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APPLICATION OF HIDDEN STATE MARKOV MODEL TO AUSTRALIAN ANNUAL RAINFALL DATA

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Application of Hidden State Markov Model to Australian Annual Rainfall Data

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1. INTRODUCTION

In the past, the stochastic generation of annual data was performed generally with a first order autogressive model which does not explicitly models the observed long periods of wet and dry periods in the annual data. Though geographers and geomorphologists have observed long cycles or changes in the mean level of rainfall and streamflow, it was not explicitly included in annual stochastic data models until the recent work of Thyer and Kuczera (1999, 2000). Using 180 years of flood stage records at Windsor and 90 years of discharge data at Penrith, Warner (1987) defined alternating flood dominated and drought dominated regimes for the Hawkesbury-Nepean system. The drought dominated regime periods are 1821 – 1863 and 1901 – 1948 and those of the flood dominated regimes are 1799 – 1820, 1864 – 1900 and 1948 onwards. In order to model the long periods of wet and dry spells explicitly in the annual rainfall data, Thyer and Kuzcera used a first order Markov chain. The model is referred to as the hidden state Markov (HSM) model. They showed that Sydney and Brisbane data exhibited two-state persistence structure. However, data from Melbourne, Adelaide and Perth did not show the existence of this persistence. The purpose of this study is to apply the HSM model to annual rainfall data from a number of rainfall sites across Australia and identify the the sites where a two-state persistence structure was likely to exist.

2. ANNUAL RAINFALL DATA

Based on the analysis of both the Sydney rainfall data and stochastically generated data, Thyer and Kuzcera (2000) observed that long-term records of data with lengths in excess of 120 years are required to detect two-state persistence. Because this length of data is not typically available for Australian rainfall stations, it was decided to utilise 40 sites with long records (but shorter than that recommended by Thyer and Kuczera) to cover various parts of Australia. In addition, as the level of persistence in the annual data varied with the start of the water year, monthly rainfall data for the 40 stations were obtained. From the monthly rainfall data, annual rainfall data can be formed using the desired starting month for the water year. The details of the stations are given in Table 1 and their locations are shown in Figure 1.

Because a part of the investigation is to determine the appropriate starting month for forming the annual totals, the annual characteristics were calculated for annual data formed by starting in 12 different months form January to December and the results are given in Table A1 in Appendix A. Also, the monthly means and the monthly serial correlations are given in Tables A2 and A3 respectively.

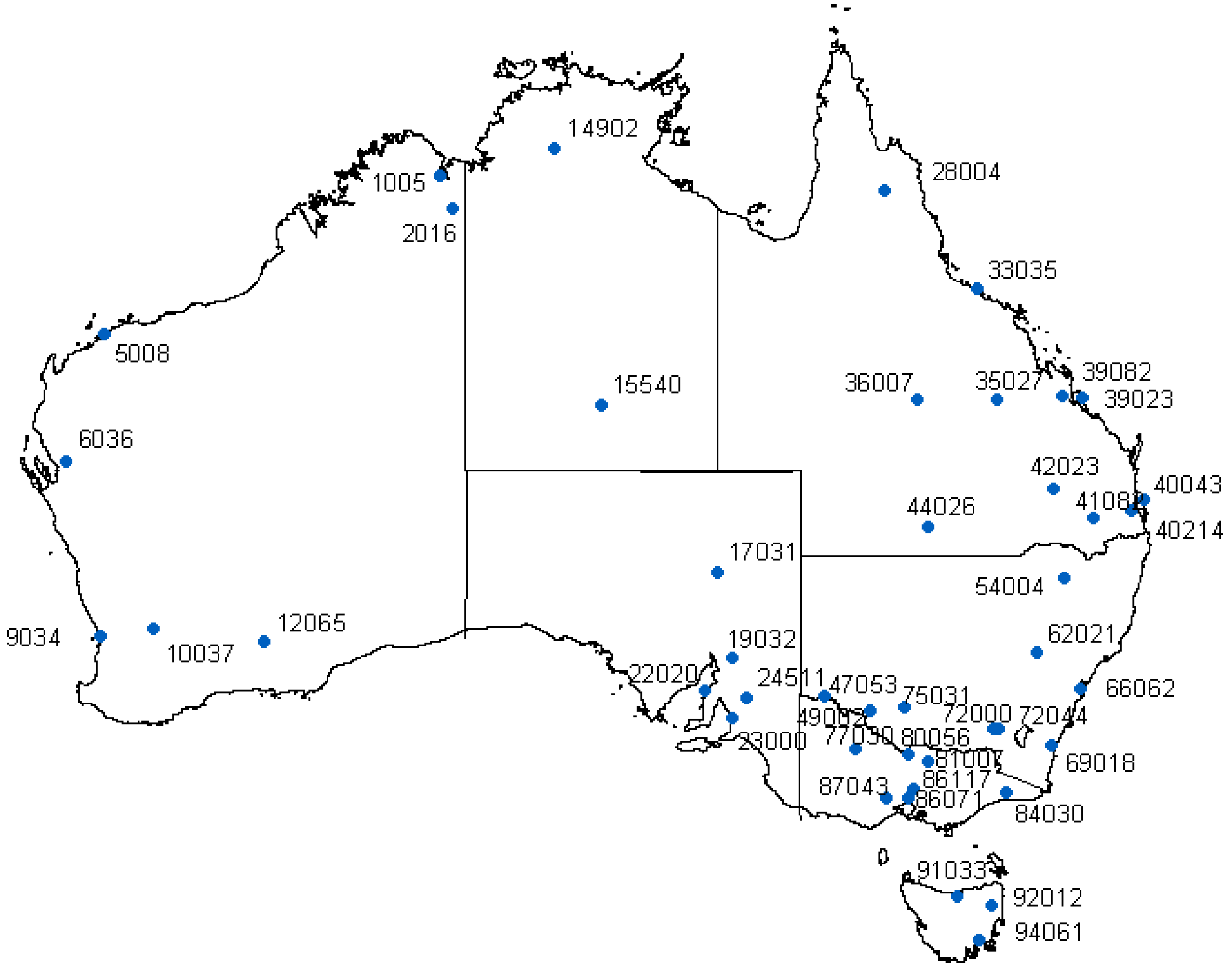


Figure 1. Locations of the rainfall stations used.

Table 1. Details of the rainfall stations selected.

No	Number	Name	Latitude	Longitude	Record Length (Years)
1	005008	Mardie	-21.19	115.98	109
2	006036	Meedo	-25.66	114.62	95
3	009034	Perth	-34.93	138.58	116
4	010037	Cuttening	-31.73	117.76	97
5	012065	Norseman Post Office	-32.20	121.78	103
6	017031	Marree	-29.65	138.06	114
7	019032	Orroroo	-32.74	138.61	119
8	022020	Wallaroo	-33.93	137.63	136
9	023000	Adelaide	-31.95	115.84	140
10	024511	Eudunda	-34.18	139.09	119
11	028004	Palmerville	-16.00	144.08	110
12	033035	Kalamia Estate	-19.54	147.41	113
13	035027	Emerald Post Office	-23.53	148.16	109
14	036007	Barcaldine Post Office	-23.55	145.29	113
15	039023	Cape Capricorn Lighthouse	-23.48	151.23	88
16	039082	Rockhampton Post Office	-23.40	150.50	97
17	040043	Cape Moreton Lighthouse	-27.03	153.47	130
18	040214	Brisbane	-27.48	153.03	134
19	041082	Pittsworth Post Office	-27.71	151.63	113
20	042023	Miles Post Office	-26.66	150.18	115
21	044026	Cunnamulla Post Office	-28.07	145.68	121
22	047053	Wentworth Post office	-34.11	141.91	132
23	049002	Balranald RSL	-34.64	143.56	122
24	054004	Bingara Post Office	-29.87	150.57	114
25	062021	Mudgee (George Street)	-32.59	149.58	123
26	066062	Sydney	-33.86	151.20	141
27	069018	Moruya Heads Pilot Station	-35.91	150.15	124
28	072000	Adelong	-35.31	148.06	116
29	072044	Tumut	-35.30	148.22	114
30	075031	Hay Miller Street	-34.52	144.85	120
31	077030	Narraport	-36.01	143.03	113
32	080056	Tongala	-36.25	144.95	70
33	081007	Caniambo	-36.46	145.66	96
34	084030	Orbost	-37.63	148.46	116
35	086071	Melbourne	-37.81	144.97	144
36	086117	Toorourrong Reservoir	-37.48	145.15	107
37	087043	Meredith (Darra)	-37.82	144.15	125
38	091033	Frankford (Rossville)	-41.32	146.73	107
39	092012	Fingal (Forestry Legge Street)	-41.64	147.97	111
40	094061	Sandford (Maydena)	-42.93	147.52	112
41	1005	Wyndham Port	-15.46	128.10	79
42	2016	Lissadell	-16.67	128.57	105
43	14902	Katherine Council	14.46	132.26	111
44	15540	Alice Springs Post Office	-23.71	133.87	112

3. HIDDEN STATE MARKOV (HSM) MODEL

The HSM model (Figure 2) assumes the climate is in one of two states: wet (W) or dry (D). 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

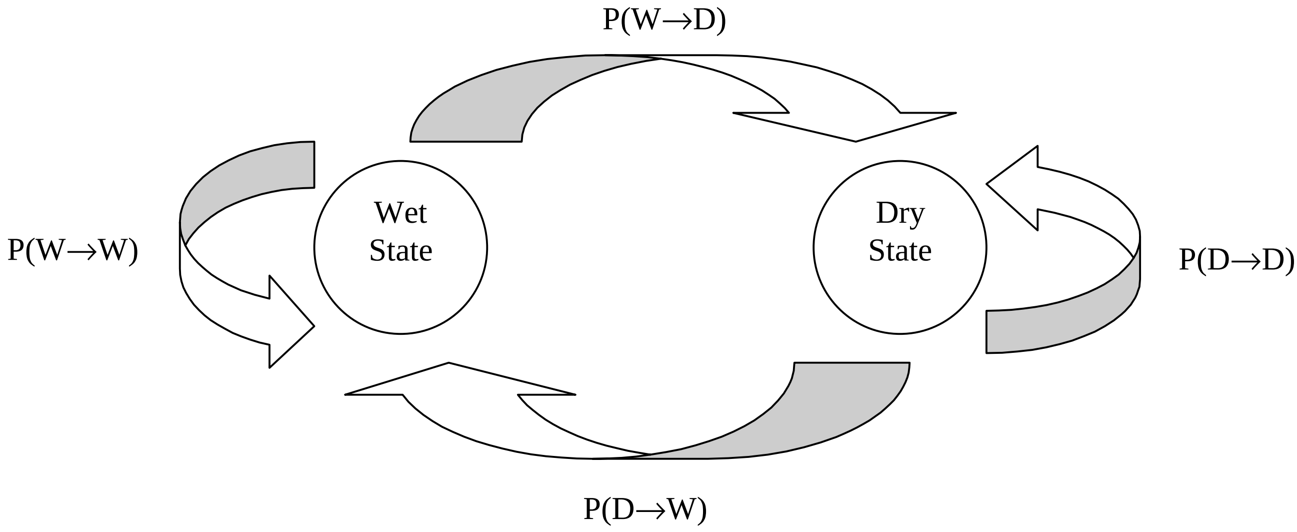


Figure 2. Schematic representation of the HSM model

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.

4. CALIBRATION OF HSM MODEL

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, $p(\boldsymbol{\theta},Y_N)$. 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, $p(\boldsymbol{\theta},Y_N)$. 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).

The HSM model was calibrated for the annual series formed by using the 12 different starting months (January to December). Several indices are used to interpret the results and these are briefly defined below. The wet and dry separation index (WADSI) is defined as

$$\text{WADSI} = \frac{\mu_W - \mu_D}{\sqrt{\left(\sigma_W^2 + \sigma_D^2\right)}} \tag{5}$$

This index is a convenient measure of the separation between the wet and dry states. If the difference between the wet and dry means is large then the value of WADI will be relatively high.

The state signal index (SSI) is defined as follows:

$$\text{SSI} = \frac{\sum \left| P(W) - 0.5 \right|}{N} \tag{6}$$

As values of SSI tend to zero states are hard to identify. As SSI tends to 0.5, states are well defined.

The strength of the two-state persistence is assessed using the expected state resident times (SRT) and is obtained as the reciprocal of the transition probabilities.

$$\begin{aligned} E(SRT_D) &= \frac{1}{p_{DW}} \\ E(SRT_W) &= \frac{1}{p_{WD}} \end{aligned} \tag{7}$$

The strength of two-state persistence structure was classified from the state residence times using the following table (Thyer, 2001).

Table 2. The classification of the strength of two-state persistence structure.

Expected state residence time (years)	Classification
1 - 4	Weak (W)
4 - 10	Medium (M)
10 - 25	Strong (S)
> 25	Very Strong (VS)

5. DISCUSSION OF RESULTS

The results from the calibration runs are assessed first to determine the appropriate starting months for the selected stations. Once this is done, the existence of two-state persistence is investigated by looking the calibration plots and the estimates of the model parameters.

5.1 Starting month of water year

The wet and dry separation index (WADSI), the state signal indicator (SSI) and the state resident times were calculated and are given in Tables A4, A5 and A6 respectively. The maximum values of WADSI, SSI, the starting months of the water years in which they occur and the strength of two-state persistence structure are given in Table 3.

It can be seen from Table 3 that for 19 stations, both the WADSI and SSI were the largest for the same starting month. Adjacent months resulted for 8 stations and a gap of one month for 4 stations. For the remaining stations, the months were separated by more than 2 months. Because of these large variations, it was decided to look at other criteria used for selecting a water year. A water year is usually defined to start in a month of low monthly rainfalls and hence the months of lowest monthly means were computed. Also, it is desirable to break the record into years such that there is a small correlation between adjacent months. In terms of annual totals, it was found that a hydrological year should be defined so that the resulting annual series should have the largest coefficient of variation (Srikanthan and McMahon, 1984). The starting months for these various criteria are given in Table 4. The persistence parameter or the first order autocorrelation for the Markov chain in Table 4 is defined as (Katz, 1983)

$$\text{Persistence} = p_{DD} - p_{WD} = p_{WW} - p_{DW} \quad (8)$$

There are large variations in the starting months for different criteria although there is some consistency between methods. Since the main purpose of this study is to apply the HSM model, the criteria associated with the HSM model were given more weight than the other criteria. By comparing the values of WADSI and SSI for different months (Tables A4 and A5), a compromise is made to adopt starting months for which the two indices are large but not necessarily the largest. These are shown in Figure 3a.

Table 3. The maximum values for WADSI, SSI, the starting months for the water year in which they occur and the strength of two-state persistence structure.

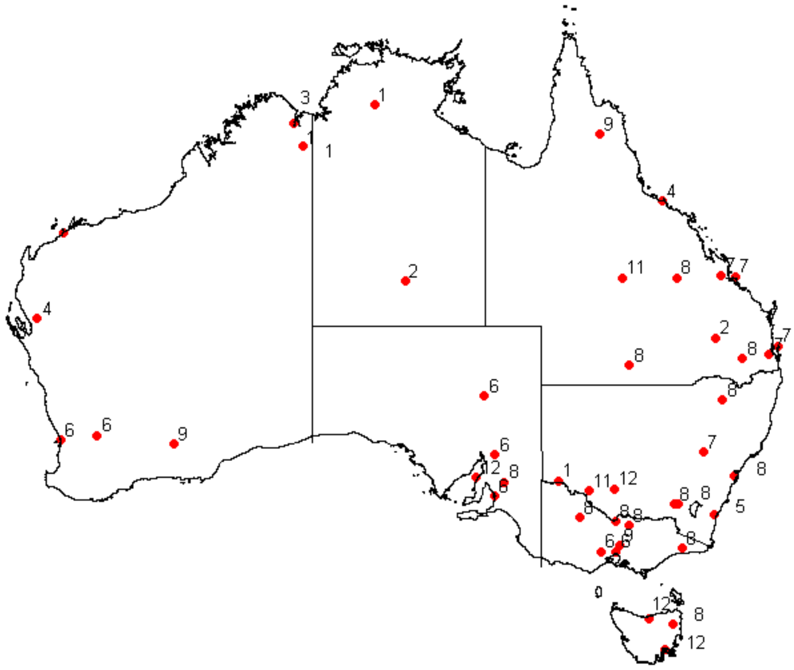
	Magnitude		Starting month		Strength of TSP	
Station	WADSI	SSI	WADSI	SSI	Wet state	Dry State
005008	0.970	0.329	4	2	W	M
006036	0.991	0.329	3	5	W	M
009034	0.609	0.210	6	6	W	W
010037	0.613	0.165	6	11	W	W
012065	0.834	0.355	9	11	W	M
017031	1.116	0.381	1	3	W	M
019032	0.794	0.349	6	6	W	M
022020	1.014	0.240	12	12	W	W
023000	0.779	0.230	9	6	W	W
024511	0.822	0.350	8	8	W	M
028004	0.724	0.236	12	9	W	M
033035	1.173	0.332	5	4	W	W
035027	0.924	0.306	8	8	W	M
036007	1.176	0.339	11	11	W	W
039023	0.839	0.237	7	7	W	W
039082	1.183	0.336	7	8	W	W
040043	0.842	0.247	12	7	W	W
040214	0.890	0.330	8	7	W	M
041082	0.669	0.208	8	9	W	W
042023	1.013	0.262	2	4	W	M
044026	1.183	0.410	8	8	W	M
047053	0.922	0.414	1	12	W	S
049002	0.938	0.404	11	11	W	M
054004	0.826	0.271	3	8	W	W
062021	0.764	0.257	7	12	W	M
066062	0.993	0.328	5	9	W	M
069018	1.323	0.382	5	5	W	M
072000	0.612	0.183	5	8	W	W
072044	0.618	0.241	8	8	W	W
075031	0.926	0.395	1	1	W	M
077030	0.650	0.173	9	8	W	W
080056	0.940	0.406	8	8	W	M
081007	0.842	0.311	8	8	W	M
084030	0.808	0.294	10	3	W	W
086071	0.643	0.163	6	6	W	W
086117	0.554	0.159	9	9	W	W
087043	0.900	0.229	6	6	W	W
091033	0.910	0.231	12	12	W	W
092012	0.986	0.337	8	7	W	M
094061	1.429	0.382	12	11	W	W
001005	1.203	0.333	3	3	W	W
002016	0.776	0.369	1	1	W	M
014902	0.615	0.283	4	4	W	M
015540	1.236	0.476	2	2	W	S

Table 4. The starting month for forming annual series by using various criteria.

