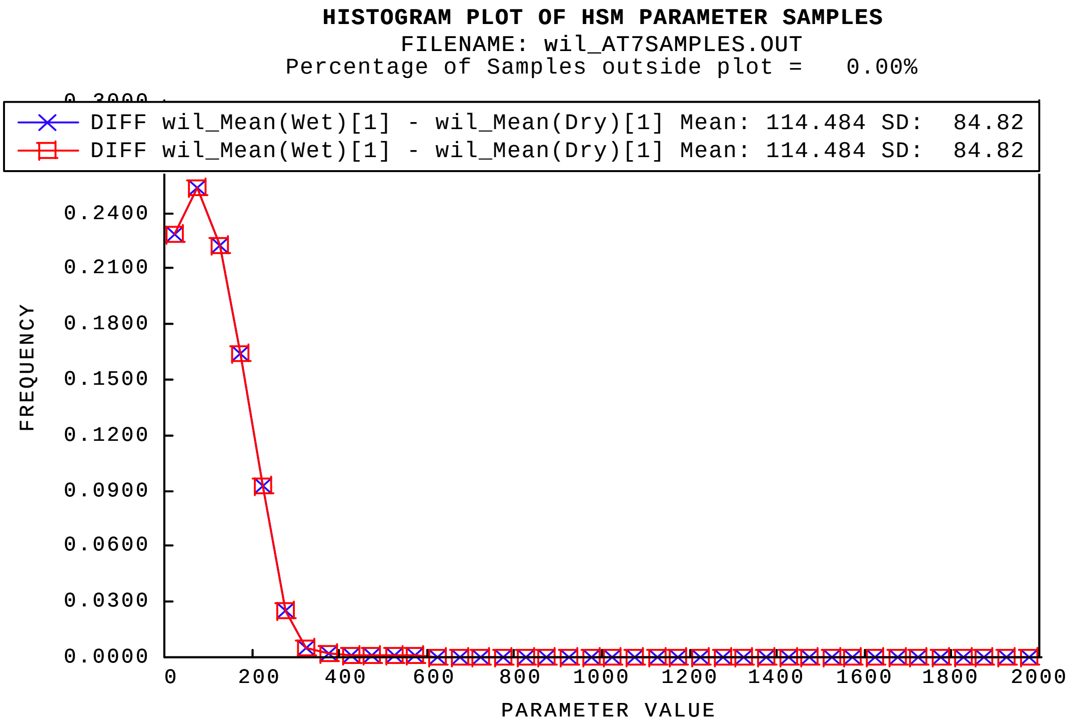


Figure B26. The probability distribution of the difference between the wet and dry state means for Wilson's Promontory.

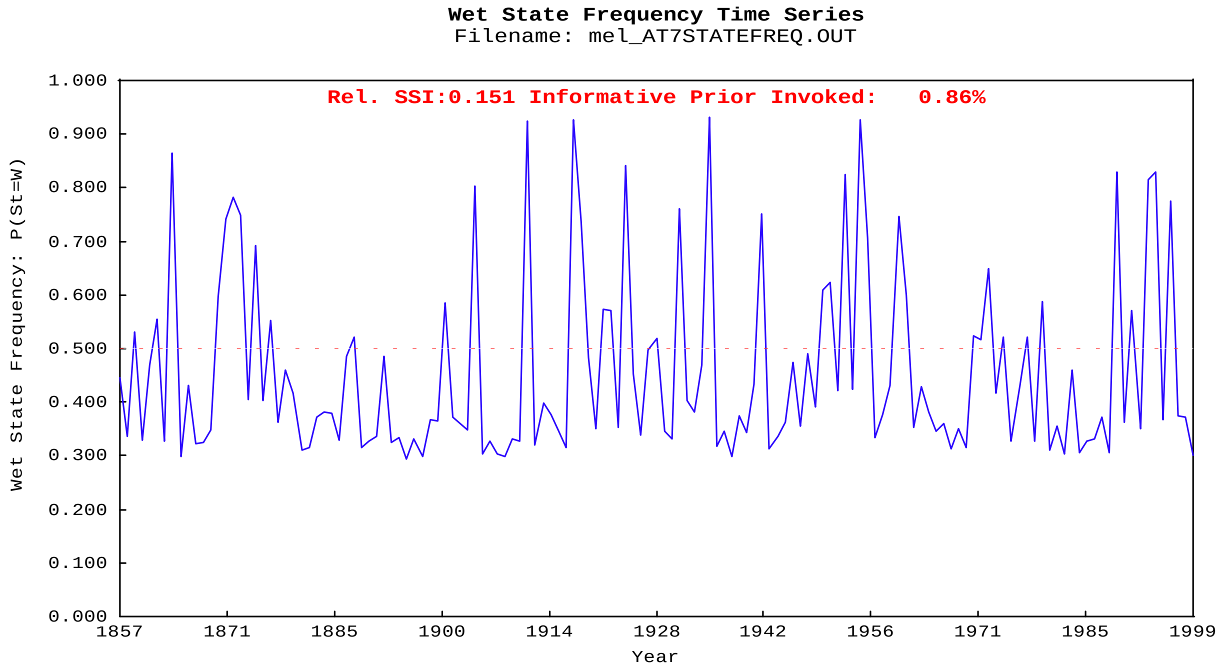


Figure B27. The wet state frequency time series for Melbourne.

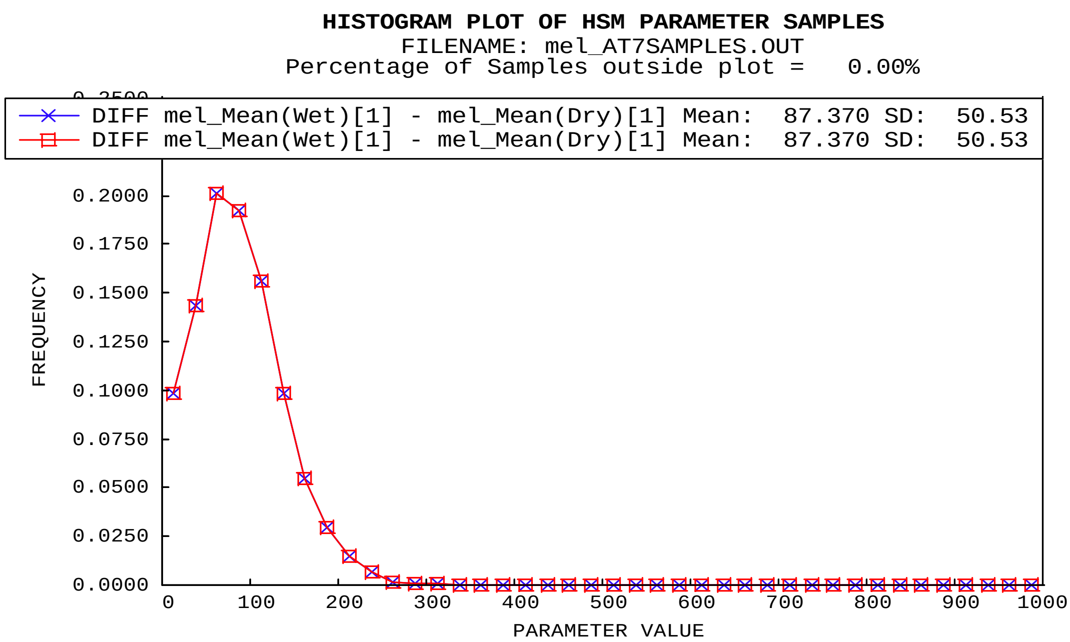


Figure B28. The probability distribution of the difference between the wet and dry state means for Melbourne.

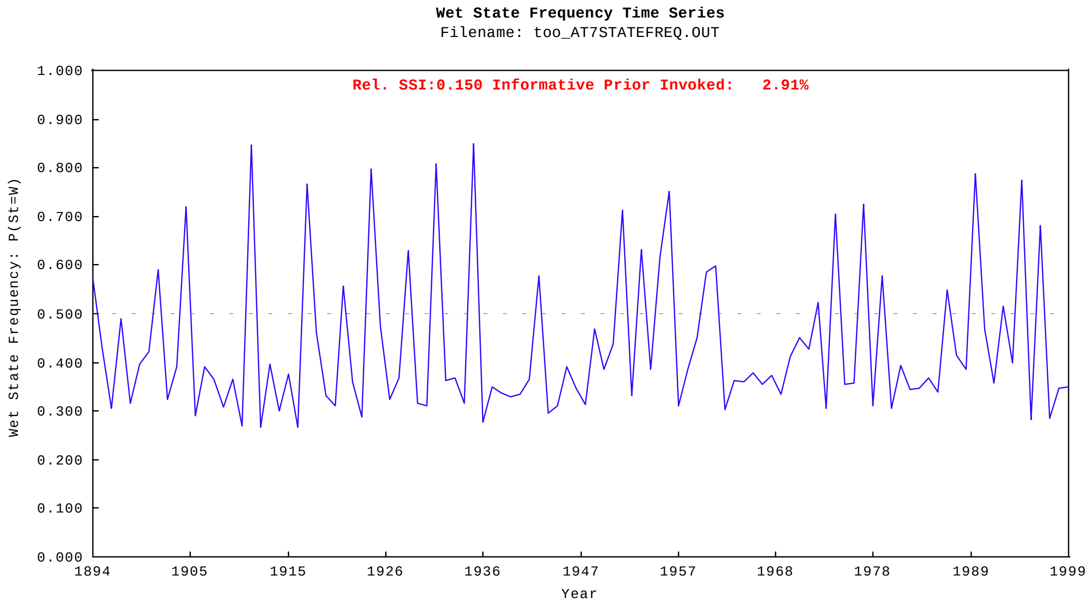


Figure B29. The wet state frequency time series for Toorourrong.

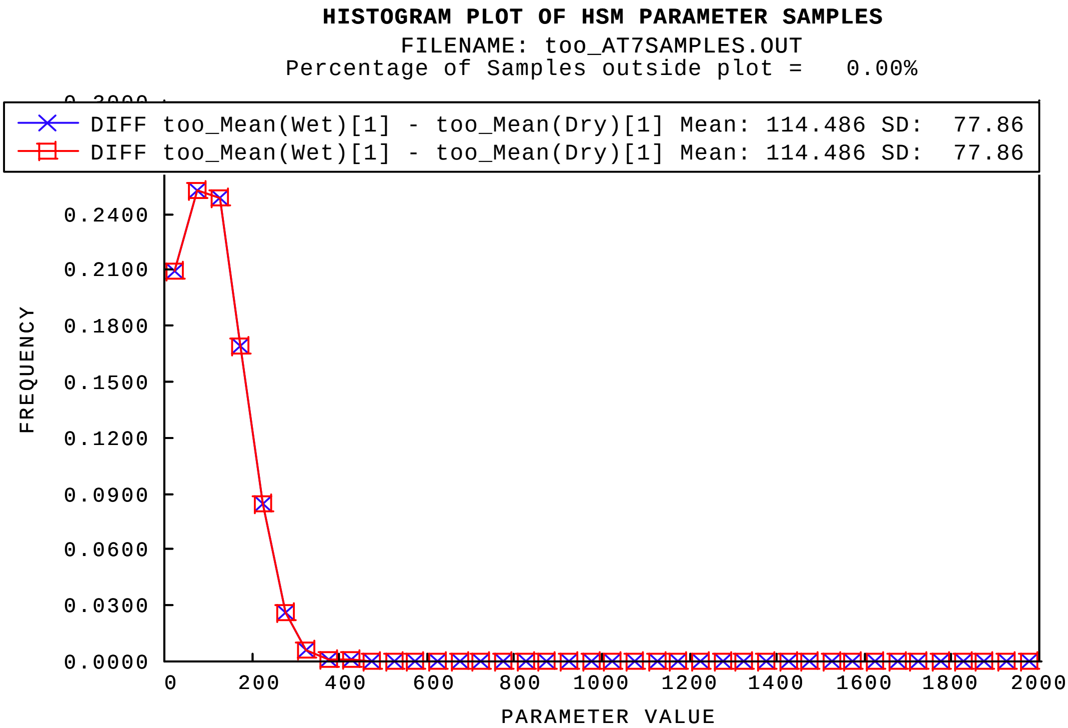


Figure B30. The probability distribution of the difference between the wet and dry state means for Toorourrong.

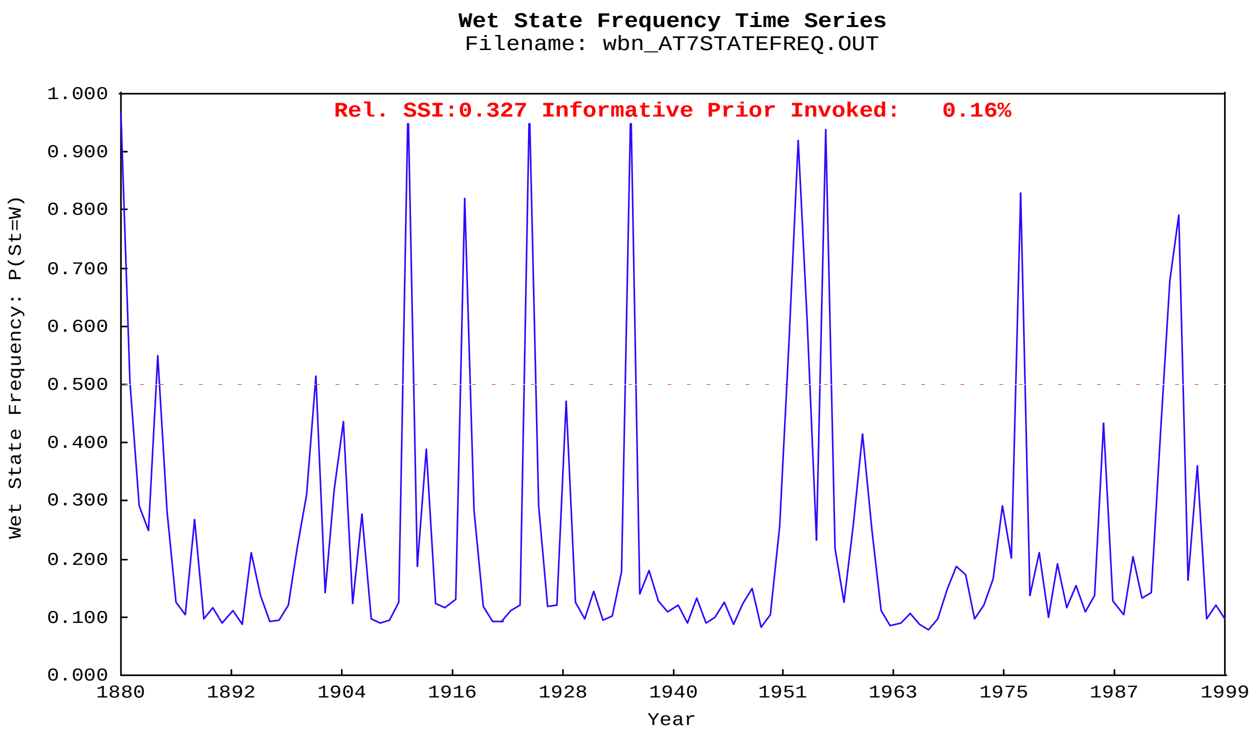


Figure B31. The wet state frequency time series for Warburton.

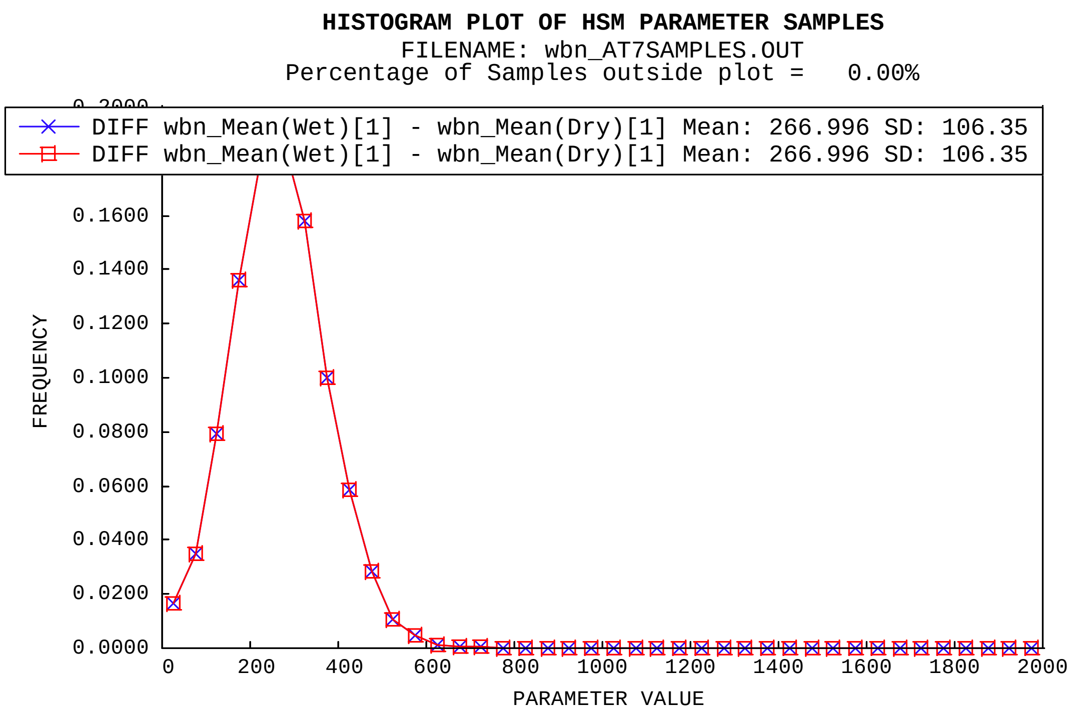


Figure B32. The probability distribution of the difference between the wet and dry state means for Warburton.

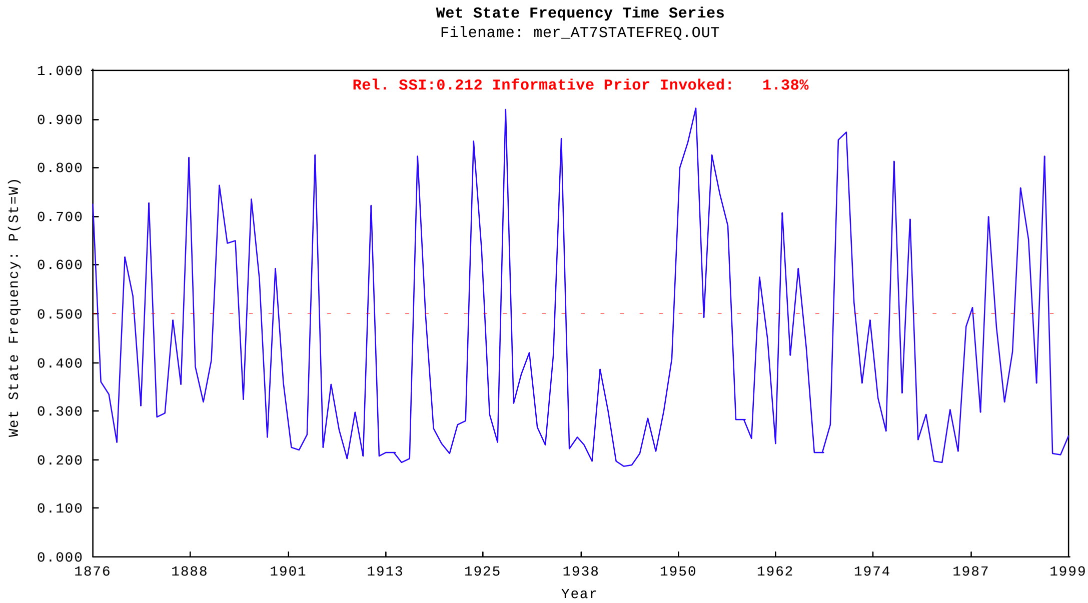


Figure B33. The wet state frequency time series for Meredith.

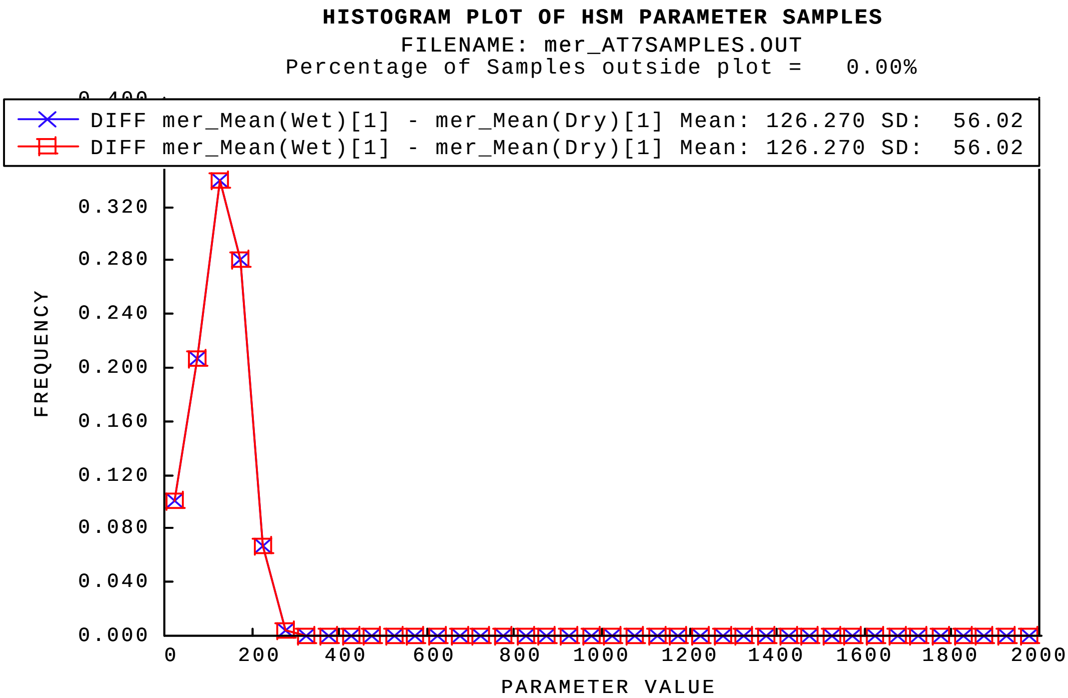


Figure B34. The probability distribution of the difference between the wet and dry state means for Meredith.

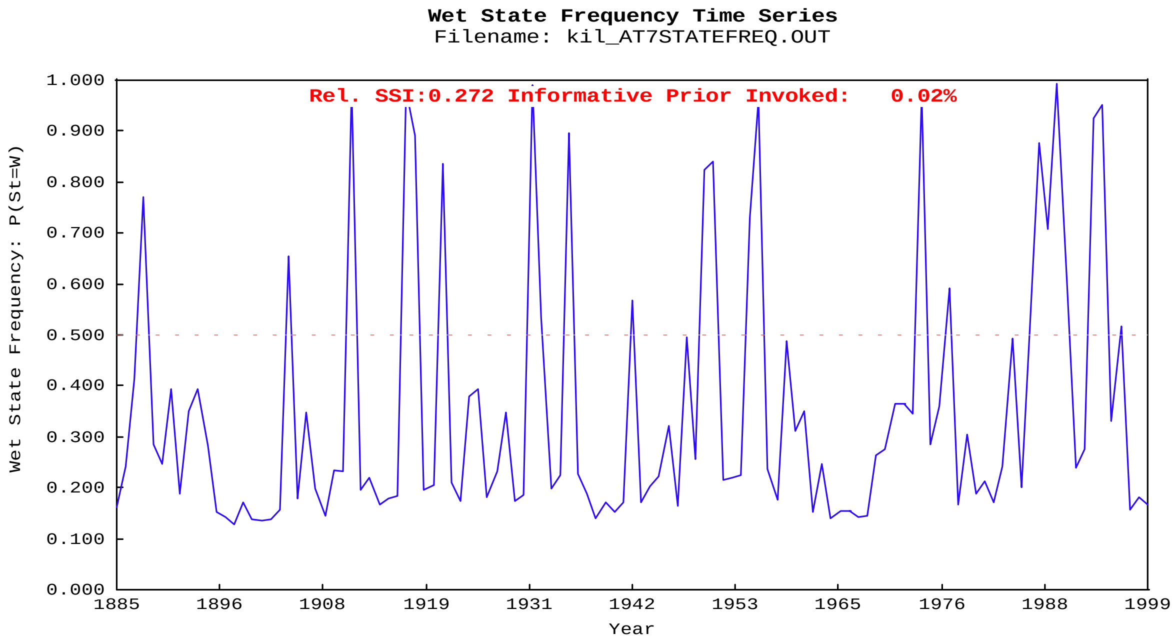


Figure B35. The wet state frequency time series for Kilmore.

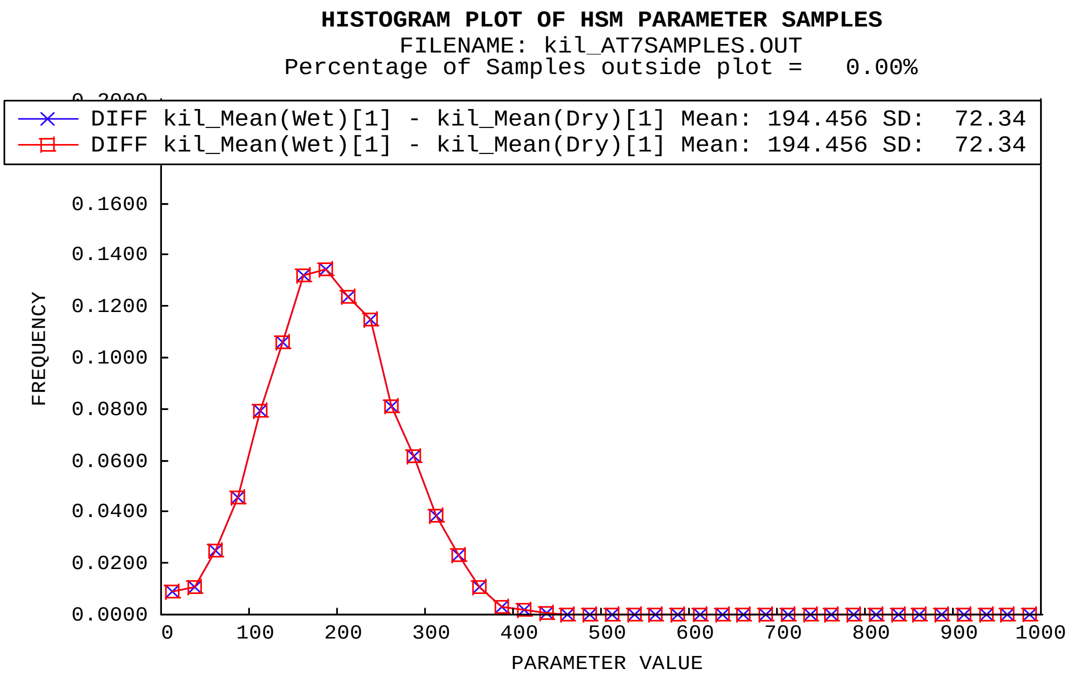


Figure B36. The probability distribution of the difference between the wet and dry state means for Kilmore.

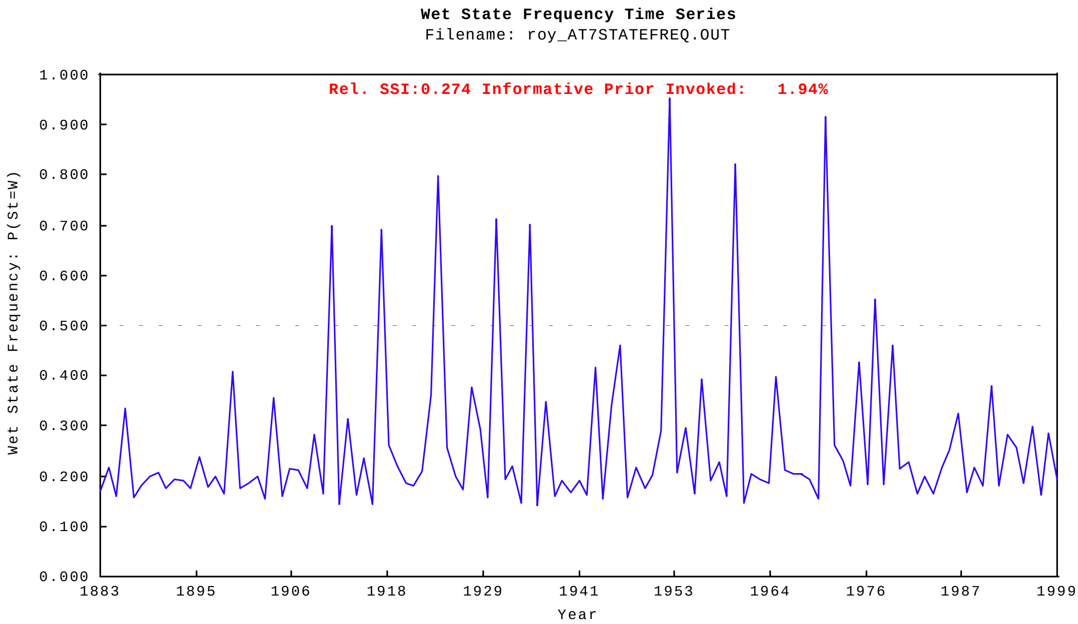


Figure B37. The wet state frequency time series for Pennyroyal Creek.

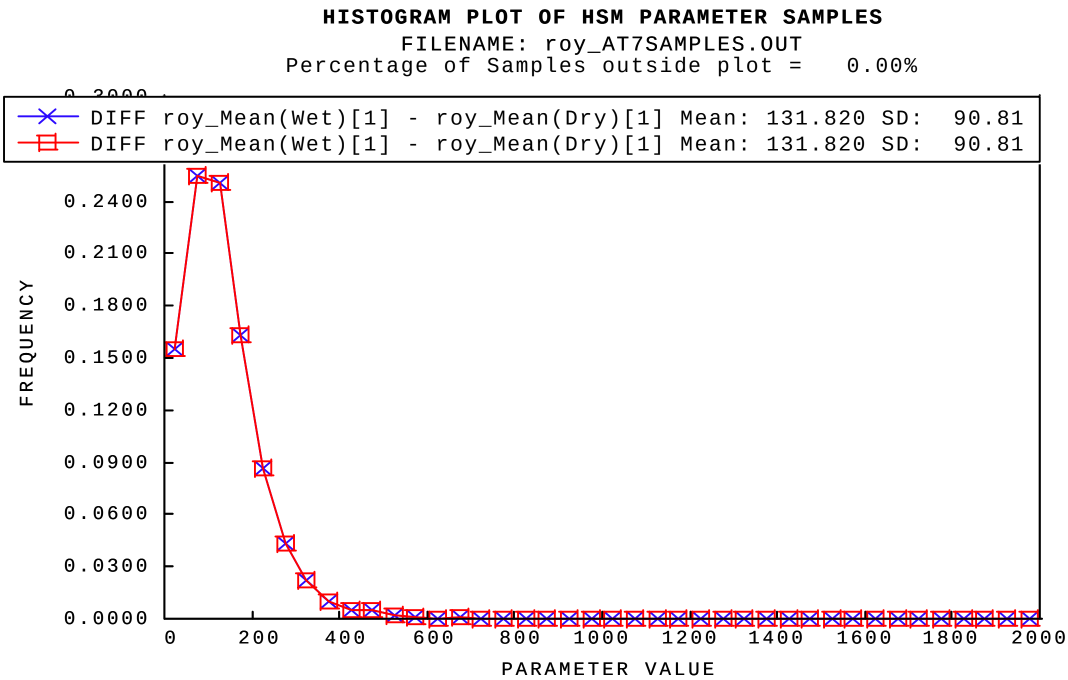


Figure B38. The probability distribution of the difference between the wet and dry state means for Pennyroyal Creek.

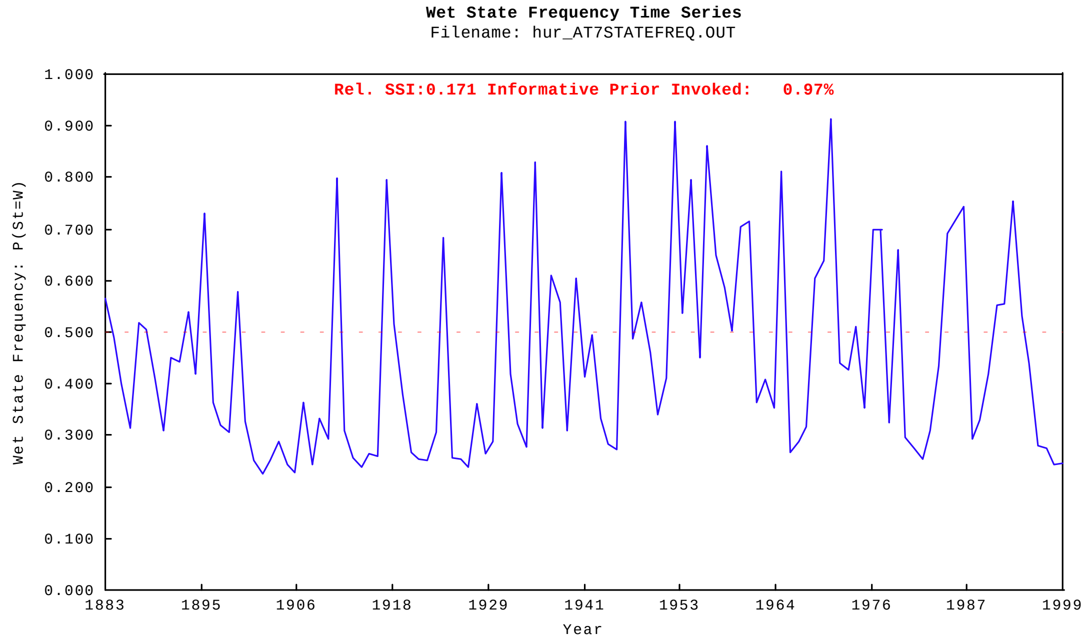


Figure B39. The wet state frequency time series for Penshurst.

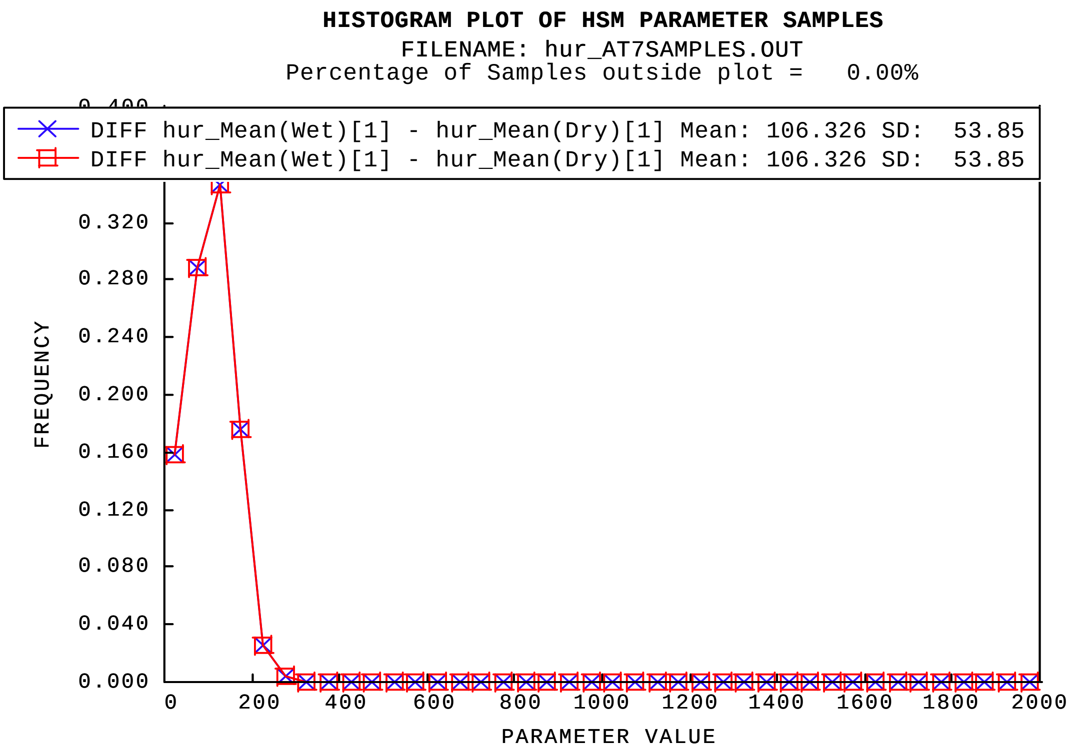


Figure B40. The probability distribution of the difference between the wet and dry state means for Penshurst.

APPENDIX C

AUTOCORRELATION AND PARTIAL AUTOCORRELATION FUNCTIONS

Table C1. The autocorrelation function and partial autocorrelation function for annual rainfall data

(a) Irymple

Lag	Acc	Pacc	SE(acc)
1	0.081	0.081	0.111
2	-0.085	-0.092	0.114
3	0.052	0.067	0.111
4	-0.036	-0.055	0.118
5	0.137	0.16	0.122
6	-0.088	-0.137	0.111
7	0.064	0.136	0.13
8	-0.019	-0.103	0.11
9	-0.141	-0.07	0.118
10	0.072	0.036	0.128
11	-0.076	-0.07	0.116
12	-0.07	-0.071	0.117
13	0.109	0.136	0.115
14	0.116	0.113	0.117
15	0.145	0.122	0.112
16	-0.076	-0.06	0.118
17	-0.016	0.014	0.121
18	0.016	-0.069	0.118
19	0.089	0.15	0.118
20	0.078	-0.038	0.117

(b) Beulah Post Office

Lag	Acc	Pacc	SE(acc)
1	-0.01	-0.01	0.101
2	-0.146	-0.146	0.096
3	0.031	0.028	0.132
4	-0.154	-0.179	0.114
5	0.039	0.049	0.114
6	0.136	0.088	0.107
7	0.073	0.104	0.133
8	-0.014	-0.008	0.094
9	-0.116	-0.088	0.116
10	-0.004	0.02	0.132
11	-0.093	-0.117	0.113
12	-0.126	-0.152	0.117
13	0.072	-0.016	0.117
14	0.144	0.135	0.115
15	0.021	0.05	0.116
16	-0.244	-0.253	0.106
17	0.035	0.084	0.12
18	0.026	0.047	0.118
19	0.052	0.112	0.119
20	0.079	-0.09	0.116

Note:

Acc - Autocorrelation coefficient
Pacc - Partial autocorrelation coefficient
SEacc - Standard error of autocorrelation coefficient

Table C1. (Cont)

(c) Natimuk

Lag	Acc	Pacc	SE(acc)
1	0.023	0.023	0.112
2	-0.086	-0.086	0.105
3	-0.063	-0.059	0.138
4	-0.133	-0.14	0.126
5	-0.032	-0.04	0.108
6	0.169	0.146	0.1
7	0.057	0.033	0.142
8	0.055	0.062	0.102
9	-0.105	-0.096	0.113
10	-0.08	-0.028	0.125
11	-0.006	0.007	0.123
12	-0.175	-0.214	0.116
13	0.057	0.027	0.12
14	0.185	0.127	0.117
15	0.078	0.099	0.121
16	-0.206	-0.23	0.115
17	0.104	0.169	0.124
18	-0.043	0.032	0.123
19	0.026	0.043	0.124
20	0.011	-0.09	0.124

(d) Moyston Barton Estate

Lag	Acc	Pacc	SE(acc)
1	0.045	0.045	0.101
2	-0.15	-0.152	0.131
3	-0.151	-0.14	0.131
4	0.088	0.081	0.125
5	0.029	-0.021	0.128
6	0.113	0.121	0.115
7	0.108	0.132	0.146
8	-0.041	-0.026	0.09
9	-0.14	-0.079	0.142
10	-0.008	0.002	0.122
11	0.027	-0.042	0.128
12	-0.163	-0.222	0.129
13	0.074	0.094	0.126
14	0.18	0.141	0.126
15	0.032	0.024	0.125
16	-0.323	-0.229	0.105
17	0.017	0.094	0.126
18	0.142	0.099	0.127
19	0.066	-0.017	0.128
20	-0.093	-0.098	0.129

(e) St Arnaud

Lag	Acc	Pacc	SE(acc)
1	0.133	0.133	0.110
2	0.023	0.006	0.115
3	0.078	0.076	0.111
4	0.020	0.000	0.106
5	0.144	0.143	0.104
6	0.004	-0.041	0.105
7	0.120	0.129	0.125
8	-0.060	-0.124	0.108
9	-0.143	-0.119	0.121
10	-0.063	-0.076	0.123
11	-0.048	-0.012	0.112
12	-0.110	-0.132	0.110
13	0.105	0.198	0.106
14	0.186	0.191	0.104
15	0.117	0.163	0.106
16	-0.050	-0.076	0.114
17	0.076	0.117	0.111
18	0.140	0.008	0.106
19	0.040	-0.025	0.112
20	0.102	-0.046	0.108

(f) Caniambo

Lag	Acc	Pacc	SE(acc)
1	-0.035	-0.035	0.115
2	-0.132	-0.133	0.121
3	0.027	0.018	0.115
4	-0.027	-0.044	0.121
5	-0.058	-0.056	0.128
6	-0.053	-0.068	0.101
7	0.118	0.102	0.125
8	-0.036	-0.045	0.112
9	-0.243	-0.228	0.123
10	-0.030	-0.076	0.134
11	-0.127	-0.206	0.122
12	-0.220	-0.284	0.113
13	0.084	-0.033	0.118
14	0.005	-0.150	0.127
15	0.125	0.067	0.122
16	-0.099	-0.148	0.122
17	0.148	0.119	0.119
18	0.163	0.103	0.118
19	-0.058	0.013	0.125
20	0.075	0.016	0.124

Table C1. (Cont)

(g) Beechworth

Lag	Acc	Pacc	SE(acc)
1	0.182	0.182	0.098
2	-0.032	-0.067	0.125
3	0.143	0.168	0.104
4	0.166	0.110	0.102
5	0.020	-0.015	0.111
6	0.023	0.021	0.109
7	0.137	0.097	0.116
8	0.045	-0.016	0.106
9	-0.149	-0.156	0.124
10	-0.013	0.012	0.113
11	0.038	-0.015	0.110
12	-0.005	0.023	0.110
13	0.077	0.126	0.106
14	0.108	0.069	0.104
15	0.066	0.048	0.107
16	-0.059	-0.068	0.111
17	0.158	0.167	0.101
18	0.209	0.094	0.096
19	0.018	-0.030	0.108
20	0.048	0.030	0.107

(h) Omeo

Lag	Acc	Pacc	SE(acc)
1	-0.028	-0.028	0.107
2	0.057	0.056	0.122
3	0.076	0.079	0.091
4	0.137	0.140	0.100
5	-0.024	-0.023	0.110
6	-0.119	-0.147	0.100
7	0.201	0.180	0.104
8	-0.062	-0.054	0.093
9	-0.193	-0.210	0.106
10	0.012	0.025	0.103
11	0.047	0.034	0.112
12	-0.017	0.013	0.106
13	-0.022	0.076	0.108
14	0.040	-0.031	0.107
15	0.189	0.172	0.099
16	-0.142	-0.071	0.104
17	0.084	0.019	0.106
18	0.091	0.053	0.107
19	0.071	0.044	0.107
20	-0.039	-0.022	0.108

(i) Ensay

Lag	Acc	Pacc	SE(acc)
1	0.039	0.039	0.122
2	-0.045	-0.047	0.144
3	-0.007	-0.003	0.115
4	0.097	0.095	0.129
5	-0.264	-0.275	0.102
6	-0.138	-0.111	0.105
7	0.037	0.031	0.143
8	-0.026	-0.061	0.133
9	-0.167	-0.125	0.140
10	-0.039	-0.085	0.120
11	-0.004	-0.097	0.136
12	-0.164	-0.194	0.120
13	-0.168	-0.197	0.123
14	0.062	-0.059	0.126
15	0.271	0.198	0.112
16	0.011	-0.027	0.136
17	0.066	-0.016	0.131
18	0.143	0.005	0.125
19	-0.027	-0.143	0.132
20	-0.044	0.066	0.131

(j) Orbost

Lag	Acc	Pacc	SE(acc)
1	-0.117	-0.117	0.099
2	0.003	-0.011	0.104
3	0.070	0.070	0.097
4	0.001	0.018	0.110
5	-0.055	-0.053	0.093
6	-0.062	-0.081	0.107
7	0.055	0.038	0.109
8	0.093	0.117	0.106
9	-0.001	0.036	0.111
10	-0.089	-0.103	0.102
11	-0.006	-0.059	0.104
12	0.045	0.043	0.102
13	-0.075	-0.026	0.101
14	0.105	0.115	0.100
15	0.195	0.207	0.097
16	0.079	0.116	0.103
17	0.002	0.011	0.103
18	0.087	0.080	0.101
19	-0.040	-0.023	0.103
20	0.025	0.046	0.103

Table C1. (Cont)

(k) Seaspray

Lag	Acc	Pacc	SE(acc)
1	0.176	0.176	0.137
2	0.153	0.126	0.143
3	0.112	0.070	0.141
4	0.210	0.172	0.121
5	0.083	0.008	0.131
6	0.182	0.129	0.124
7	0.113	0.039	0.136
8	0.034	-0.059	0.131
9	0.031	-0.012	0.145
10	-0.019	-0.089	0.137
11	0.134	0.126	0.124
12	-0.012	-0.063	0.132
13	0.069	0.049	0.127
14	0.089	0.101	0.124
15	0.246	0.205	0.109
16	-0.053	-0.121	0.132
17	0.088	0.026	0.124
18	0.173	0.138	0.117
19	0.122	0.000	0.120
20	0.034	-0.040	0.125

(l) Warragul

Lag	Acc	Pacc	SE(acc)
1	0.021	0.021	0.112
2	-0.018	-0.018	0.119
3	-0.140	-0.139	0.142
4	0.010	0.016	0.103
5	0.162	0.160	0.106
6	0.185	0.167	0.132
7	0.162	0.178	0.100
8	-0.144	-0.104	0.116
9	-0.185	-0.166	0.133
10	-0.100	-0.118	0.102
11	0.212	0.135	0.112
12	0.113	0.030	0.128
13	0.024	0.005	0.116
14	-0.107	-0.012	0.125
15	-0.182	-0.082	0.119
16	0.004	0.017	0.121
17	0.261	0.220	0.111
18	0.193	0.096	0.116
19	0.043	0.060	0.125
20	-0.158	-0.053	0.118

(m) Wilson's Promontory

Lag	Acc	Pacc	SE(acc)
1	0.064	0.064	0.109
2	0.110	0.106	0.105
3	-0.101	-0.116	0.115
4	0.077	0.081	0.095
5	-0.004	0.009	0.104
6	0.207	0.183	0.097
7	-0.017	-0.032	0.092
8	-0.051	-0.099	0.107
9	-0.028	0.030	0.101
10	0.009	-0.007	0.092
11	0.025	0.017	0.101
12	0.091	0.062	0.098
13	-0.059	-0.074	0.099
14	-0.078	-0.054	0.100
15	0.095	0.140	0.098
16	0.077	0.051	0.100
17	0.159	0.126	0.095
18	-0.005	-0.047	0.101
19	0.037	0.037	0.101
20	-0.072	-0.016	0.099

(n) Melbourne

Lag	Acc	Pacc	SE(acc)
1	0.076	0.076	0.097
2	0.003	-0.003	0.095
3	-0.038	-0.038	0.091
4	-0.065	-0.059	0.081
5	-0.042	-0.033	0.085
6	-0.103	-0.099	0.086
7	0.121	0.134	0.102
8	-0.140	-0.172	0.094
9	-0.171	-0.165	0.102
10	-0.123	-0.111	0.098
11	0.013	0.027	0.095
12	-0.127	-0.184	0.094
13	0.106	0.126	0.091
14	0.072	-0.035	0.094
15	-0.023	-0.044	0.097
16	0.036	0.024	0.097
17	0.164	0.186	0.093
18	0.135	0.006	0.092
19	-0.010	0.033	0.098
20	0.043	-0.010	0.097

Table C1. (Cont)

(o) Toorourrong

Lag	Acc	Pacc	SE(acc)
1	-0.027	-0.027	0.109
2	-0.052	-0.053	0.132
3	0.000	-0.003	0.118
4	0.046	0.043	0.102
5	-0.055	-0.053	0.131
6	-0.088	-0.087	0.102
7	0.287	0.281	0.115
8	-0.206	-0.228	0.096
9	-0.266	-0.266	0.120
10	0.036	0.052	0.131
11	-0.010	-0.073	0.122
12	-0.184	-0.207	0.123
13	0.000	0.083	0.116
14	0.103	-0.049	0.123
15	-0.086	-0.062	0.120
16	-0.126	0.011	0.120
17	0.178	0.045	0.116
18	0.182	0.123	0.117
19	-0.051	0.070	0.125
20	0.070	-0.026	0.125

(p) Warburton

Lag	Acc	Pacc	SE(acc)
1	0.021	0.021	0.109
2	0.016	0.016	0.114
3	-0.014	-0.015	0.102
4	0.058	0.058	0.086
5	-0.054	-0.056	0.100
6	-0.105	-0.105	0.096
7	0.150	0.161	0.102
8	-0.190	-0.209	0.095
9	-0.198	-0.199	0.112
10	-0.071	-0.032	0.108
11	-0.015	-0.052	0.109
12	-0.109	-0.103	0.109
13	-0.066	-0.032	0.104
14	-0.051	-0.149	0.108
15	-0.158	-0.180	0.102
16	-0.023	-0.010	0.106
17	0.147	0.072	0.103
18	0.141	0.050	0.103
19	0.036	0.025	0.108
20	-0.008	-0.092	0.108

(q) Meredith

Lag	Acc	Pacc	SE(acc)
1	0.109	0.109	0.102
2	0.066	0.055	0.102
3	0.035	0.023	0.105
4	-0.002	-0.012	0.086
5	0.041	0.040	0.088
6	0.031	0.023	0.095
7	0.145	0.137	0.089
8	-0.137	-0.177	0.090
9	-0.188	-0.182	0.097
10	-0.115	-0.076	0.094
11	-0.010	0.048	0.102
12	-0.054	-0.050	0.103
13	-0.044	-0.036	0.099
14	-0.081	-0.084	0.099
15	-0.079	0.005	0.099
16	-0.029	0.033	0.100
17	0.061	0.059	0.100
18	0.050	-0.025	0.100
19	0.008	-0.014	0.101
20	-0.040	-0.050	0.101

(r) Kilmore

Lag	Acc	Pacc	SE(acc)
1	0.119	0.119	0.103
2	-0.083	-0.099	0.121
3	0.005	0.028	0.112
4	0.046	0.034	0.100
5	-0.045	-0.054	0.112
6	-0.050	-0.030	0.099
7	0.176	0.182	0.127
8	-0.161	-0.231	0.099
9	-0.306	-0.237	0.105
10	-0.033	0.018	0.126
11	-0.064	-0.139	0.115
12	-0.164	-0.148	0.110
13	0.081	0.173	0.110
14	0.161	0.046	0.109
15	0.084	0.116	0.114
16	-0.097	-0.011	0.116
17	0.104	0.022	0.114
18	0.162	0.089	0.110
19	0.001	0.006	0.119
20	0.101	-0.009	0.115

Table C1. (Cont)

(s) Pennyroyal Creek

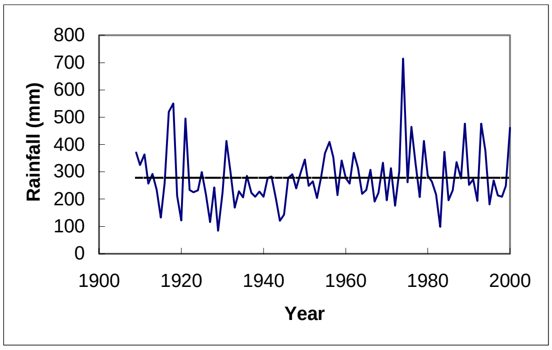
Lag	Acc	Pacc	SE(acc)
1	0.172	0.172	0.096
2	-0.015	-0.046	0.108
3	-0.063	-0.055	0.114
4	0.087	0.111	0.106
5	0.008	-0.032	0.089
6	0.123	0.134	0.104
7	-0.021	-0.058	0.105
8	0.079	0.095	0.096
9	-0.085	-0.108	0.112
10	-0.155	-0.155	0.100
11	0.031	0.121	0.103
12	0.032	-0.065	0.103
13	-0.034	-0.008	0.105
14	0.028	0.057	0.102
15	0.005	-0.009	0.103
16	-0.097	-0.075	0.102
17	0.121	0.169	0.100
18	0.099	0.065	0.102
19	0.082	0.012	0.102
20	0.009	0.010	0.104

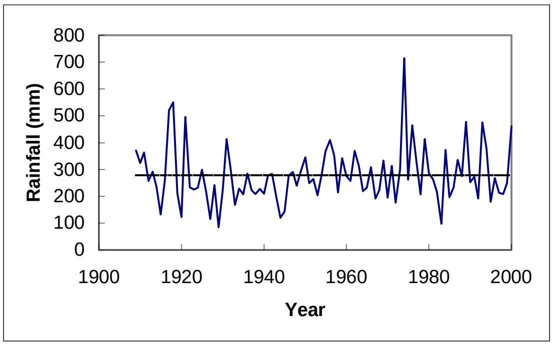
(t) Penshurst

Lag	Acc	Pacc	SE(acc)
1	0.087	0.087	0.112
2	0.026	0.019	0.117
3	-0.003	-0.007	0.125
4	0.097	0.098	0.122
5	-0.002	-0.018	0.113
6	0.209	0.210	0.100
7	0.104	0.074	0.119
8	0.138	0.117	0.110
9	0.026	0.016	0.117
10	-0.041	-0.086	0.109
11	0.113	0.128	0.110
12	-0.041	-0.135	0.111
13	-0.070	-0.098	0.110
14	0.159	0.147	0.101
15	0.156	0.079	0.102
16	0.083	0.111	0.109
17	0.117	0.095	0.105
18	0.097	0.104	0.106
19	-0.005	0.002	0.108
20	-0.035	-0.096	0.109

APPENDIX D

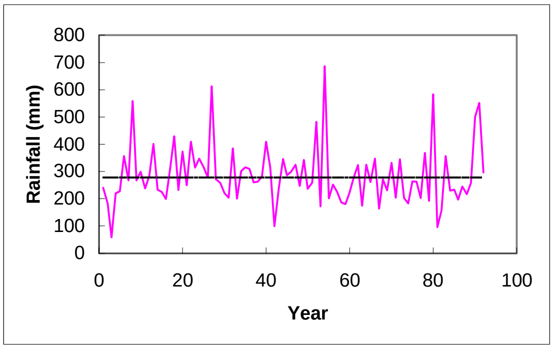
TIME SERIES PLOTS AND RESIDUAL MASS CURVES FOR HISTORICAL DATA AND THREE RANDOMLY SELECTED REPLICATES

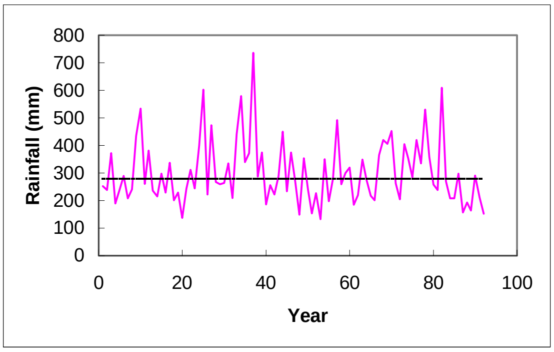




Historical

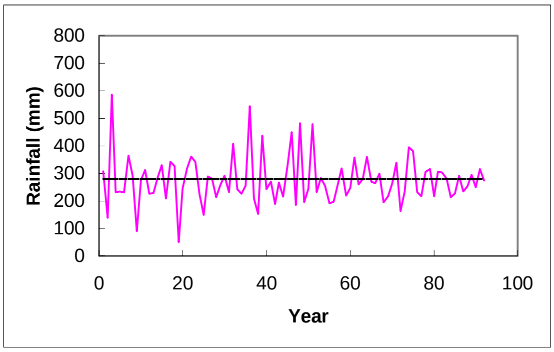
Historical

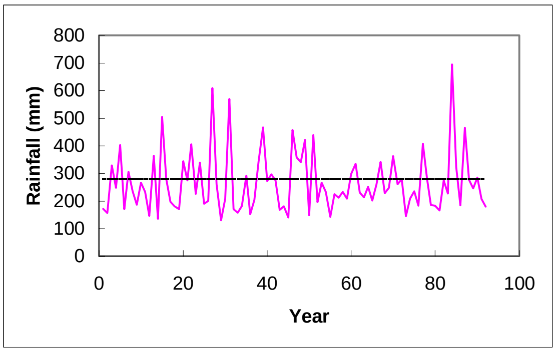




HSM - Replicate 72

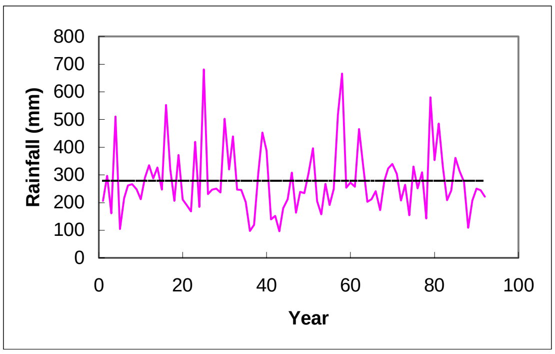
ARM - Replicate 73





HSM - Replicate 35

ARM - Replicate 15



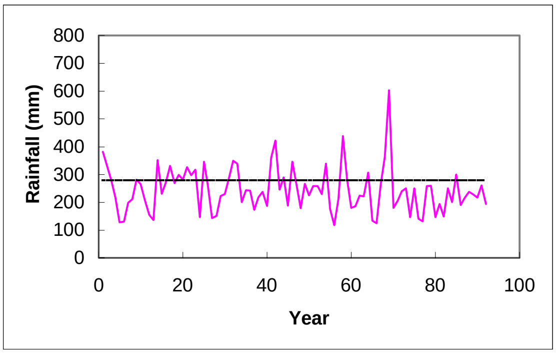
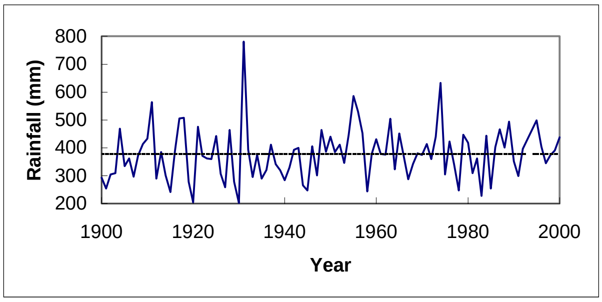
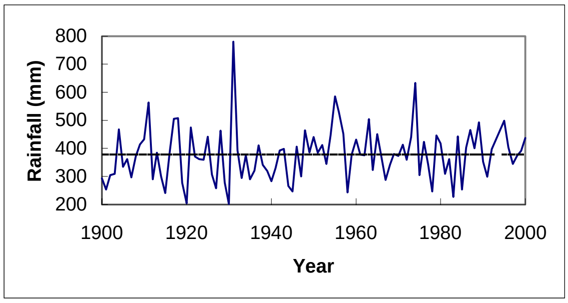


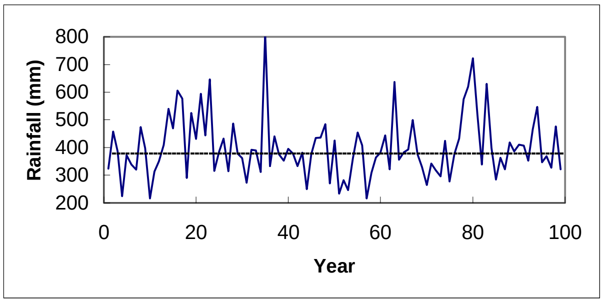
Figure D1. Time series plots of historical and three replicates of generated data from HSM and AR models for Irymple.



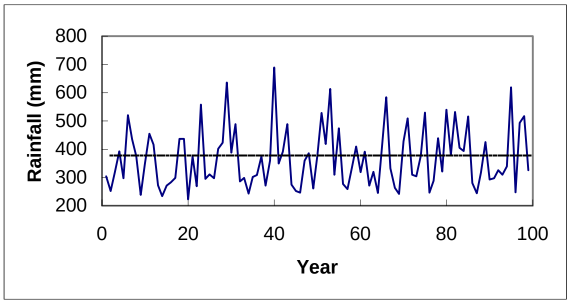
Historical



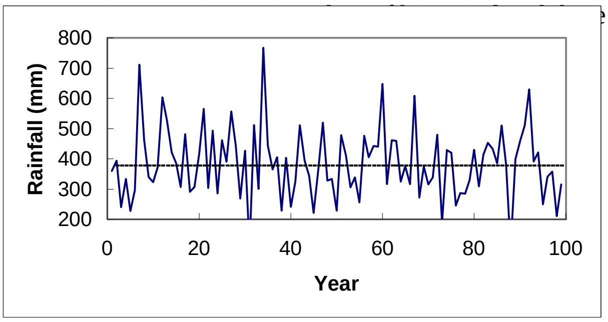
Historical



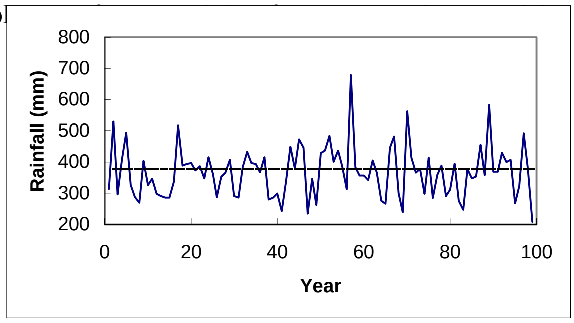
HSM - Replicate 78



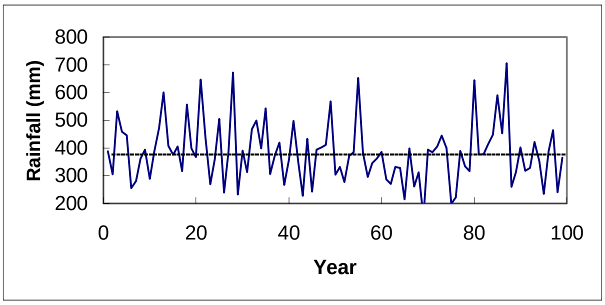
ARM - Replicate 79



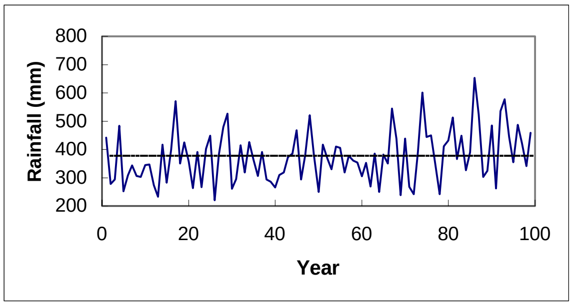
HSM - Replicate 75



ARM - Replicate 57

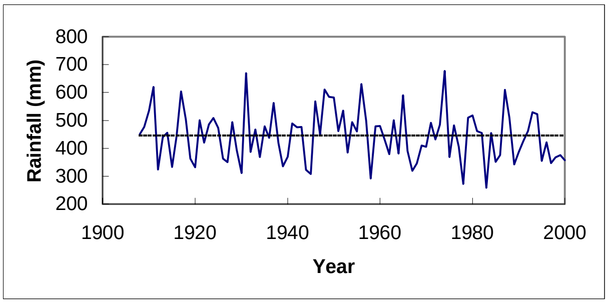


HSM - Replicate 51

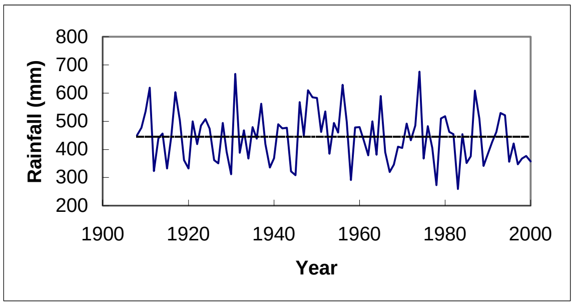


ARM - Replicate 92

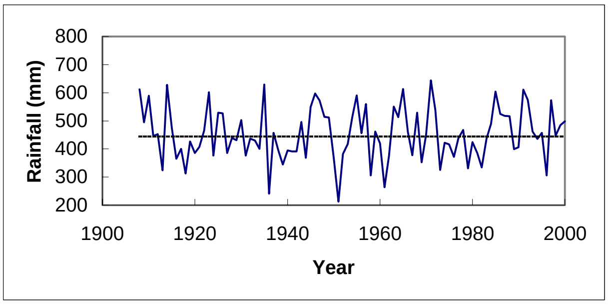
Figure D2. Time series plots of historical and three replicates of generated data from HSM and AR models for Beulah.