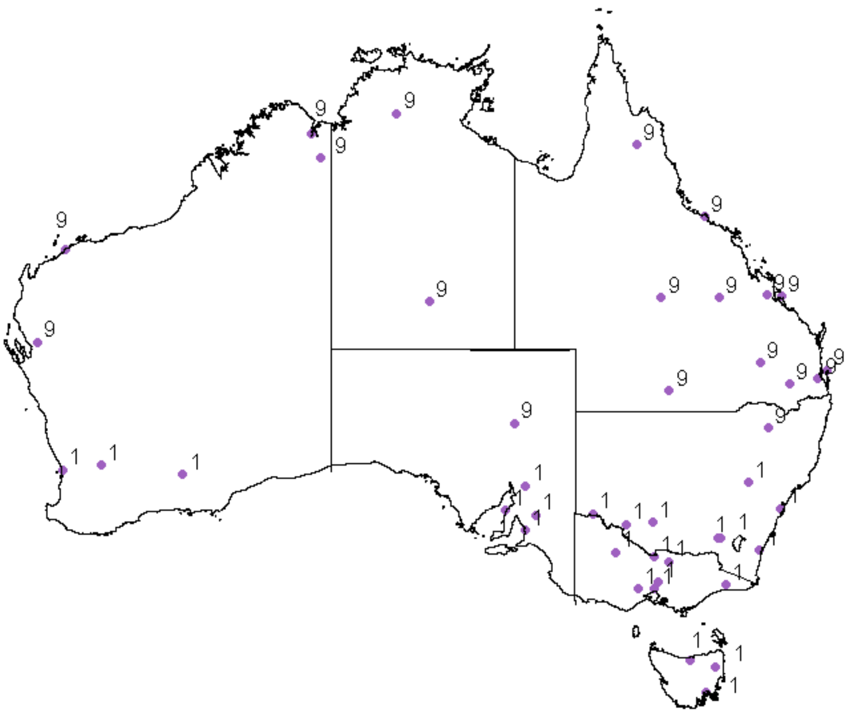
Station	mean	C_v	Ann Correl[1]	WADSI	SSI	Persistence	Mon Correl[2]	Wet RT	Dry RT
005008	10	4	2	4	2	2	7	10	2
006036	11	7	5	3	5	5	3	5	5
009034	1	11	9	6	6	9	9	9	9
010037	1	12	4	6	11	8	6	5	8
012065	1	10	3	9	11	6	10	5	1
017031	8	8	10	1	3	11	6	11	3
019032	3	8	10	6	6	12	11	1	4
022020	1	1	10	12	12	12	1	11	6
023000	1	3	9	9	6	6	1	9	6
024511	3	2	7	8	8	6	1	12	6
028004	8	5	2	12	9	9	3	11	9
033035	8	2	1	5	4	3	2	1	3
035027	8	2	8	8	8	3	11	3	2
036007	9	3	9	11	11	3	11	4	8
039023	8	3	11	7	7	10	12	10	10
039082	8	3	11	7	8	12	10	1	2
040043	9	7	8	12	7	3	5	11	2
040214	8	5	8	8	7	3	7	3	3
041082	8	4	11	4	9	2	1	1	2
042023	8	2	8	2	4	3	6	3	4
044026	8	5	1	8	8	1	1	1	8
047053	4	5	9	1	12	9	4	9	12
049002	1	2	9	11	11	1	2	1	6
054004	4	2	11	3	8	1	3	1	4
062021	4	12	8	7	12	4	9	4	12
066062	9	3	9	5	9	7	4	11	9
069018	8	8	11	5	5	10	2	5	10
072000	2	5	9	3	8	1	2	1	9
072044	2	5	9	8	8	4	5	2	8
075031	11	2	11	1	1	11	2	5	11
077030	1	5	9	9	8	11	2	9	11
080056	2	12	9	8	8	1	1	1	8
081007	2	1	8	8	8	2	1	3	8
084030	2	4	2	9	3	6	5	1	6
086071	2	1	8	6	6	1	8	1	12
086117	2	1	8	9	9	2	8	2	5
087043	1	1	8	6	6	8	9	8	10
091033	2	4	9	12	12	1	9	1	8
092012	2	5	2	8	7	2	8	2	1
094061	2	1	5	12	11	8	9	8	10
001005	9	8	12	3	3	11	3	2	10
002016	8	4	11	1	1	1	8	2	1
014902	8	4	2	4	12	3,8	1	3	11
015540	9	6	5	2	7	12	11	1	7

1 Correlation between annual rainfalls
2 Correlation between successive months

There is no noticeable pattern in the starting months. But the starting months occurred in the high rainfall months for a number of stations. This is not desirable in forming the annual series as the same wet season will be split into two successive years. Hence it was decided to recommend two starting months as shown in Figure 3b. In using a multi-site analysis of HSM model, Thyer (2000) found that the starting month did not have any significant effect on the persistence structure.



(a) Starting month based on WADSI and SSI



(b) Recommended starting month

Figure 3. The starting months for forming water years

The largest values of WADSI and SSI and the corresponding starting months for the water year are shown in Figures B1 to B4 (Appendix B) to detect any spatial patterns. The strength of persistence in the dry state is shown in Figure B5.

5.2 Identification of two-state persistence

The rainfall stations were classified into the following three categories.

1. Highly unlikely to have two-state persistence

The posterior probability density function of WADI has a mode less than or equal to zero. There is significant posterior probability mass for both p_{DW} and p_{WD} at = 0 and 1 so that the transition probabilities are not identifiable or posterior probability is fairly uniform over wide range of transition probabilities resulting in poor identified transition probabilities.

2. Highly likely to have two-state persistence

To have two-state persistence, wet and dry distributions must be separate (high WADSI). There is zero or very small posterior mass for WADSI less than or equal to zero. Zero posterior probability mass for both p_{DW} and p_{WD} at = 0 and 1 and well defined transition probabilities so that the annual climate can move between states.

3. Possibly have two-state persistence

All the remaining sites fall into this category meaning that we are unsure.

To determine the existence of two states, the empirical distributions of the difference in the means and the WADSI for the starting months having the largest WADSI and SSI are examined in Figures C1 to C44. For each site the figures corresponding to the largest WADSI are presented first followed by those corresponding to the largest SSI. There is zero or very small posterior mass for WADSI less than zero for 22 stations shown in Table 5.

Table 5. List of stations with zero or very small posterior mass for WADSI < 0.

No	Station	Figure Number	No	Station	Figure Number
1	Mardie	C1	12	Brisbane	C18
2	Meedo	C2	13	Cunnamulla	C21
3	Norseman	C5	14	Wentworth	C22
4	Maree	C6	15	Sydney	C26
5	Orrorro	C7	16	Moruya	C27
6	Wallaroo	C8	17	Hay	C30
7	Eudunda	C10	18	Frankford	C38
8	Kalamia	C12	19	Fingal	C39
9	Emerald	C13	20	Sandford	C40
10	Barcaldine	C14	21	Wyndham	C41
11	Rockhampton	C16	22	Alice Springs	C44

The stations with small posterior mass for WADSI less than zero are given in Table 6 and the stations which did not indicate no separation between wet and dry states are given in Table 7.

The stations in Table 7 belong to category 1 as they are very unlikely to have two state persistence.

Table 6. List of stations with small posterior mass for WADSI < 0.

No	Station	Figure Number	No	Station	Figure Number
1	Palmerville	C11	7	Bingara	C24
2	Cape Capricorn	C15	8	Mudgee	C25
3	Cape Moreton	C17	9	Tongala	C32
4	Pittsworth	C17	10	Caniambo	C33
5	Miles	C20	11	Orbost	C34
6	Balranald	C23			

Table 7. List of stations indicating no separation between wet and dry states

No	Station	Figure Number	No	Station	Figure Number
1	Perth	C3	7	Melbourne	C35
2	Cuttening	C4	8	Toorourrong	C36
3	Adelaide	C9	9	Meredith	C37
4	Adelong	C28	10	Lissadell	C42
5	Tumut	C29	11	Katherine	C43
6	Narraport	C31			

The posterior probability density plots of p_{DW} and p_{WD} are also shown in Appendix C. The estimated values and their standard deviations of the transition probabilities are given in Table C1.

From the posterior distribution of the transition probabilities, 22 stations listed in Table 8 have well defined transition probabilities. Eleven stations (Table 9) have well defined transition probabilities for $P(D \rightarrow W)$, but the other transition probabilities $P(W \rightarrow D)$ are not well defined. The remaining 11 stations (Table 10) have no well defined transition probabilities.

Table 8. List of stations with well defined transition probabilities.

No	Station	Figure Number	No	Station	Figure Number
1	Meedo	C46	12	Moruya	C71
2	Kalamia	C56	13	Hay	C74
3	Emerald	C57	14	Tongala	C76
4	Barcaldine	C58	15	Caniambo	C77
5	Rockhampton	C60	16	Meredith	C81
6	Miles	C64	17	Frankford	C82
7	Cunnamulla	C65	18	Fingal	C83
8	Wentworth	C66	19	Sandford	C84
9	Balranald	C67	20	Wyndham	C85
10	Mudgee	C69	21	Alice Springs	C88
11	Sydney	C70			

Table 9. List of stations with one well defined transition probabilities.

No	Station	Figure Number	No	Station	Figure Number
1	Mardie	C45	7	Palmerville	C55
2	Norseman	C49	8	Cape Capricorn	C59
3	Maree	C50	9	Cape Moreton	C61
4	Orrooro	C51	10	Brisbane	C62
5	Wallaroo	C52	11	Bingara	C68
6	Eudunda	C54			

Table 10. List of stations with no well defined transition probabilities.

No	Station	Figure Number	No	Station	Figure Number
1	Perth	C47	7	Narraport	C75
2	Cuttening	C48	8	Orbost	C78
3	Adelaide	C53	9	Melbourne	C79
4	Pittsworth	C63	10	Toorourrong	C80
5	Adelong	C72	11	Lissadell	C86
6	Tumut	C73	12	Katherine	C87

Comparing Tables 7 and 10, 12 stations fall into category 1. From Tables 5 and 8, 15 stations fall into category 2. The remaining 17 stations belong to category 3. The rainfall stations falling in the 3 categories are given in Table 5. The locations of these stations are shown in Figure 4.

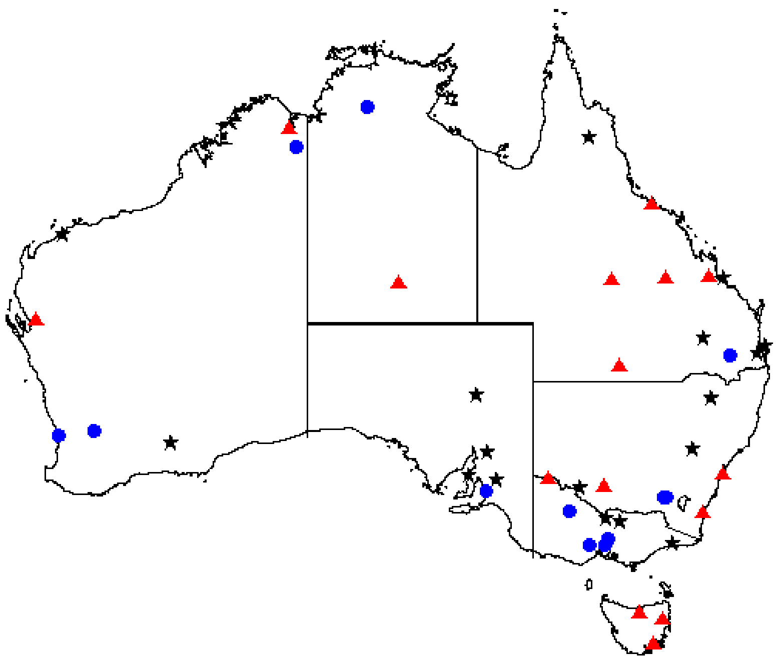


Figure 4. The locations of the stations that are highly unlikely to have two-state persistence (circles), highly likely to have two-state persistence (triangles) and possibly have two-state persistence (stars).

Table 11. The rainfall stations falling in the three categories.

Category 1	Category 2	Category 3
Perth	Meedo	Mardie
Cuttening	Kalamia Estate	Norseman Post Office
Adelaide	Emerald Post Office	Marree
Pittsworth	Barcaldine Post Office	Orroroo
Adelong	Rockhampton Post Office	Wallaroo
Tumut	Cunnamulla Post Office	Eudunda
Narraport	Wentworth Post office	Palmerville
Melbourne	Sydney	Cape Capricorn
Toorourrong	Moruya Heads Pilot Station	Cape Moreton
Meredith	Hay Miller Street	Brisbane
Lissadell	Frankford (Rossville)	Bingara
Katherine	Fingal (Forestry Legge Street)	Mudgee
	Sandford (Maydena)	Miles Post Office
	Wyndham	Balranald RSL
	Alice Springs	Tongala
		Caniambo
		Orbost

The probability distribution of the historical and generated annual rainfalls is shown in Appendix D. The generated rainfall distribution closely matches the historical distribution for all the cases.

6. CONCLUSIONS

Long sequences of annual rainfall data from 44 stations from various parts of Australia was used to examine the persistence in wet and dry states as defined in the hidden state Markov (HSM) model. Since the level persistence was dependent on the water year, 12 annual series were formed by starting the water from January to December. The HSM model was then calibrated to all these 12 series for the 44 stations. The starting months occurred right throughout the year for different stations. Since it is not advisable to split a year during heavy rainfall months and the annual parameters did not vary much with the choice of starting months, January (stations below 30° south) or September (above 30° south) was recommended as starting months.

It was difficult to identify the existence of two-state persistence due to limited data length. From the calibration results, 15 stations are identified to be highly likely to have two-state persistence and 12 stations to be highly unlikely to have two-state persistence structure. The remaining 17 stations possibly will have two-state persistence. Multi-site calibration will better identify the transition probabilities and this work is being carried out at the University of Newcastle.

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APPENDIX A – CALIBRATION RESULTS

Table A1. The coefficient of variation, skewness and lag one autocorrelation coefficient of annual rainfall for different starting months.

Station		January	February	March	April	May	June	July	August	September	October	November	December
005008	Cv	0.596	0.577	0.613	0.622	0.602	0.612	0.616	0.614	0.607	0.603	0.602	0.605
	Skew	0.948	1.090	1.026	0.791	0.959	0.905	0.877	0.985	0.962	0.968	0.965	0.932
	Correl	-0.036	0.034	-0.007	-0.083	-0.037	-0.060	-0.085	-0.060	-0.068	-0.063	-0.059	-0.063
006036	Cv	0.475	0.436	0.410	0.415	0.412	0.442	0.478	0.460	0.456	0.458	0.466	0.474
	Skew	1.105	0.991	0.888	0.876	1.351	1.083	1.248	1.155	1.087	1.070	1.072	1.157
	Correl	0.015	0.163	0.308	0.304	0.331	0.211	0.068	0.077	0.064	0.066	0.060	0.053
009034	Cv	0.187	0.189	0.181	0.182	0.178	0.182	0.181	0.182	0.172	0.178	0.190	0.188
	Skew	0.103	0.119	0.161	0.192	0.319	0.725	0.522	0.289	0.083	0.121	0.181	0.101
	Correl	0.197	0.194	0.253	0.266	0.296	0.248	0.258	0.298	0.337	0.266	0.163	0.183
010037	Cv	0.267	0.257	0.242	0.233	0.244	0.242	0.255	0.241	0.254	0.268	0.271	0.273
	Skew	0.574	0.593	0.707	0.270	0.255	0.506	0.224	0.318	0.439	0.517	0.505	0.419
	Correl	0.035	0.040	0.188	0.280	0.233	0.235	0.055	0.195	0.084	0.012	0.007	0.005
012065	Cv	0.302	0.291	0.281	0.284	0.293	0.299	0.304	0.309	0.316	0.322	0.309	0.306
	Skew	1.337	1.215	0.702	0.657	0.571	0.869	0.778	0.945	1.241	1.238	1.202	1.213
	Correl	0.162	0.189	0.260	0.242	0.177	0.129	0.081	0.103	0.105	0.066	0.100	0.142
017031	Cv	0.487	0.488	0.509	0.498	0.511	0.511	0.511	0.512	0.488	0.487	0.495	0.507
	Skew	1.118	1.289	1.346	1.189	1.349	1.533	1.414	1.346	1.216	1.091	1.162	1.233
	Correl	0.113	0.084	0.101	0.152	0.068	0.090	0.089	0.094	0.145	0.154	0.146	0.089
019032	Cv	0.303	0.298	0.306	0.316	0.306	0.324	0.315	0.326	0.315	0.309	0.319	0.303
	Skew	0.510	0.671	0.775	1.101	1.118	1.443	1.211	1.300	1.133	0.968	0.771	0.464
	Correl	0.187	0.173	0.138	0.108	0.152	0.104	0.170	0.171	0.228	0.257	0.223	0.232
022020	Cv	0.238	0.234	0.230	0.224	0.221	0.223	0.223	0.222	0.217	0.219	0.228	0.232
	Skew	0.415	0.438	0.416	0.446	0.351	0.643	0.346	0.444	0.357	0.392	0.350	0.285
	Correl	0.063	0.072	0.060	0.151	0.140	0.140	0.119	0.116	0.140	0.164	0.144	0.095

Table A1. (Cont)

Station		January	February	March	April	May	June	July	August	September	October	November	December
023000	Cv	0.205	0.206	0.214	0.208	0.209	0.199	0.194	0.196	0.191	0.200	0.204	0.207
	Skew	0.058	0.161	0.273	0.442	0.403	0.628	0.258	0.143	0.144	0.102	0.050	0.065
	Correl	0.162	0.131	0.110	0.194	0.187	0.268	0.249	0.226	0.269	0.207	0.213	0.184
024511	Cv	0.266	0.277	0.276	0.277	0.256	0.253	0.241	0.254	0.246	0.251	0.255	0.256
	Skew	0.642	0.891	0.879	0.909	0.740	0.975	0.921	1.211	0.871	0.791	0.569	0.515
	Correl	0.152	0.101	0.102	0.108	0.218	0.216	0.267	0.206	0.229	0.213	0.218	0.175
028004	Cv	0.292	0.276	0.290	0.296	0.308	0.307	0.307	0.307	0.306	0.303	0.301	0.298
	Skew	0.661	0.263	0.173	0.459	0.588	0.615	0.595	0.608	0.617	0.564	0.534	0.415
	Correl	0.177	0.301	0.127	0.178	0.158	0.163	0.170	0.170	0.167	0.178	0.177	0.185
033035	Cv	0.428	0.477	0.460	0.462	0.453	0.457	0.455	0.453	0.450	0.451	0.445	0.452
	Skew	0.686	0.711	0.954	0.847	0.732	0.710	0.780	0.805	0.763	0.847	0.831	0.795
	Correl	0.156	0.048	0.134	0.098	0.095	0.091	0.112	0.109	0.110	0.101	0.117	0.086
035027	Cv	0.325	0.363	0.361	0.360	0.354	0.361	0.347	0.330	0.328	0.333	0.332	0.328
	Skew	0.698	0.942	0.672	0.594	0.608	0.646	0.725	0.753	0.690	0.698	0.672	0.680
	Correl	0.250	0.072	0.120	0.131	0.161	0.160	0.232	0.304	0.294	0.266	0.232	0.243
036007	Cv	0.441	0.448	0.449	0.424	0.413	0.427	0.426	0.425	0.420	0.422	0.432	0.443
	Skew	0.787	1.073	0.860	0.633	0.693	0.911	0.971	1.087	1.066	1.000	0.876	0.869
	Correl	0.191	0.087	0.099	0.179	0.259	0.224	0.272	0.277	0.289	0.271	0.217	0.182
039023	Cv	0.339	0.334	0.370	0.351	0.345	0.345	0.337	0.322	0.325	0.321	0.313	0.322
	Skew	0.502	0.209	0.510	0.429	0.509	0.728	0.674	0.721	0.682	0.659	0.545	0.643
	Correl	0.179	0.130	0.021	0.086	0.094	0.111	0.202	0.270	0.226	0.261	0.271	0.167
039082	Cv	0.347	0.386	0.409	0.385	0.387	0.382	0.381	0.365	0.368	0.360	0.349	0.346
	Skew	0.755	1.103	0.688	0.755	0.761	0.858	0.967	0.942	0.919	0.923	0.874	0.855
	Correl	0.233	0.117	0.033	0.097	0.085	0.135	0.166	0.224	0.204	0.226	0.282	0.266
040043	Cv	0.240	0.247	0.246	0.248	0.239	0.251	0.255	0.242	0.243	0.241	0.240	0.246
	Skew	0.371	0.150	0.143	0.390	0.483	0.772	0.954	0.605	0.546	0.455	0.437	0.466
	Correl	0.174	0.131	0.136	0.100	0.133	0.128	0.121	0.226	0.216	0.222	0.206	0.137

Table A1. (Cont)

Station		January	February	March	April	May	June	July	August	September	October	November	December
040214	Cv	0.310	0.316	0.312	0.317	0.321	0.320	0.320	0.313	0.321	0.317	0.309	0.315
	Skew	0.592	0.344	0.796	0.720	0.721	0.820	1.009	0.852	0.959	0.906	0.886	0.820
	Correl	0.094	0.126	0.143	0.142	0.112	0.116	0.125	0.178	0.112	0.126	0.142	0.081
041082	Cv	0.224	0.243	0.241	0.248	0.237	0.235	0.235	0.232	0.237	0.236	0.228	0.228
	Skew	0.027	0.256	0.342	0.415	0.489	0.473	0.585	0.857	0.873	0.856	0.527	0.381
	Correl	0.078	0.021	0.024	-0.039	0.006	0.013	0.050	0.049	0.024	0.020	0.089	0.077
042023	Cv	0.279	0.324	0.298	0.315	0.309	0.297	0.289	0.277	0.282	0.283	0.279	0.290
	Skew	0.470	0.506	0.506	0.983	0.822	0.754	0.831	0.575	0.579	0.540	0.373	0.409
	Correl	0.096	-0.031	0.063	-0.018	0.037	0.089	0.158	0.186	0.151	0.133	0.140	0.089
044026	Cv	0.422	0.432	0.438	0.439	0.441	0.438	0.429	0.422	0.417	0.433	0.430	0.429
	Skew	0.823	0.954	1.054	1.174	1.177	1.069	1.174	1.249	1.112	1.050	0.934	0.838
	Correl	0.206	0.082	0.068	0.068	0.066	0.094	0.141	0.151	0.117	0.084	0.097	0.117
047053	Cv	0.347	0.344	0.357	0.353	0.358	0.357	0.343	0.337	0.322	0.317	0.328	0.342
	Skew	1.167	1.050	1.400	1.029	1.037	1.166	0.918	0.952	0.756	0.918	1.046	1.064
	Correl	0.219	0.240	0.181	0.168	0.146	0.138	0.214	0.231	0.293	0.281	0.226	0.198
049002	Cv	0.338	0.351	0.344	0.337	0.332	0.340	0.333	0.335	0.325	0.338	0.337	0.342
	Skew	0.719	0.879	0.803	0.935	0.815	1.148	1.108	1.241	1.110	1.142	1.001	0.780
	Correl	0.201	0.117	0.140	0.192	0.217	0.196	0.263	0.257	0.291	0.231	0.249	0.189
054004	Cv	0.255	0.286	0.278	0.285	0.273	0.270	0.253	0.256	0.251	0.248	0.238	0.249
	Skew	0.284	0.497	0.644	0.678	0.618	0.541	0.560	0.659	0.591	0.446	0.349	0.262
	Correl	0.228	0.081	0.107	0.058	0.105	0.162	0.220	0.213	0.220	0.246	0.274	0.226
062021	Cv	0.297	0.292	0.275	0.276	0.272	0.265	0.260	0.261	0.270	0.273	0.285	0.301
	Skew	0.752	0.712	0.354	0.450	0.484	0.564	0.785	0.838	0.713	0.624	0.731	0.862
	Correl	0.080	0.072	0.132	0.113	0.159	0.196	0.216	0.238	0.222	0.232	0.164	0.099
066062	Cv	0.270	0.277	0.278	0.271	0.266	0.260	0.273	0.273	0.272	0.272	0.270	0.278
	Skew	0.607	0.467	0.439	0.560	0.628	0.559	0.540	0.729	0.632	0.593	0.600	0.487
	Correl	0.199	0.105	0.083	0.110	0.232	0.262	0.226	0.261	0.285	0.266	0.272	0.173