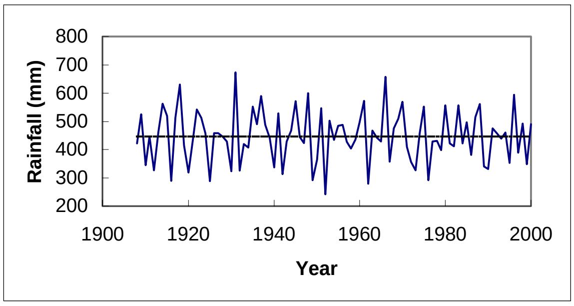
Historical



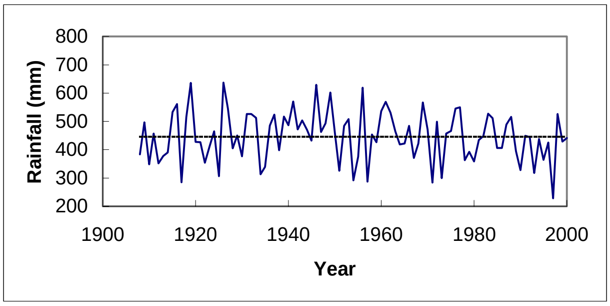
Historical



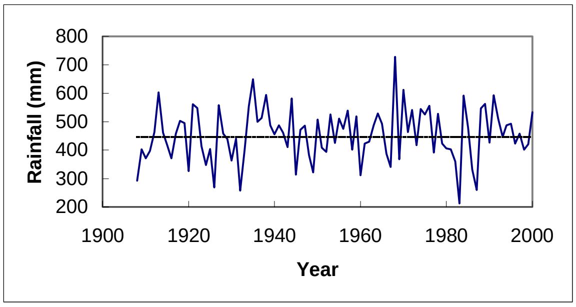
HSM - Replicate 80



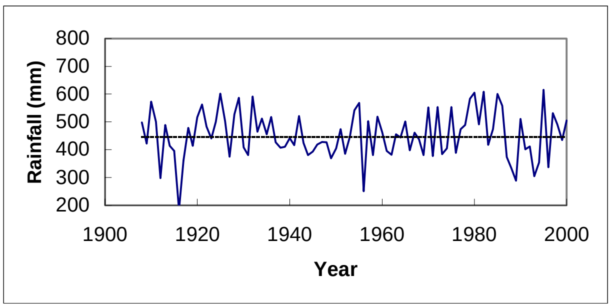
ARM - Replicate 81



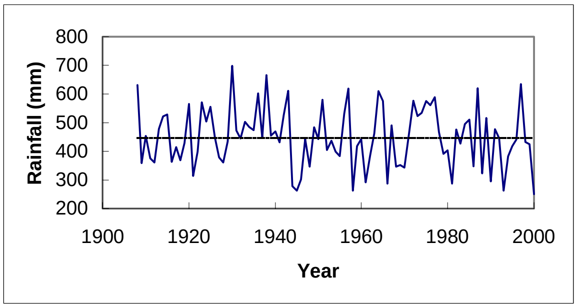
HSM - Replicate 54



ARM - Replicate 2

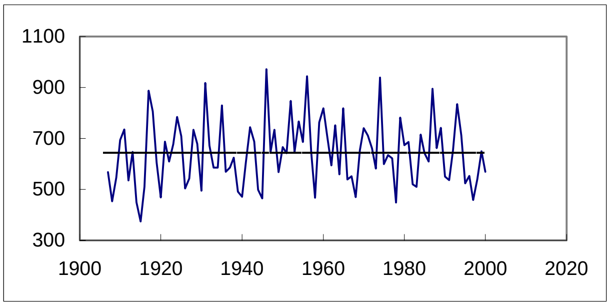


HSM - Replicate 48

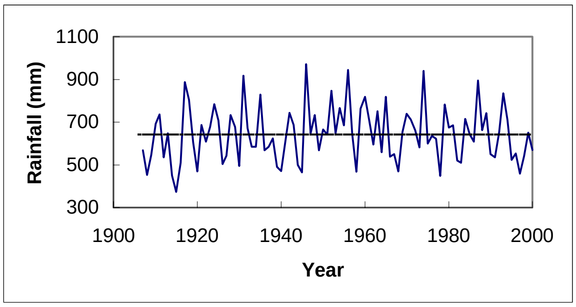


ARM - Replicate 10

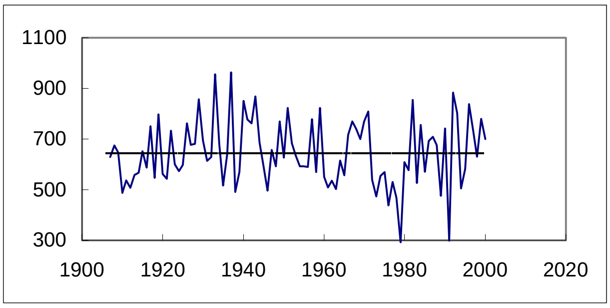
Figure D3. Time series plots of historical and three replicates of generated data from HSM and AR models for Natimuk.



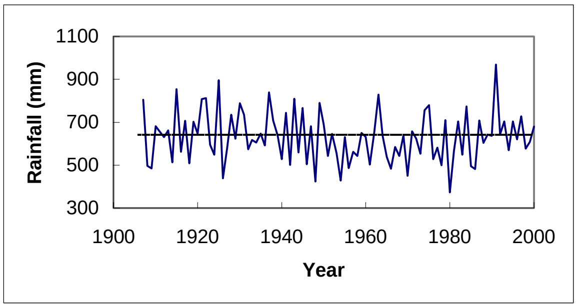
Historical



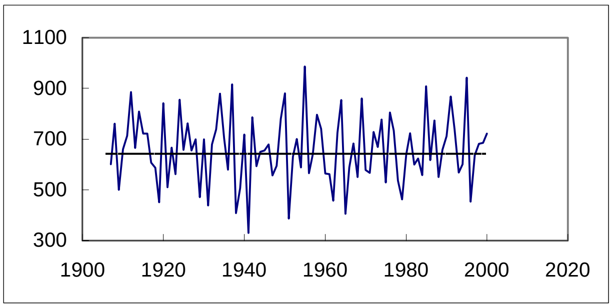
Historical



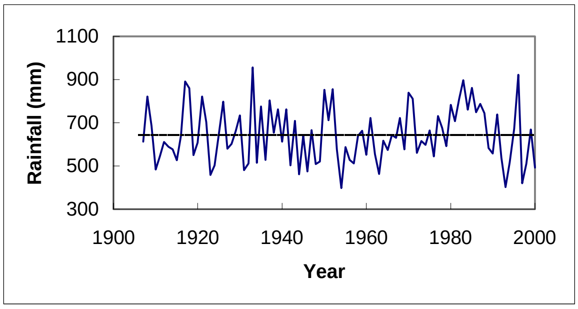
HSM - Replicate 81



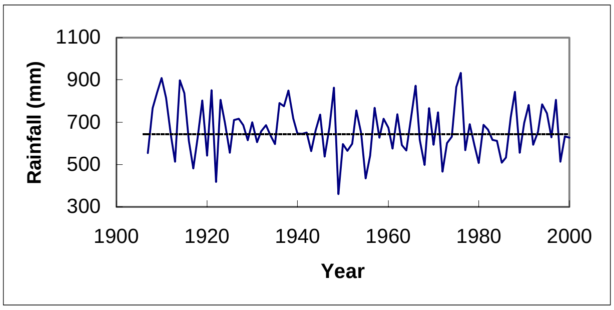
ARM - Replicate 81



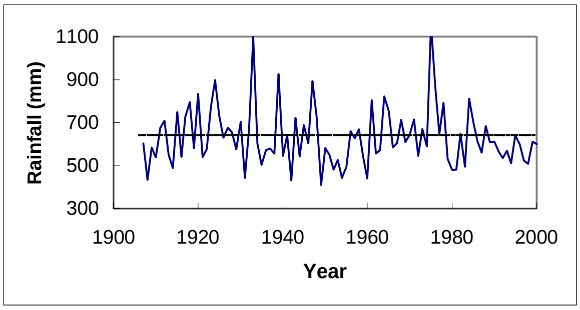
HSM - Replicate 55



ARM - Replicate 63

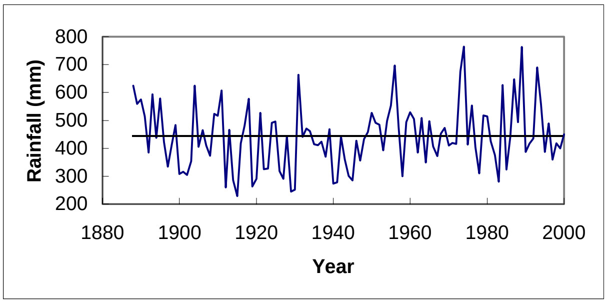


HSM - Replicate 34

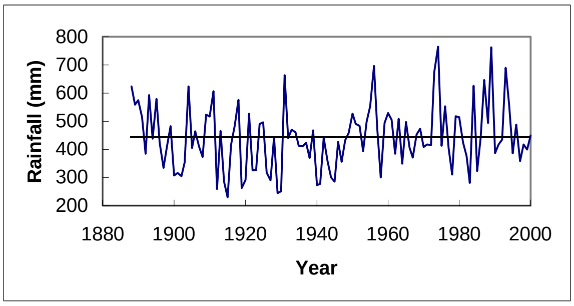


ARM - Replicate 98

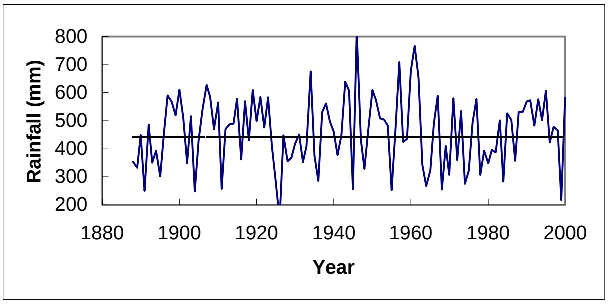
Figure D4. Time series plots of historical and three replicates of generated data from HSM and AR models for Moyston.



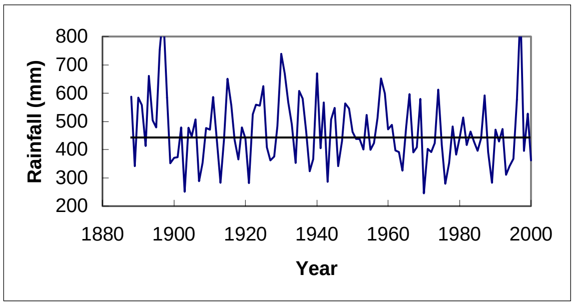
Historical



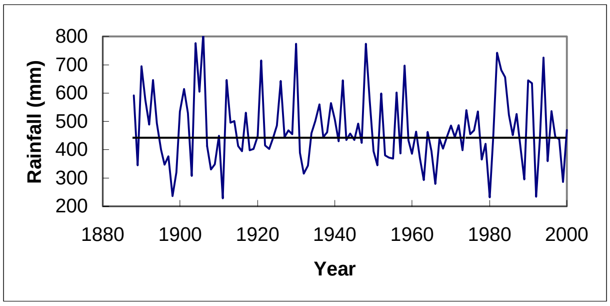
Historical



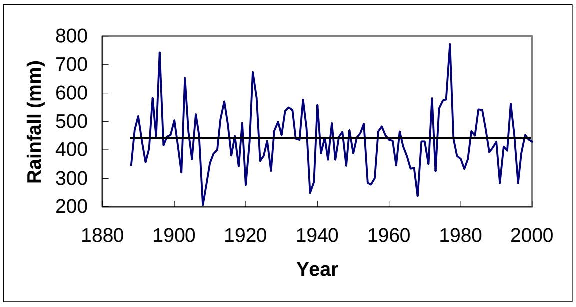
HSM - Replicate 82



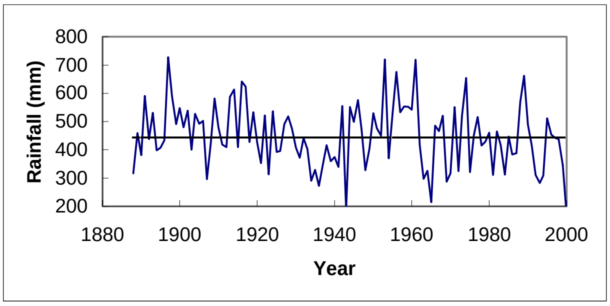
ARM - Replicate 41



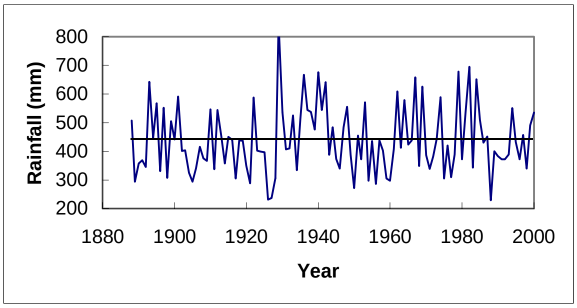
HSM - Replicate 62



ARM - Replicate 94

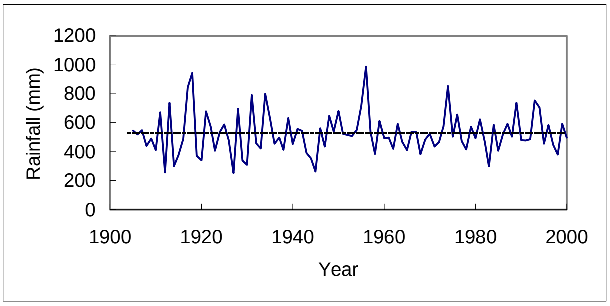


HSM - Replicate 43

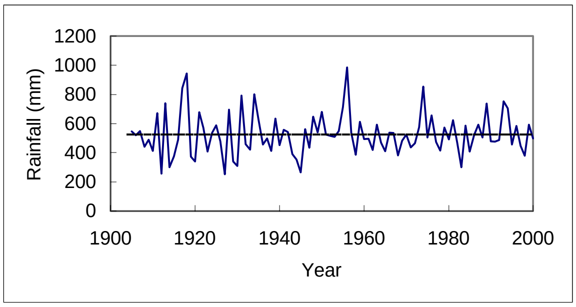


ARM - Replicate 14

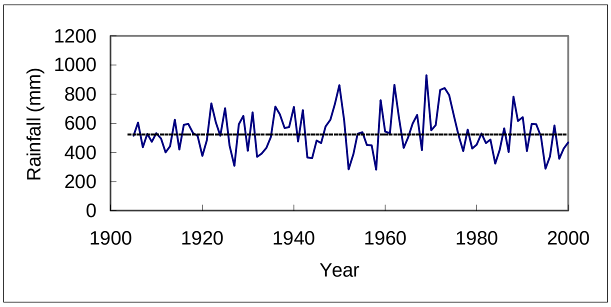
Figure D5. Time series plots of historical and three replicates of generated data from HSM and AR models for St Arnaud



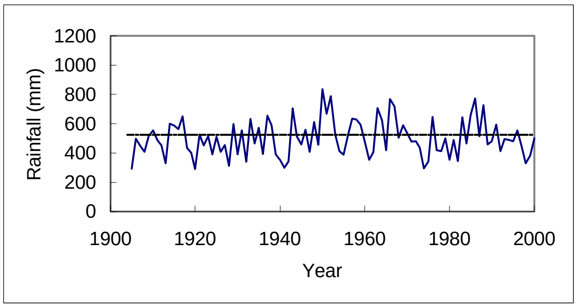
Historical



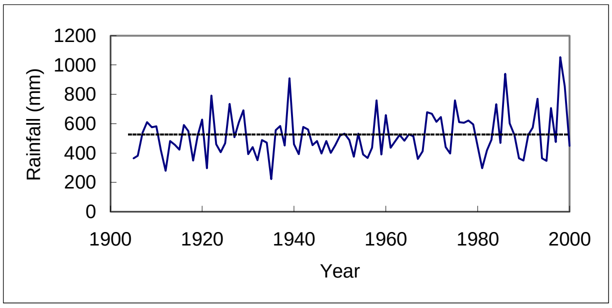
Historical



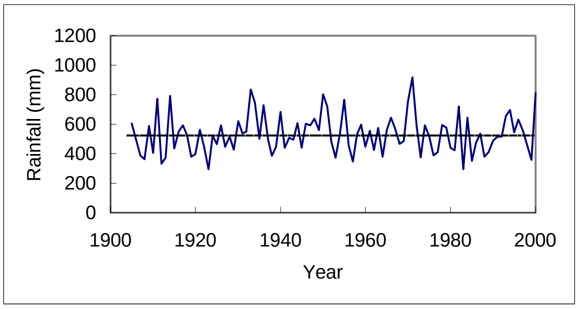
HSM - Replicate39



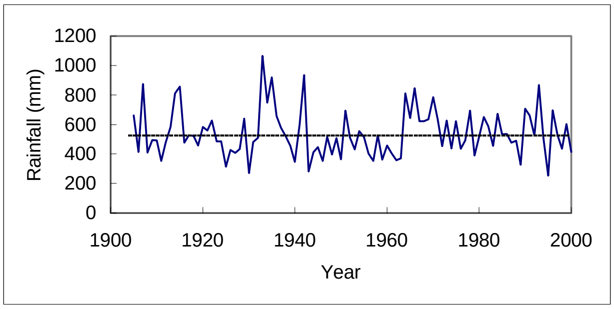
ARM - Replicate 40



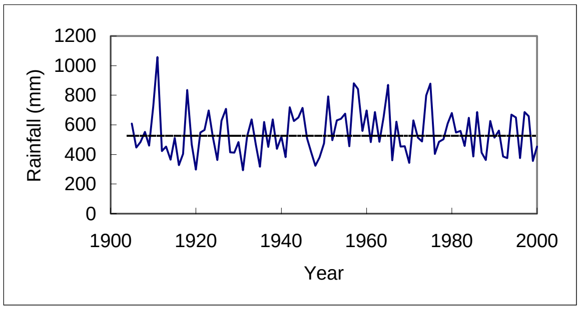
HSM - Replicate 43



ARM - Replicate 66

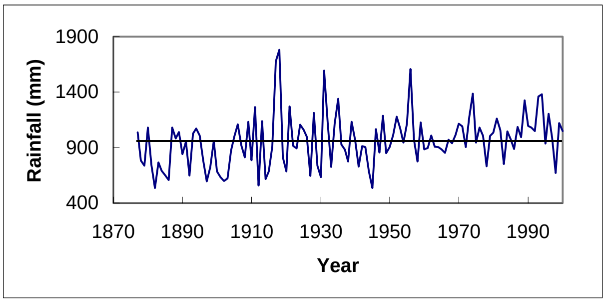


HSM - Replicate 98

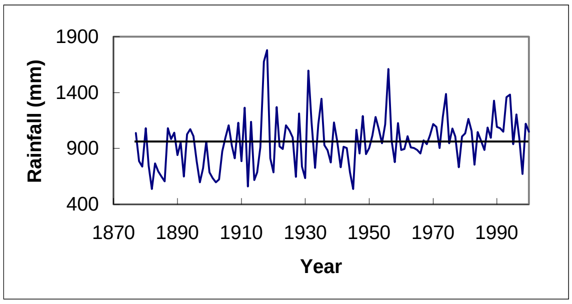


ARM - Replicate24

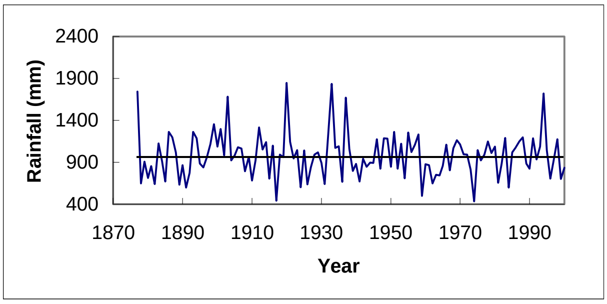
Figure D6. Time series plots of historical and three replicates of generated data from HSM and AR models for Caniambo.



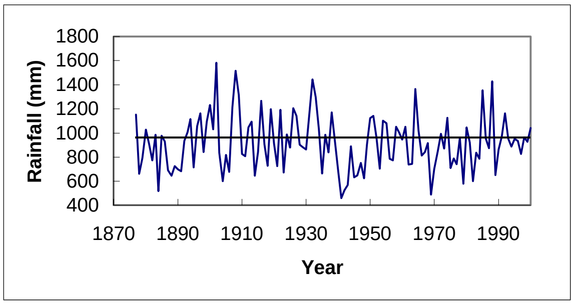
Historical



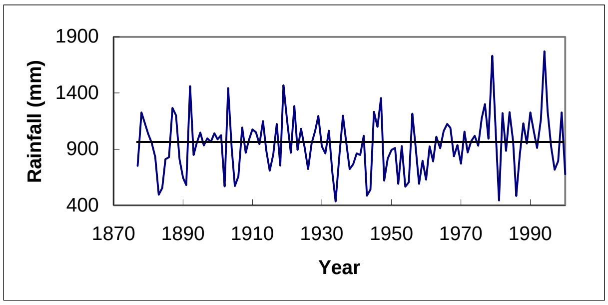
Historical



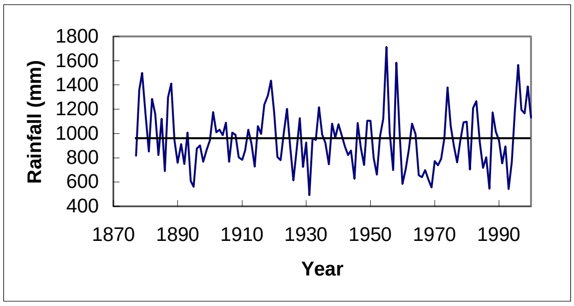
HSM - Replicate 60



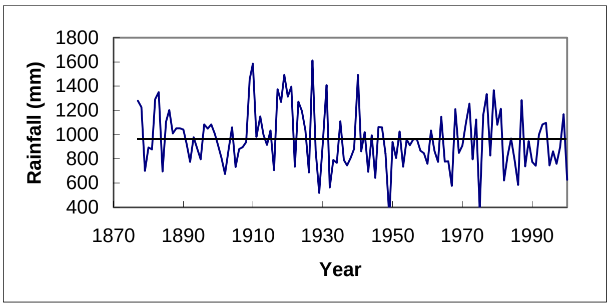
ARM - Replicate 22



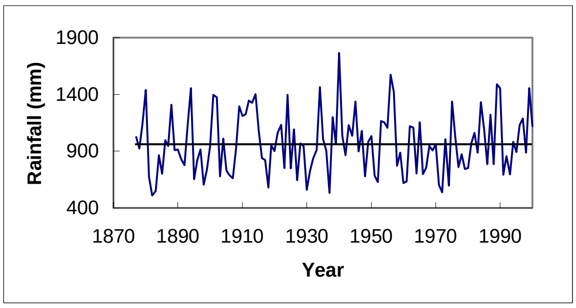
HSM - Replicate 47



ARM - Replicate 1

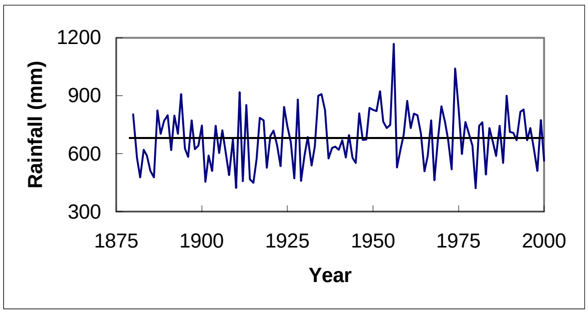


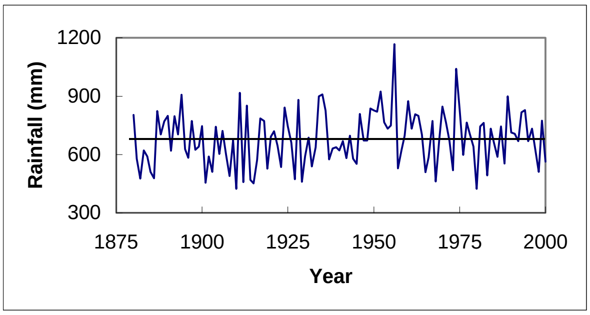
HSM - Replicate 5



ARM - Replicate 8

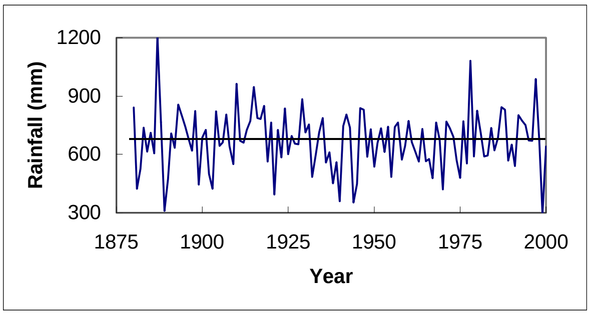
Figure D7. Time series plots of historical and three replicates of generated data from HSM and AR models for Beechworth.

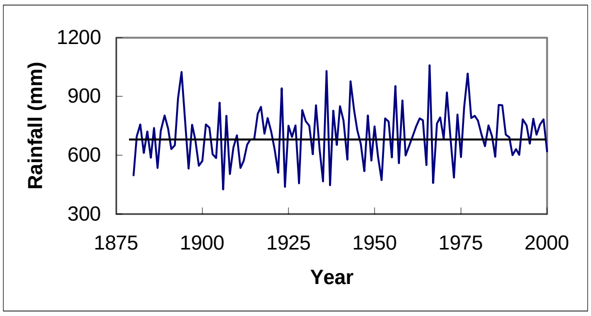




Historical

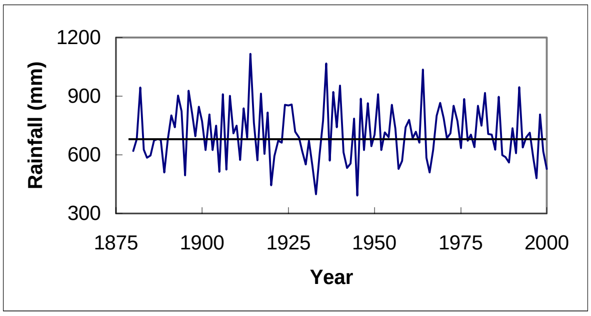
Historical

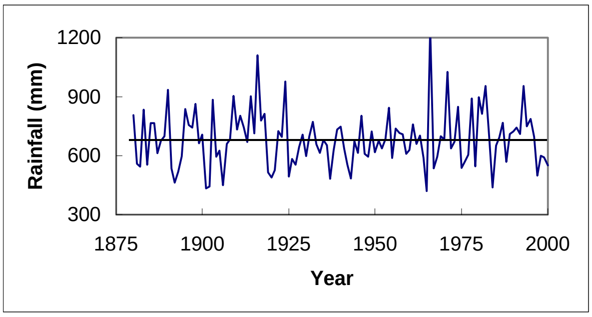




HSM - Replicate 54

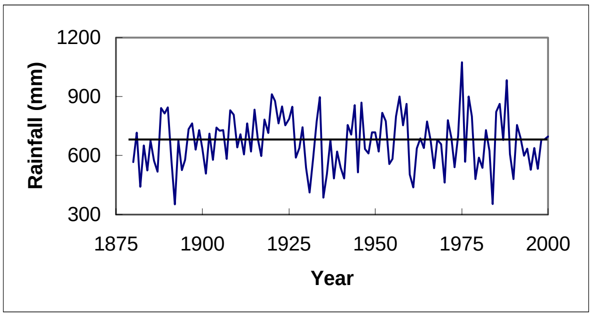
ARM - Replicate 53

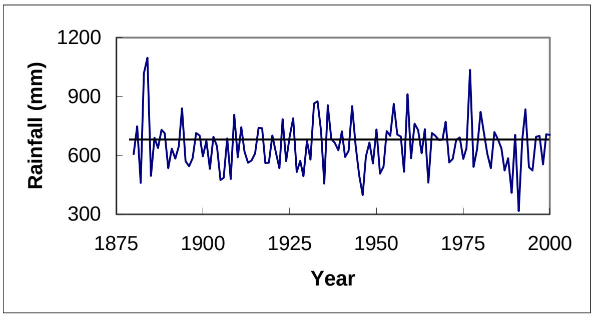




HSM - Replicate 56

ARM - Replicate 41

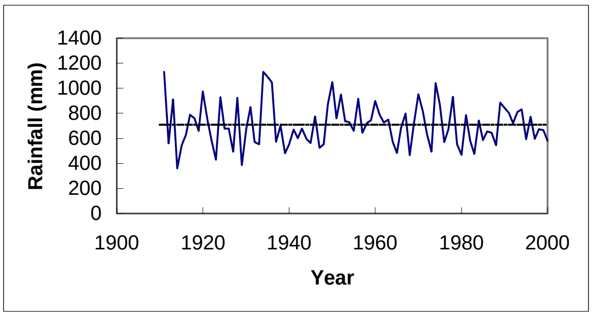




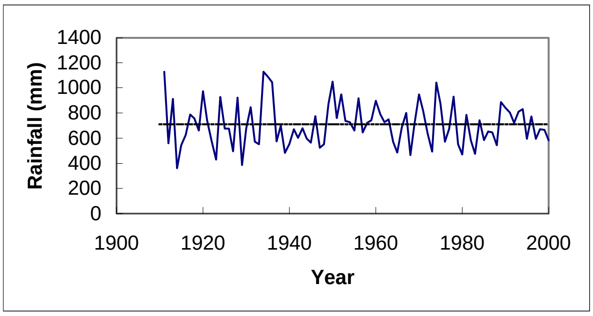
HSM - Replicate 34

ARM - Replicate 5

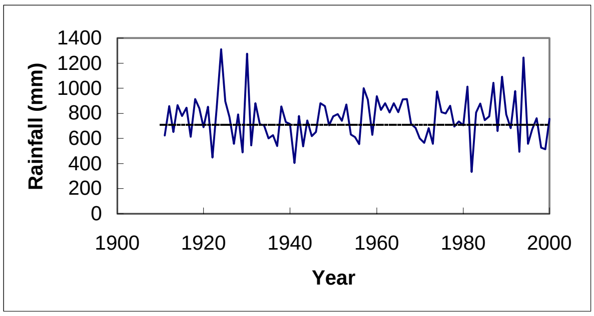
Figure D8. Time series plots of historical and three replicates of generated data from HSM and AR models for Omeo.



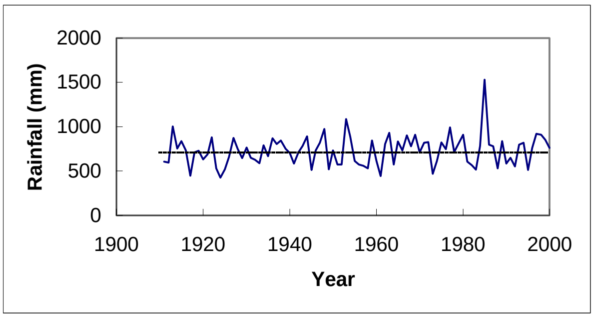
Historical



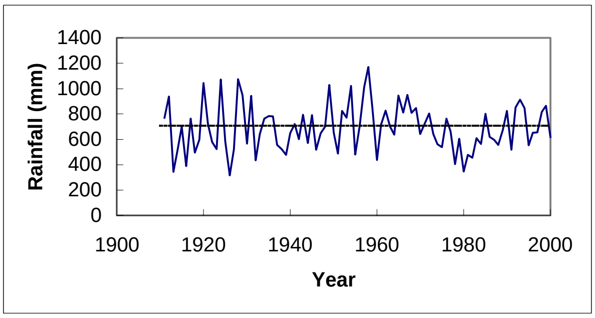
Historical



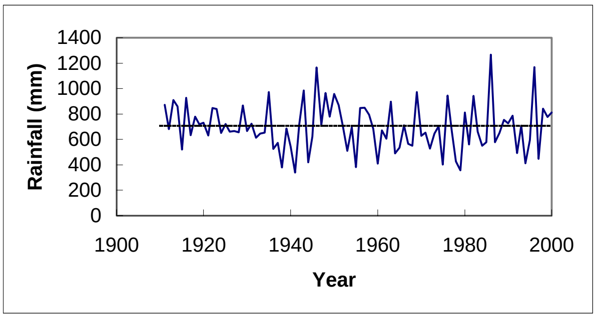
HSM - Replicate 73



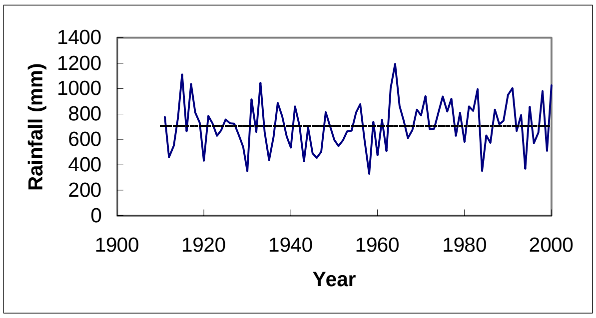
ARM - Replicate 97



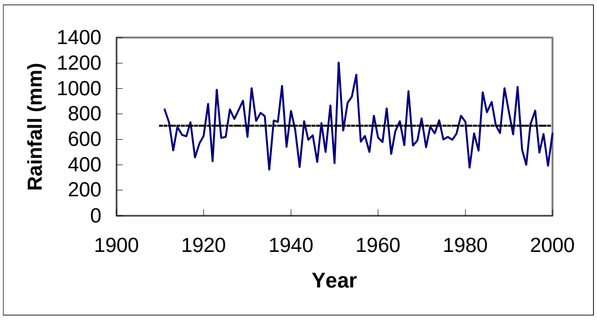
HSM - Replicate 94



ARM - Replicate 21

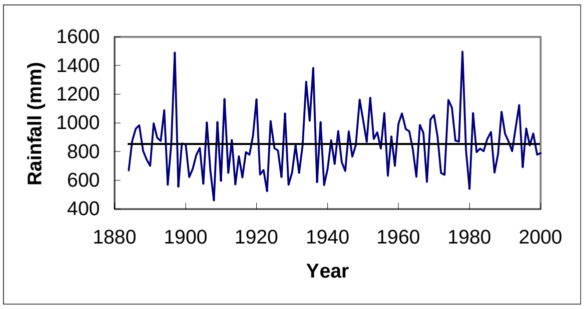


HSM - Replicate 28

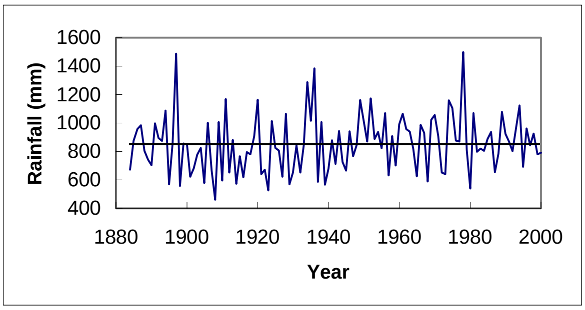


ARM - Replicate 93

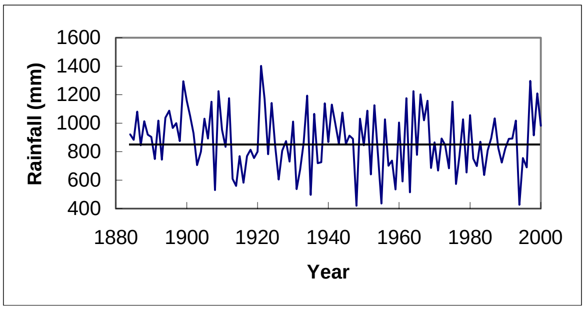
Figure D9. Time series plots of historical and three replicates of generated data from HSM and AR models for Ensay.