Table A1. (Cont)

Station		January	February	March	April	May	June	July	August	September	October	November	December
069018	Cv	0.317	0.320	0.332	0.326	0.322	0.322	0.327	0.338	0.332	0.324	0.323	0.325
	Skew	0.775	0.565	0.813	0.812	0.708	0.781	0.825	0.929	0.987	0.912	0.914	0.762
	Correl	0.377	0.318	0.267	0.314	0.345	0.363	0.321	0.256	0.293	0.361	0.399	0.349
072000	Cv	0.256	0.267	0.266	0.263	0.273	0.246	0.236	0.240	0.239	0.245	0.253	0.262
	Skew	0.077	0.224	0.234	0.149	0.392	0.379	0.591	0.721	0.513	0.486	0.287	0.210
	Correl	0.164	0.107	0.109	0.097	0.031	0.199	0.233	0.233	0.254	0.212	0.179	0.134
072044	Cv	0.245	0.256	0.252	0.255	0.264	0.236	0.229	0.233	0.230	0.238	0.245	0.251
	Skew	0.019	0.065	0.034	0.012	0.292	0.184	0.548	0.674	0.418	0.454	0.167	0.079
	Correl	0.129	0.117	0.126	0.095	0.025	0.210	0.221	0.217	0.237	0.208	0.153	0.118
075031	Cv	0.347	0.350	0.341	0.327	0.334	0.348	0.341	0.338	0.333	0.339	0.340	0.344
	Skew	1.147	1.073	0.735	0.543	0.608	0.916	0.950	1.195	1.159	1.214	1.219	1.218
	Correl	0.200	0.145	0.143	0.209	0.195	0.167	0.217	0.250	0.276	0.255	0.277	0.230
077030	Cv	0.300	0.302	0.304	0.307	0.308	0.306	0.296	0.289	0.282	0.287	0.291	0.306
	Skew	0.176	0.204	0.197	0.164	0.183	0.329	0.346	0.482	0.362	0.362	0.202	0.290
	Correl	0.200	0.190	0.160	0.157	0.177	0.203	0.223	0.276	0.303	0.288	0.301	0.182
080056	Cv	0.301	0.308	0.299	0.302	0.293	0.277	0.274	0.275	0.275	0.282	0.303	0.312
	Skew	0.445	0.656	0.473	0.633	0.834	1.628	1.473	1.592	1.111	1.011	0.813	0.636
	Correl	0.192	0.134	0.121	0.139	0.127	0.256	0.313	0.403	0.410	0.361	0.292	0.171
081007	Cv	0.292	0.279	0.272	0.279	0.282	0.278	0.272	0.264	0.266	0.263	0.284	0.285
	Skew	0.375	0.467	0.228	0.351	0.528	0.851	0.771	1.003	0.848	0.727	0.654	0.576
	Correl	0.034	0.086	0.114	0.129	0.044	0.097	0.110	0.211	0.167	0.163	0.086	0.062
084030	Cv	0.231	0.233	0.239	0.252	0.248	0.248	0.234	0.235	0.232	0.221	0.219	0.222
	Skew	0.703	0.837	1.053	0.790	0.834	0.799	0.618	0.737	0.680	0.606	0.703	0.717
	Correl	0.138	0.149	0.103	0.043	0.026	0.062	0.041	0.002	0.000	0.060	0.099	0.051
086071	Cv	0.196	0.190	0.190	0.192	0.188	0.185	0.184	0.185	0.189	0.190	0.193	0.189
	Skew	-0.034	0.111	0.277	0.274	0.291	0.447	0.484	0.507	0.484	0.411	0.154	0.027
	Correl	0.196	0.215	0.201	0.201	0.303	0.301	0.281	0.310	0.280	0.225	0.197	0.223

Table A1. (Cont)

Station		January	February	March	April	May	June	July	August	September	October	November	December
086117	Cv	0.204	0.201	0.202	0.199	0.199	0.198	0.197	0.195	0.198	0.191	0.195	0.200
	Skew	0.019	0.003	0.113	-0.053	0.056	0.230	0.398	0.440	0.427	0.400	0.199	0.205
	Correl	0.218	0.233	0.178	0.177	0.214	0.224	0.240	0.304	0.273	0.295	0.249	0.226
087043	Cv	0.205	0.203	0.201	0.205	0.197	0.190	0.184	0.180	0.186	0.190	0.190	0.201
	Skew	0.472	0.378	0.573	0.361	0.359	0.359	0.461	0.343	0.253	0.320	0.165	0.273
	Correl	0.175	0.163	0.169	0.153	0.267	0.313	0.347	0.415	0.371	0.309	0.294	0.231
091033	Cv	0.214	0.215	0.216	0.219	0.213	0.211	0.210	0.198	0.188	0.194	0.204	0.217
	Skew	0.402	0.389	0.402	0.502	0.793	0.640	0.708	0.880	0.582	0.697	0.448	0.522
	Correl	0.277	0.210	0.176	0.194	0.179	0.221	0.224	0.360	0.421	0.376	0.291	0.208
092012	Cv	0.268	0.266	0.265	0.271	0.281	0.279	0.274	0.274	0.266	0.269	0.275	0.277
	Skew	0.523	0.541	0.461	0.461	0.687	0.902	1.173	1.286	0.980	0.863	0.678	0.528
	Correl	0.338	0.346	0.332	0.285	0.205	0.226	0.198	0.229	0.215	0.215	0.153	0.184
094061	Cv	0.228	0.222	0.211	0.214	0.200	0.203	0.202	0.201	0.201	0.204	0.214	0.218
	Skew	0.432	0.376	0.480	0.353	0.504	0.451	0.667	0.646	0.722	0.837	0.855	0.630
	Correl	0.184	0.275	0.323	0.290	0.374	0.336	0.334	0.356	0.356	0.371	0.280	0.288

Table A2. The mean monthly rainfall (mm).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
005008	35.6	60.1	46.8	18.9	38.3	40.0	13.8	7.7	1.5	0.9	1.4	9.2
006036	15.4	20.4	18.6	13.5	34.5	41.8	33.8	18.6	5.0	5.8	3.2	3.7
009034	8.7	12.3	19.1	45.7	122.7	182.4	172.9	134.6	79.9	54.5	21.7	13.9
010037	10.1	15.0	20.3	21.3	40.5	54.3	48.7	37.5	24.0	17.7	11.9	11.7
012065	17.1	24.0	23.3	23.0	31.7	31.7	27.4	25.2	20.8	20.3	20.5	20.9
017031	17.4	20.7	14.8	10.9	14.3	13.5	10.2	9.5	10.6	13.2	11.5	16.6
019032	23.3	19.6	17.0	21.3	32.4	37.2	35.9	40.3	33.8	31.1	25.6	22.7
022020	15.2	16.7	19.4	31.3	44.3	47.9	41.9	40.3	34.6	31.1	21.1	16.6
023000	19.9	20.8	24.0	44.3	68.2	71.7	66.5	61.5	51.1	44.5	30.7	26.3
024511	21.5	21.6	20.7	32.8	45.7	51.9	51.2	56.1	48.6	41.2	29.7	25.2
028004	261.5	259.8	182.7	49.6	15.9	11.7	5.3	3.5	7.9	19.0	61.6	156.8
033035	259.6	254.3	187.2	67.4	41.0	32.9	18.5	16.5	20.0	26.9	46.2	115.1
035027	104.0	99.1	69.8	36.1	35.1	34.3	28.8	20.7	23.6	39.2	58.8	91.0
036007	84.7	77.6	62.5	37.6	32.4	24.0	24.0	16.5	15.2	29.6	34.6	59.2
039023	119.6	129.2	97.0	64.7	60.4	52.9	43.6	24.6	24.8	36.5	54.4	83.5
039082	179.1	189.4	109.7	58.1	41.2	57.8	41.1	21.6	29.4	45.4	61.5	112.8
040043	156.5	164.6	188.6	152.2	176.2	140.3	119.8	80.8	68.3	83.1	94.7	129.6
040214	158.7	163.3	144.9	94.8	73.9	70.0	56.9	44.7	44.9	76.6	97.6	127.4
041082	94.3	77.4	63.4	39.7	42.5	41.5	42.6	30.5	37.2	64.1	74.4	96.1
042023	97.9	74.5	59.2	37.4	41.1	38.9	39.5	29.3	31.9	54.3	66.6	89.2
044026	45.9	51.0	39.6	28.1	30.5	26.1	23.6	17.7	18.8	25.9	28.7	40.0
047053	21.7	21.8	19.7	17.9	28.8	27.4	24.4	26.1	27.4	28.3	23.6	20.9
049002	21.5	23.9	22.2	23.9	32.7	29.6	26.2	30.0	29.9	31.8	26.0	24.5
054004	94.5	85.7	62.1	42.0	50.5	51.7	53.6	45.8	44.5	67.5	68.0	79.4
062021	68.5	62.0	50.2	45.8	50.0	54.0	53.8	53.6	52.4	60.0	57.6	62.9
066062	104.1	116.8	131.4	128.0	121.5	131.2	99.8	83.1	70.3	77.4	82.9	79.0
069018	98.0	92.8	110.2	88.8	87.4	89.1	55.7	54.8	62.3	78.5	75.9	75.4
072000	56.8	41.3	56.3	58.1	70.0	84.3	82.1	83.4	71.5	78.0	58.1	55.8
072044	59.4	41.7	59.0	60.7	72.1	85.3	85.9	85.9	73.6	79.9	60.2	57.2
075031	27.7	27.2	29.2	28.7	36.6	36.6	31.0	32.7	31.8	35.9	24.7	26.7
077030	19.1	22.6	22.1	24.7	35.9	36.1	34.9	35.7	36.4	37.3	27.7	22.5
080056	31.9	26.6	31.2	33.8	43.1	40.6	45.0	43.9	40.1	45.1	31.7	28.4
081007	33.8	29.4	37.0	38.4	50.2	53.2	53.9	53.1	49.9	49.4	35.5	35.8
084030	68.8	57.7	67.7	73.4	70.9	86.2	68.2	58.8	71.6	78.2	71.5	79.4
086071	48.7	47.6	51.2	57.8	57.4	50.1	48.3	50.7	58.7	67.3	60.0	59.3
086117	55.3	53.5	56.8	65.0	69.7	67.5	66.8	74.9	76.7	81.5	69.6	67.2
087043	42.6	46.8	49.6	56.2	57.9	57.5	54.8	62.0	70.3	71.2	62.1	53.5
091033	52.1	50.0	57.3	84.7	112.2	123.4	140.3	125.5	97.6	91.7	66.5	67.5
092012	42.3	39.2	44.5	54.2	51.3	65.7	57.5	57.6	48.2	54.6	43.9	52.0
094061	46.1	42.2	43.2	54.2	43.9	50.6	47.0	44.9	43.0	55.1	47.9	58.0

Table A3. The monthly serial correlation coefficients.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5008	0.115	0.149	-0.048	0.015	0.044	-0.040	0.008	-0.019	-0.050	-0.044	0.312	-0.081
6036	-0.116	0.126	0.013	0.028	0.061	0.078	-0.026	-0.054	0.031	0.035	0.305	0.037
9034	-0.067	-0.009	-0.080	0.043	0.007	0.138	-0.089	-0.073	-0.006	0.129	-0.094	0.007
10037	-0.136	0.160	-0.067	0.052	-0.059	-0.025	-0.049	0.042	0.209	0.168	-0.078	-0.093
12065	-0.057	0.161	0.152	0.109	-0.086	-0.028	-0.045	-0.097	0.089	0.000	0.089	-0.044
17031	-0.021	0.157	0.044	-0.082	0.031	0.006	0.035	0.044	0.055	0.162	0.148	0.066
19032	0.089	0.383	0.143	-0.051	0.251	0.143	0.217	0.136	0.181	0.172	0.001	0.105
22020	0.002	0.128	0.100	0.073	0.018	0.163	0.116	0.053	0.135	0.201	-0.077	-0.005
23000	0.005	-0.064	-0.062	-0.009	0.042	0.060	0.087	0.156	0.079	-0.019	-0.006	-0.096
24511	0.082	0.082	0.154	-0.136	0.120	0.131	0.201	0.213	0.175	0.217	0.102	0.094
28004	0.128	0.242	0.012	0.261	-0.035	-0.075	0.052	-0.075	0.365	-0.042	0.266	0.147
33035	0.182	-0.003	0.225	0.159	0.192	0.068	0.124	-0.092	0.158	-0.020	0.110	0.069
35027	0.084	0.030	0.149	0.073	0.298	-0.031	0.263	0.083	0.233	0.184	0.018	0.050
36007	-0.149	0.121	0.026	0.153	0.339	0.038	0.102	0.105	0.263	0.136	0.003	-0.034
39023	-0.016	0.083	-0.026	-0.029	0.148	0.037	0.107	0.083	0.073	0.099	0.150	0.001
39082	-0.057	0.058	-0.029	-0.080	-0.078	0.116	0.132	0.092	0.125	-0.011	0.100	0.055
40043	0.199	-0.046	0.037	0.041	-0.032	0.112	0.017	0.142	0.086	0.052	0.157	0.052
40214	0.160	-0.021	0.051	0.147	0.027	0.058	-0.004	0.134	0.203	-0.024	0.178	0.126
41082	-0.014	-0.070	0.133	-0.064	0.067	0.040	0.213	0.159	0.066	0.145	0.093	0.069
42023	0.295	-0.150	0.011	-0.108	0.306	-0.008	0.062	0.404	0.278	0.121	0.289	-0.017
44026	-0.008	0.043	0.171	0.083	0.156	-0.016	0.304	0.244	-0.062	0.161	0.271	0.046
47053	0.141	-0.104	0.168	-0.017	0.237	0.184	0.136	0.197	0.150	0.222	0.143	-0.022
49002	0.052	-0.049	0.241	0.071	0.195	0.144	0.317	0.086	0.212	0.184	0.159	0.188
54004	0.009	-0.013	-0.004	0.078	0.076	0.117	0.252	0.096	-0.009	0.069	0.247	0.061
62021	0.131	0.100	0.023	0.181	0.232	0.124	0.307	0.222	-0.024	0.019	0.228	0.051
66062	0.128	0.138	0.081	0.003	0.037	0.019	0.041	0.030	0.066	-0.036	0.078	0.089
69018	0.175	-0.013	0.014	0.094	-0.027	0.066	0.136	-0.014	0.057	0.180	0.246	0.137
72000	0.074	0.043	-0.024	0.228	0.036	0.194	0.151	0.154	0.068	0.175	0.265	0.120
72044	0.202	0.016	0.057	0.222	-0.011	0.189	0.127	0.059	0.031	0.182	0.241	0.115
75031	0.025	0.006	0.125	0.061	0.247	0.012	0.358	0.094	0.163	0.125	0.130	0.084
77030	0.046	-0.011	0.127	0.127	0.064	0.168	0.136	0.175	0.259	0.157	0.049	0.082
80056	0.015	-0.098	0.050	0.099	0.208	0.105	0.161	0.129	0.126	0.298	0.184	0.203
81007	-0.031	0.032	0.252	0.189	0.071	0.125	0.260	0.067	0.130	0.405	0.161	0.271
84030	0.215	0.198	-0.060	-0.062	0.035	-0.045	0.118	-0.016	0.144	-0.058	0.094	0.047
86071	-0.099	-0.006	0.106	-0.020	-0.042	-0.086	0.065	-0.018	0.067	0.178	0.187	0.290
86117	-0.068	0.050	0.065	0.055	0.053	-0.092	0.053	-0.032	0.081	0.260	0.183	0.158
87043	0.032	0.098	0.081	-0.070	-0.033	0.112	0.214	0.165	0.031	0.045	0.290	0.157
91033	-0.089	0.095	0.037	-0.053	0.036	0.236	0.063	0.065	0.003	0.218	0.333	-0.069
92012	0.100	-0.069	0.116	-0.040	-0.027	0.060	0.143	0.003	0.058	-0.037	0.255	0.063
94061	0.043	0.033	0.041	-0.146	0.058	0.085	0.019	0.102	-0.004	-0.088	0.075	0.118

Table A4. The WADSI values for the rainfall data

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
005008	0.769	*0.707*	0.841	**0.970**	0.896	0.966	0.867	0.961	0.935	0.905	0.893	0.872
006036	0.936	0.858	**0.991**	0.961	*0.824*	0.720	0.759	0.886	0.893	0.872	0.944	0.897
009034	0.425	0.435	0.431	0.430	0.420	***0.609***	0.524	0.485	0.455	0.440	0.434	0.428
010037	0.539	0.544	0.521	0.527	0.572	**0.613**	0.608	0.523	0.473	0.518	*0.550*	0.497
012065	0.800	0.755	0.646	0.724	0.698	0.805	0.649	0.732	**0.834**	0.830	*0.808*	0.744
017031	**1.116**	1.027	*1.018*	0.936	0.930	0.921	0.951	0.994	0.982	0.978	0.962	1.077
019032	0.655	0.624	0.606	0.666	0.659	***0.794***	0.735	0.789	0.756	0.661	0.648	0.645
022020	0.805	0.657	0.579	0.593	0.616	0.665	0.447	0.520	0.549	0.936	0.660	***1.014***
023000	0.470	0.511	0.515	0.465	0.485	*0.571*	0.496	0.496	**0.779**	0.589	0.521	0.479
024511	0.637	0.660	0.669	0.674	0.627	0.667	0.672	***0.822***	0.676	0.612	0.532	0.546
028004	0.674	0.641	0.504	0.603	0.632	0.621	0.621	0.638	*0.646*	0.657	0.657	**0.724**
033035	0.789	1.159	1.000	*1.171*	**1.173**	1.100	1.114	1.122	1.063	0.954	0.948	0.891
035027	0.691	0.724	0.548	0.510	0.579	0.676	0.856	***0.924***	0.837	0.764	0.742	0.703
036007	1.038	1.060	1.005	1.136	1.110	1.035	1.062	1.030	1.072	1.128	***1.176***	1.035
039023	0.517	0.436	0.614	0.651	0.645	0.837	***0.839***	0.670	0.606	0.540	0.509	0.535
039082	1.036	0.751	0.970	0.801	1.059	1.152	**1.183**	*1.180*	1.144	1.137	1.104	0.866
040043	0.677	0.482	0.392	0.401	0.450	0.651	*0.703*	0.687	0.786	0.782	0.771	**0.842**
040214	0.597	0.540	0.569	0.616	0.660	0.745	*0.846*	**0.890**	0.879	0.846	0.775	0.771
041082	0.397	0.446	0.519	0.611	0.609	0.548	0.538	**0.669**	*0.589*	0.594	0.465	0.434
042023	0.627	**1.013**	0.543	*0.579*	0.605	0.585	0.594	0.494	0.530	0.593	0.406	0.511
044026	1.007	0.944	1.141	1.153	1.141	1.077	1.157	***1.183***	1.044	0.968	0.936	0.950
047053	**0.922**	0.894	0.896	0.893	0.841	0.881	0.848	0.858	0.843	0.757	0.692	*0.829*
049002	0.802	0.737	0.747	0.740	0.691	0.738	0.765	0.834	0.833	0.842	***0.938***	0.799
054004	0.623	0.568	**0.826**	0.705	0.675	0.685	0.698	*0.736*	0.682	0.621	0.484	0.433
062021	0.609	0.643	0.520	0.533	0.651	0.658	**0.764**	0.677	0.584	0.670	0.625	*0.655*
066062	0.822	0.683	0.786	0.631	**0.993**	0.951	0.874	0.989	*0.964*	0.973	0.882	0.684
069018	1.224	1.125	1.149	1.252	***1.323***	1.292	1.170	1.141	1.097	1.200	1.160	1.134
072000	0.450	0.474	0.589	0.441	**0.612**	0.414	0.511	*0.554*	0.469	0.412	0.364	0.433
072044	0.412	0.432	0.531	0.409	0.555	0.405	0.569	***0.618***	0.465	0.429	0.341	0.359
075031	***0.926***	0.788	0.662	0.797	0.632	0.597	0.697	0.794	0.761	0.782	0.875	0.847
077030	0.464	0.457	0.456	0.563	0.512	0.537	0.549	*0.633*	**0.650**	0.579	0.507	0.430
080056	0.576	0.443	0.460	0.535	0.548	0.661	0.862	***0.940***	0.884	0.852	0.895	0.765
081007	0.484	0.472	0.481	0.489	0.499	0.596	0.614	***0.842***	0.749	0.716	0.668	0.598
084030	0.650	0.711	*0.721*	0.587	0.591	0.606	0.546	0.773	0.807	**0.808**	0.722	0.680
086071	0.485	0.457	0.503	0.464	0.502	***0.643***	0.520	0.585	0.543	0.469	0.421	0.611
086117	0.515	0.491	0.522	0.523	0.517	0.545	0.503	0.544	***0.554***	0.514	0.459	0.490
087043	0.556	0.520	0.604	0.602	0.587	***0.900***	0.797	0.826	0.609	0.569	0.438	0.519
091033	0.805	0.635	0.690	0.644	0.752	0.532	0.581	0.684	0.581	0.653	0.799	***0.910***
092012	0.871	0.901	0.832	0.769	0.864	0.926	*0.896*	**0.986**	0.916	0.857	0.698	0.799
094061	0.877	1.007	1.242	0.723	0.694	0.824	1.075	1.293	1.334	1.395	*1.407*	**1.429**
001005	0.745	0.650	**1.203**	0.727	0.832	0.798	0.764	0.710	0.710	0.723	0.744	0.714
002016	**0.776**	0.526	0.523	0.576	0.634	0.637	0.645	0.627	0.637	0.637	0.729	0.688
014902	0.565	0.569	0.517	**0.615**	0.498	0.536	0.510	0.548	0.532	0.529	0.556	*0.571*
015540	1.083	**1.236**	1.117	1.129	1.050	1.100	1.124	1.091	1.083	1.076	1.058	1.069

Note: The largest values of WADSI are shown in bold and the values of WASI for the month in which SSI is the largest is shown in Italics with shading.

Table A5. The SSI values for the rainfall data

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
005008	0.246	**0.329**	0.285	*0.295*	0.307	0.277	0.252	0.278	0.268	0.257	0.262	0.251
006036	0.304	0.314	*0.308*	0.318	**0.329**	0.257	0.276	0.303	0.295	0.289	0.301	0.302
009034	0.083	0.080	0.083	0.079	0.102	***0.210***	0.144	0.096	0.097	0.094	0.083	0.080
010037	0.156	0.157	0.168	0.111	0.119	*0.142*	0.144	0.129	0.156	0.148	**0.165**	0.141
012065	0.343	0.313	0.176	0.200	0.191	0.248	0.223	0.280	*0.332*	0.348	**0.355**	0.311
017031	*0.350*	0.352	**0.397**	0.359	0.361	0.386	0.348	0.367	0.378	0.377	0.374	0.381
019032	0.146	0.205	0.242	0.343	0.263	***0.349***	0.291	0.310	0.291	0.264	0.216	0.162
022020	0.194	0.156	0.134	0.126	0.140	0.181	0.121	0.115	0.120	0.230	0.145	***0.240***
023000	0.091	0.108	0.112	0.125	0.106	**0.230**	0.103	0.095	*0.179*	0.131	0.116	0.092
024511	0.248	0.271	0.332	0.306	0.283	0.330	0.297	***0.350***	0.246	0.229	0.185	0.186
028004	0.223	0.178	0.124	0.148	0.214	0.183	0.216	0.198	**0.236**	0.222	0.217	*0.200*
033035	0.227	0.305	0.316	**0.332**	*0.318*	0.307	0.314	0.318	0.299	0.286	0.282	0.266
035027	0.250	0.301	0.253	0.215	0.201	0.222	0.279	***0.306***	0.284	0.274	0.262	0.255
036007	0.285	0.331	0.279	0.296	0.291	0.303	0.321	0.323	0.323	0.334	***0.339***	0.299
039023	0.176	0.119	0.160	0.154	0.166	0.233	***0.237***	0.223	0.212	0.232	0.207	0.155
039082	0.281	0.328	0.270	0.245	0.299	0.328	*0.334*	**0.336**	0.323	0.320	0.305	0.252
040043	0.178	0.128	0.105	0.139	0.161	0.187	**0.247**	0.177	0.209	0.198	0.190	*0.217*
040214	0.208	0.182	0.280	0.286	0.248	0.299	**0.330**	*0.305*	0.323	0.322	0.305	0.271
041082	0.071	0.103	0.117	0.150	0.162	0.155	0.160	*0.208*	**0.208**	0.191	0.145	0.138
042023	0.163	*0.251*	0.183	**0.262**	0.247	0.222	0.249	0.160	0.188	0.217	0.155	0.162
044026	0.335	0.338	0.386	0.394	0.393	0.381	0.397	***0.410***	0.381	0.371	0.357	0.349
047053	*0.405*	0.373	0.377	0.341	0.330	0.349	0.290	0.301	0.301	0.369	0.324	**0.414**
049002	0.350	0.300	0.339	0.352	0.358	0.395	0.363	0.376	0.369	0.397	***0.404***	0.321
054004	0.143	0.224	*0.259*	0.268	0.229	0.205	0.235	**0.271**	0.220	0.185	0.135	0.117
062021	0.161	0.177	0.127	0.169	0.176	0.194	*0.234*	0.231	0.217	0.214	0.215	**0.257**
066062	0.240	0.165	0.187	0.187	*0.323*	0.318	0.284	0.322	**0.328**	0.315	0.287	0.208
069018	0.377	0.332	0.338	0.372	***0.382***	0.362	0.352	0.340	0.348	0.376	0.360	0.346
072000	0.087	0.094	0.135	0.076	*0.140*	0.086	0.145	**0.183**	0.132	0.107	0.063	0.074
072044	0.076	0.078	0.115	0.076	0.145	0.097	0.189	***0.241***	0.154	0.149	0.068	0.074
075031	***0.395***	0.272	0.222	0.214	0.148	0.238	0.238	0.318	0.278	0.317	0.373	0.380
077030	0.123	0.136	0.106	0.123	0.105	0.137	0.149	**0.173**	*0.169*	0.163	0.157	0.092
080056	0.202	0.166	0.099	0.153	0.192	0.378	0.384	***0.406***	0.352	0.325	0.341	0.290
081007	0.120	0.137	0.093	0.103	0.118	0.251	0.206	***0.311***	0.271	0.245	0.206	0.162
084030	0.180	0.244	**0.294**	0.188	0.202	0.227	0.164	0.243	0.221	*0.204*	0.208	0.195
086071	0.092	0.091	0.133	0.128	0.115	***0.163***	0.141	0.161	0.154	0.138	0.083	0.149
086117	0.104	0.098	0.120	0.109	0.107	0.112	0.138	0.153	***0.159***	0.129	0.107	0.103
087043	0.195	0.146	0.223	0.145	0.149	***0.229***	0.208	0.196	0.139	0.160	0.090	0.120
091033	0.201	0.142	0.160	0.157	0.230	0.153	0.187	0.226	0.150	0.173	0.198	***0.231***
092012	0.316	0.290	0.285	0.273	0.301	0.333	**0.337**	*0.324*	0.313	0.269	0.251	0.223
094061	0.222	0.248	0.327	0.173	0.178	0.210	0.300	0.356	0.356	0.382	**0.382**	*0.375*
001005	0.226	0.162	**0.333**	0.214	0.298	0.289	0.279	0.260	0.255	0.270	0.306	0.254
002016	**0.369**	0.109	0.122	0.156	0.207	0.212	0.212	0.197	0.207	0.212	0.341	0.287
014902	0.172	0.187	0.150	*0.231*	0.182	0.207	0.203	0.228	0.209	0.223	0.234	**0.283**
015540	0.381	0.403	0.397	0.458	0.450	0.476	**0.476**	0.456	0.451	0.451	0.442	0.424

Note: The largest values of SSI are shown in bold and the values of SSI for the month in which WADSI is the largest is shown in Italics with shading.

Table A6. The expected residence times (years) in the wet and dry states.

Station	Wet State												Dry State											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5008	1.4	1.4	1.3	1.3	1.2	1.4	1.4	1.4	1.4	1.5	1.4	1.5	2.4	4.6	2.4	1.6	1.6	2.1	1.9	2.1	2.0	2.0	2.1	2.1
6036	1.4	1.7	2.0	2.1	2.2	1.7	1.5	1.5	1.5	1.5	1.5	1.5	2.7	4.4	4.2	4.8	6.2	3.5	2.8	3.3	2.8	2.9	2.7	2.9
9034	2.2	2.2	2.2	2.2	2.0	1.5	1.8	2.2	2.9	2.5	2.2	2.3	1.9	2.0	2.1	2.4	2.5	2.5	2.0	2.1	2.8	2.1	2.2	2.1
10037	1.5	1.6	1.5	2.0	2.0	2.0	1.7	1.9	1.7	1.6	1.6	1.6	2.1	2.2	2.3	2.4	2.2	2.5	2.0	2.8	2.7	2.3	2.4	2.4
12065	1.4	1.5	2.2	2.5	2.6	2.3	2.1	1.8	1.6	1.4	1.3	1.4	4.8	4.4	2.7	2.9	2.8	3.7	3.4	3.6	4.5	4.6	4.5	3.6
17031	1.6	1.7	1.6	1.8	1.6	1.3	1.4	1.4	1.6	1.7	2.0	1.7	4.1	4.6	7.5	6.2	5.4	5.8	4.4	4.7	5.9	6.2	6.1	5.4
19032	2.4	1.8	1.4	1.3	1.4	1.2	1.4	1.3	1.4	1.5	1.9	2.3	2.7	3.1	3.0	4.5	3.1	4.1	3.7	4.1	3.6	3.6	3.6	3.0
22020	2.1	2.0	1.9	2.0	2.3	1.7	1.7	2.0	2.0	2.1	2.3	2.2	1.8	1.8	1.9	2.0	1.8	2.2	2.0	1.8	2.0	1.8	1.9	1.7
23000	2.2	1.9	2.0	1.8	1.9	1.7	2.0	2.2	2.3	2.0	2.0	2.1	2.0	2.1	1.9	1.9	2.0	3.5	2.1	2.1	2.1	2.2	2.6	2.1
24511	1.8	1.7	1.4	1.4	1.6	1.6	1.5	1.3	1.6	1.7	2.0	2.0	3.9	4.2	5.0	4.3	4.3	5.4	4.1	4.8	3.4	3.5	3.3	3.2
28004	2.3	2.5	2.1	2.4	2.3	2.4	2.5	2.4	2.6	2.5	2.6	2.5	3.6	3.4	2.7	2.6	3.6	3.0	3.7	3.2	4.1	3.7	3.6	3.0
33035	2.1	1.9	2.0	1.9	1.9	2.0	1.9	1.8	1.9	1.8	1.9	1.8	3.3	2.2	4.3	3.3	3.3	3.2	3.1	3.1	3.1	3.2	3.3	2.9
35027	2.4	1.9	4.2	3.0	2.4	2.3	2.1	2.2	2.3	2.2	2.1	2.2	4.9	5.1	4.2	4.9	4.0	3.6	4.2	4.4	4.4	4.6	4.1	3.9
36007	2.2	1.9	2.4	2.5	2.3	2.0	2.1	2.0	2.0	1.9	1.8	1.9	3.5	3.6	3.1	2.7	2.8	2.9	3.3	3.7	3.7	3.4	3.2	2.7
39023	1.7	1.7	1.8	2.2	2.1	1.9	2.4	2.7	2.7	3.3	3.0	2.2	2.6	1.6	2.0	2.0	2.2	2.5	2.8	3.7	3.7	4.1	3.8	2.6
39082	2.5	1.6	1.9	2.2	2.1	2.1	1.9	2.4	2.4	2.3	2.4	2.3	2.7	5.2	2.9	3.3	3.0	3.2	3.2	3.0	2.9	3.0	2.9	3.6
40043	1.8	2.0	2.1	1.8	1.8	1.7	1.4	2.0	2.1	2.1	2.2	2.0	2.5	2.9	2.8	2.7	2.9	2.5	2.6	2.4	2.0	2.0	2.2	2.2
40214	1.7	2.2	2.3	2.0	2.1	1.8	1.5	1.6	1.4	1.4	1.4	1.4	2.8	3.4	5.9	5.6	4.8	5.4	5.0	4.2	3.7	3.8	3.0	2.5
41082	2.0	1.9	1.8	1.7	1.6	1.6	1.6	1.4	1.4	1.5	1.7	1.7	2.1	2.4	2.1	1.8	1.7	1.8	1.9	1.9	2.2	1.9	2.3	2.2
42023	2.0	1.8	2.2	1.7	1.6	1.7	1.6	1.7	1.5	1.4	1.6	1.7	2.0	1.7	2.9	4.0	3.2	3.1	3.3	2.4	2.3	2.3	2.2	2.4
44026	2.1	1.8	1.7	1.5	1.5	1.9	1.8	1.5	1.5	1.5	1.8	1.9	5.7	5.2	5.7	5.8	6.3	6.5	6.8	7.2	6.4	5.8	6.0	6.1
47053	1.8	1.9	1.7	1.8	1.8	1.8	2.1	2.0	2.2	1.8	1.8	1.7	9.8	7.9	6.3	5.3	5.5	5.8	4.7	4.7	5.5	8.8	5.8	12.5
49002	2.1	2.0	1.9	2.0	1.7	1.6	1.7	1.7	1.8	1.7	1.9	2.0	8.1	5.0	6.5	8.3	8.1	10.1	8.2	8.5	7.9	9.5	9.8	5.8
54004	2.1	1.5	1.9	1.6	1.7	1.8	1.8	1.6	1.7	1.9	1.9	1.9	2.9	3.2	3.3	4.1	3.5	3.1	3.6	3.8	3.1	3.3	2.7	2.7
62021	2.0	2.0	2.4	2.5	2.3	2.2	2.1	1.9	1.8	2.1	1.8	1.6	2.6	2.5	2.6	3.2	2.9	3.2	3.4	3.8	3.2	3.3	3.3	4.0
66062	2.6	2.1	2.1	1.9	2.3	2.5	2.7	2.3	2.2	2.3	2.8	2.2	3.2	2.0	2.0	3.0	5.7	6.4	5.7	6.1	6.6	5.9	5.4	3.6

Table A6. (Cont)

Station	Wet State												Dry State											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
69018	2.9	3.2	2.8	3.3	3.3	2.9	3.3	2.3	2.7	3.2	3.1	2.9	5.8	4.9	4.1	4.4	4.8	4.4	4.7	4.2	5.2	6.1	5.9	5.2
72000	2.5	2.2	2.4	2.2	1.9	2.0	1.8	1.7	2.0	1.9	2.0	2.2	2.1	2.3	1.9	2.2	2.0	2.1	2.3	2.3	2.4	2.2	2.0	2.3
72044	2.0	2.2	2.0	2.0	1.7	2.0	1.6	1.4	1.6	1.5	1.8	1.8	2.1	2.2	2.3	2.4	2.3	2.4	2.7	2.8	2.4	2.1	1.9	2.0
75031	1.4	1.6	1.7	2.1	2.2	1.6	1.8	1.6	1.8	1.7	1.7	1.5	7.4	3.2	3.3	3.0	2.5	3.8	3.5	5.0	4.3	5.5	7.6	7.0
77030	2.0	1.8	1.9	2.1	2.1	1.9	2.0	2.0	2.1	2.0	2.0	2.0	2.9	2.9	2.6	2.7	2.5	2.8	3.1	2.8	3.0	3.0	3.4	2.3
80056	2.2	2.1	2.0	1.8	1.6	1.4	1.5	1.5	1.7	1.6	1.8	1.8	3.7	3.3	2.4	2.6	2.9	6.0	6.5	7.4	5.4	4.4	5.4	4.5
81007	2.1	2.1	2.3	2.1	1.8	1.6	1.8	1.6	1.8	1.8	1.9	2.0	2.6	2.7	2.2	2.3	2.3	3.5	2.7	4.1	3.4	3.1	3.0	2.6
84030	1.9	1.6	1.4	1.6	1.7	1.7	1.6	1.3	1.5	1.6	1.6	1.5	2.4	2.9	3.7	2.8	3.2	3.7	2.4	2.0	1.8	1.8	2.1	2.0
86071	2.2	2.1	1.8	1.8	2.1	2.0	2.0	2.0	1.9	1.7	2.0	2.0	2.5	2.0	2.0	2.1	2.3	2.2	2.2	2.5	2.5	2.2	2.3	2.5
86117	2.0	2.1	1.8	1.9	2.0	2.0	1.6	1.7	1.6	1.8	1.8	1.9	2.3	2.3	2.1	2.1	2.4	2.0	2.0	2.1	2.3	2.4	2.4	2.2
87043	1.6	1.7	1.4	1.8	1.9	2.0	2.0	2.3	2.2	2.0	2.1	1.9	2.7	2.1	2.4	2.0	2.6	2.5	2.5	2.6	2.6	3.0	2.3	2.2
91033	2.4	2.4	2.1	2.1	1.7	1.8	1.7	1.9	2.1	2.0	2.1	2.0	2.5	2.3	2.1	2.2	2.4	2.3	2.7	3.0	2.7	2.7	2.2	2.1
92012	2.0	2.2	2.2	2.1	1.8	1.7	1.4	1.7	1.6	1.9	1.6	1.9	6.4	5.7	5.7	5.3	5.1	5.5	5.1	4.1	4.2	3.7	3.8	3.1
94061	2.2	2.4	2.1	2.3	2.3	2.8	2.8	3.1	2.3	2.3	1.9	2.1	2.2	2.5	3.4	2.3	2.5	2.5	3.2	3.5	3.3	3.5	3.1	3.2
1005	1.7	1.9	1.8	1.6	1.4	1.4	1.5	1.5	1.6	1.5	1.5	1.6	2.5	2.4	2.6	2.4	3.1	3.0	3.4	3.4	3.3	3.6	4.5	3.4
2016	2.1	2.3	1.8	1.8	1.6	1.7	1.7	1.8	1.7	1.6	1.8	2.0	8.3	2.2	1.9	2.2	2.2	2.5	2.5	2.6	2.6	2.5	5.6	4.9
14902	2.0	1.8	2.2	1.9	2.0	2.0	1.9	2.0	2.0	2.0	2.0	1.8	3.2	3.3	3.4	3.9	3.4	3.5	3.4	4.0	3.8	3.9	4.2	5.0
15540	1.9	1.8	1.5	1.8	1.6	1.7	1.7	1.7	1.7	1.7	1.4	1.9	6.7	6.7	6.7	16.9	14.7	21.7	22.2	16.1	14.9	14.9	11.4	11.6