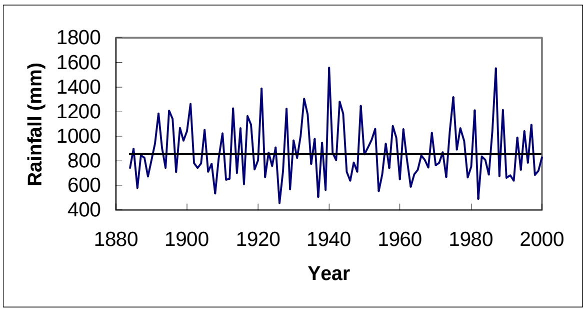
Historical



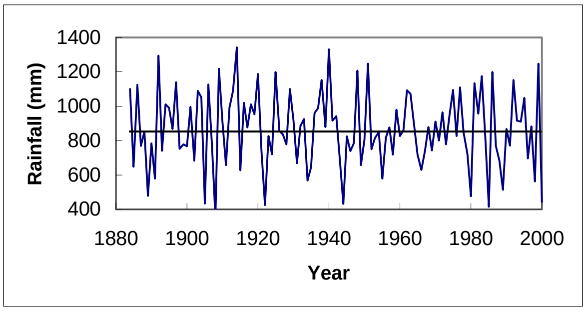
Historical



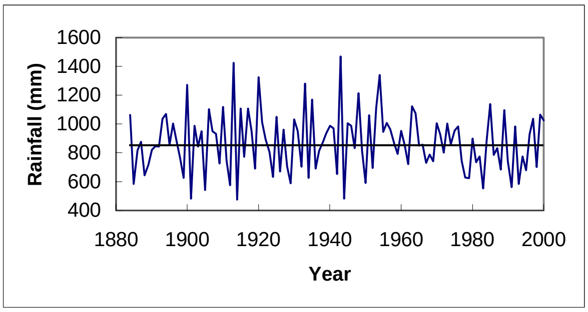
HSM - Replicate 49



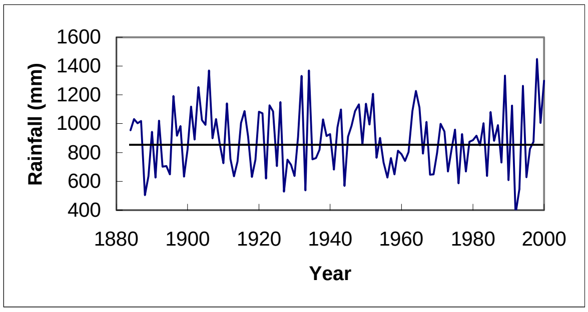
ARM - Replicate 34



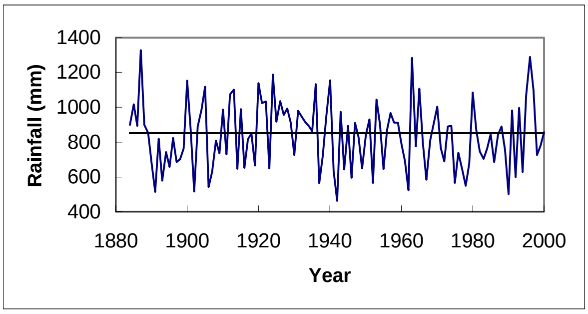
HSM - Replicate88



ARM - Replicate 55

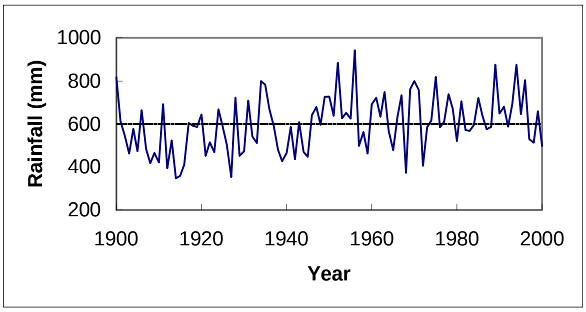


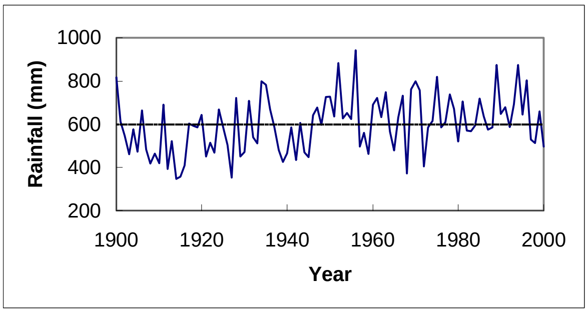
HSM - Replicate 89



ARM - Replicate 31

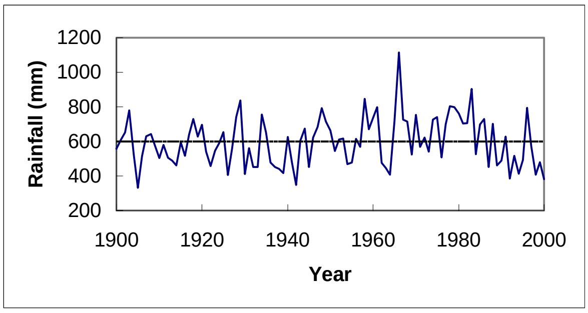
Figure D10. Time series plots of historical and three replicates of generated data from HSM and AR models for Orbost.

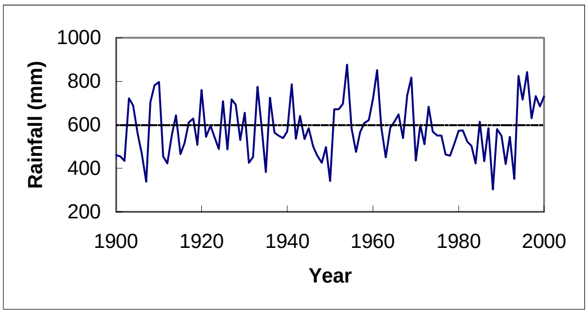




Historical

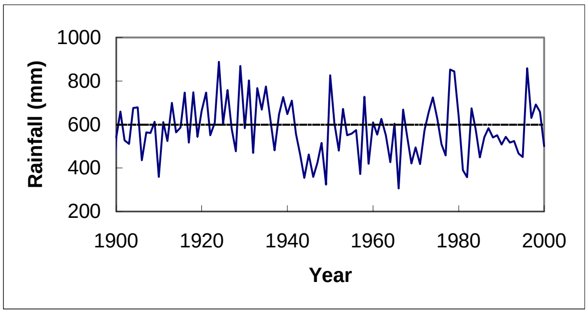
Historical

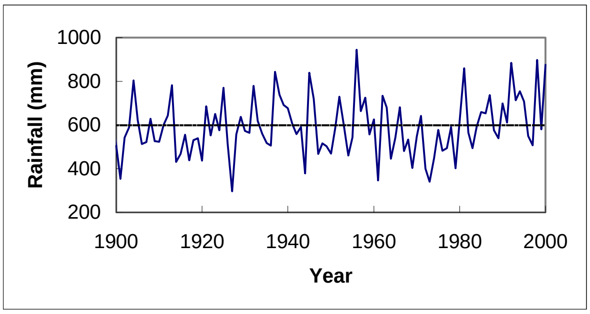




HSM - Replicate 59

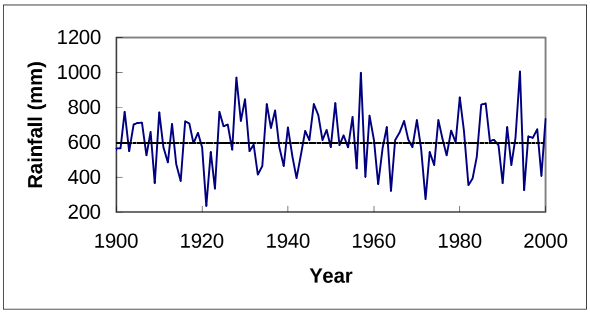
ARM - Replicate 3

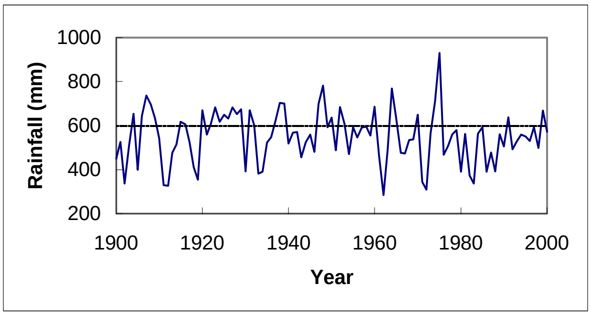




HSM - Replicate 5

ARM - Replicate 79

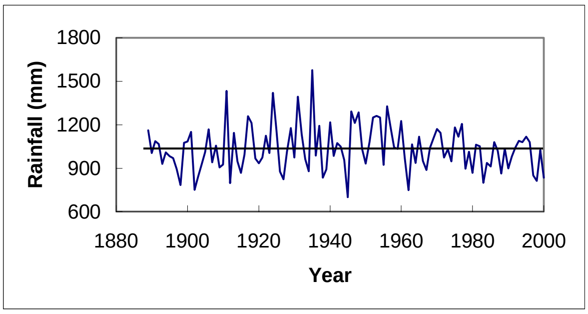




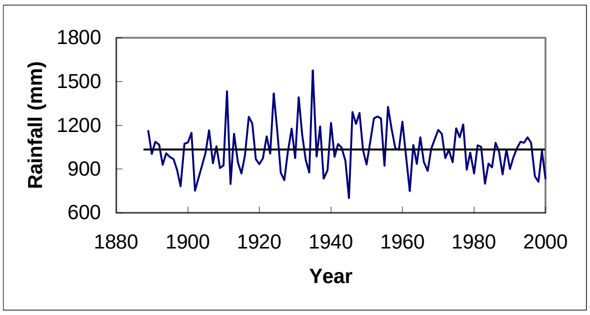
HSM - Replicate 93

ARM - Replicate 83

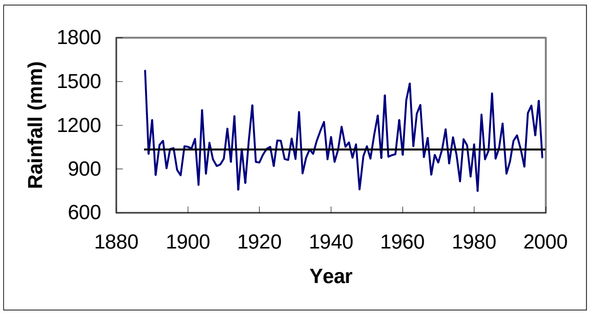
Figure D11. Time series plots of historical and three replicates of generated data from HSM and AR models for Seaspray.



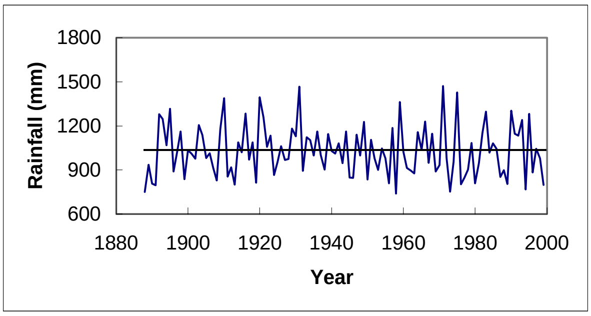
Historical



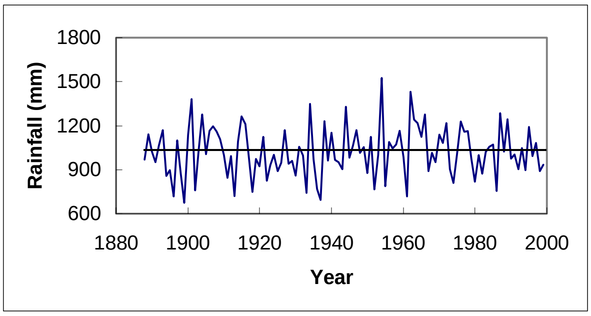
Historical



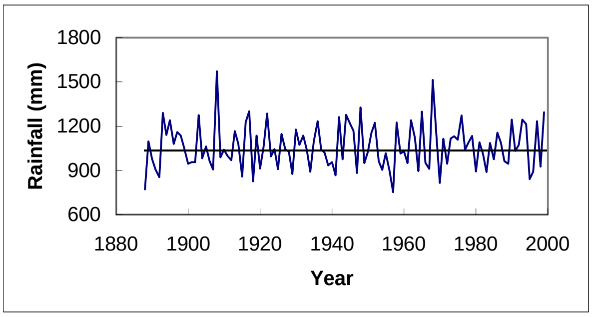
HSM - Replicate 41



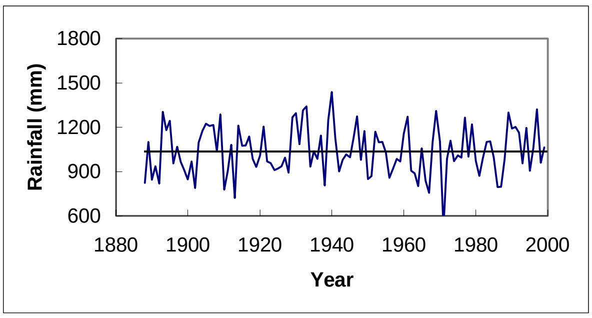
ARM - Replicate 12



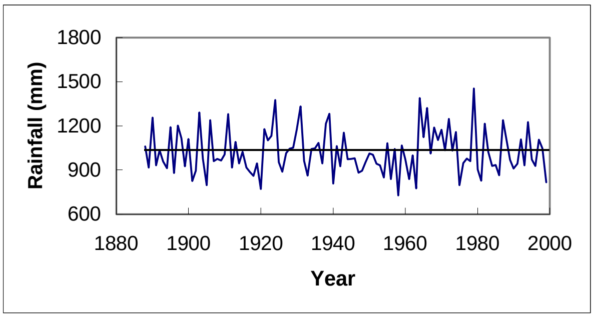
HSM - Replicate 12



ARM - Replicate 37

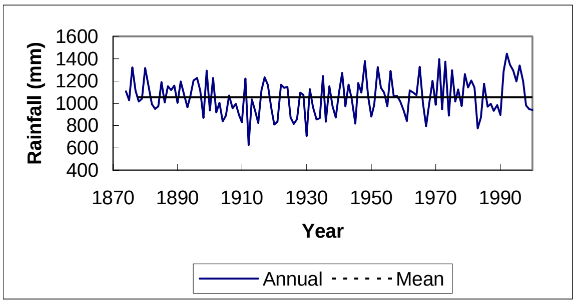


HSM - Replicate 21

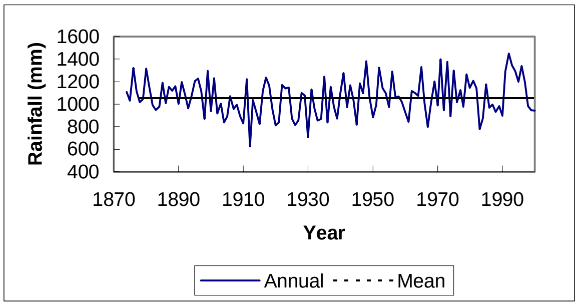


ARM - Replicate 3

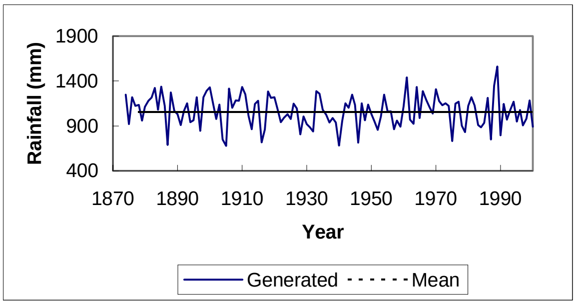
Figure D12. Time series plots of historical and three replicates of generated data from HSM and AR models for Warragul.



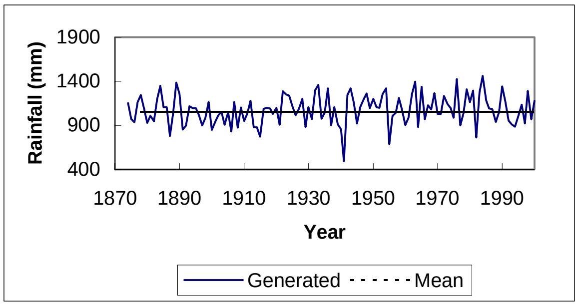
Historical



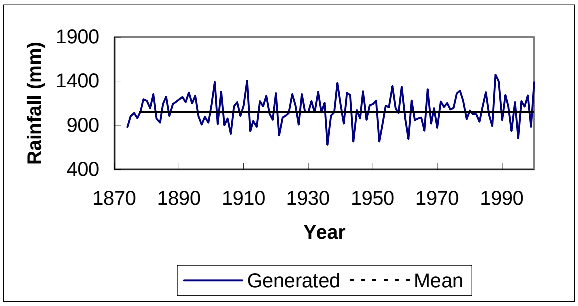
Historical



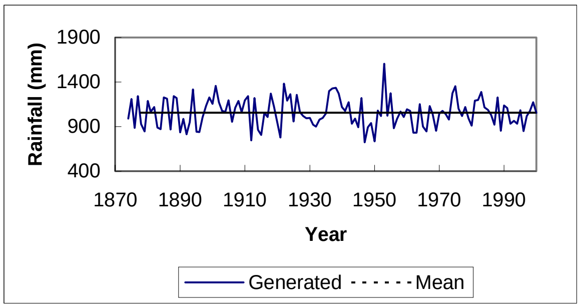
HSM - Replicate 3



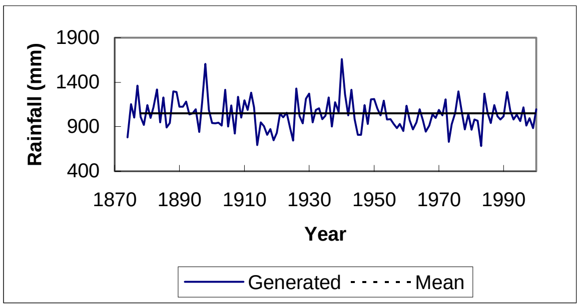
ARM - Replicate 87



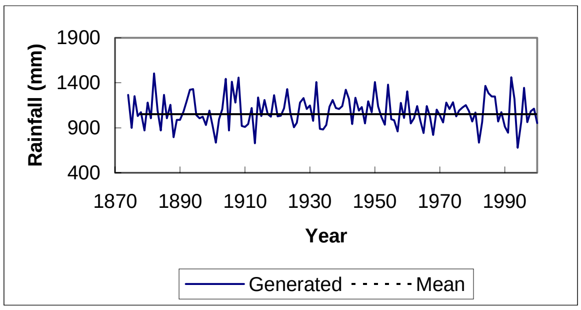
HSM - Replicate 87



ARM - Replicate 19+Q23

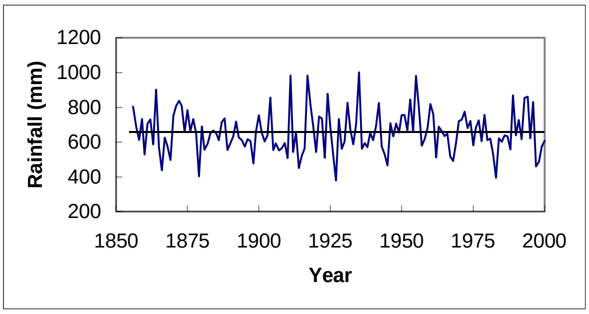


HSM - Replicate 50

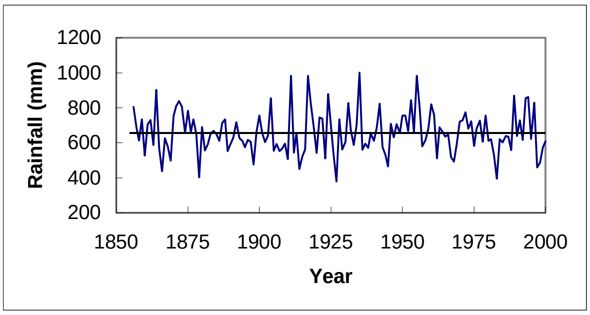


ARM - Replicate 78

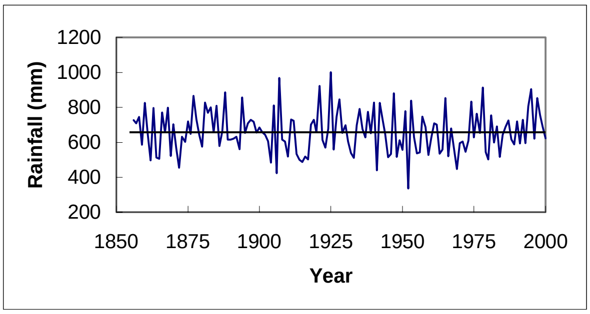
Figure D13. Time series plots of historical and three replicates of generated data from HSM and AR models for Wilson's Promontory.



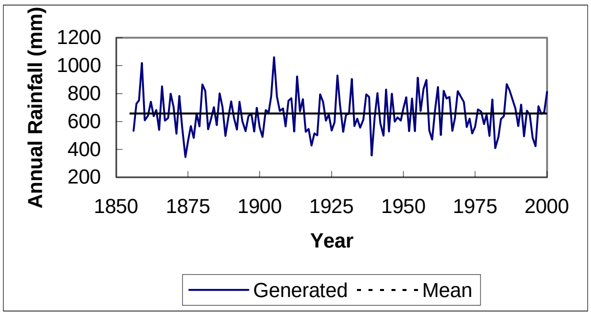
Historical



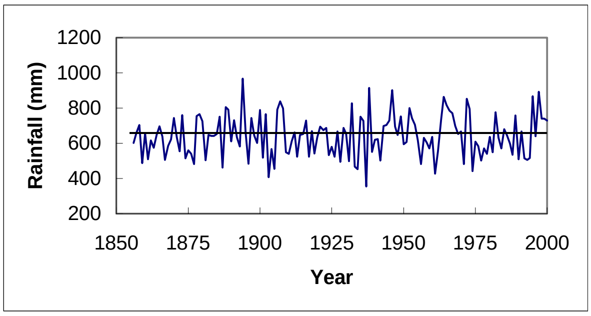
Historical



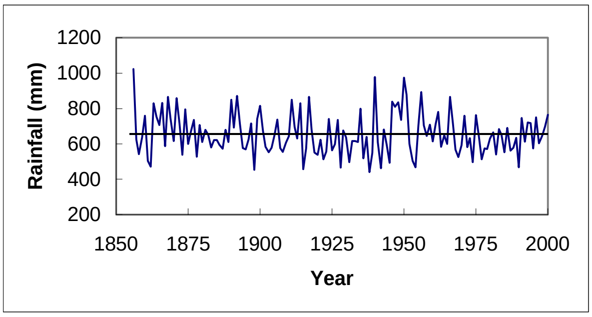
HSM - Replicate 94



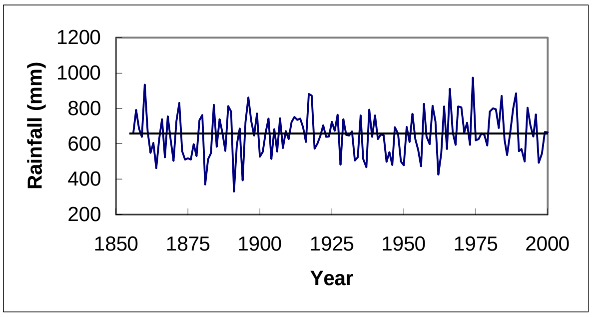
ARM - Replicate 55



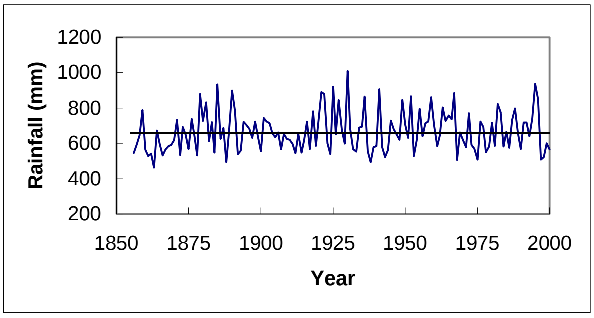
HSM - Replicate 65



ARM - Replicate 90

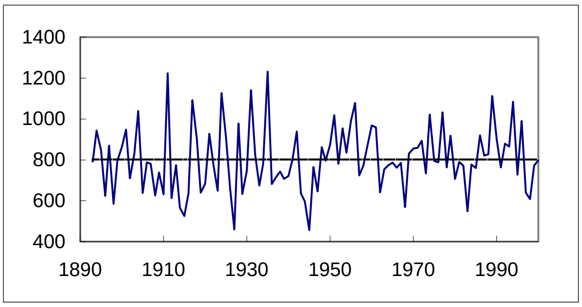


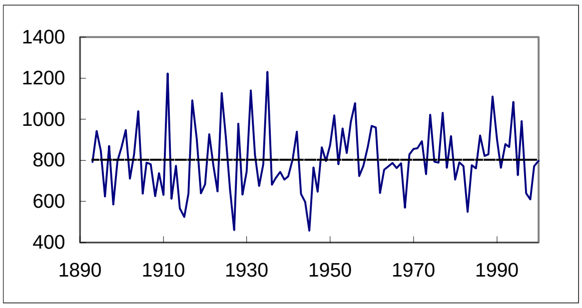
HSM - Replicate 55



ARM - Replicate 37

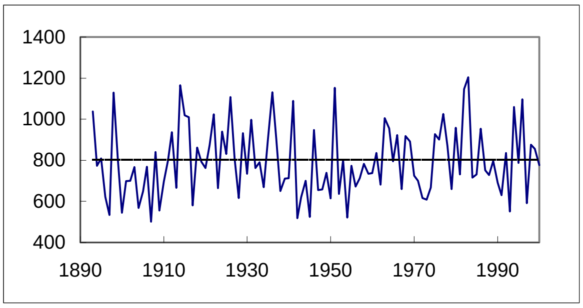
Figure D14. Time series plots of historical and three replicates of generated data from HSM and AR models for Melbourne.

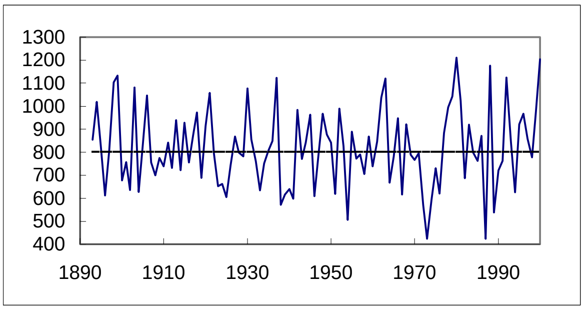




Historical

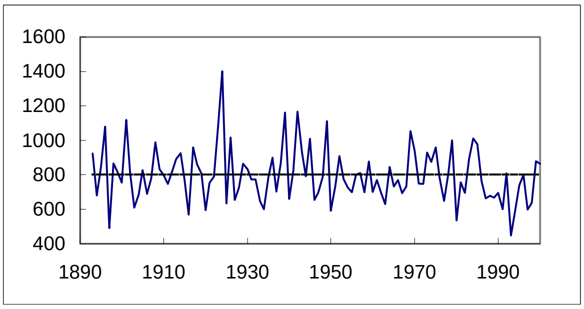
Historical

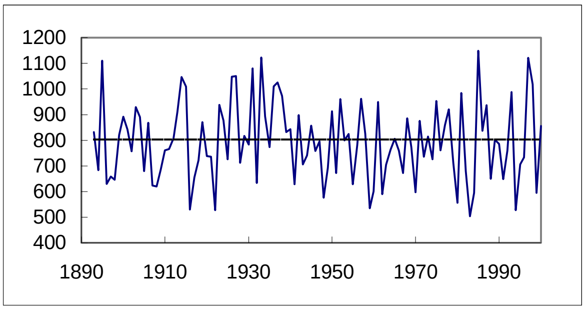




HSM - Replicate 20

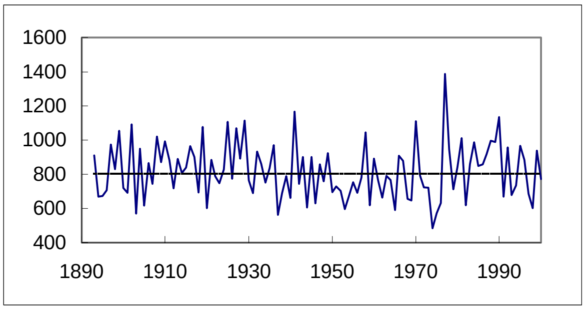
ARM - Replicate 94

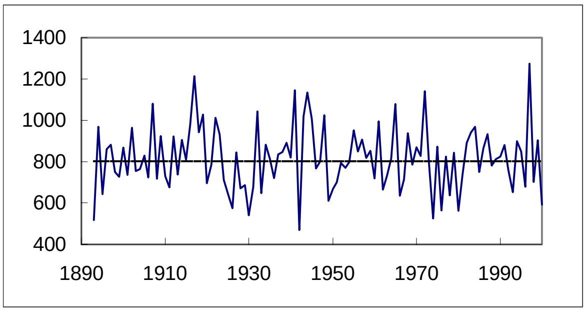




HSM - Replicate 30

ARM - Replicate 51

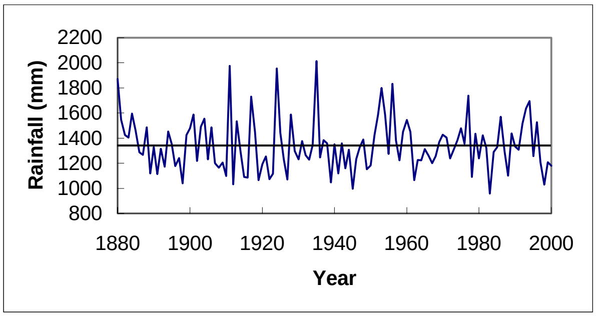


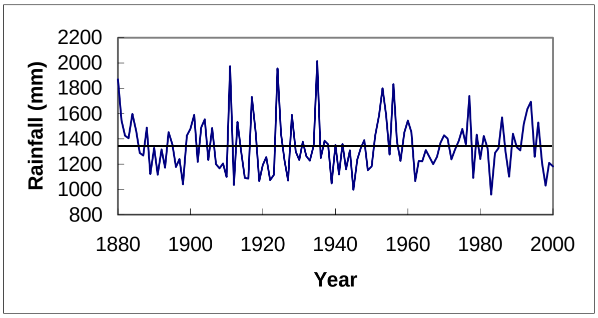


HSM - Replicate 40

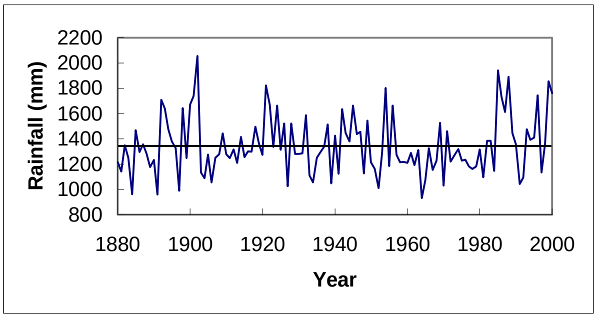
ARM - Replicate 61

Figure D15. Time series plots of historical and three replicates of generated data from HSM and AR models for Toorourrong.

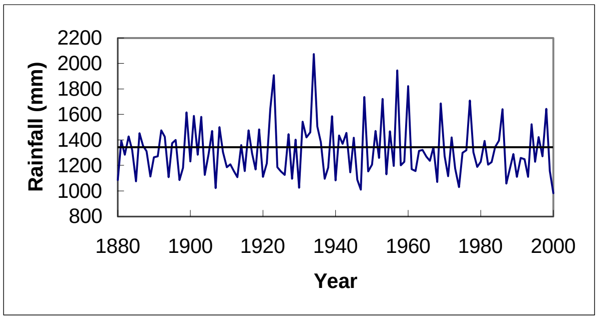




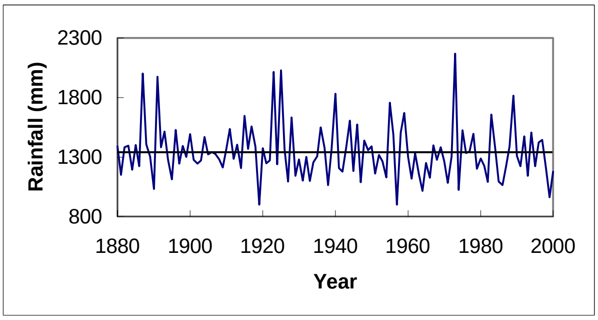
Historical Historical



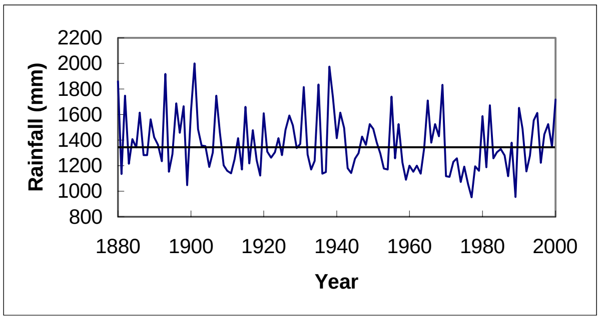
HSM - Replicate 35



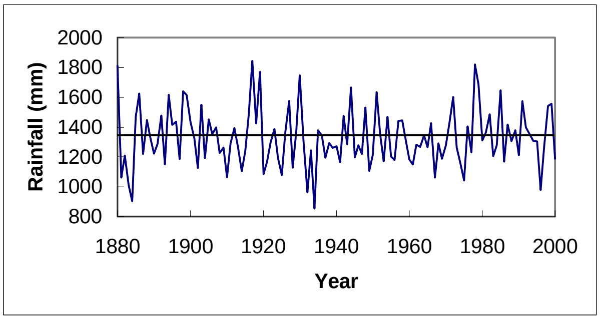
ARM - Replicate 66



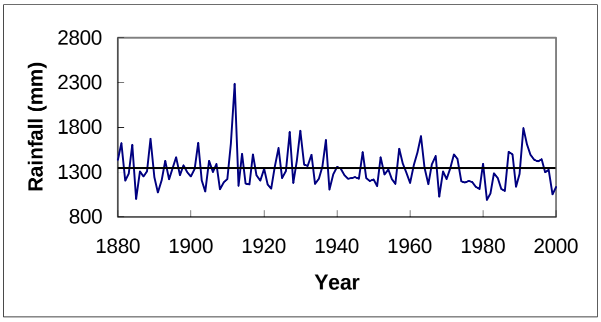
HSM - Replicate 93



ARM - Replicate 92

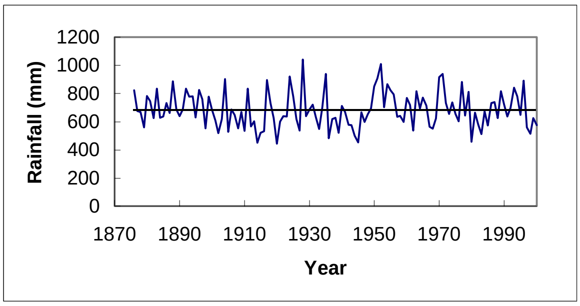


HSM - Replicate 95

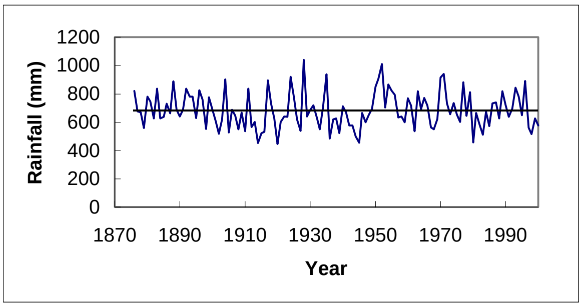


ARM - Replicate 39

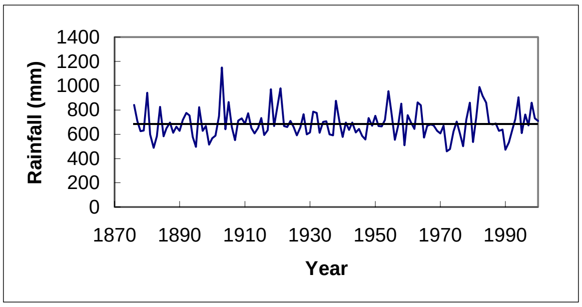
Figure D16. Time series plots of historical and three replicates of generated data from HSM and AR models for Warburton.



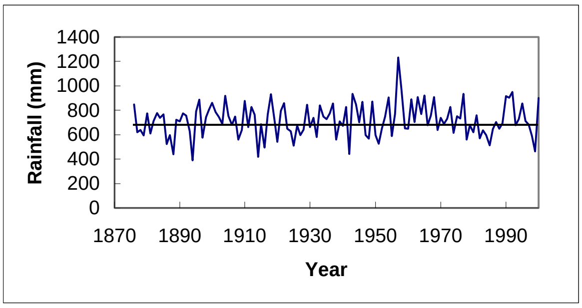
Historical



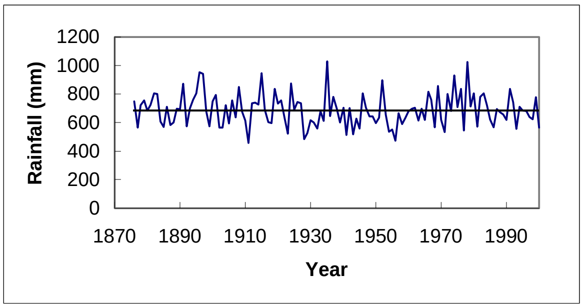
Historical



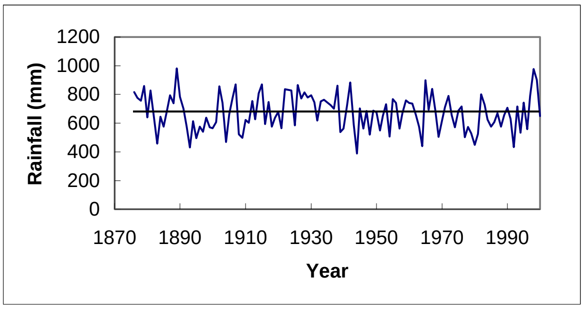
HSM - Replicate 26



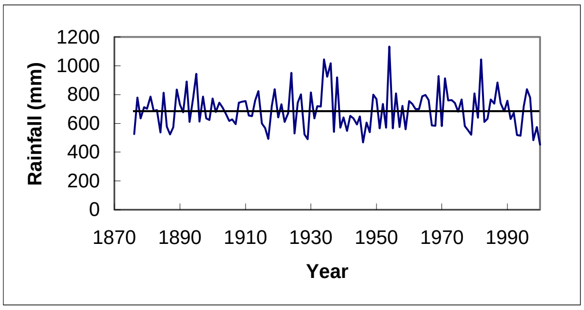
ARM - Replicate 9



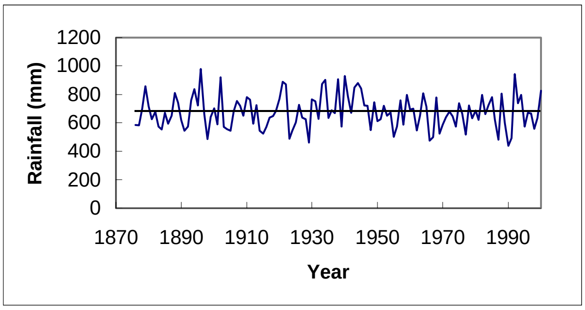
HSM - Replicate 29



ARM - Replicate 29

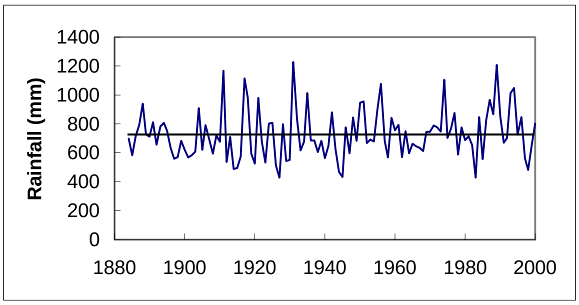


HSM - Replicate 16

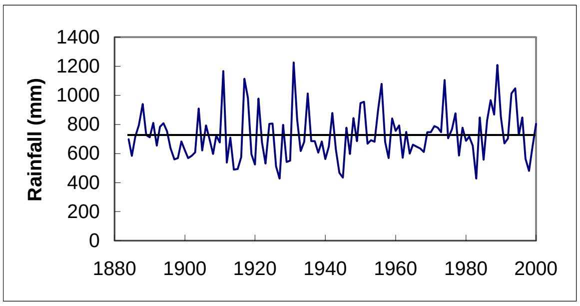


ARM - Replicate 44

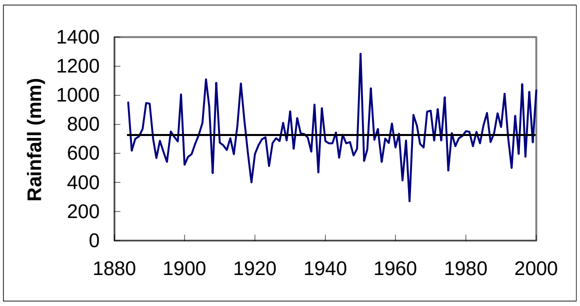
Figure D17. Time series plots of historical and three replicates of generated data from HSM and AR models for Meredith.



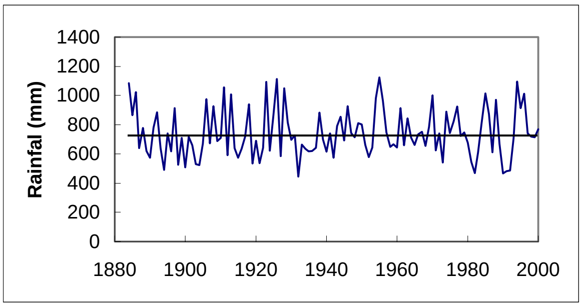
Historical



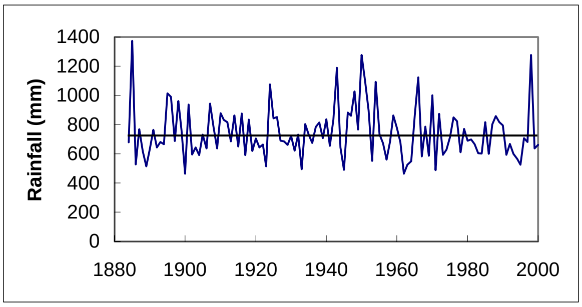
Historical



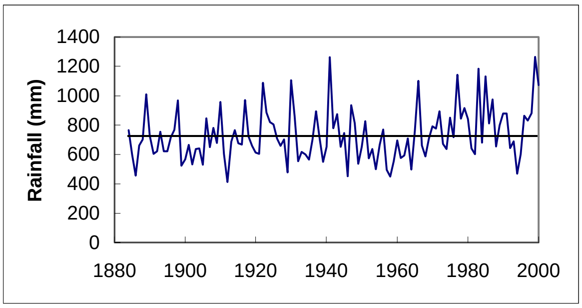
HSM - Replicate 4



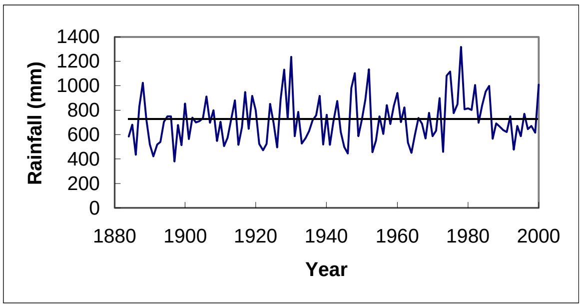
ARM - Replicate 14



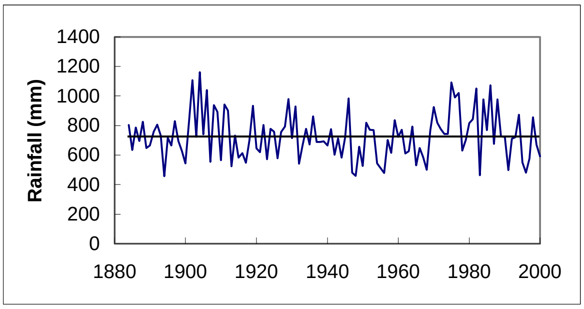
HSM - Replicate 17



ARM - Replicate 69

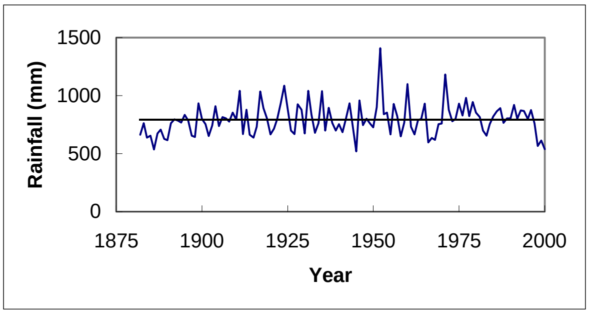


HSM - Replicate 46

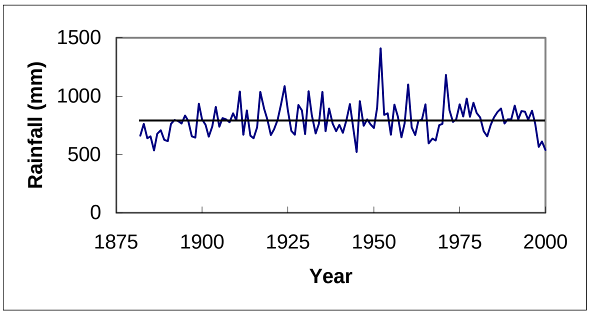


ARM - Replicate 66

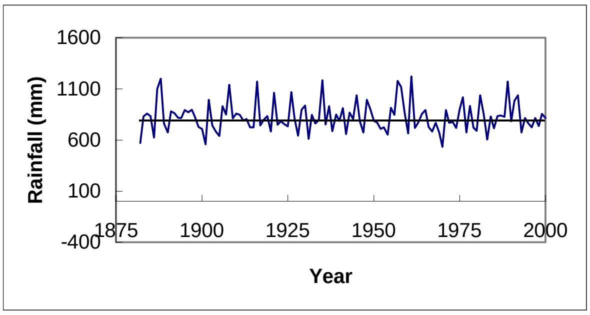
Figure D18. Time series plots of historical and three replicates of generated data from HSM and AR models for Kilmore.



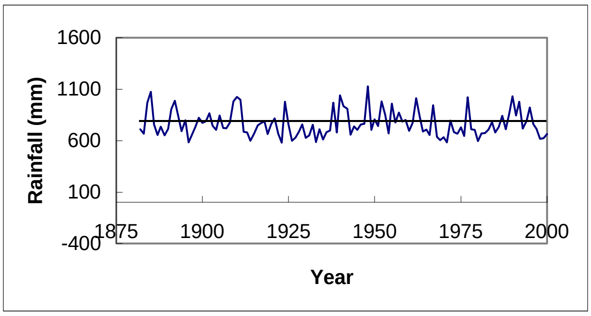
Historical



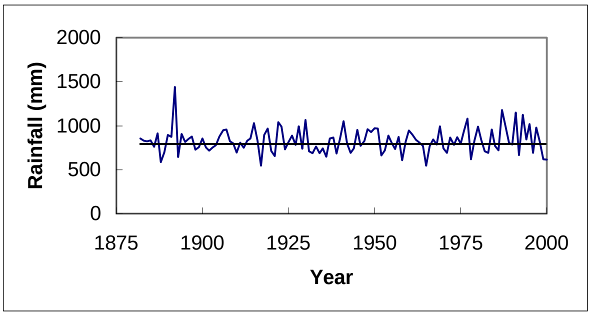
Historical



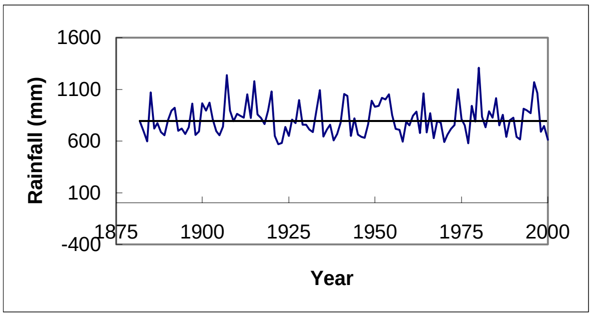
HSM - Replicate 24



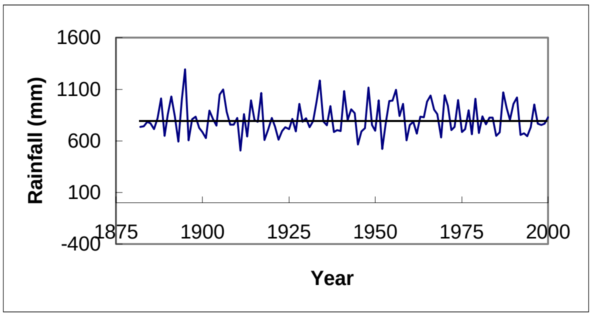
ARM - Replicate 26



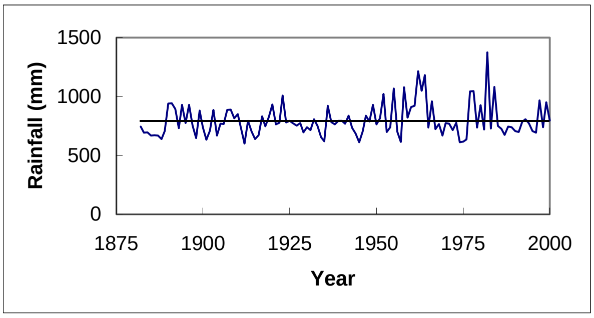
HSM - Replicate 25



ARM - Replicate 8

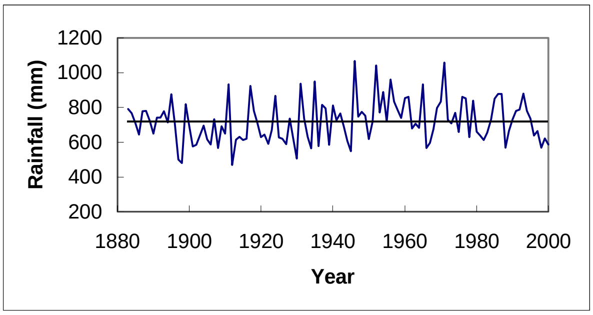


HSM - Replicate 83

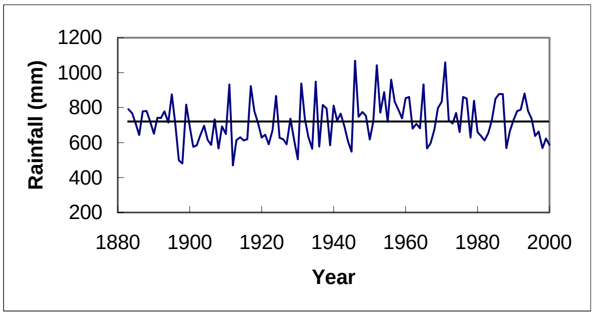


ARM - Replicate 24

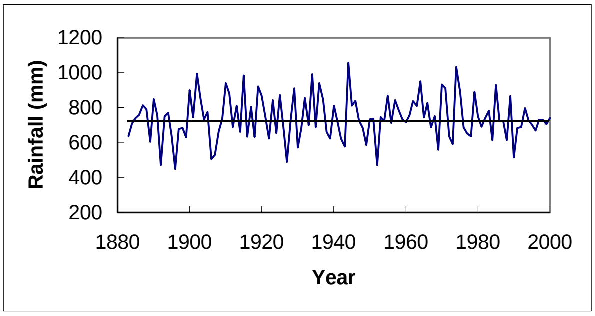
Figure D19. Time series plots of historical and three replicates of generated data from HSM and AR models for Pennyroyal Creek.



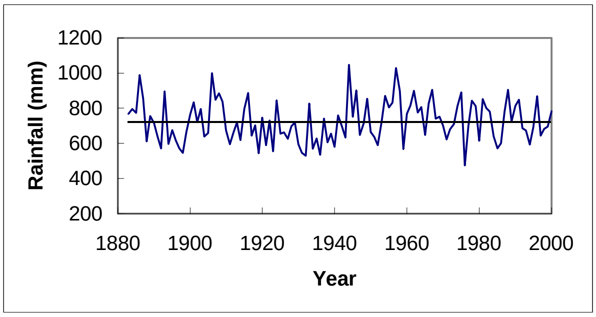
Historical



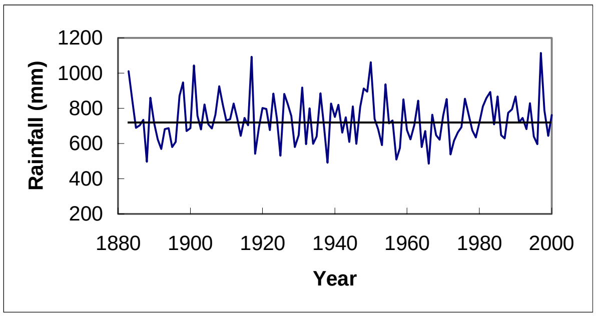
Historical



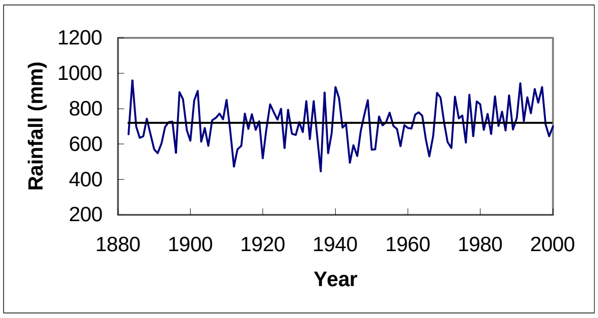
HSM - Replicate 30



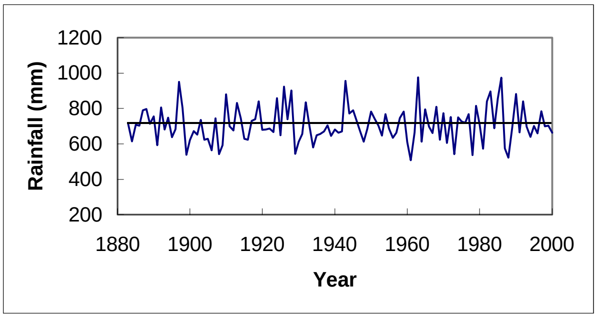
ARM - Replicate 38



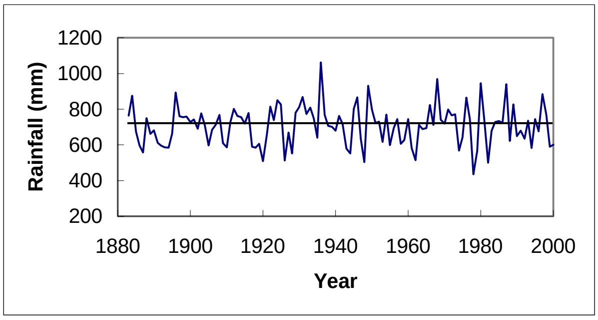
HSM - Replicate 85



ARM - Replicate 92

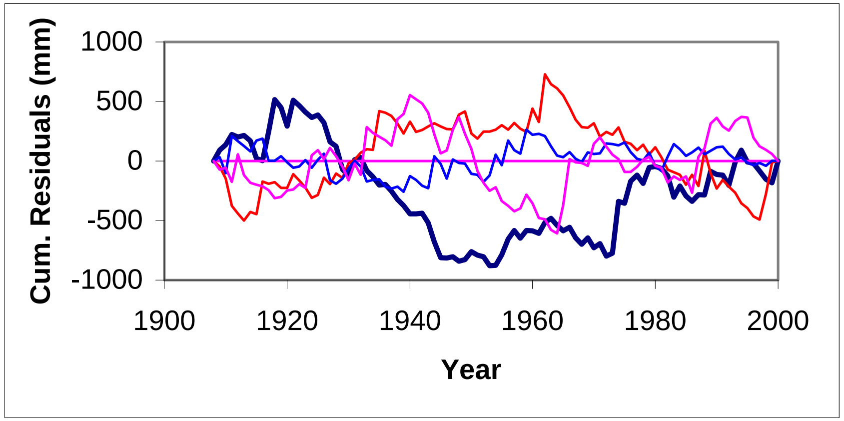


HSM - Replicate 40

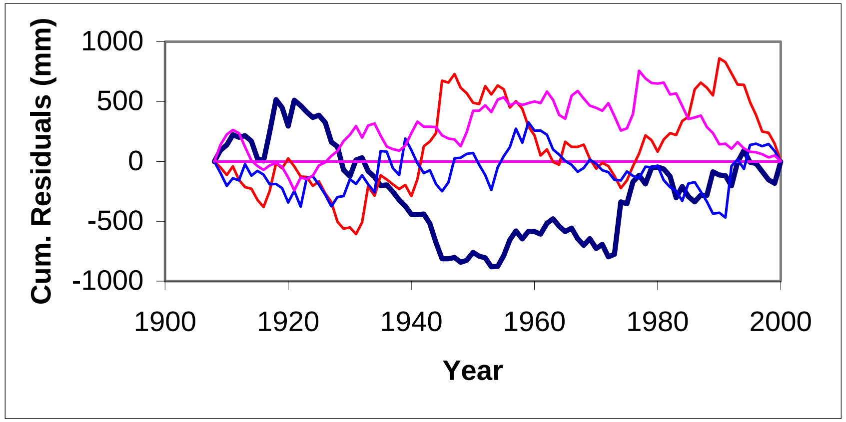


ARM - Replicate 48

Figure D20. Time series plots of historical and three replicates of generated data from HSM and AR models for Penshurst.

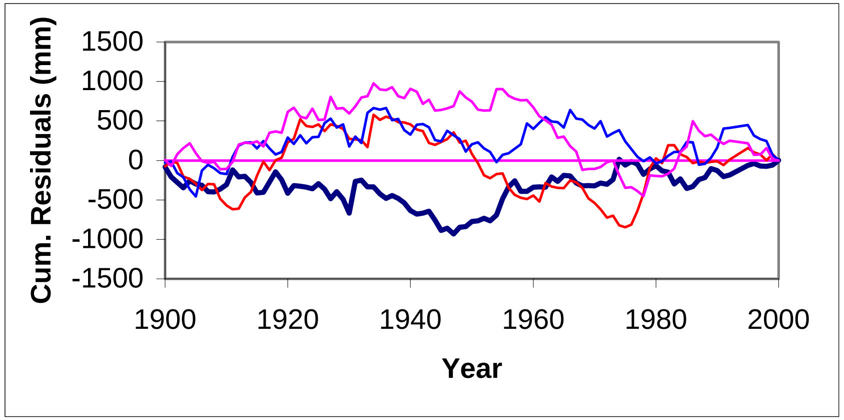


HSM

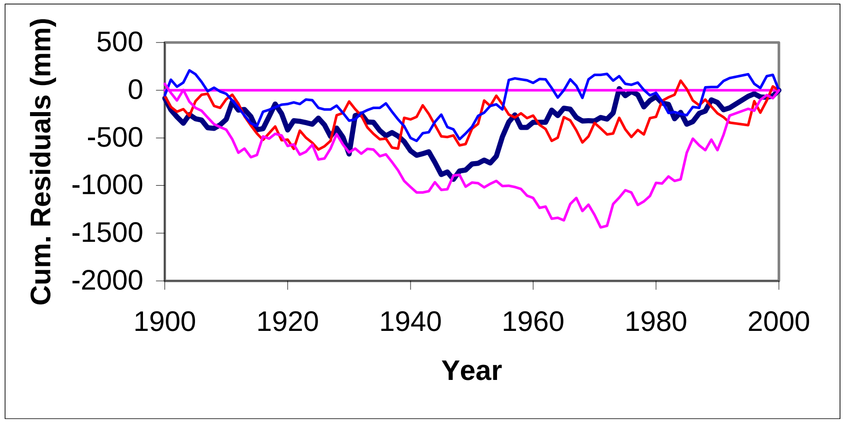


ARM

Figure D21. Residual mass curves for the historical and historical and three replicates for Irymple

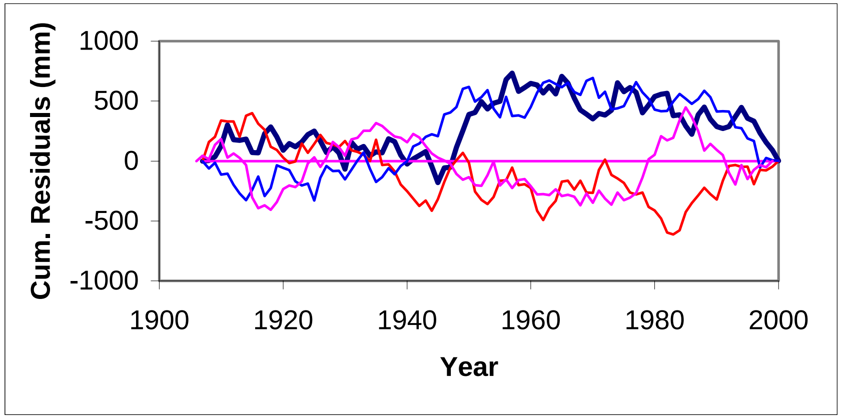


HSM



ARM

Figure D22. Residual mass curves for the three replicates for Beulah.



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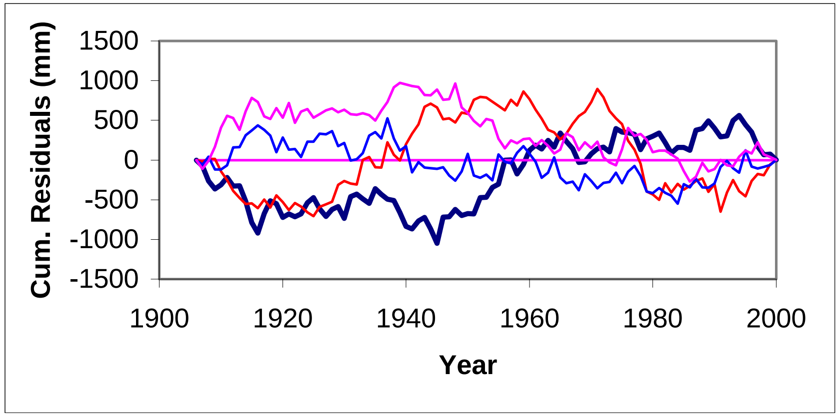

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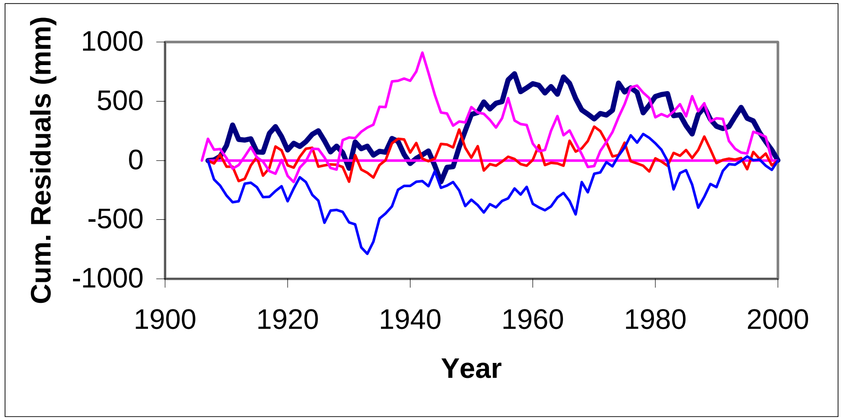

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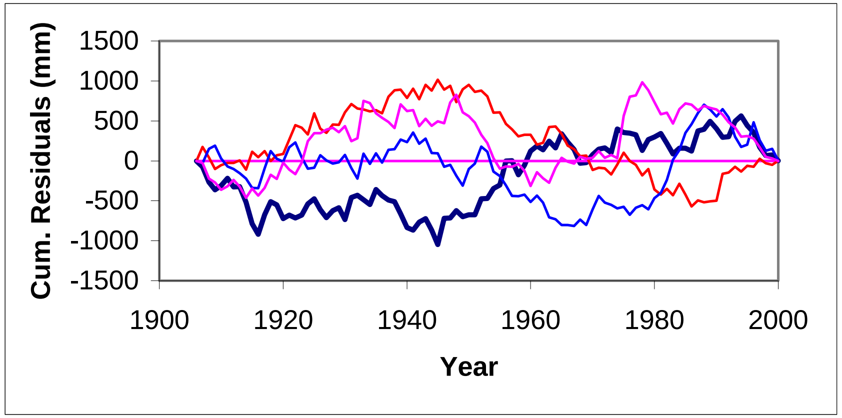
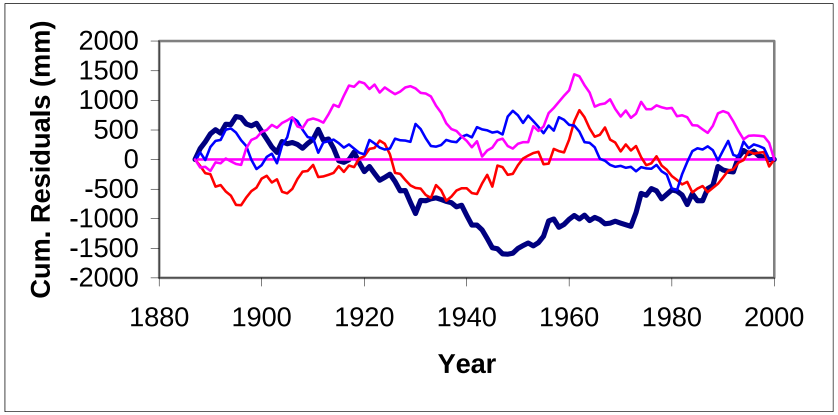


ARM

Figure D23. Residual mass curves for the historical and three replicates for Natimuk

Figure D24. Residual mass curves for the historical and three replicates for Moyston.