APPENDIX B – SPATIAL DISTRIBUTION OF HSM MODEL PARAMETERS

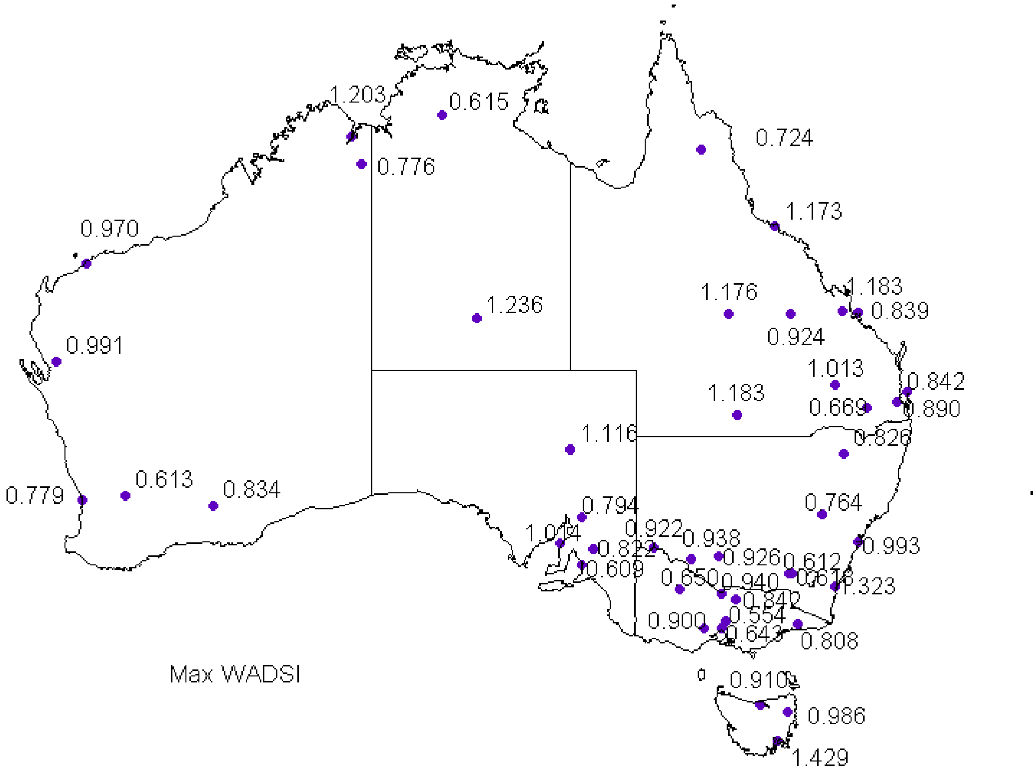


Figure B1. The largest wet and dry separation indices for the rainfall data

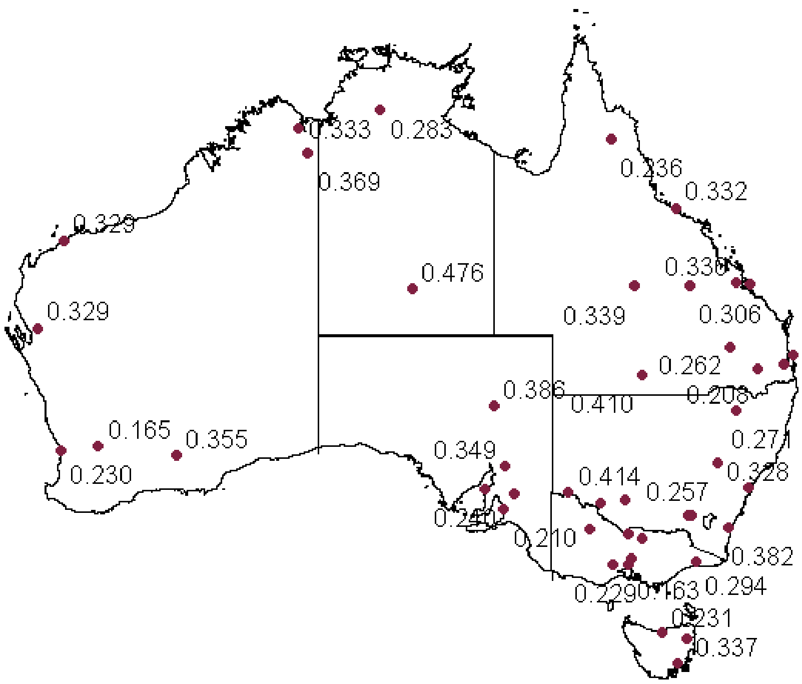


Figure B2. The largest state stability index for the rainfall data

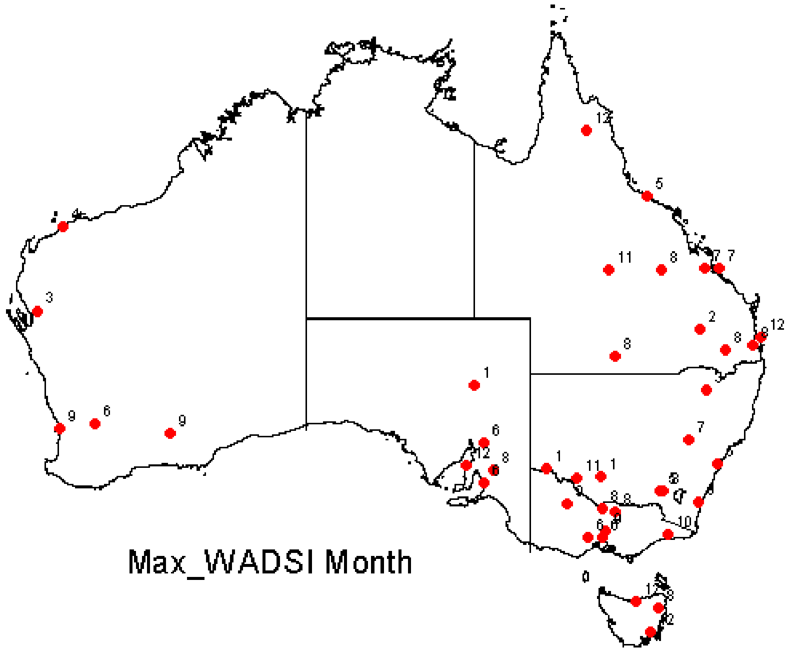


Figure B3. The starting month of the water year for which the WADSI is the largest.

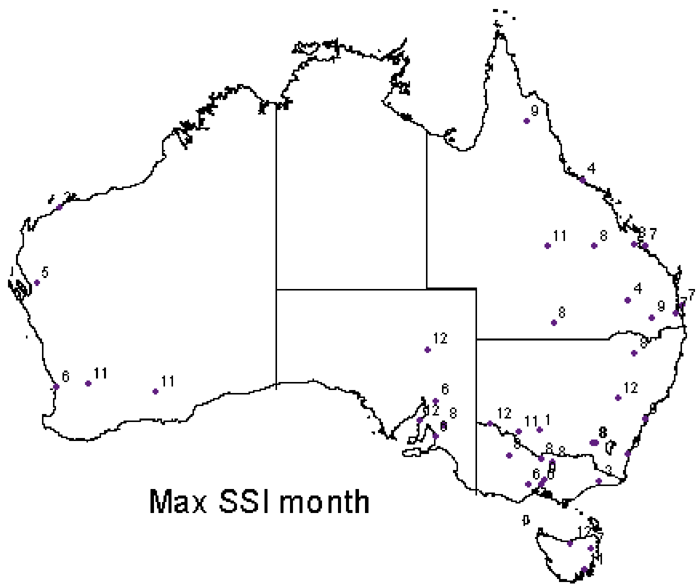


Figure B4. The starting month of the water year for which the SSI is the largest.

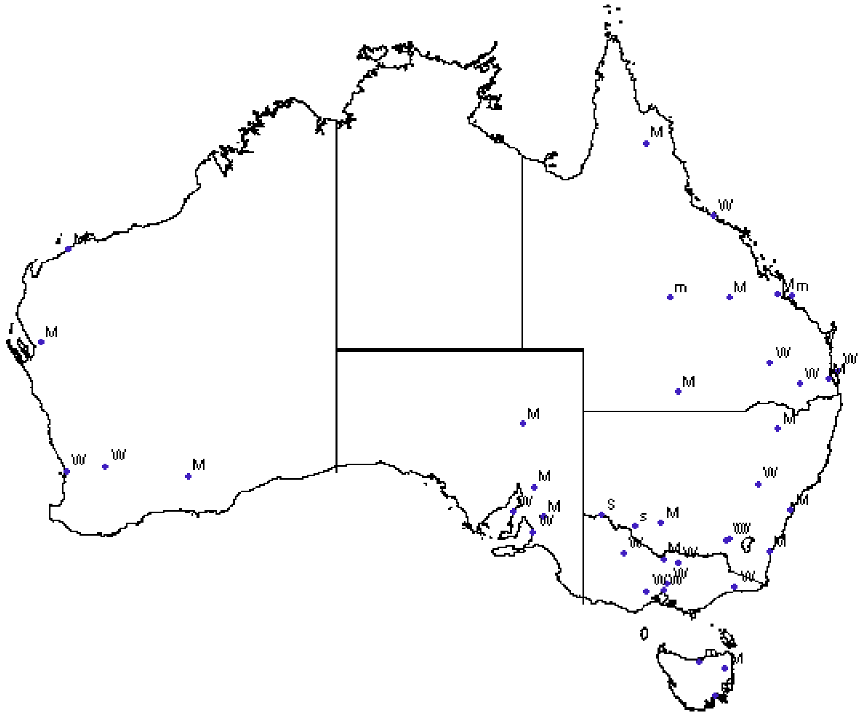
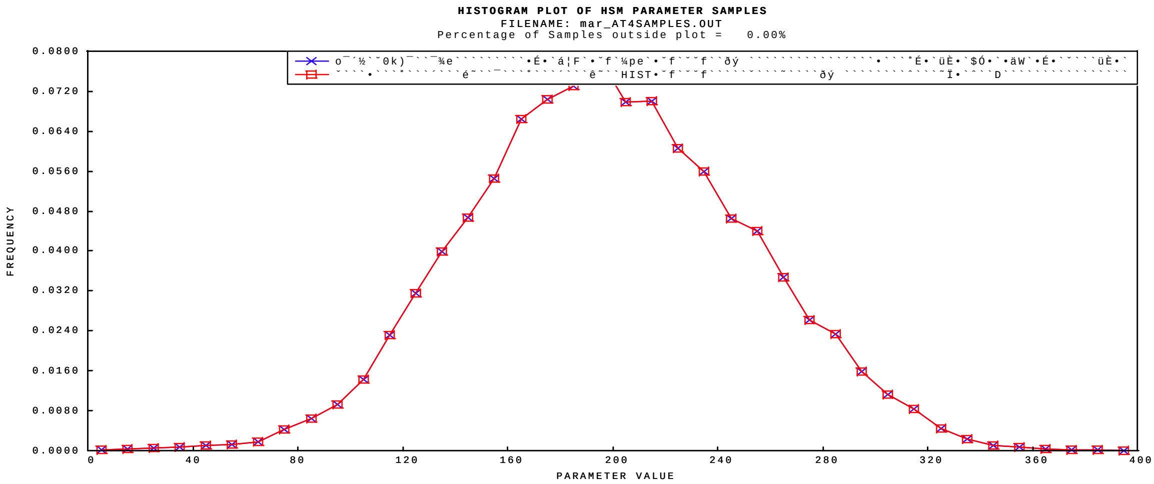
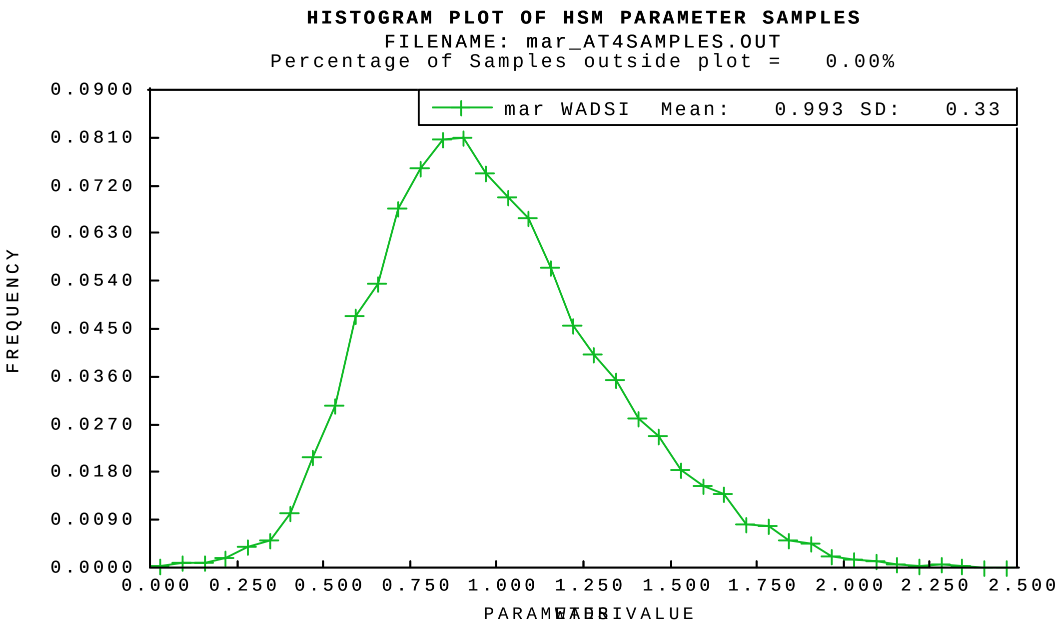
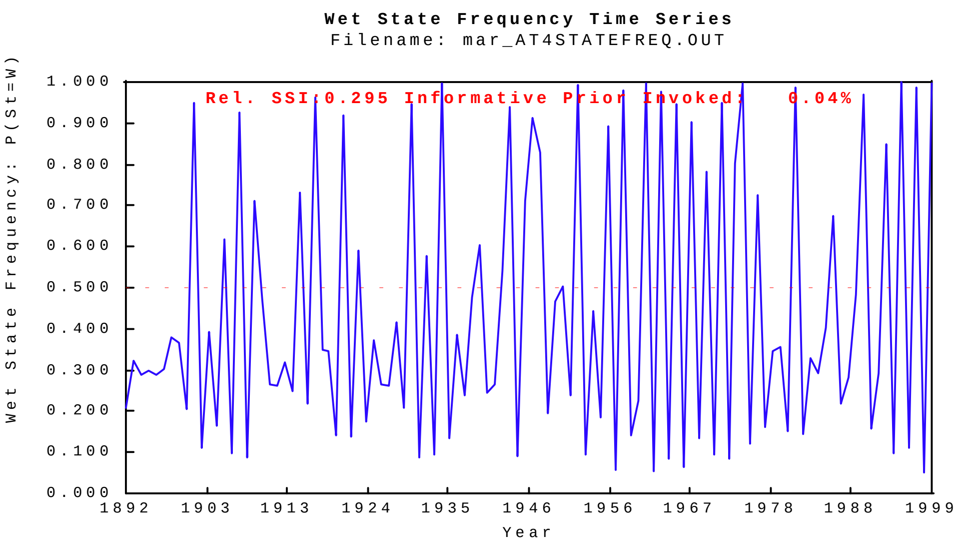


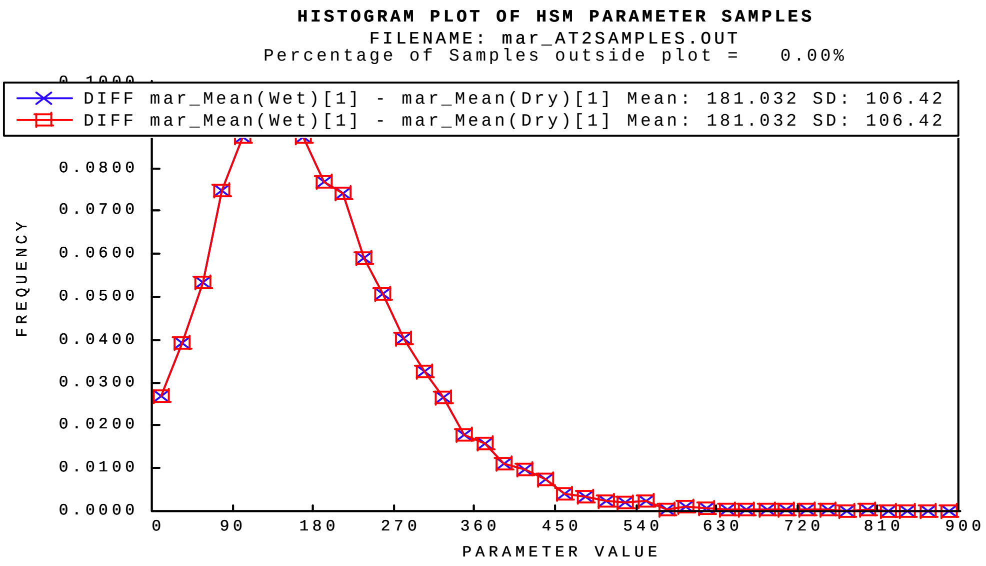
Figure B5. The strength of dry state persistence