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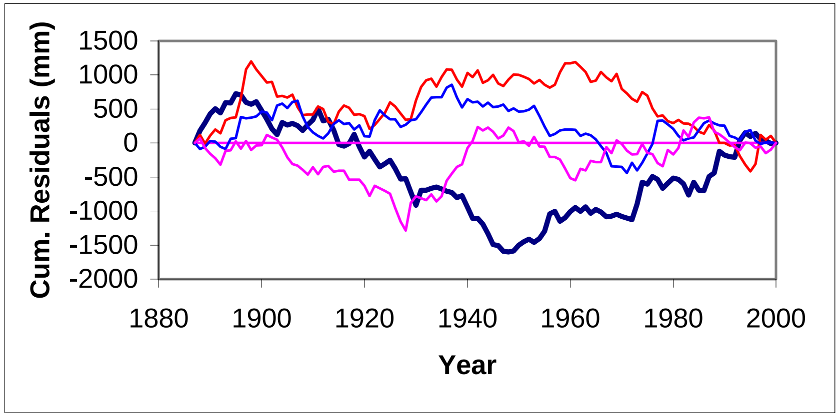

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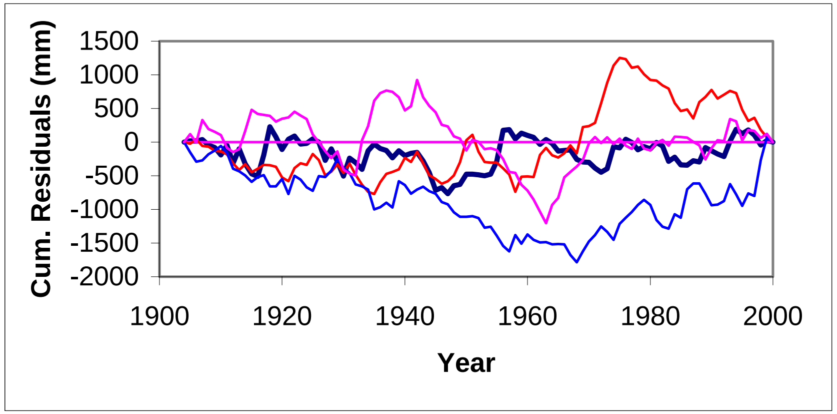
Figure D25. Residual mass curves for the historical and historical and three replicates for St Arnaud



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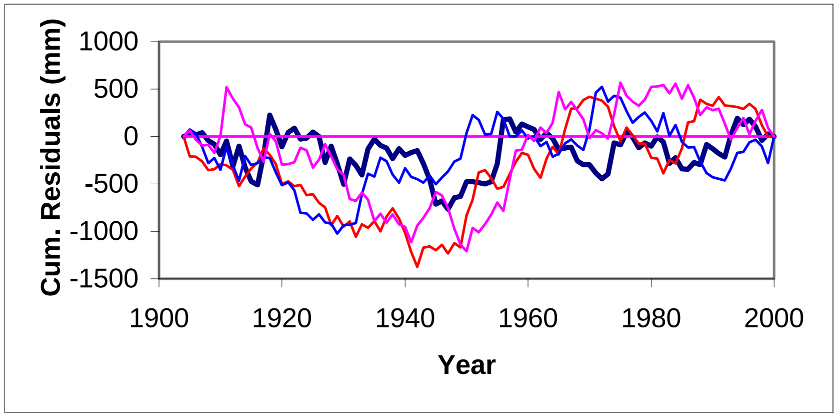
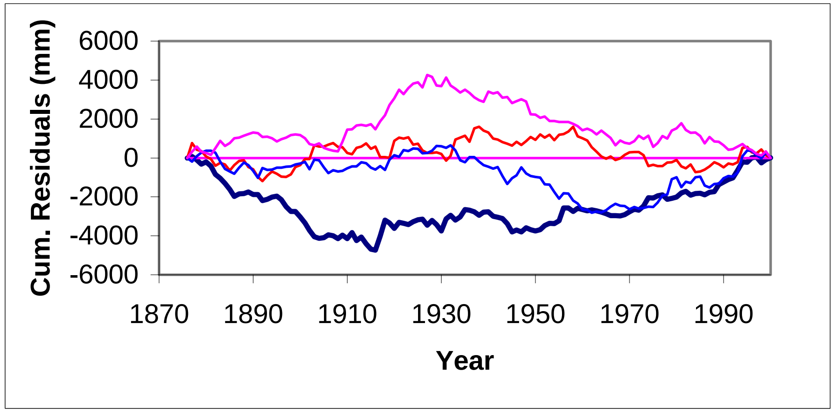


ARM

Figure D26. Residual mass curves for the three replicates for Caniambo.



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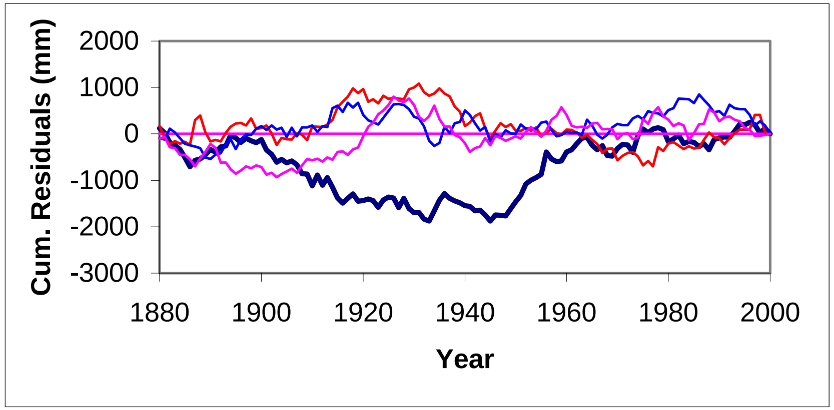

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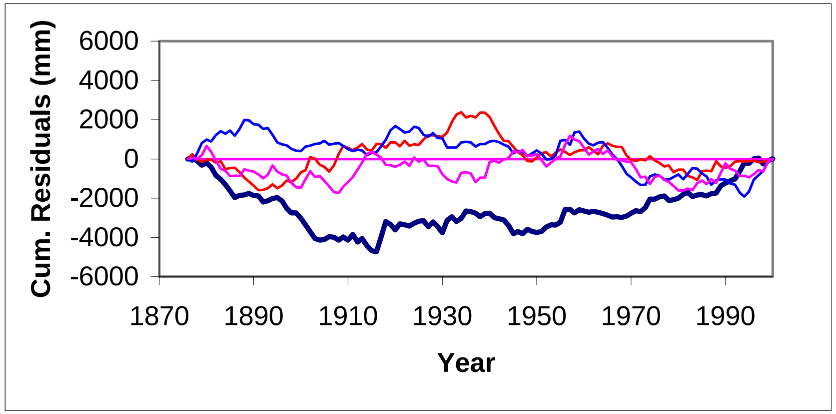

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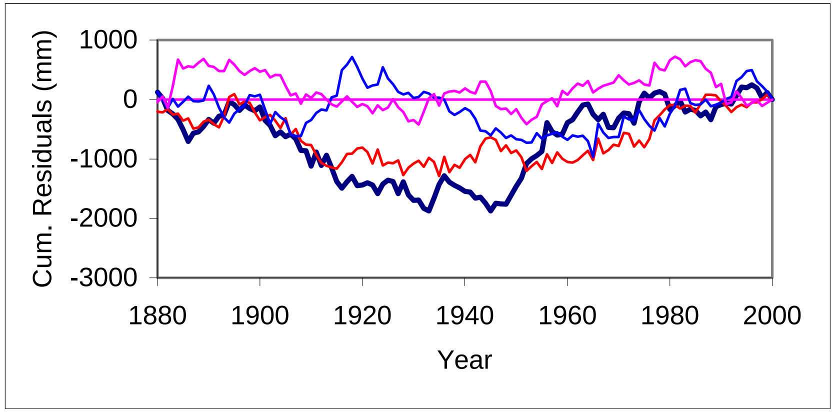
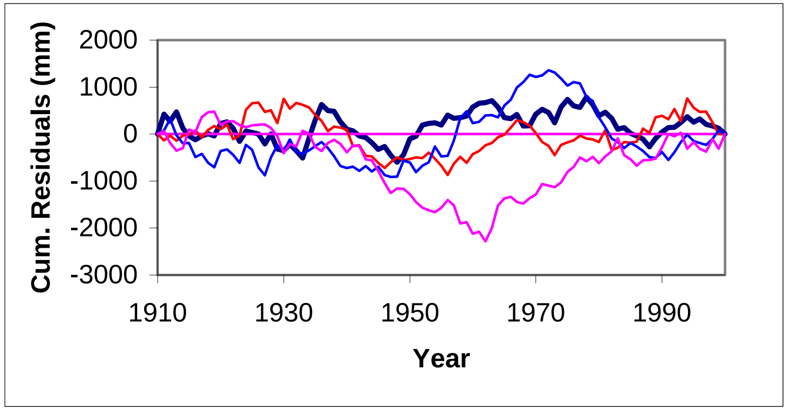


ARM

Figure D27. Residual mass curves for the historical and historical and three replicates for Beechworth.

Figure D28. Residual mass curves for the three replicates for Omeo.



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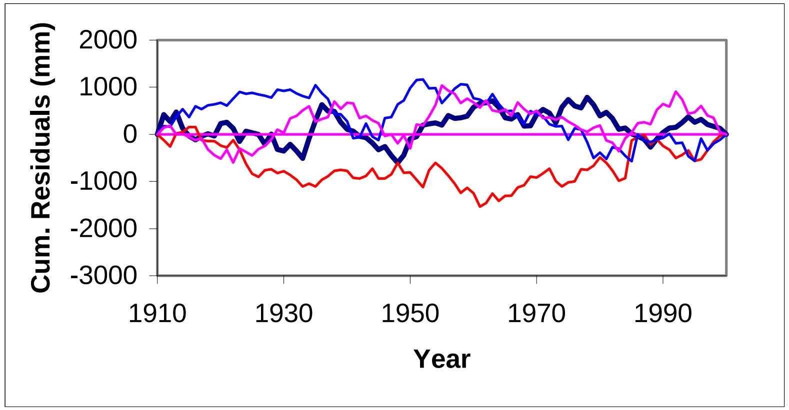

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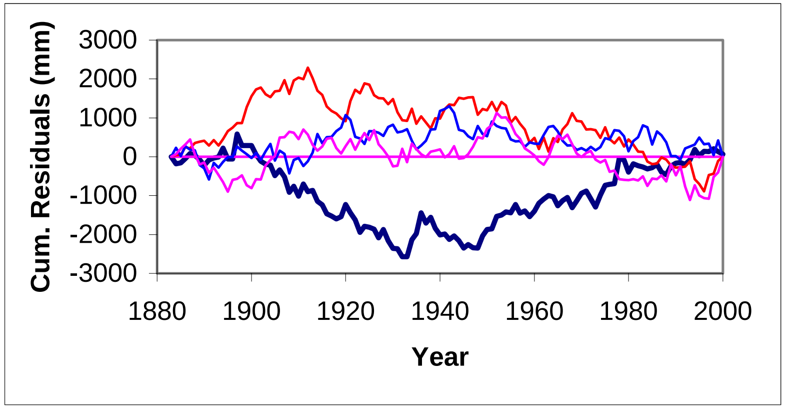
Figure D29. Residual mass curves for the historical and historical and three replicates for Ensay.



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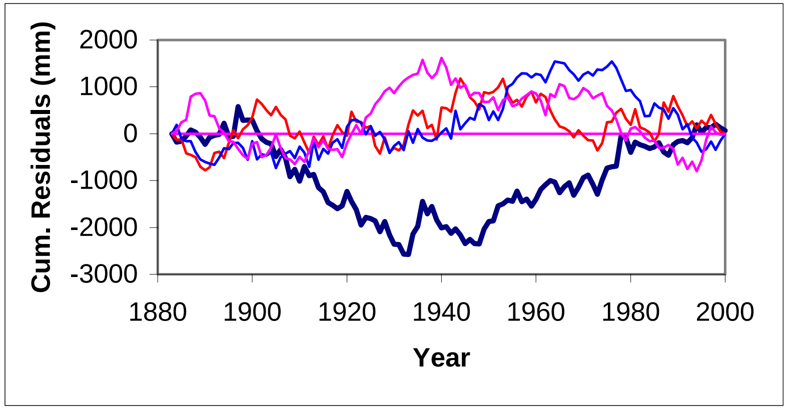
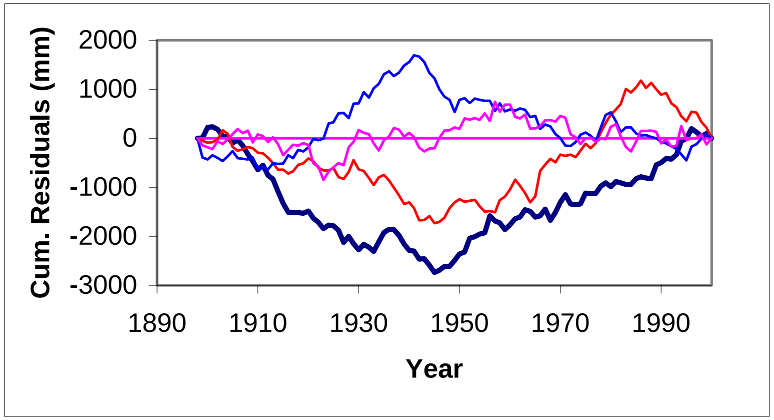


ARM

Figure D30. Residual mass curves for the three replicates for Orbost.



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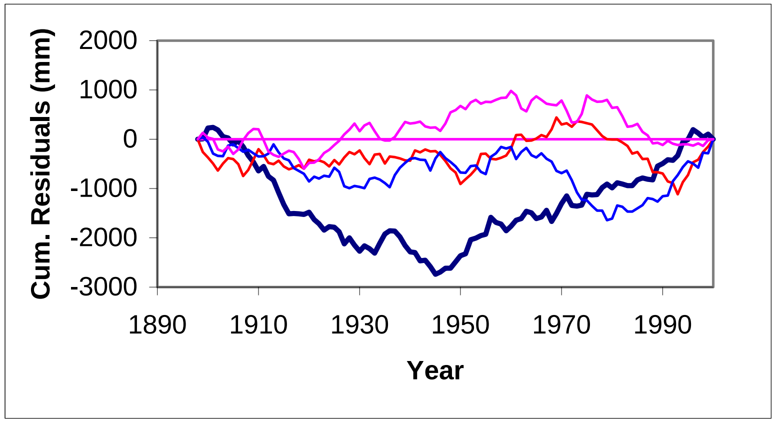
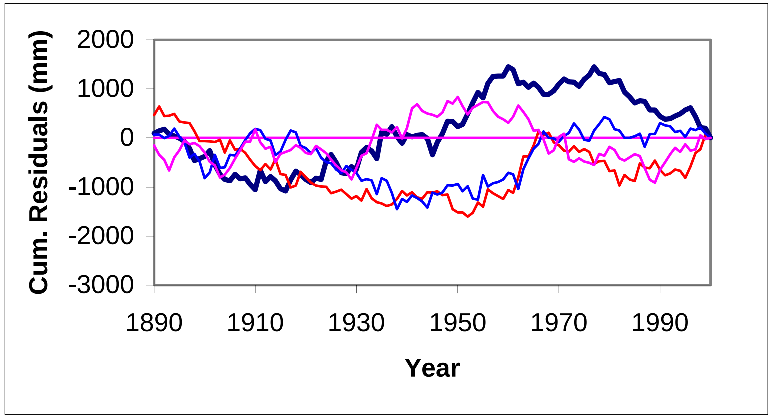


ARM

Figure D31. Residual mass curves for the historical and historical and three replicates for Seaspray.



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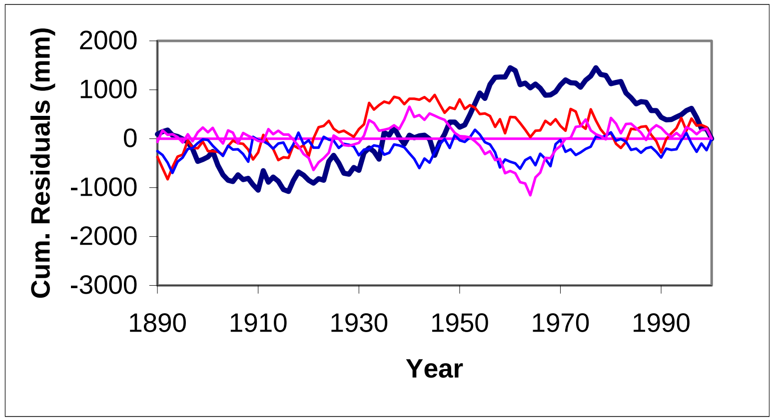
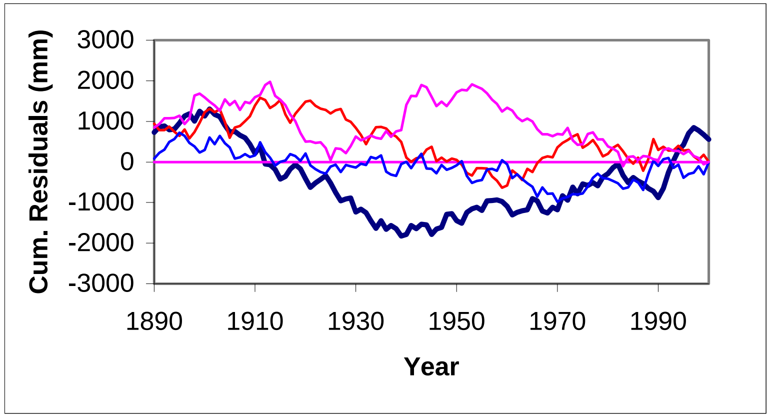


ARM

Figure D32. Residual mass curves for the three replicates for Warragul.



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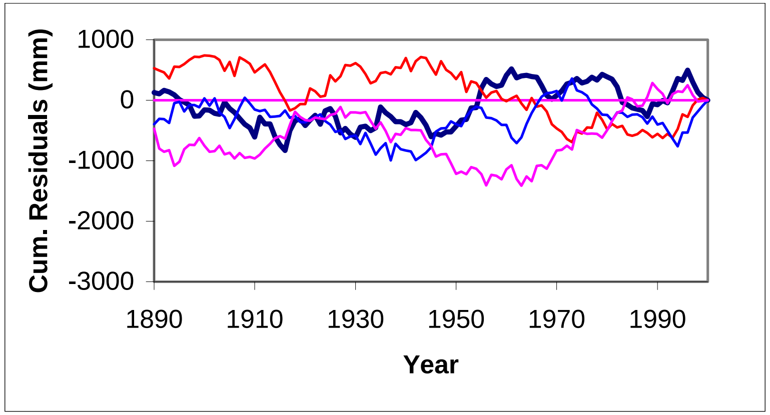

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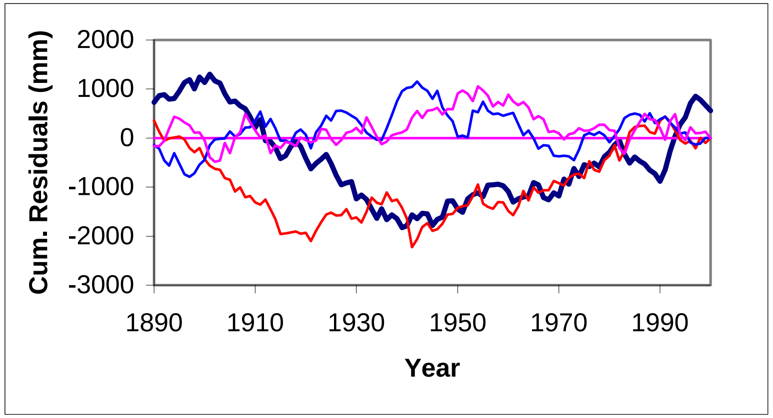

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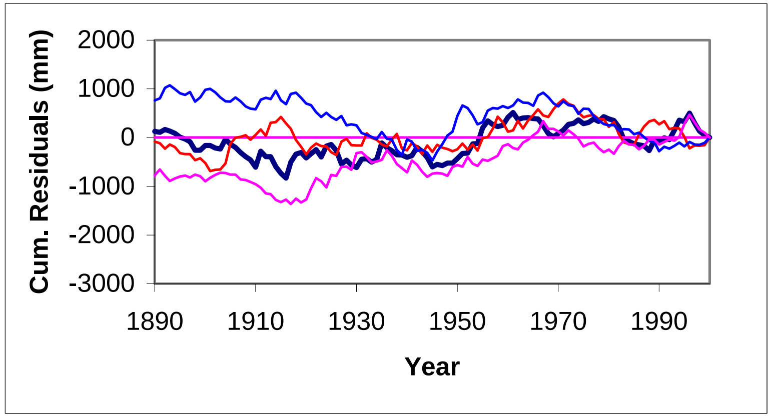
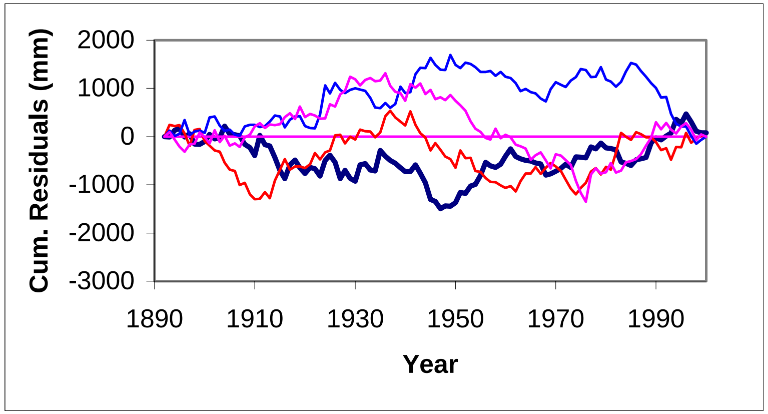


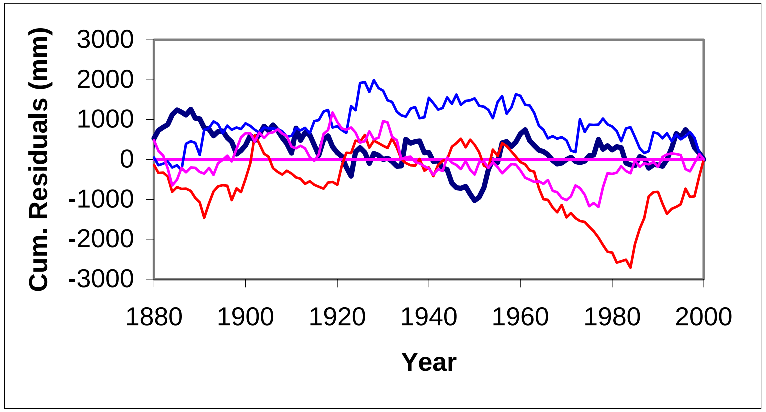
ARM

Figure D33. Residual mass curves for the historical and three replicates for Wilson's Promontory

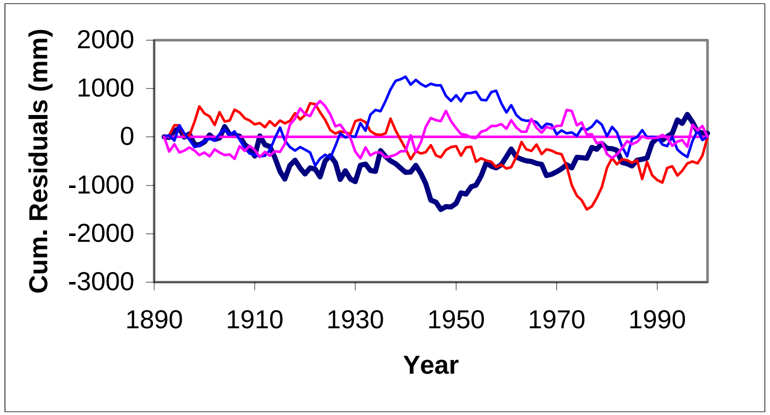
Figure D34. Residual mass curves for the historical and three replicates for Melbourne.



HSm



HSM



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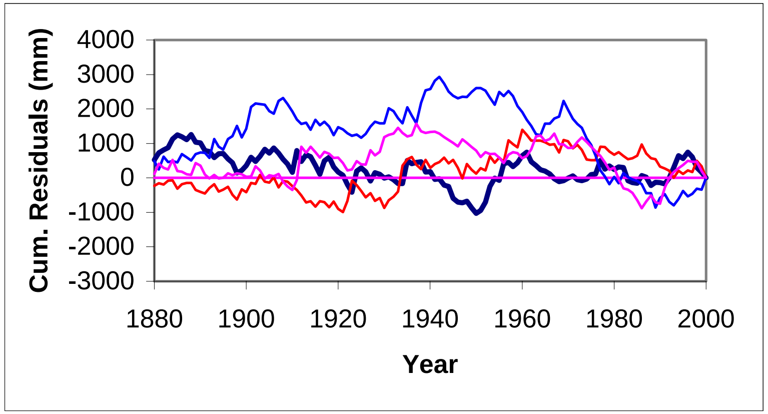
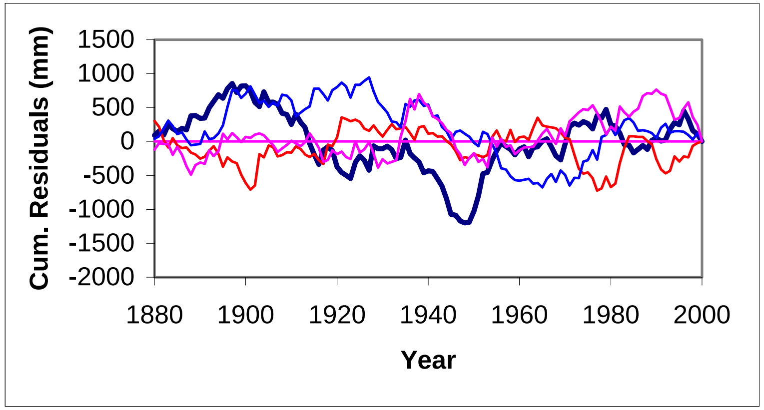


ARM

Figure D35. **Residual mass curves for the historical and three replicates for Toorourrong**

Figure D36. **Residual mass curves for the historical and three replicates for Warburton.**



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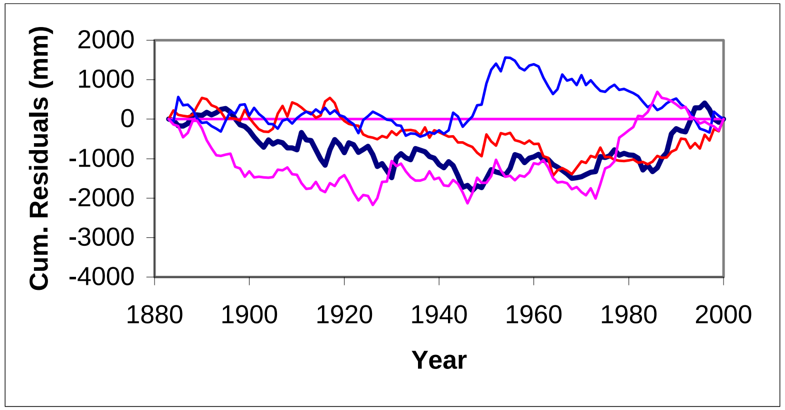

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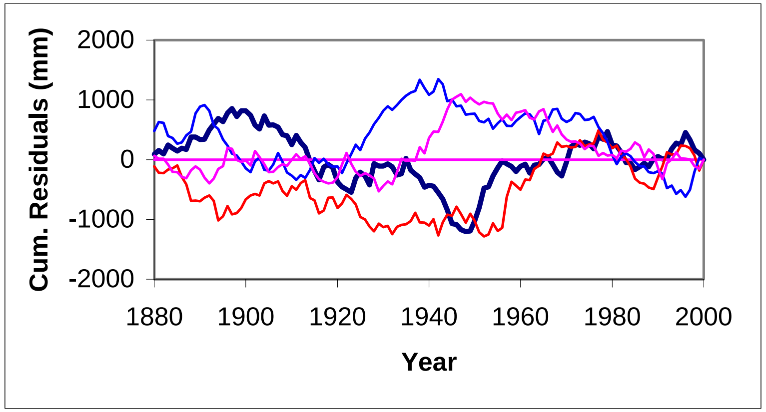
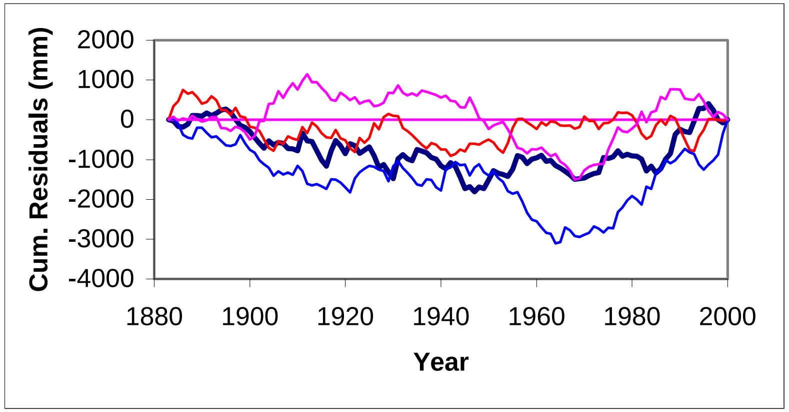


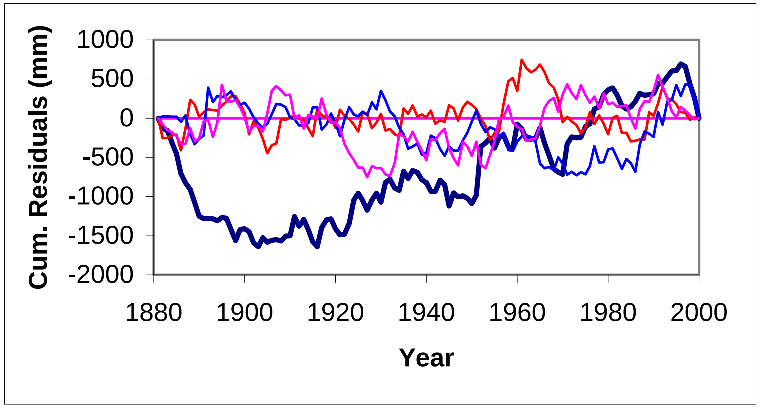
ARM



ARM

Figure D37. Residual mass curves for the historical and historical and three replicates for Meredith

Figure D38. Residual mass curves for the three replicates for Kilmore.