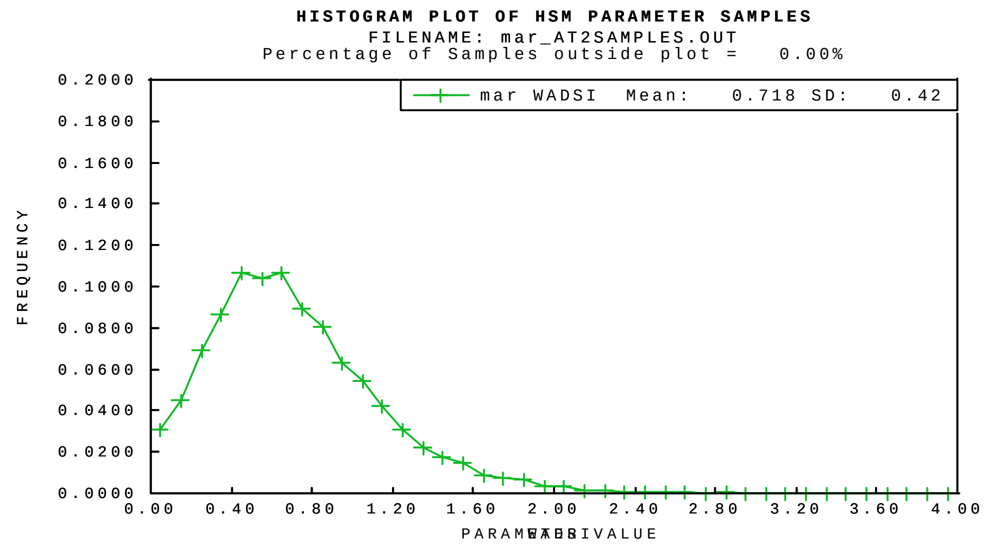


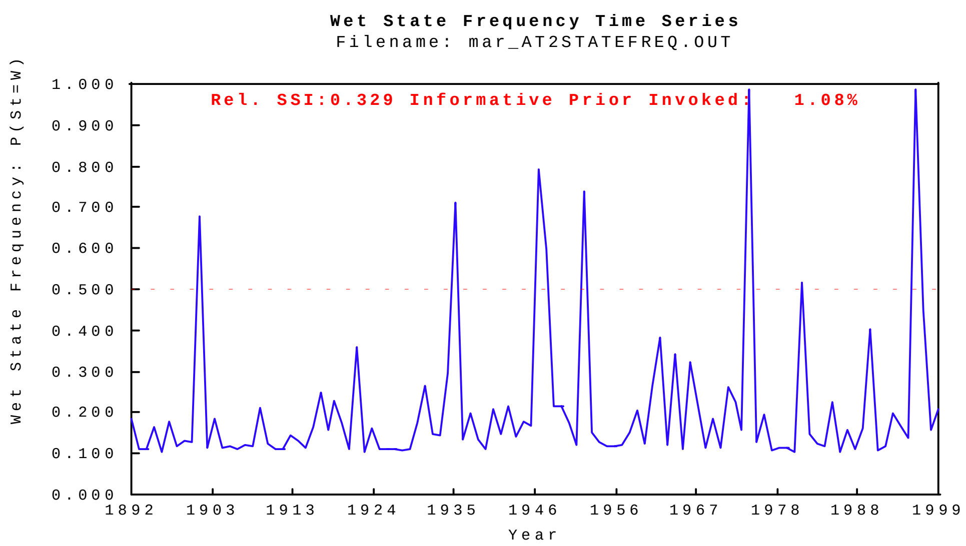




(a) Starting month April

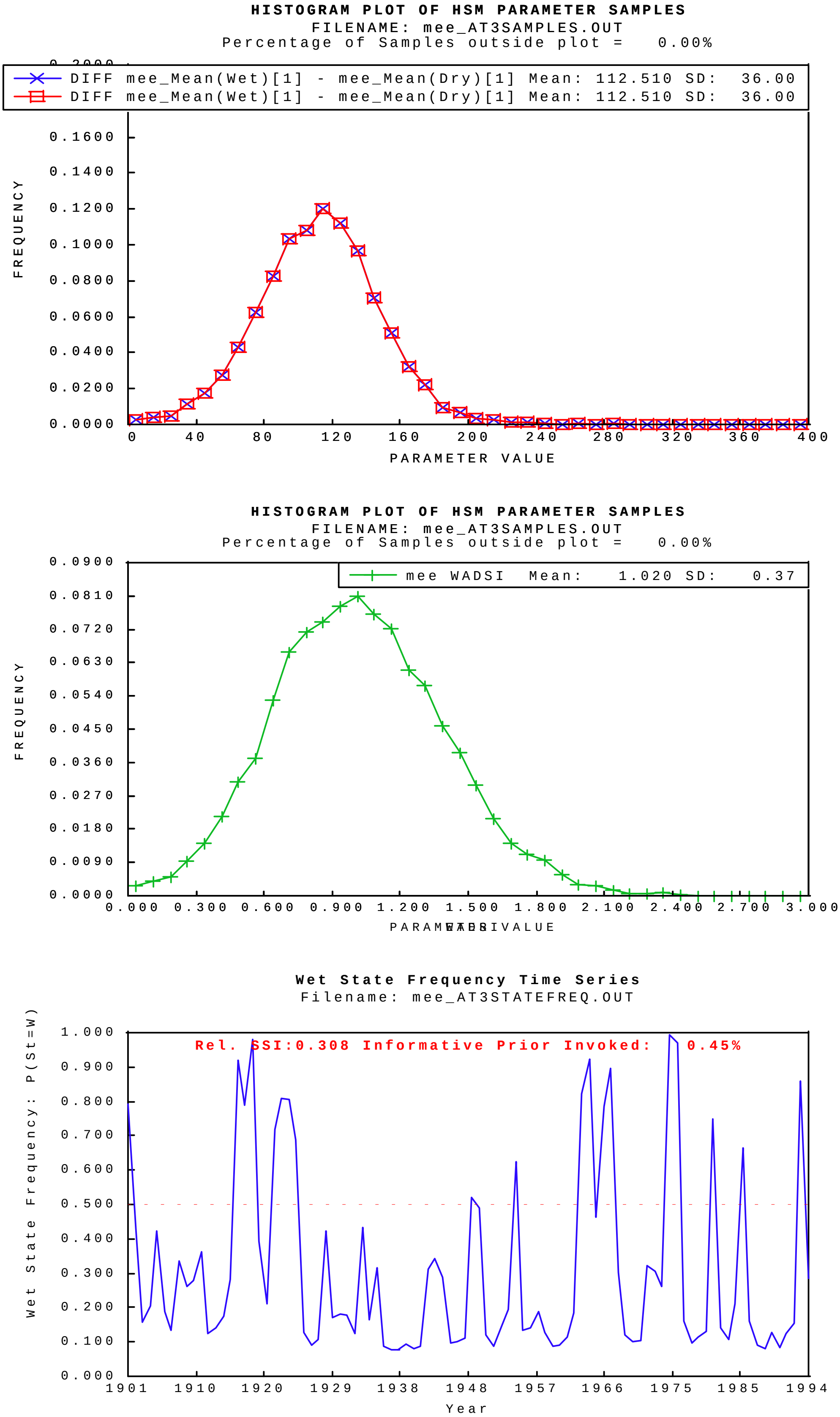




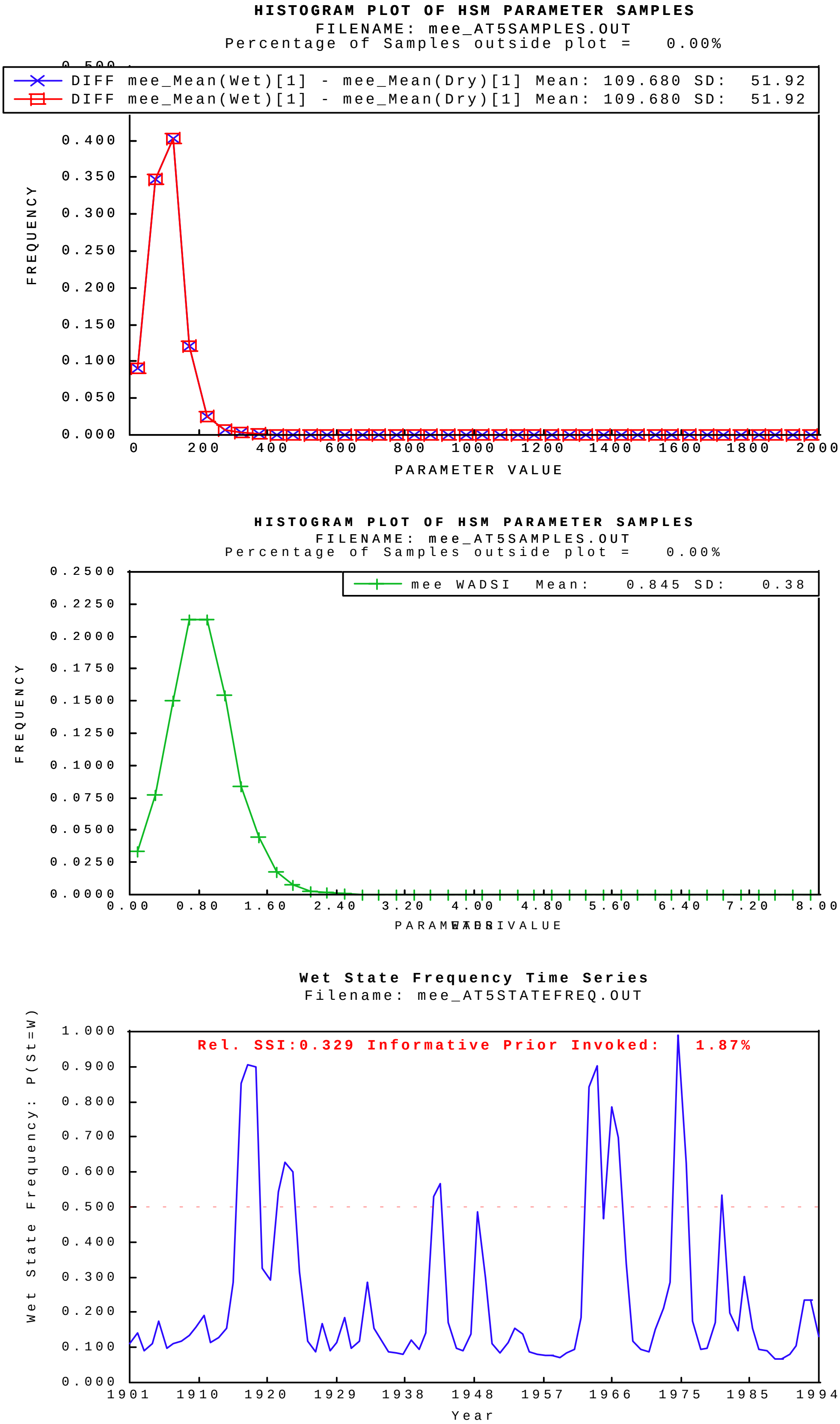


(b) Starting month February

Figure C1. Calibration plots for Mardie



(a) Starting month March



(b) Starting month May

Figure C2. Calibration plots for Meedo

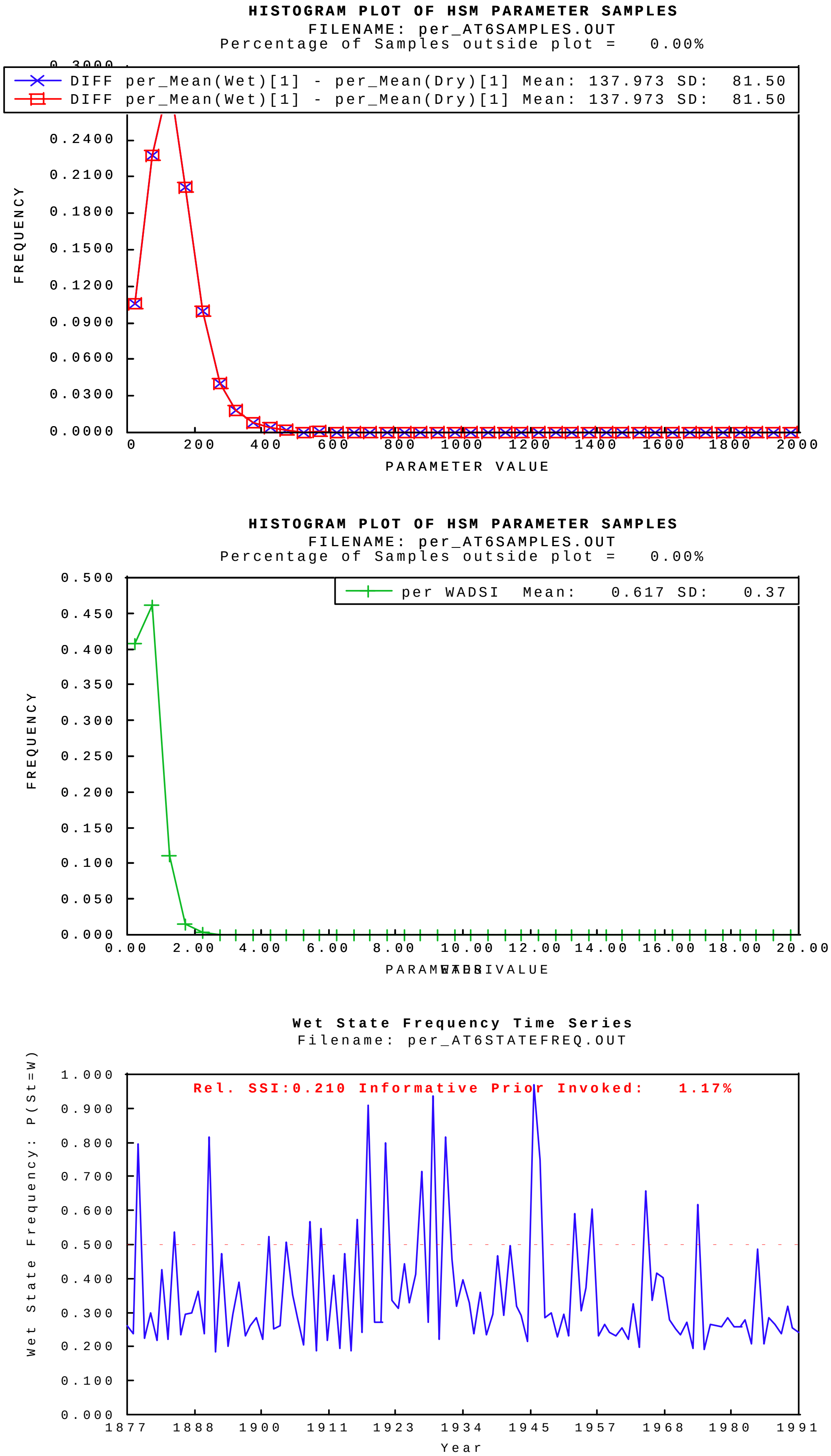
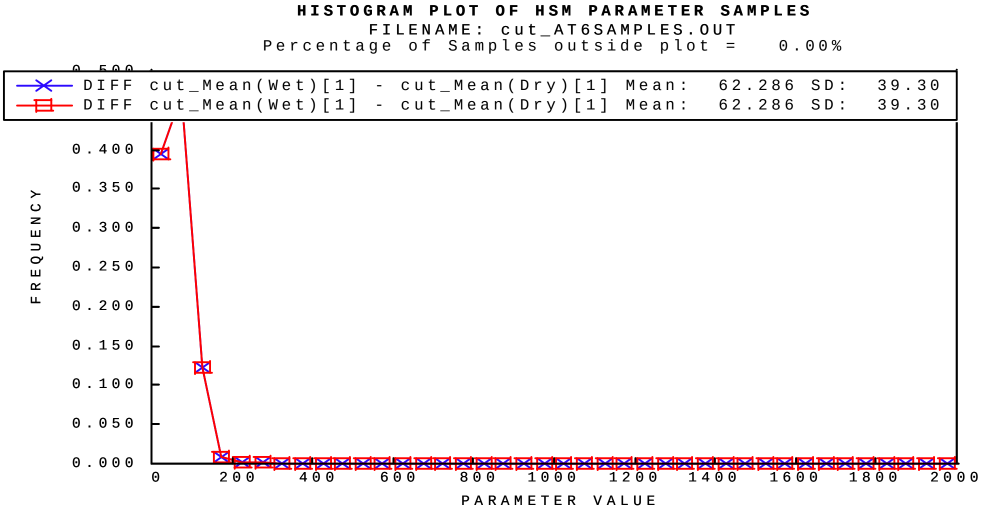
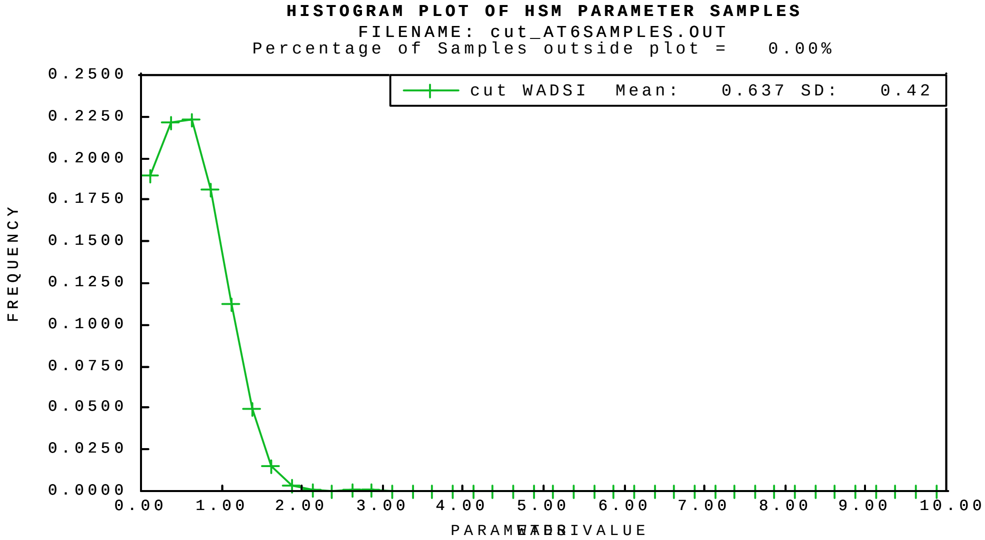
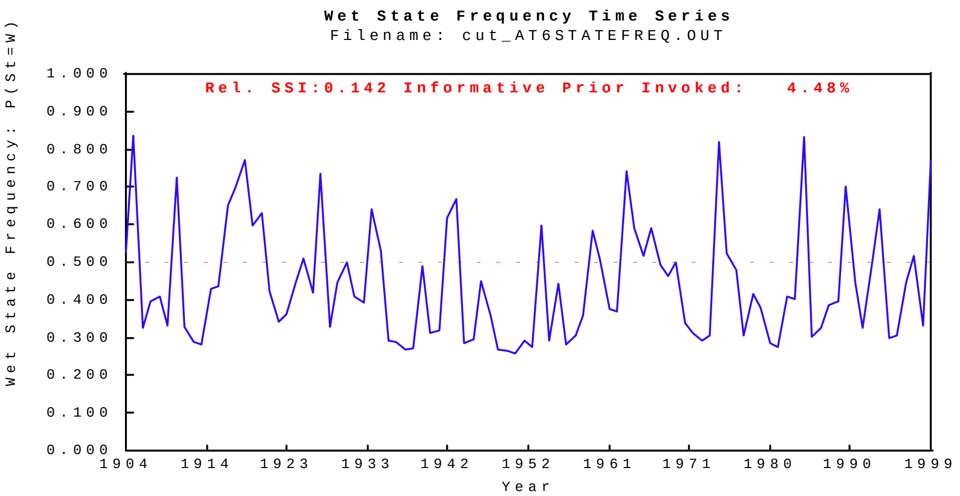