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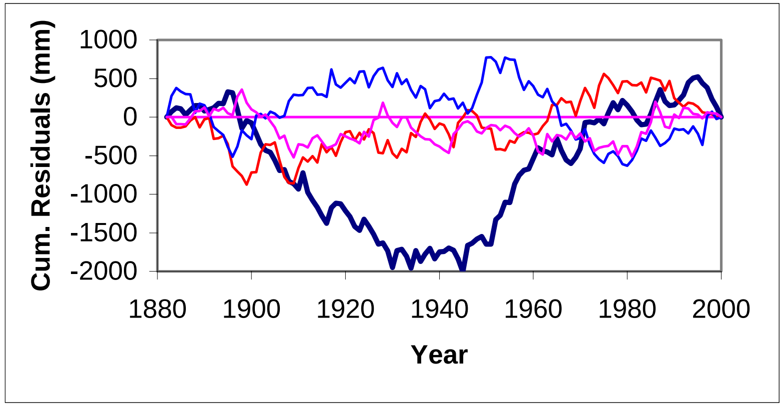

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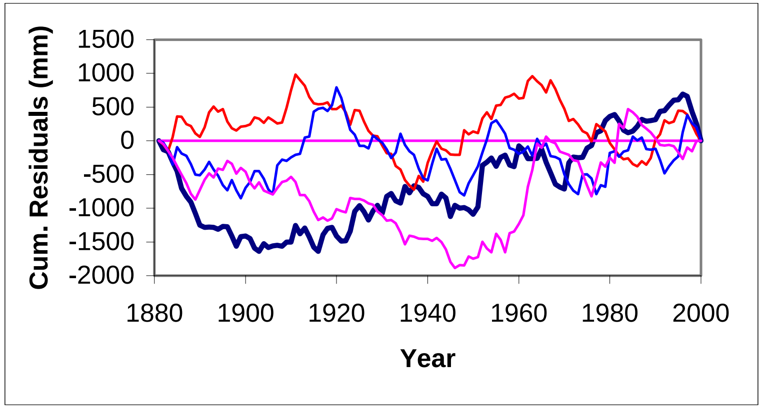
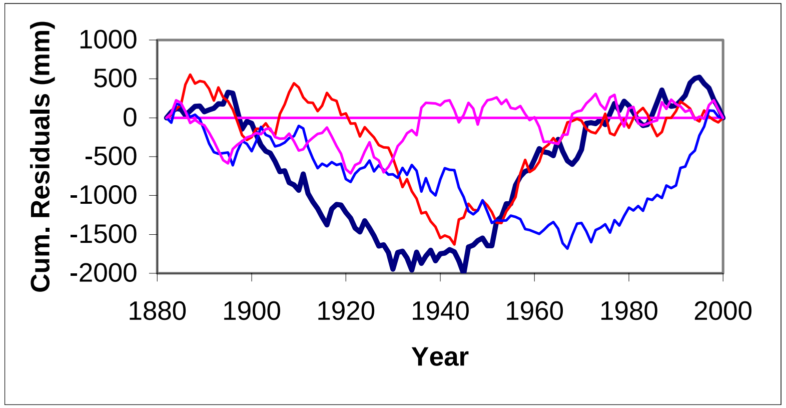


ARM



ARM

Figure D39. Residual mass curves for the historical and historical and three replicates for Pennyroyal Creek

Figure D40. Residual mass curves for the three replicates for Penshurst

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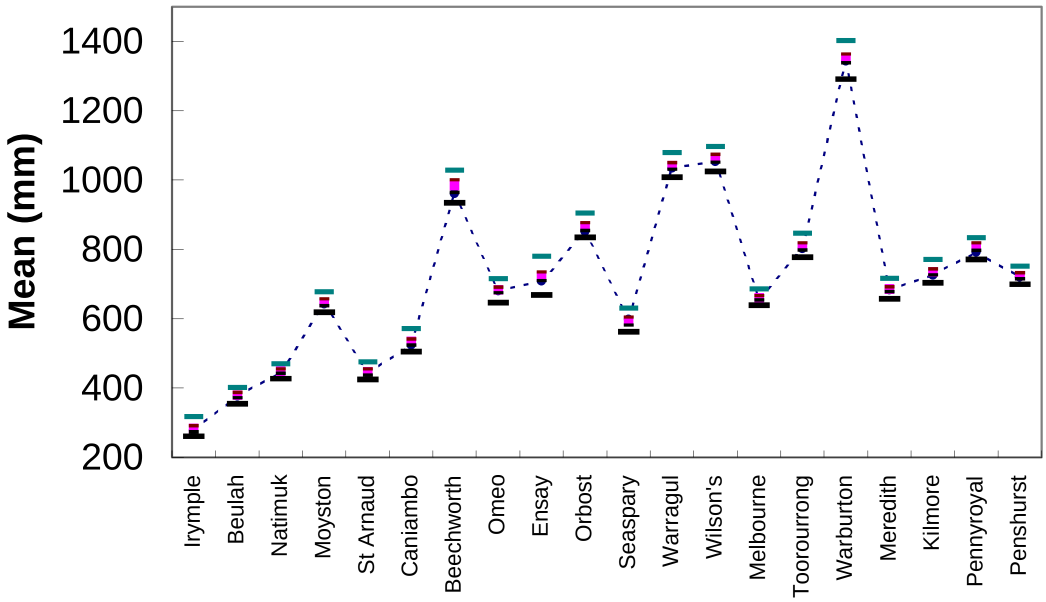
APPENDIX E

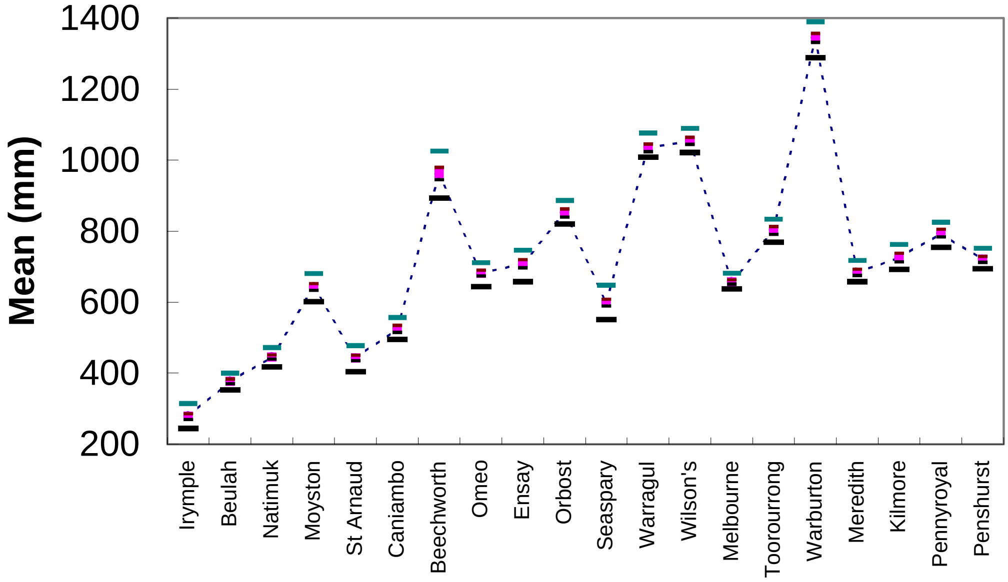
COMPARISON OF OBSERVED AND GENERATED PARAMETERS

The symbols used in the figures are:

—	Maximum
–	75^{th} percentile
•	Mean
■	Observed value
–	25^{th} percentile
—	Minimum



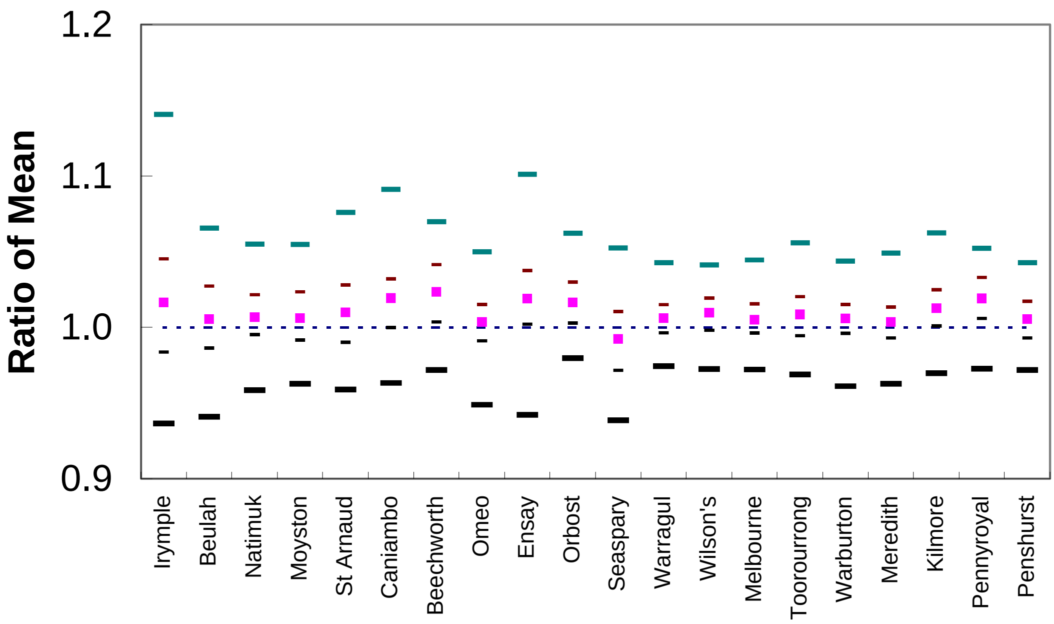
(i) HSM



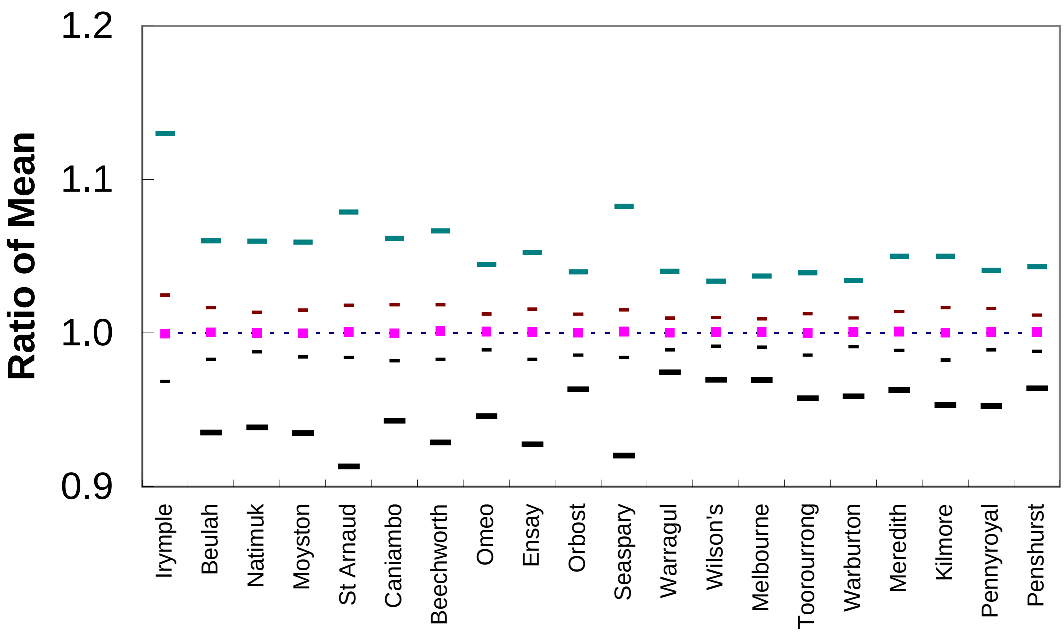
(ii) ARM

(a) Actual values

Figure E1. Comparison of observed and generated mean annual rainfall.



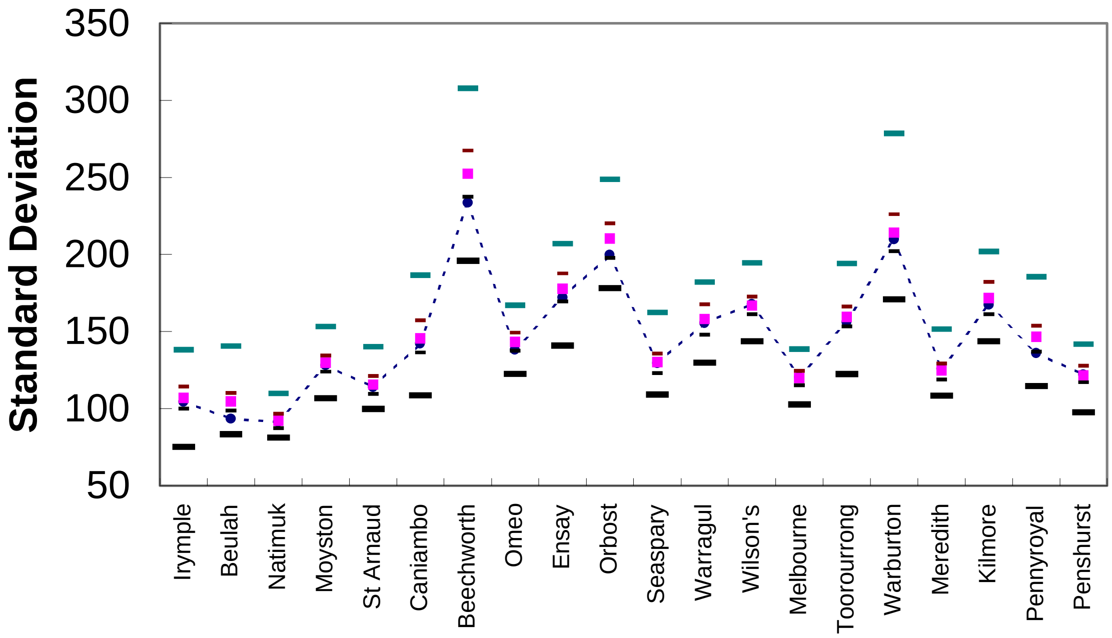
(i) HSM



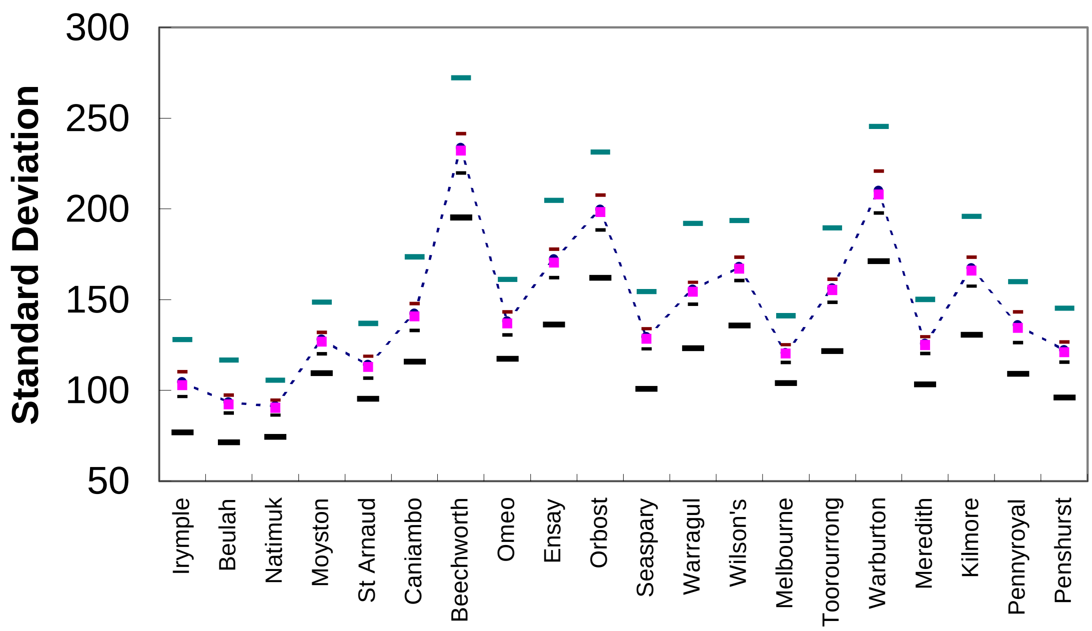
(ii) ARM

(b) Standardised by dividing by the mean

Figure E1 (Cont)



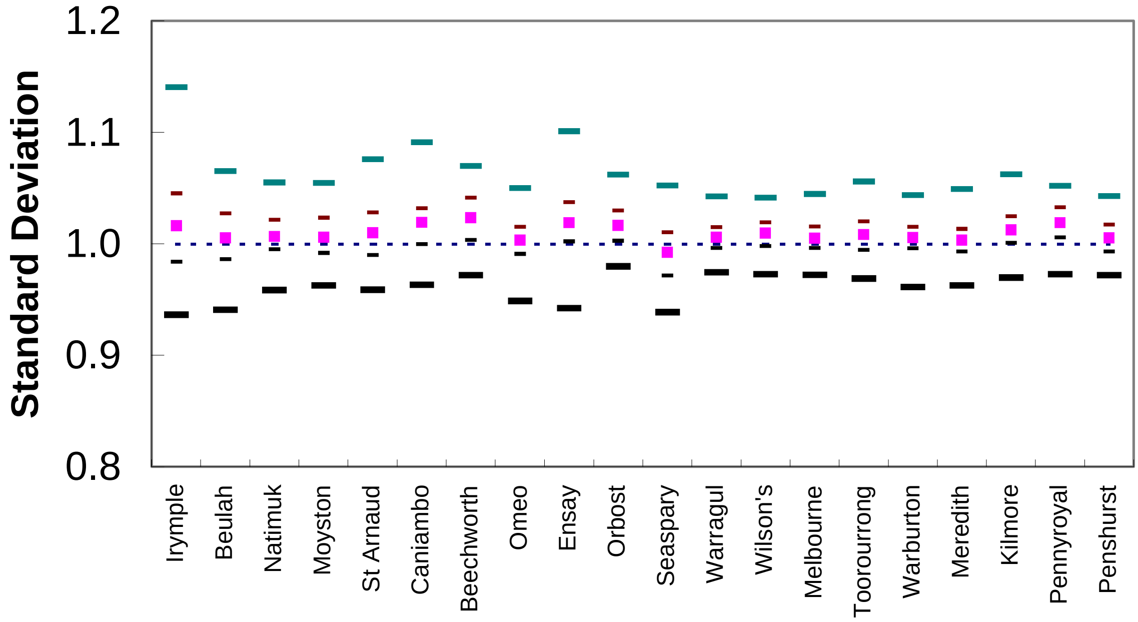
(i) HSM



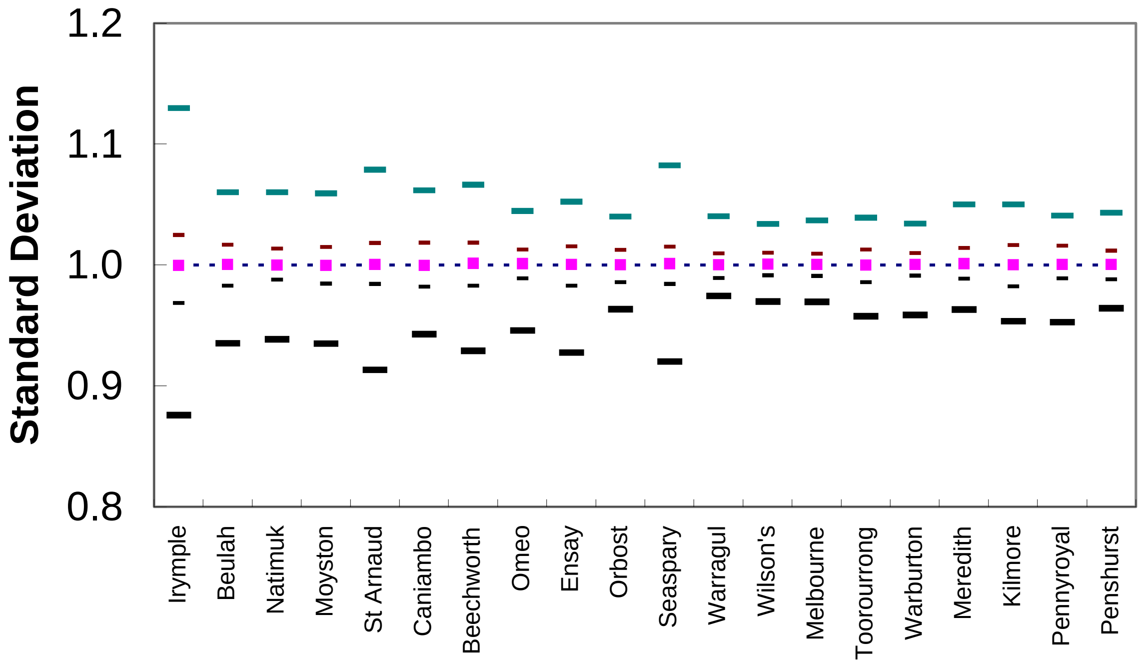
(ii) ARM

(a) Actual values

Figure E2. Comparison of observed and generated standard deviations of annual rainfall



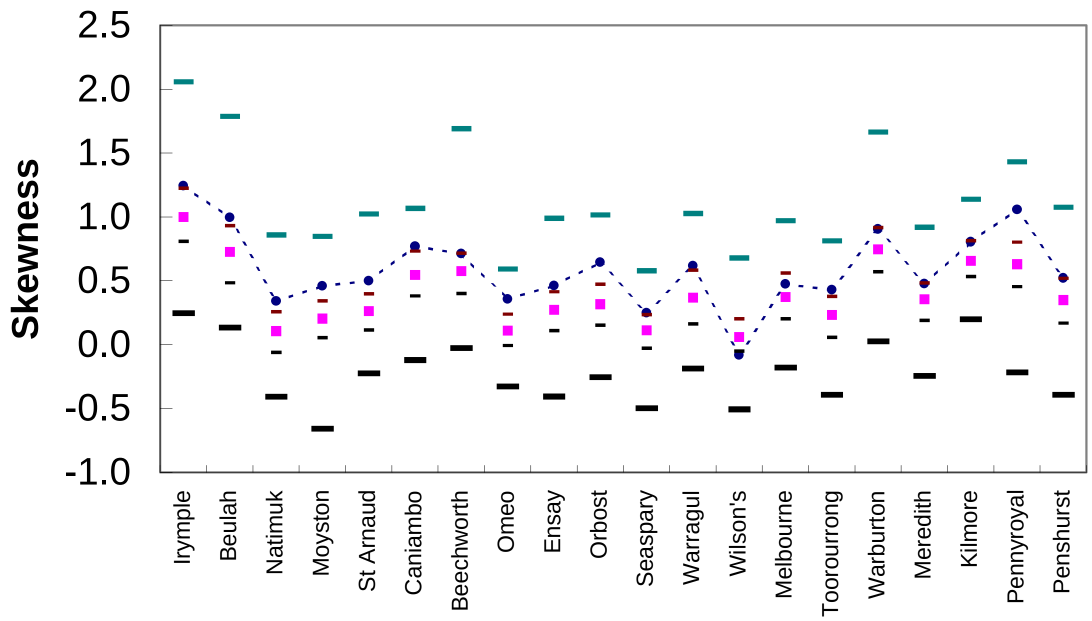
(i) HSM



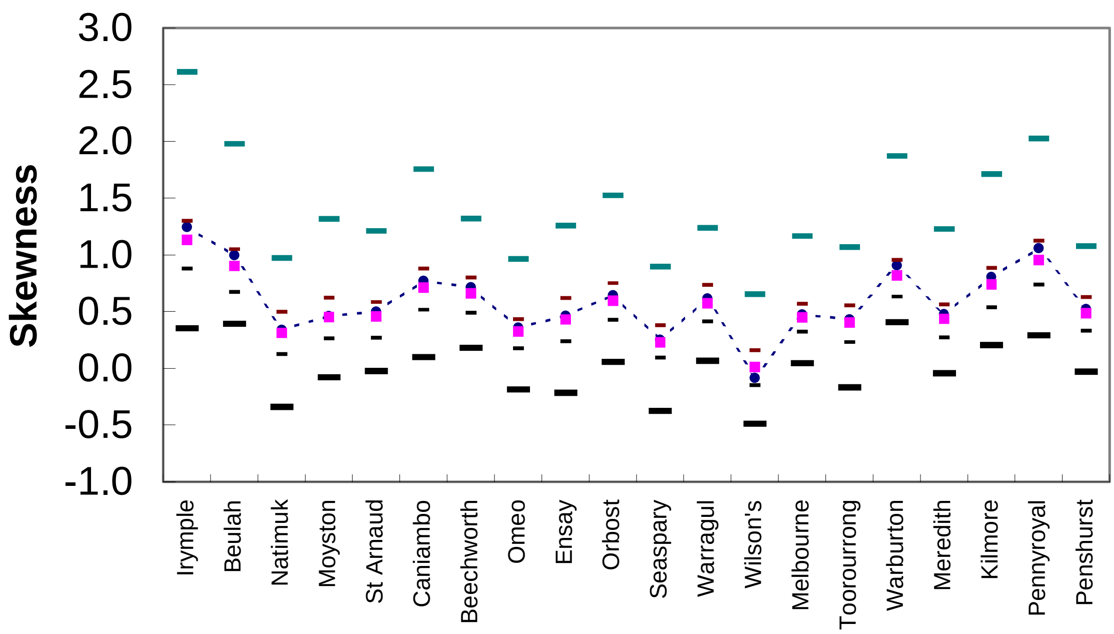
(ii) ARM

(b) Standardised by divided by the observed standard deviation

Figure E2. (Cont)

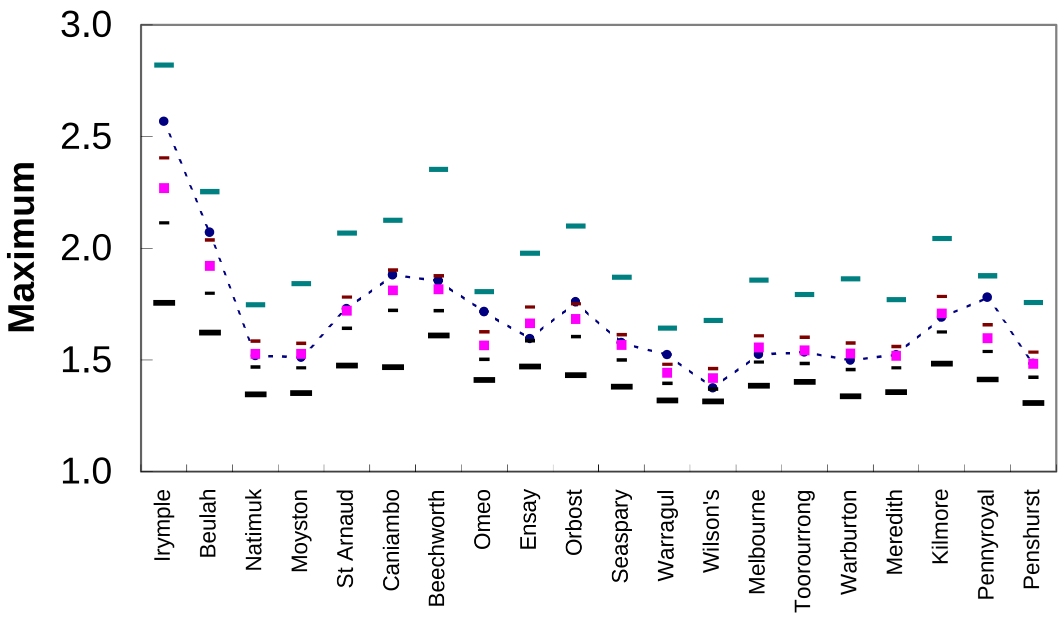


(i) HSM

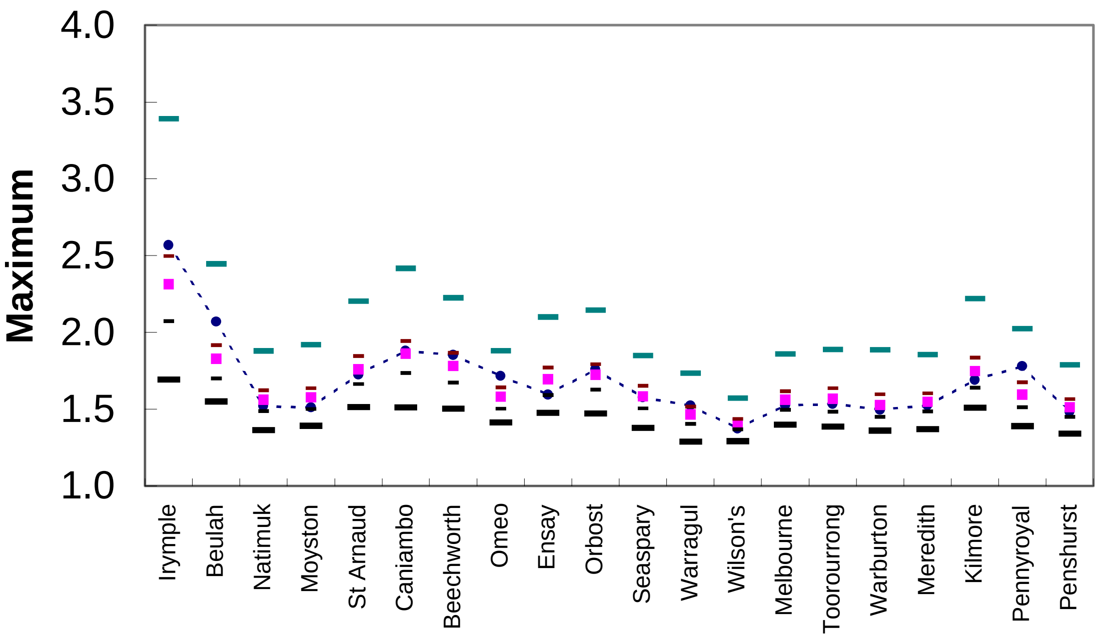


(ii) ARM

Figure E3. Comparison of observed and generated coefficient of skewness of annual rainfall.



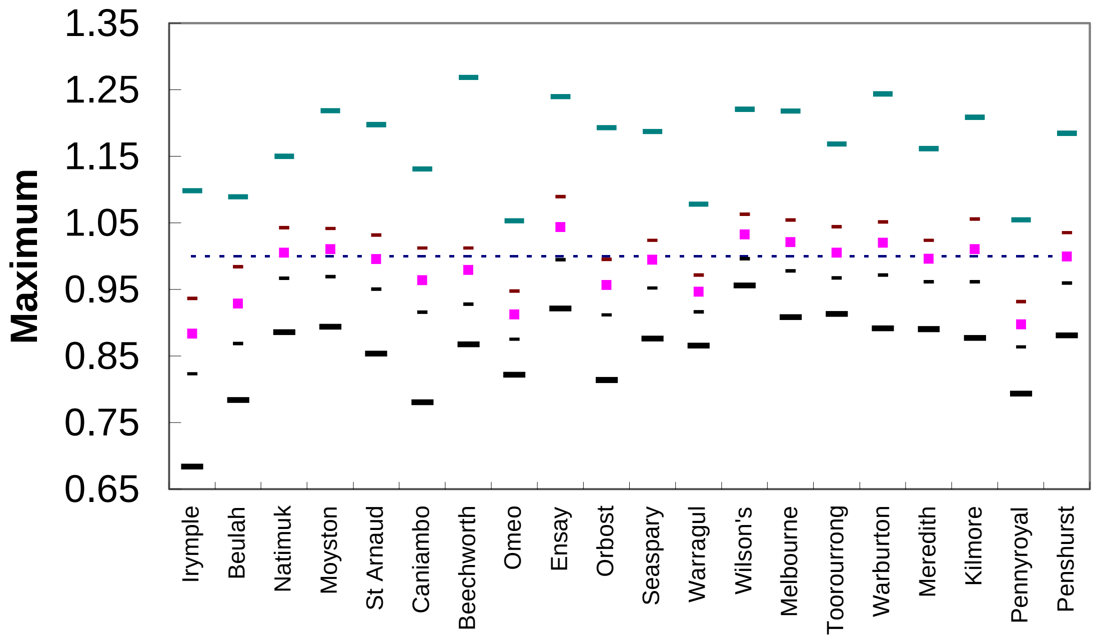
(i) HSM



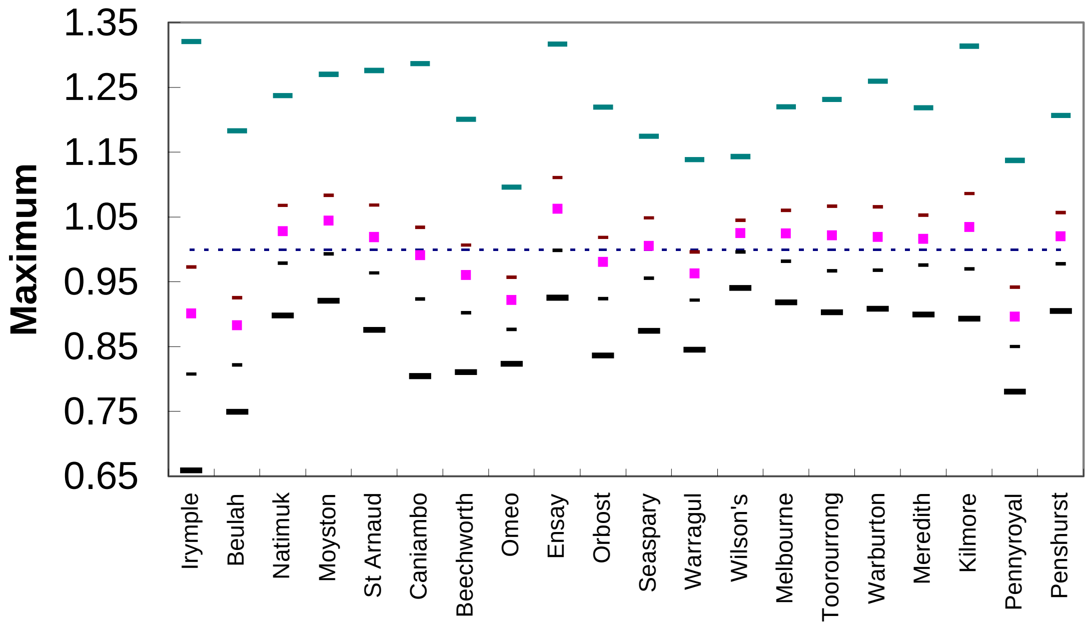
(ii) ARM

(a) Standardised by dividing by the observed mean annual rainfall

Figure E4. Comparison of observed and generated values of maximum annual rainfall.