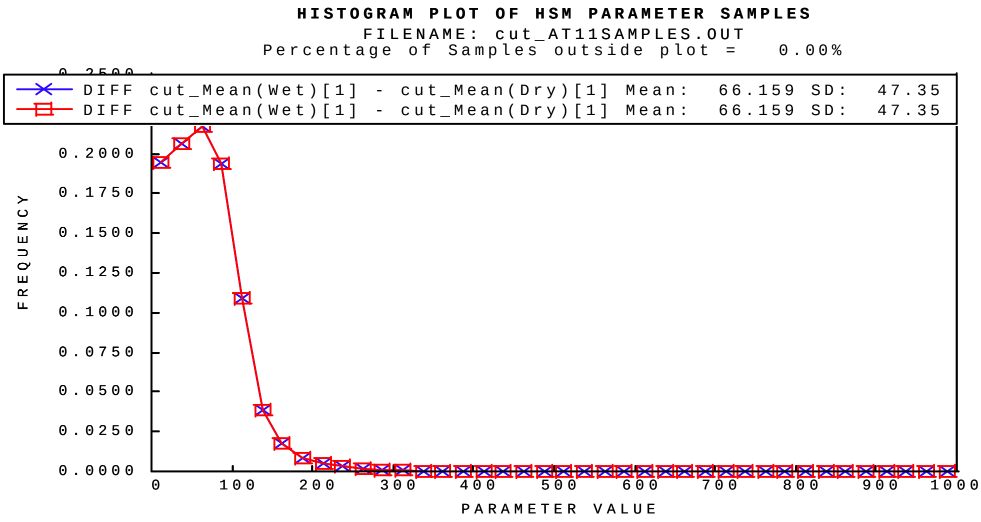
Figure C3. Calibration plots for Perth

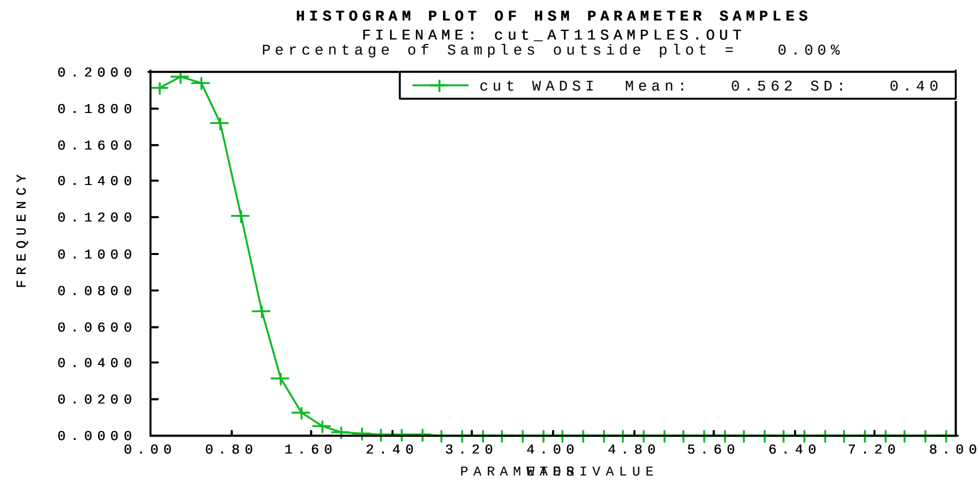


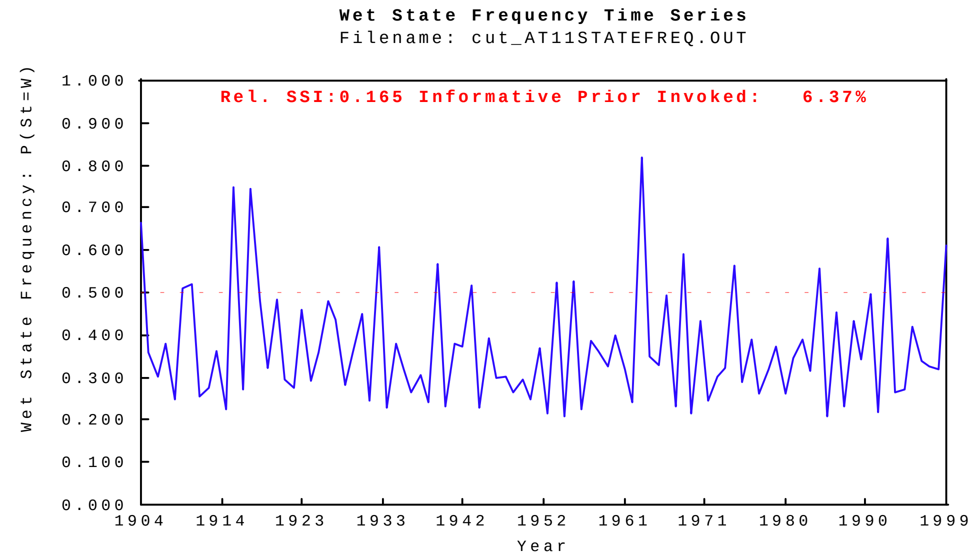




(a) Starting month June

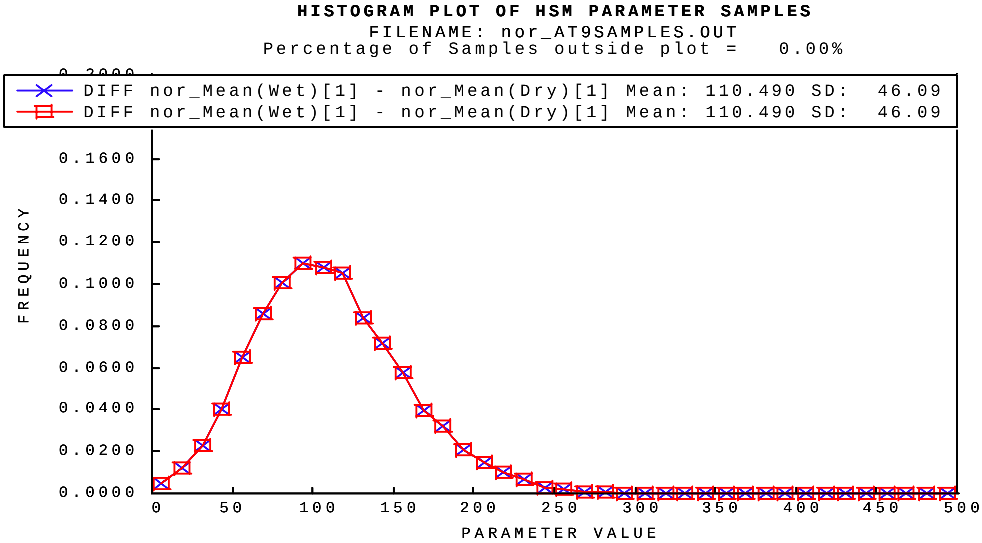


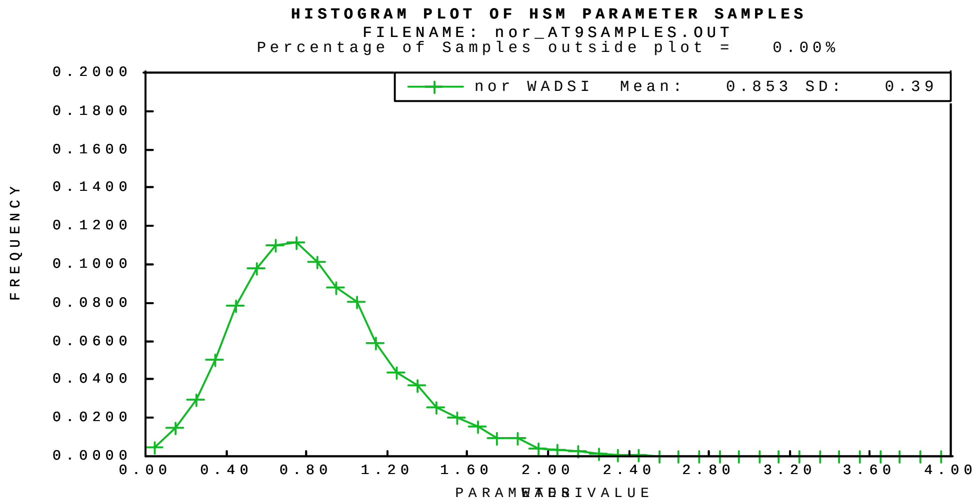


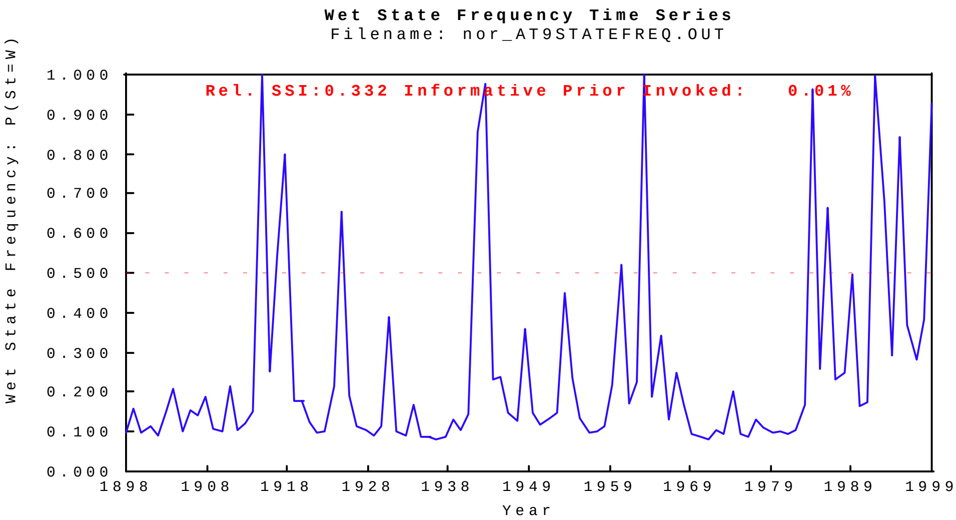


(b) Starting month November

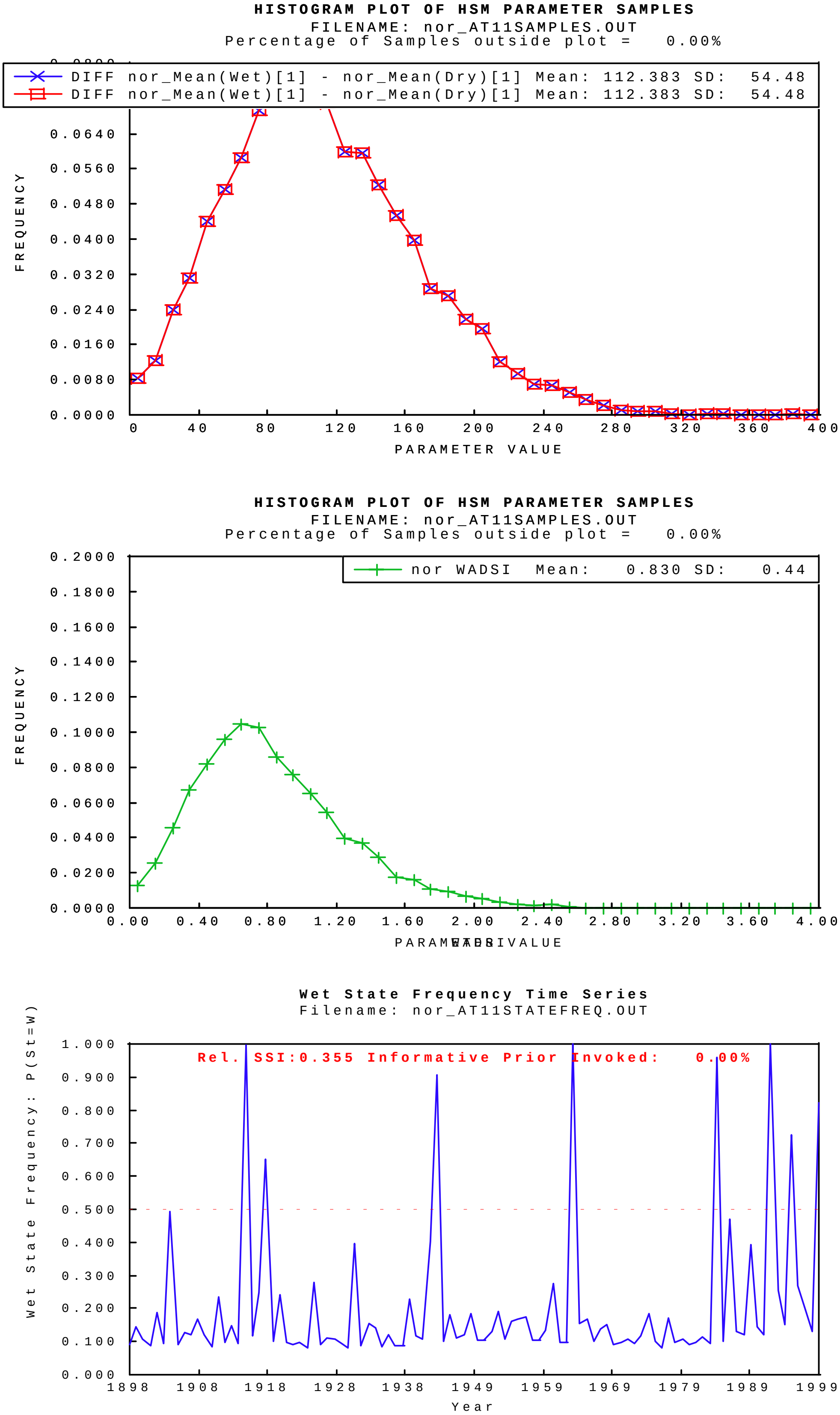
Figure C4. Calibration plots for Cuttening





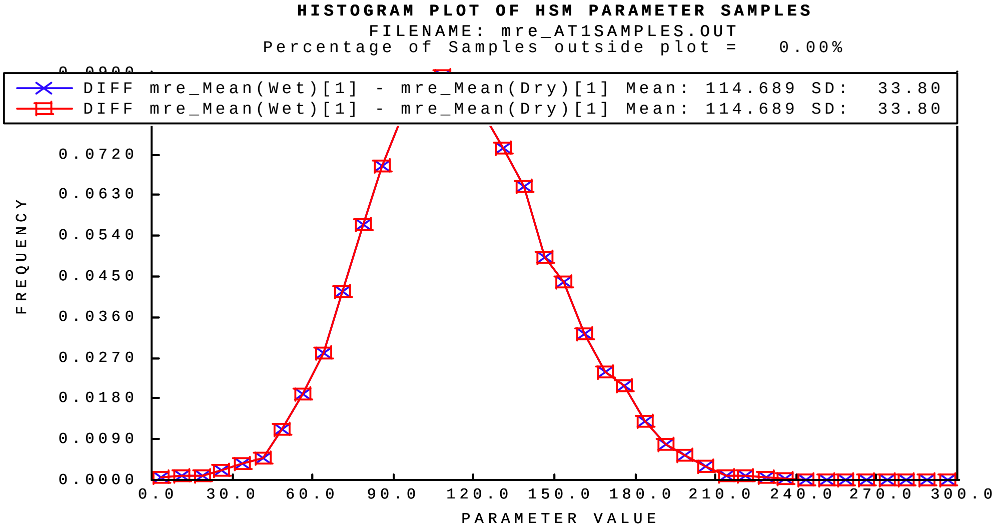


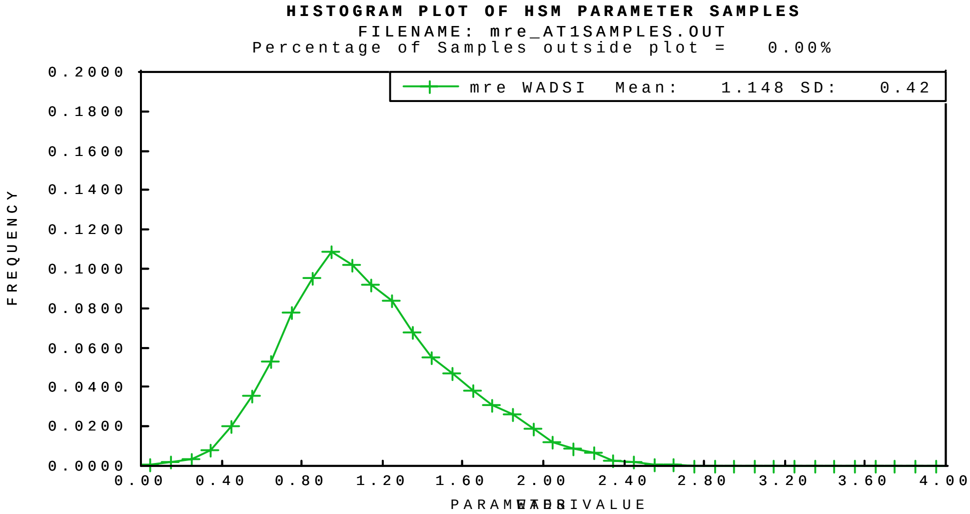
(a) Starting month September

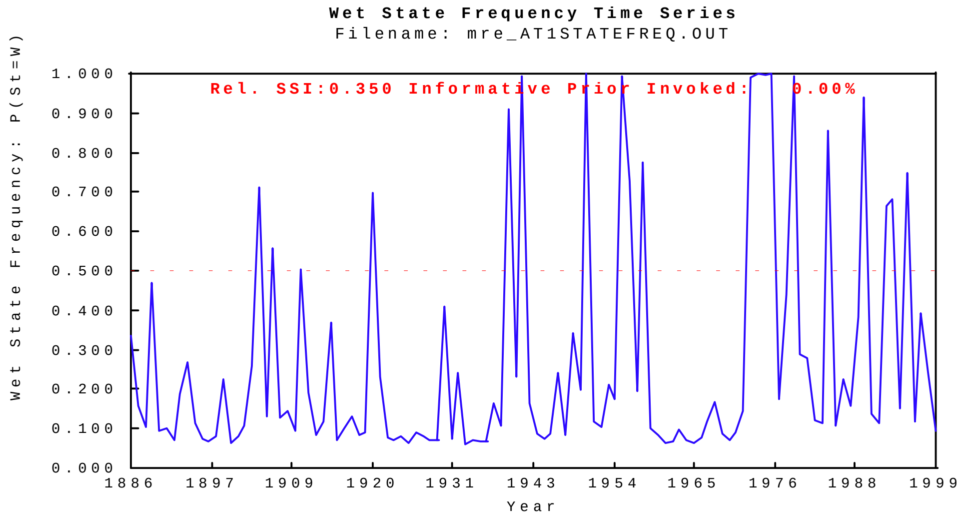


(b) Starting month November

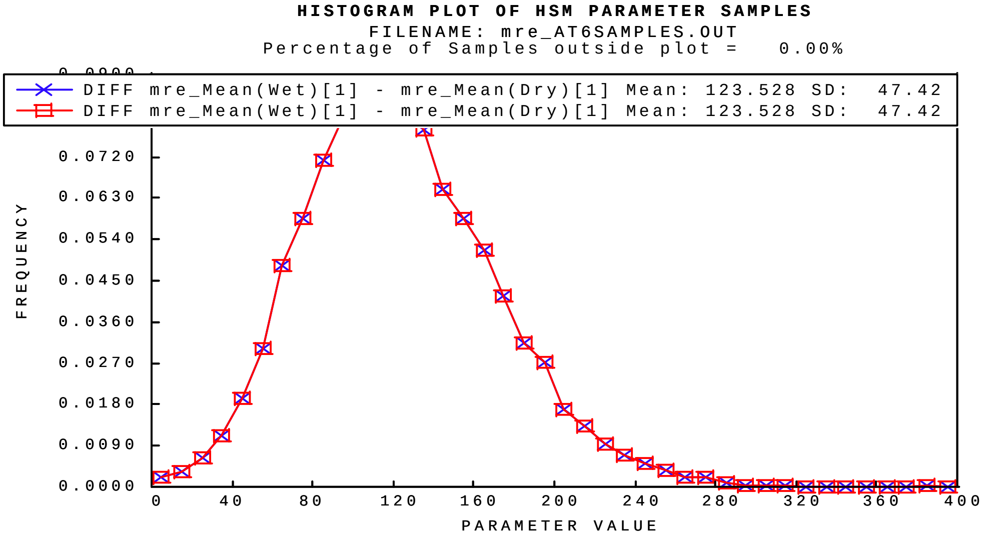
Figure C5. Calibration plots for Norseman