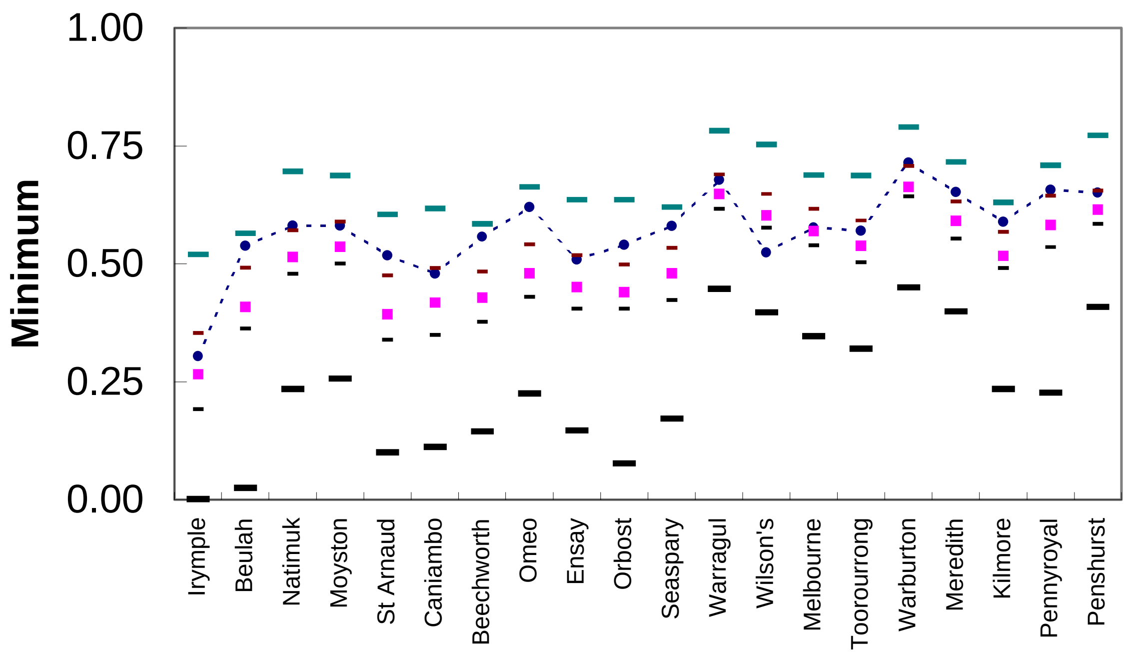
(i) HSM



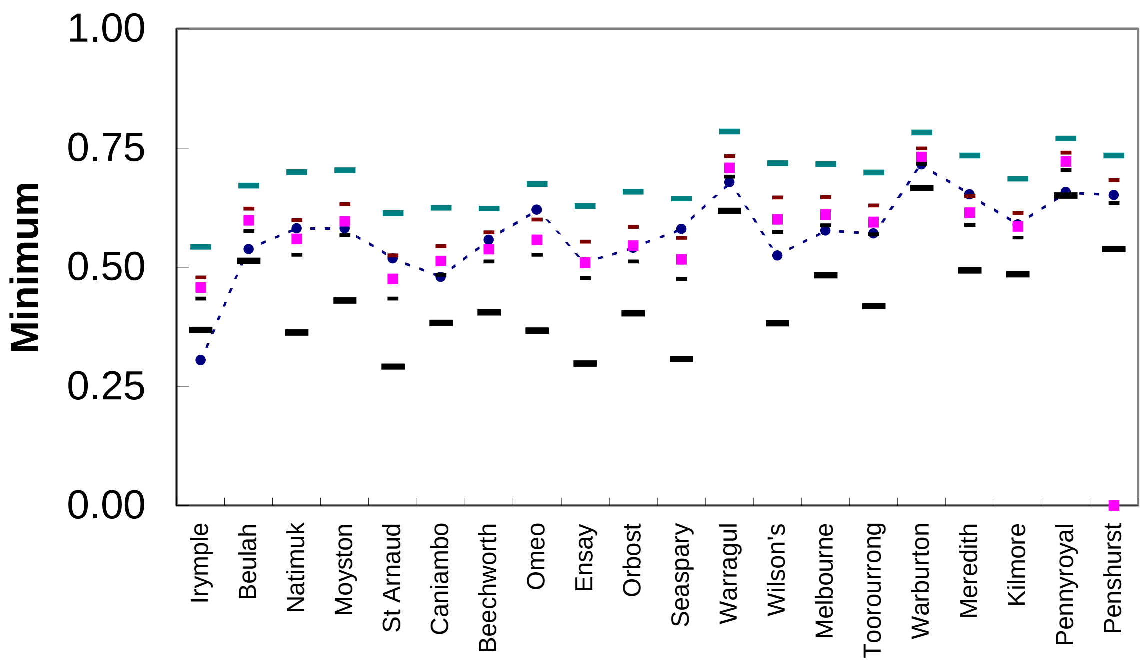
(ii) ARM

(b) Standardised by dividing by the observed maximum value

Figure E4. (Cont)



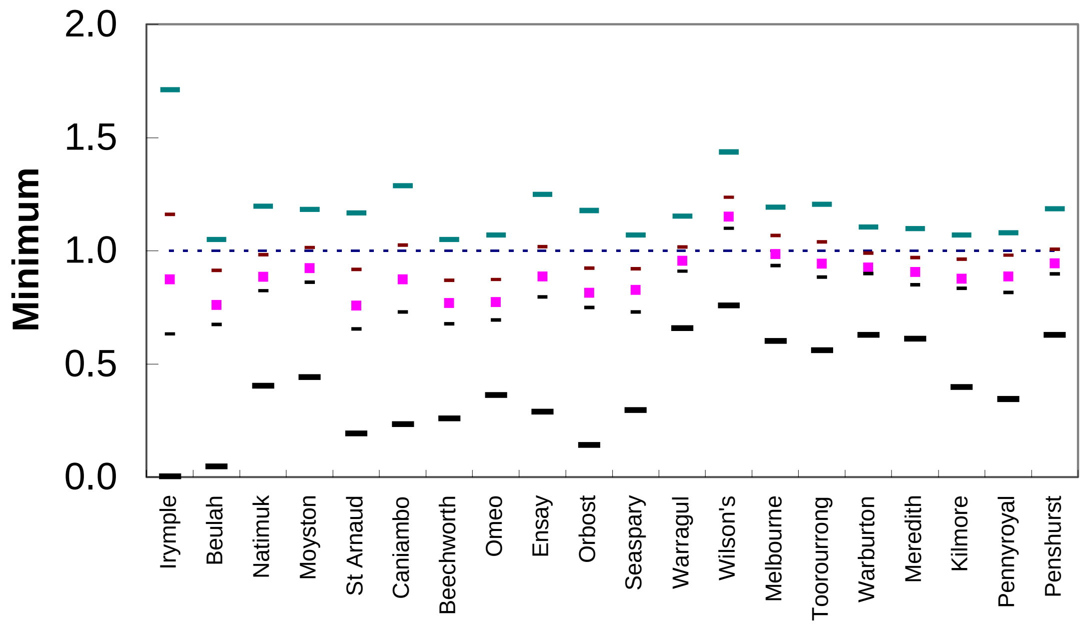
(i) HSM



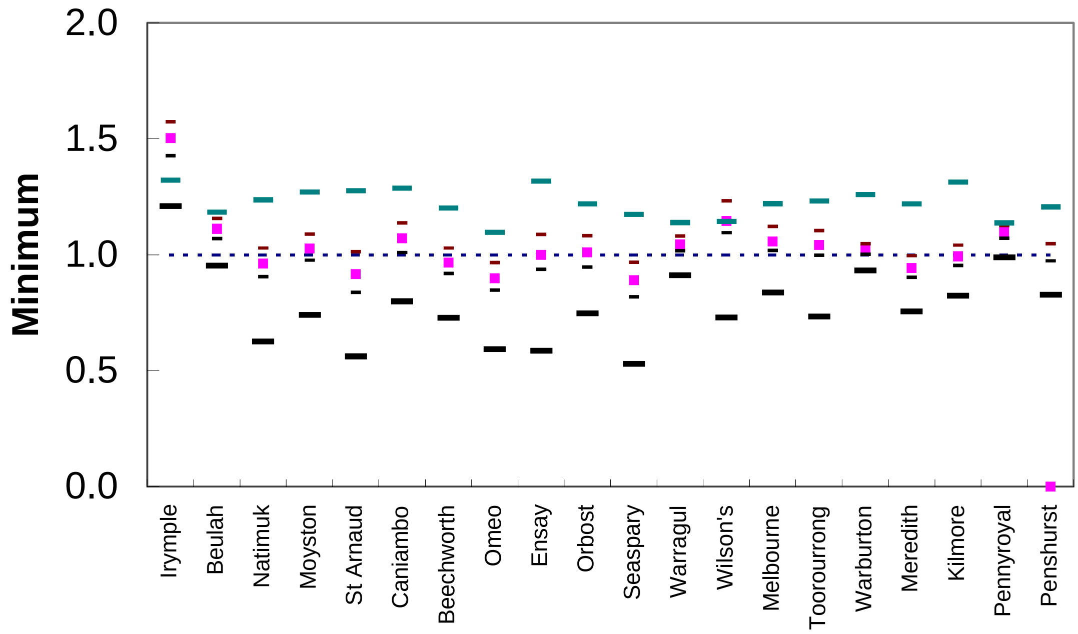
(ii) ARM

(a) Standardised by dividing by the observed mean annual rainfall

Figure E5. Comparison of observed and generated minimum annual rainfall



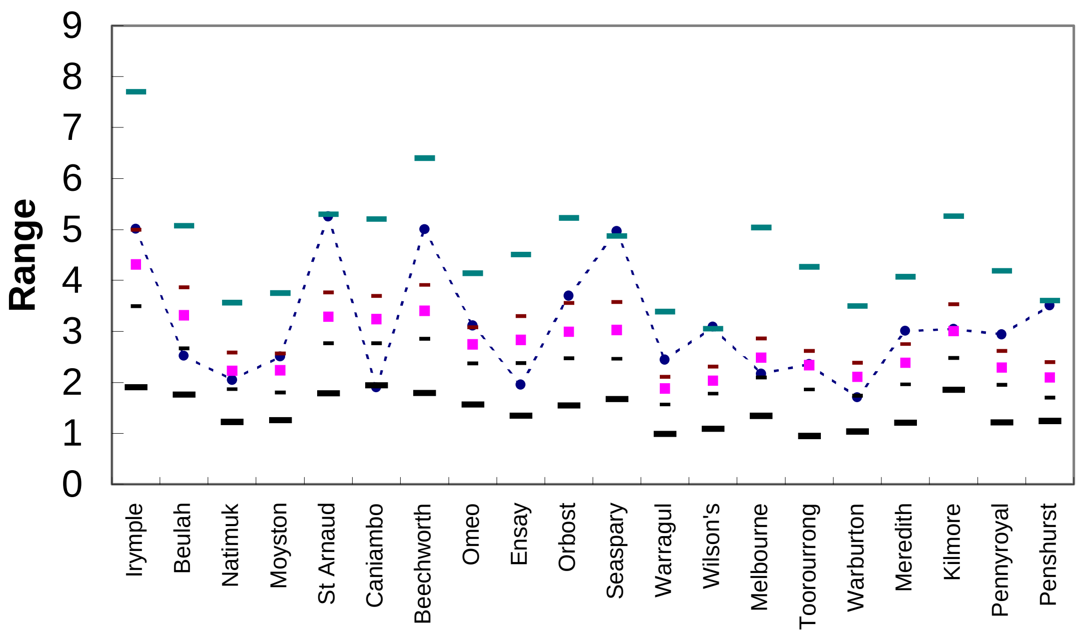
(i) HSM



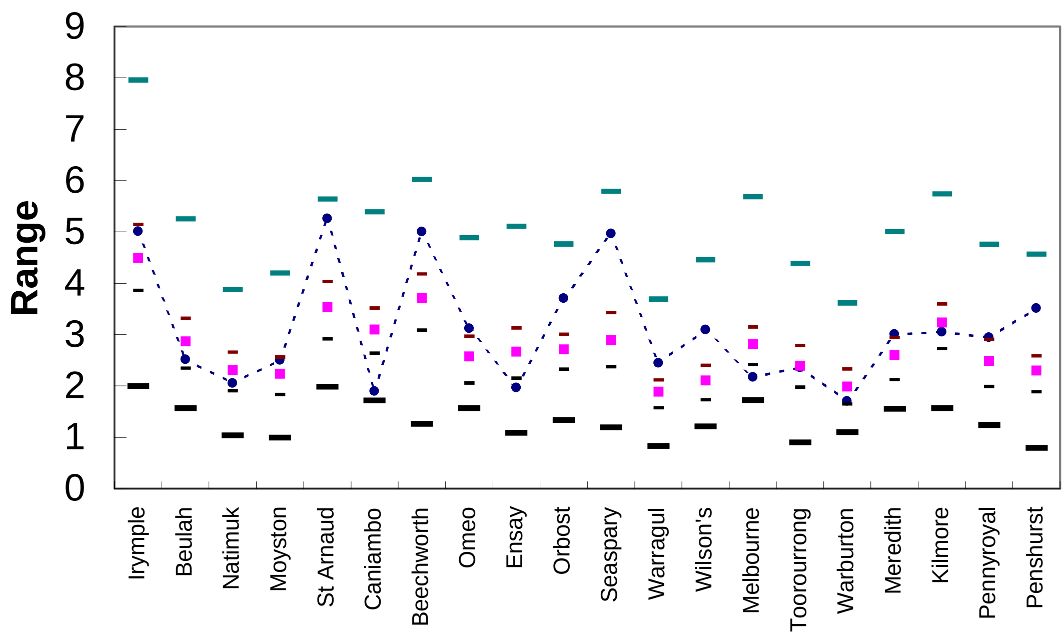
(ii) ARM

(b) Standardised by dividing by the observed minimum annual rainfall

Figure E5. (Cont)

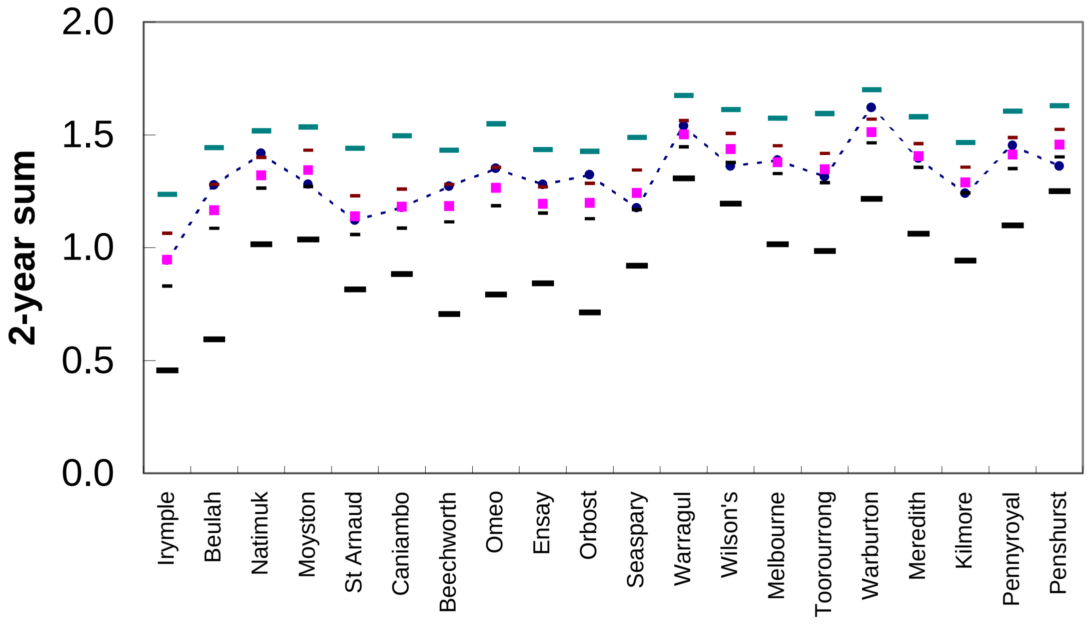


(i) HSM

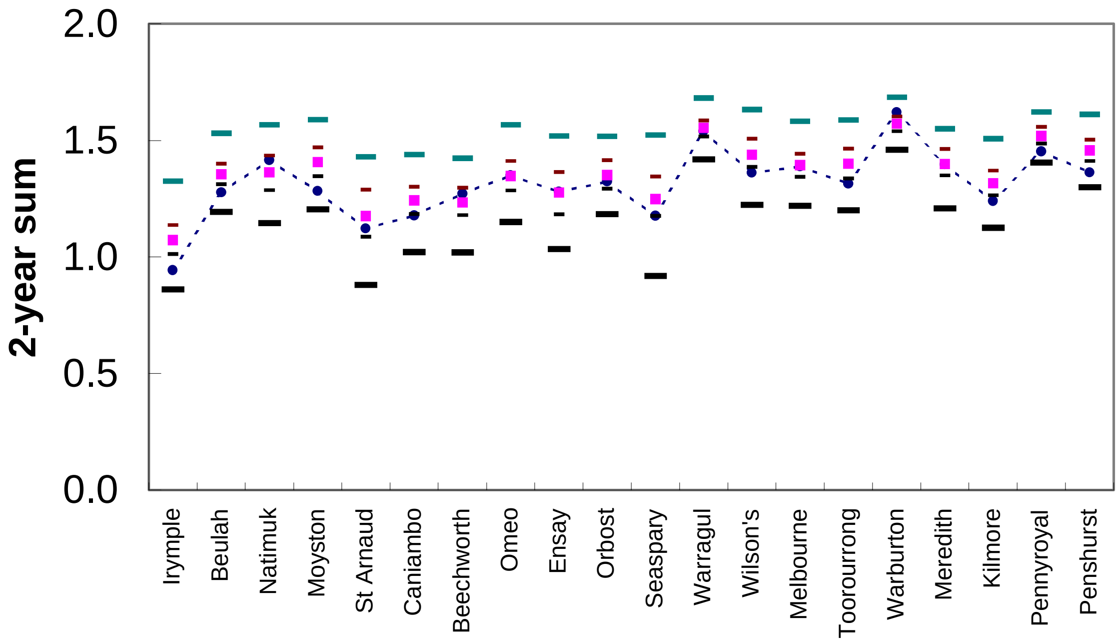


(ii) ARM

Figure E6. Comparison of observed and generated range standardised by dividing by the mean annual rainfall.

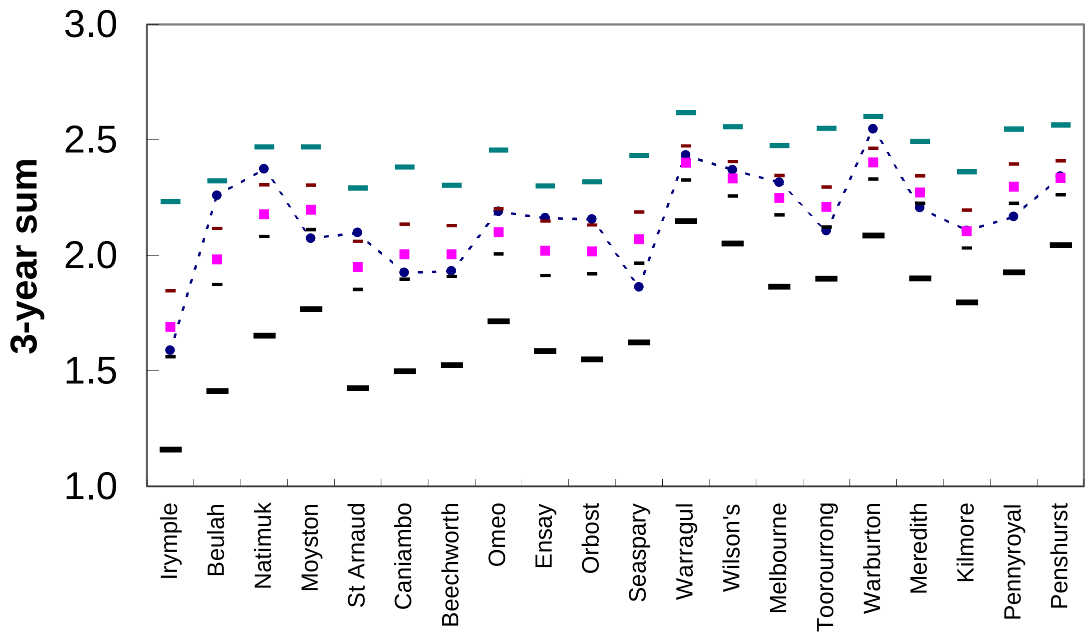


(i) HSM

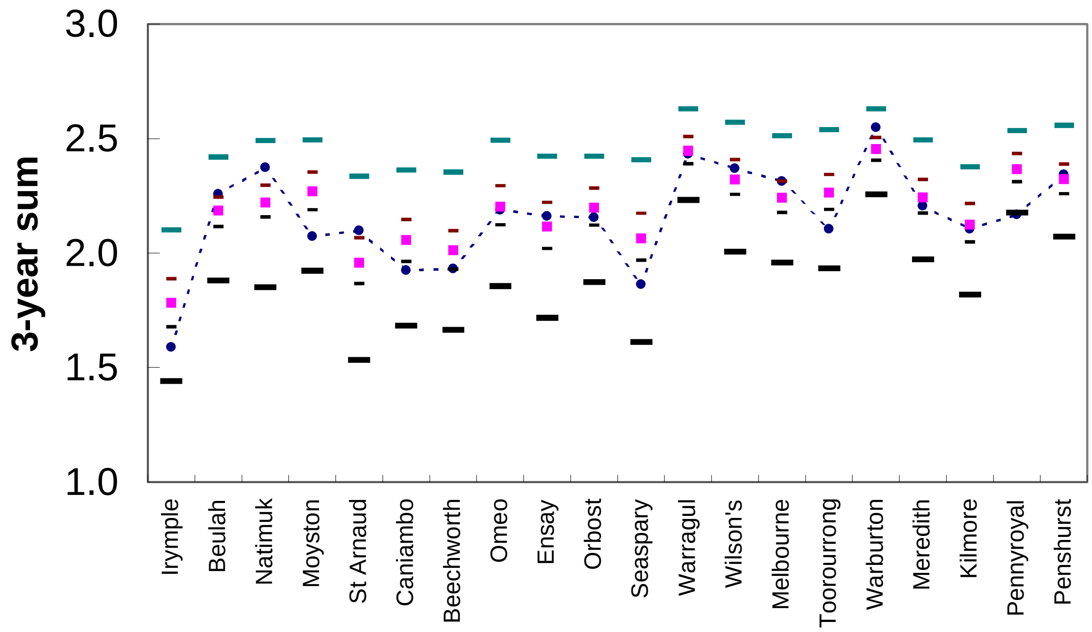


(ii) ARM

Figure E7. Comparison of observed and generated rank one 2-year sums standardised by the mean annual rainfall

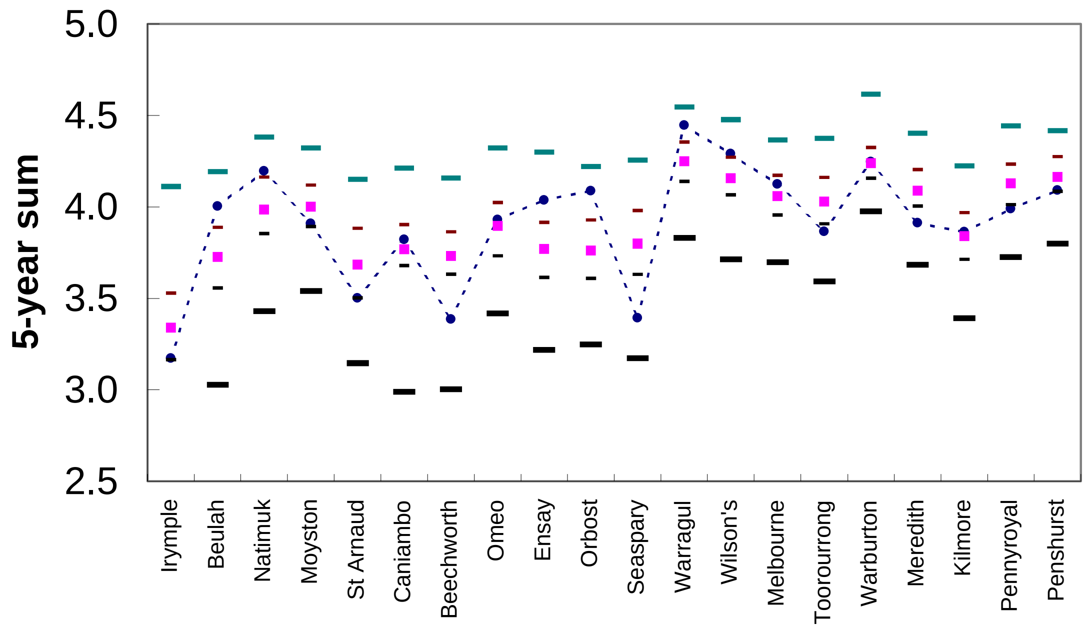


(i) HSM

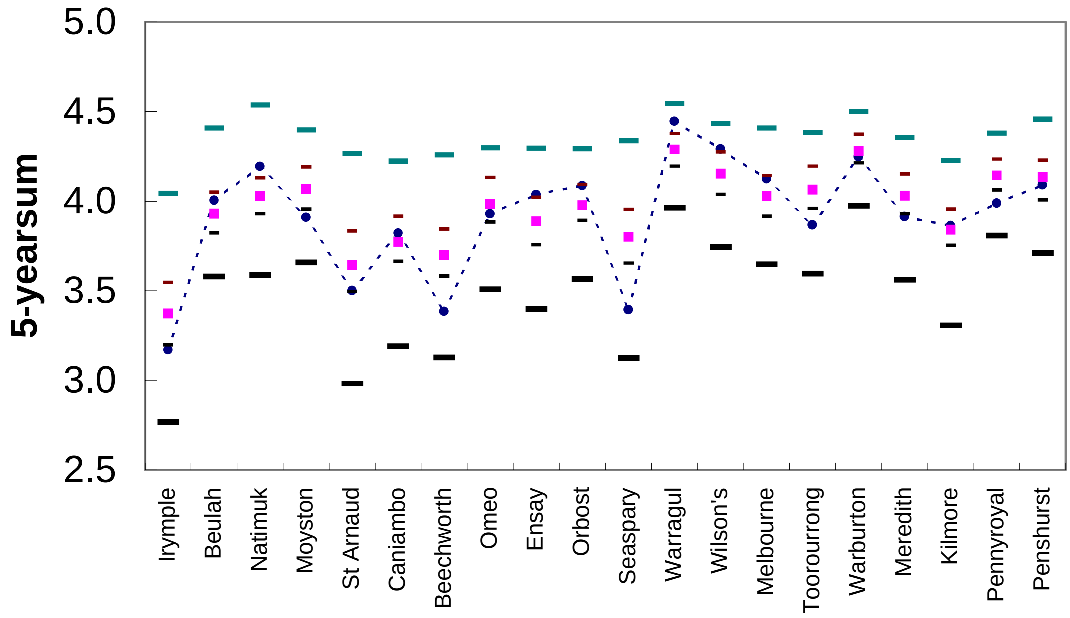


(ii) ARM

Figure E8. **Comparison of observed and generated rank one 3-year sums standardised by the mean annual rainfall**

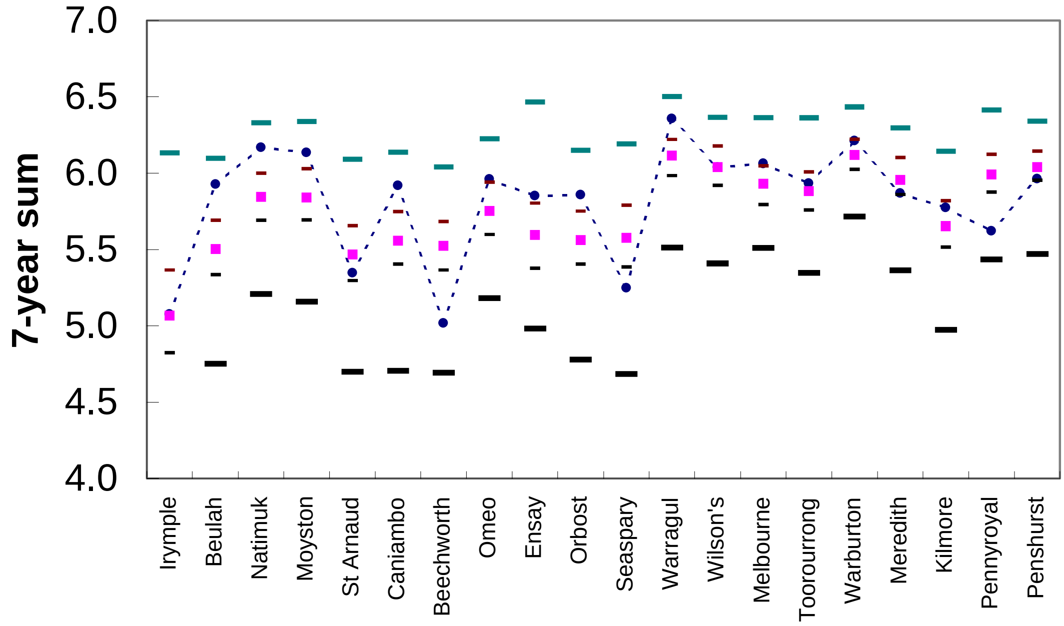


(i) HSM

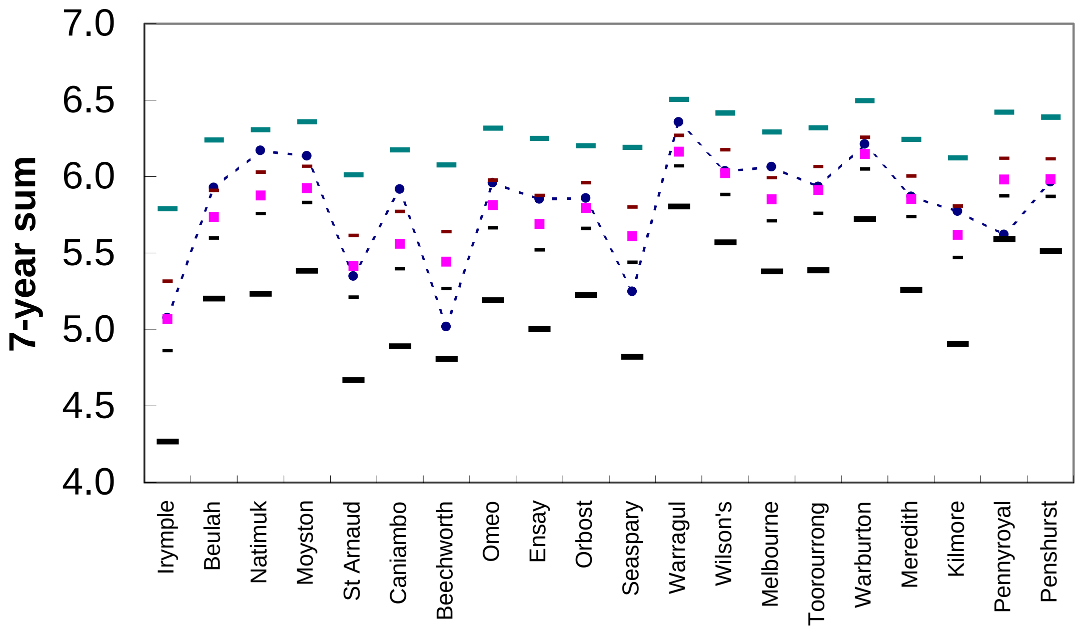


(ii) ARM

Figure E9. Comparison of observed and generated rank one 5-year sums standardised by the mean annual rainfall

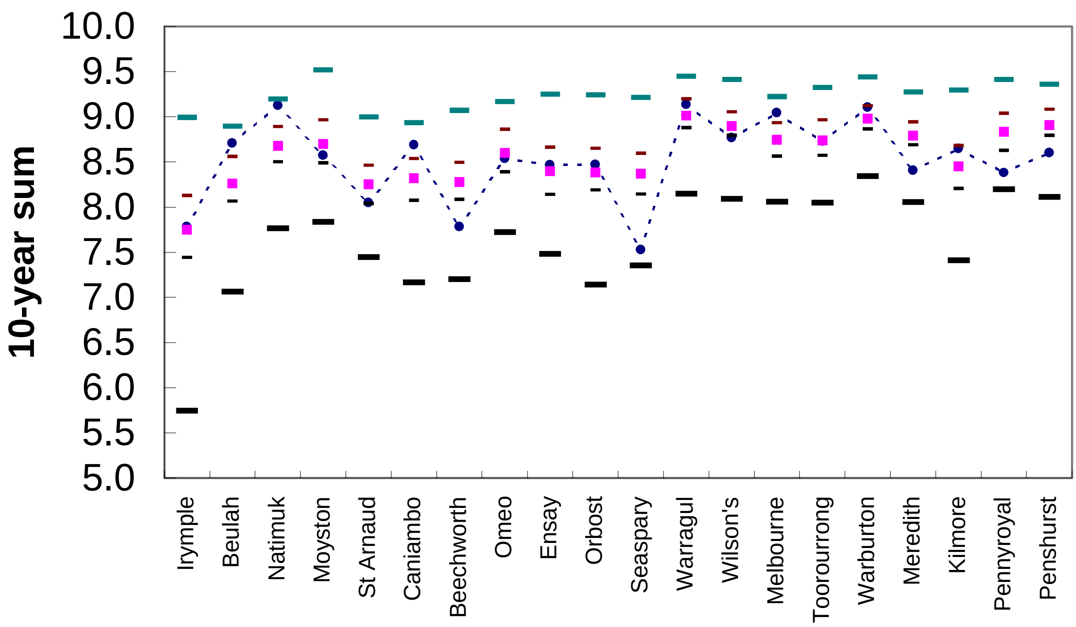


(i) HSM

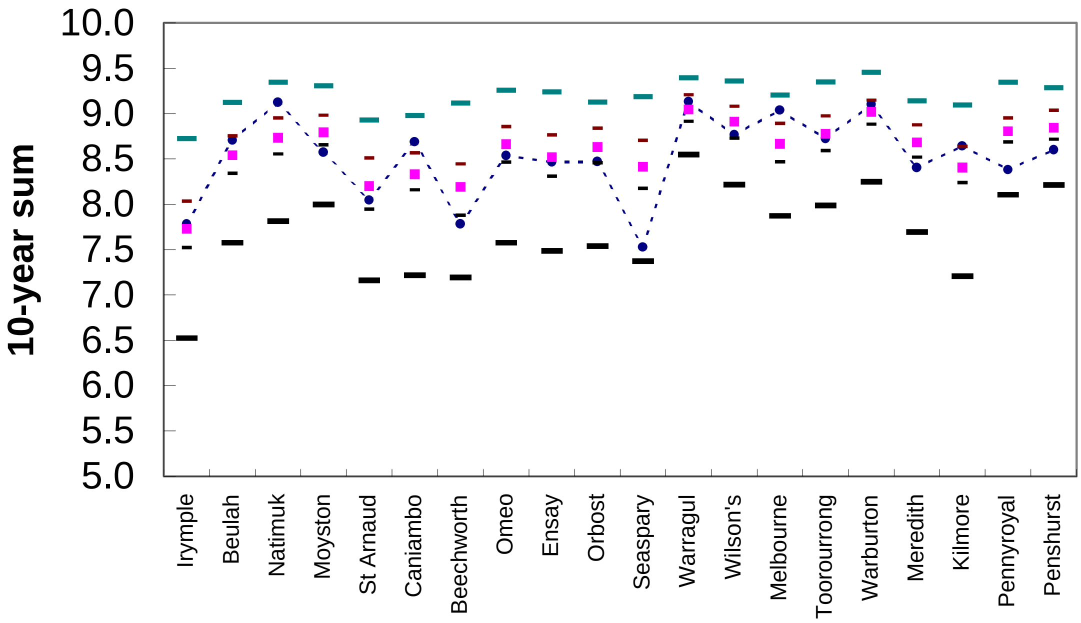


(ii) ARM

Figure E10. Comparison of observed and generated rank one 7-year sums standardised by the mean annual rainfall



(i) HSM



(ii) ARM

Figure E11. Comparison of observed and generated rank one 10-year sums standardised by the mean annual rainfall