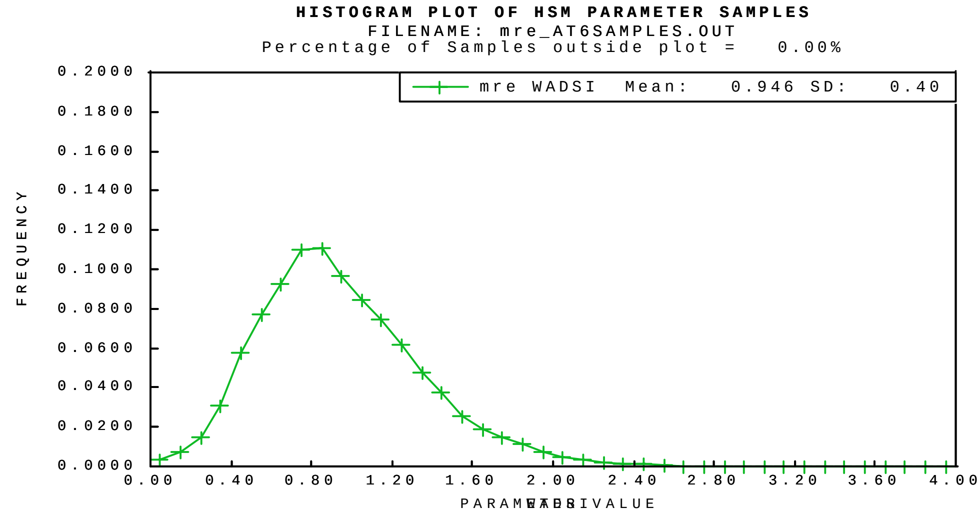


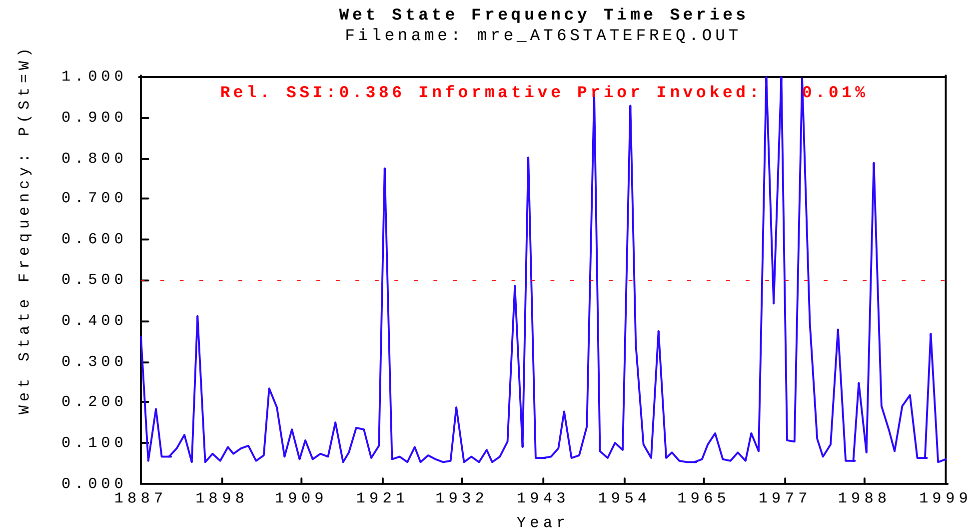




(a) Starting month January







(b) Starting month June

Figure C6. Calibration plots for Marree

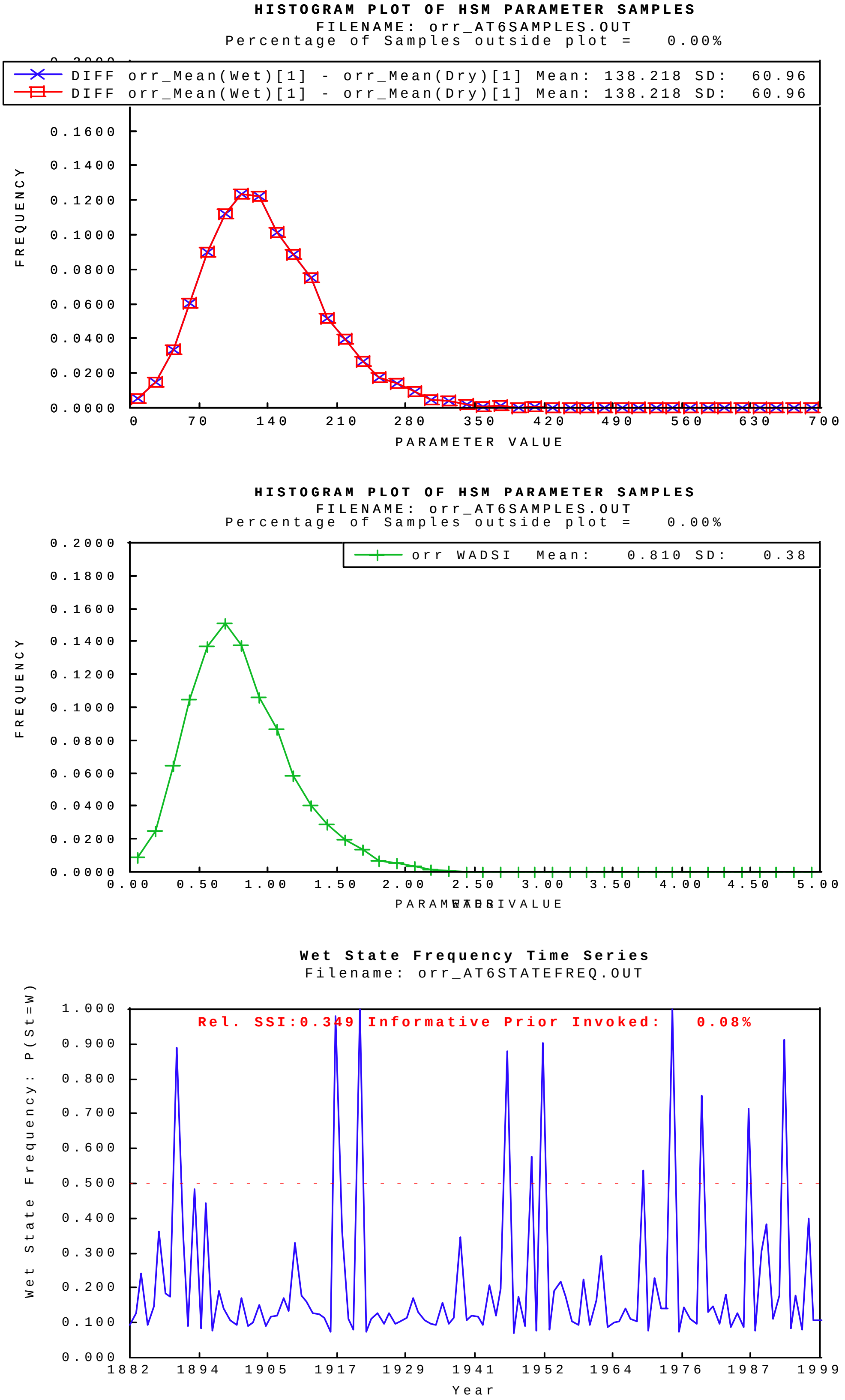


Figure C7. Calibration plots for Orroroo

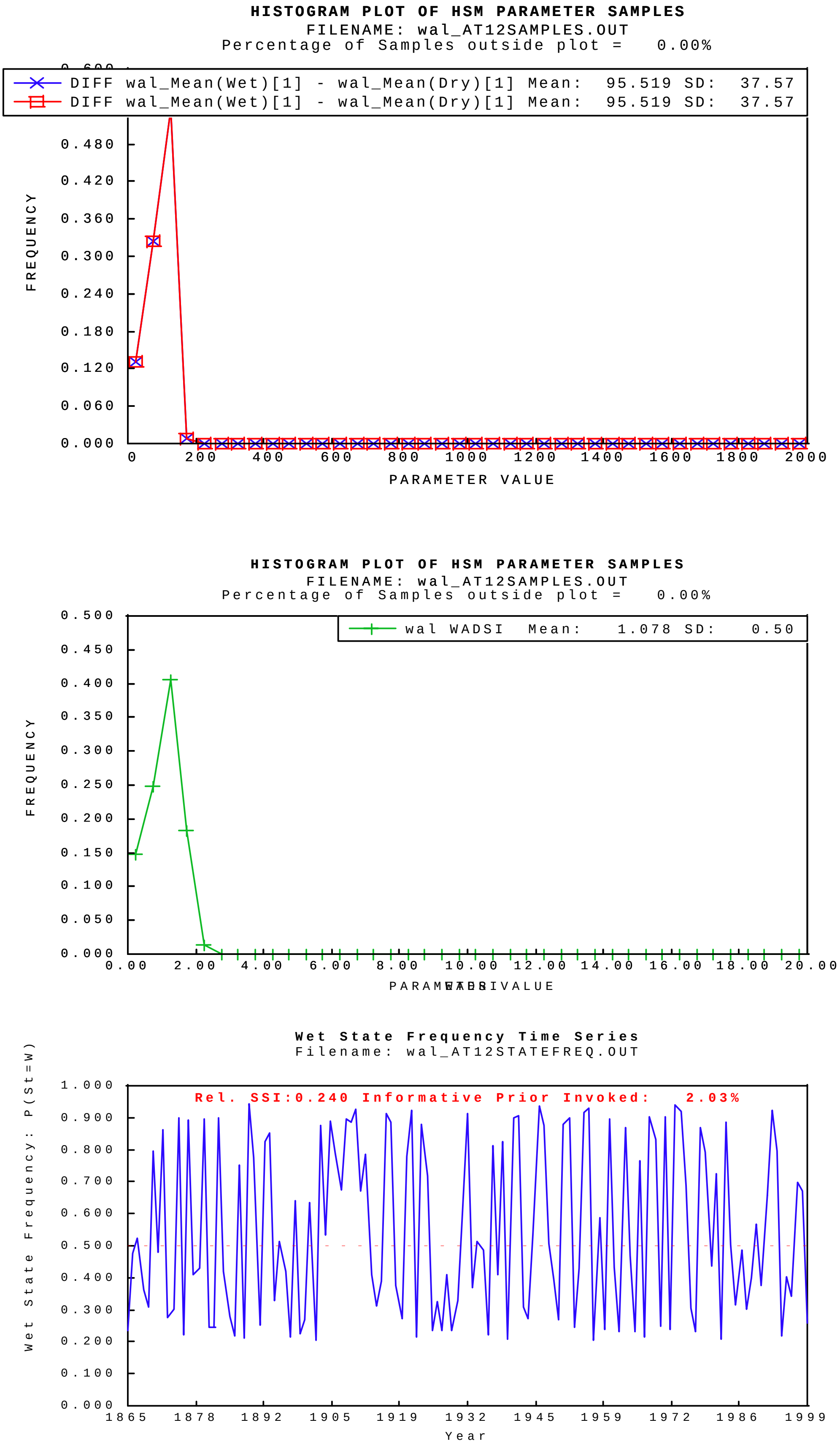
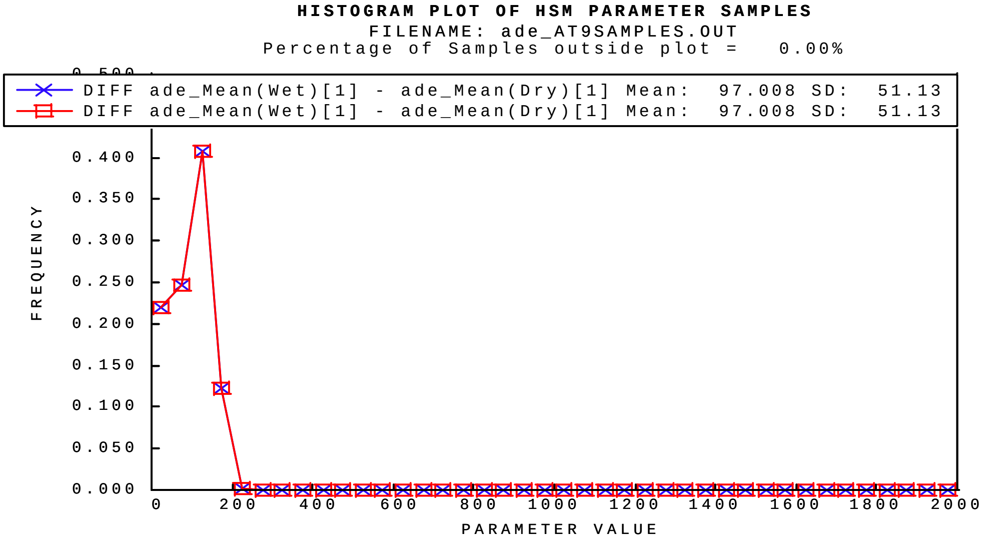
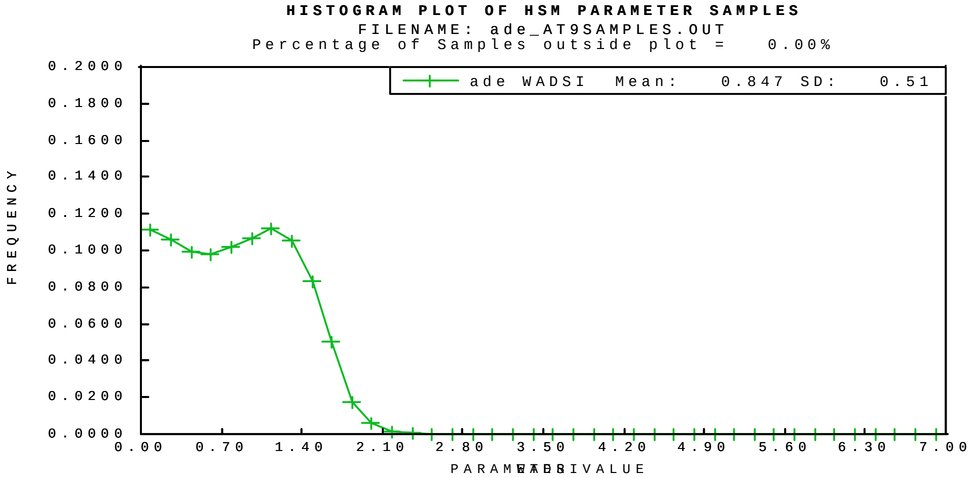
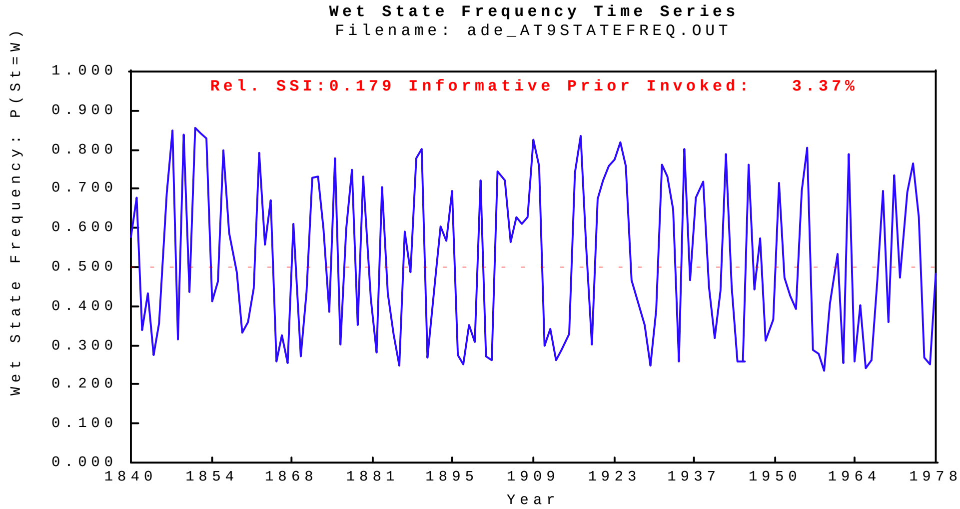


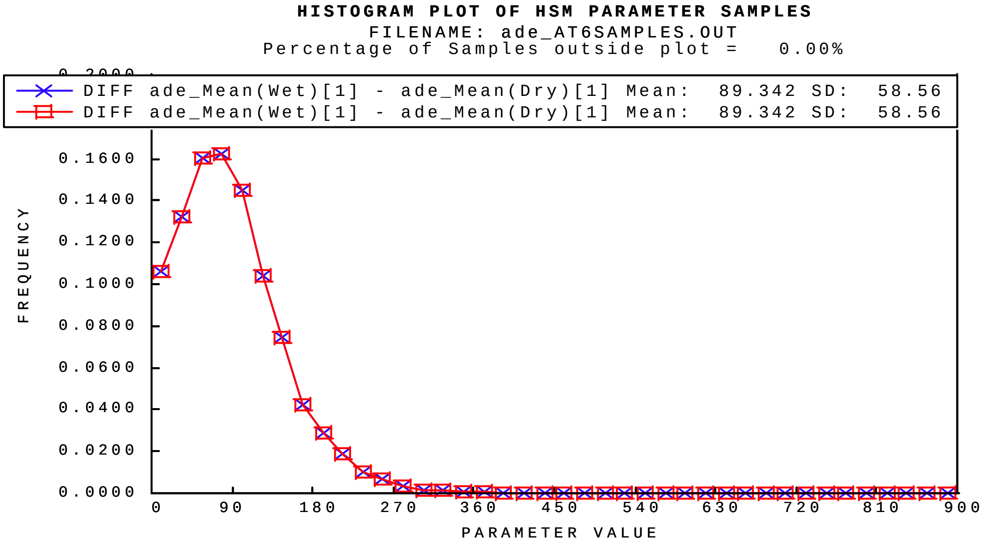
Figure C8. Calibration plots for Wallaroo

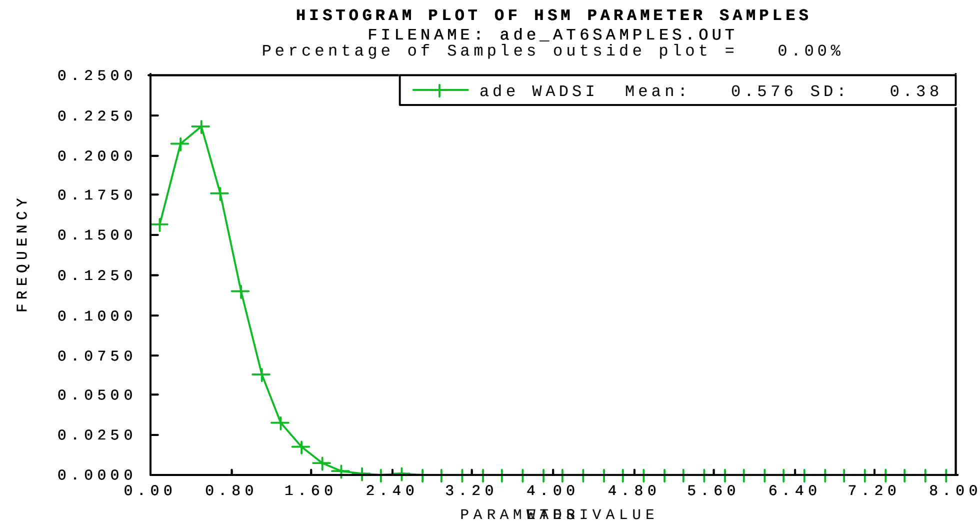


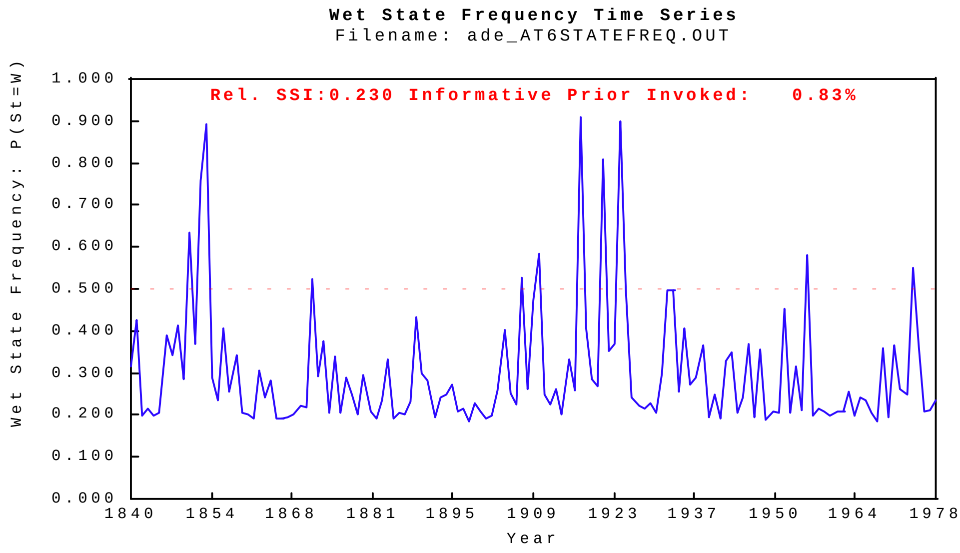




(a) Starting month September

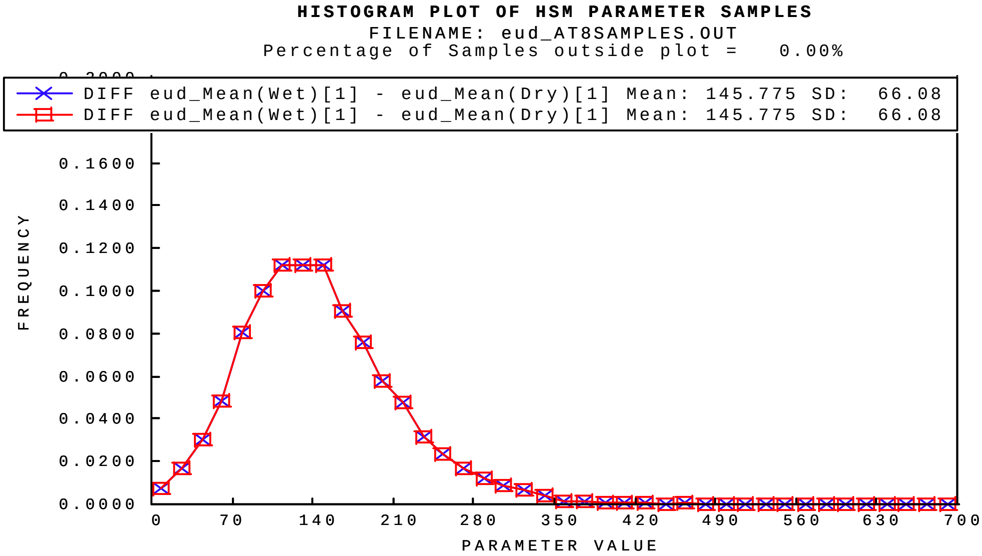


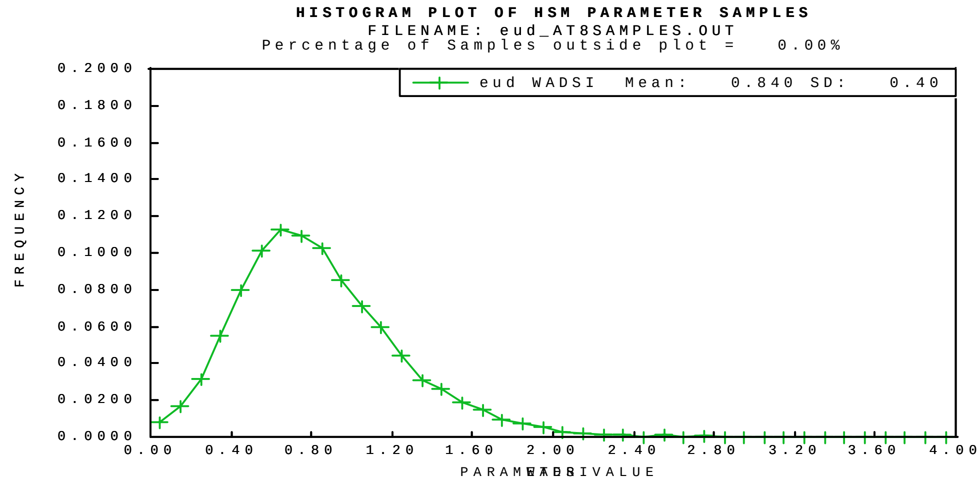




(b) Starting month June

Figure C9. Calibration plots for Adelaide





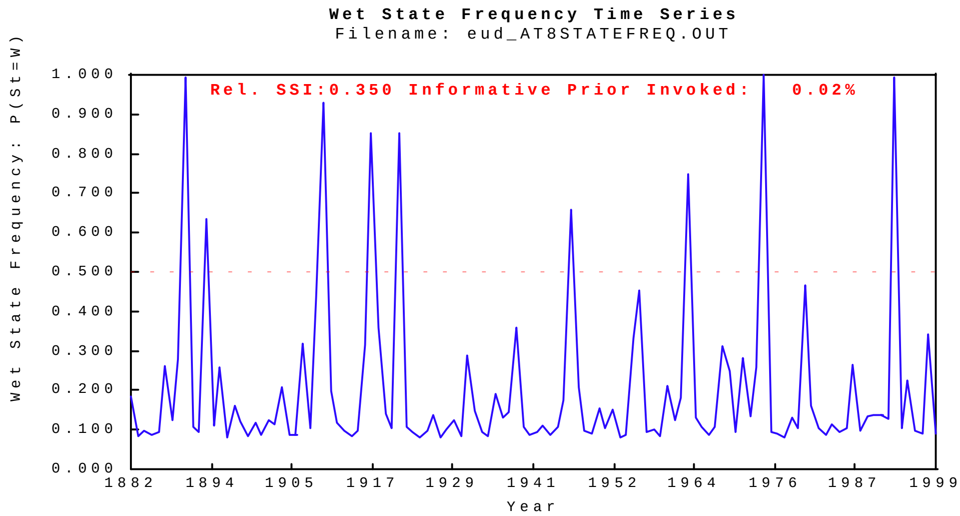
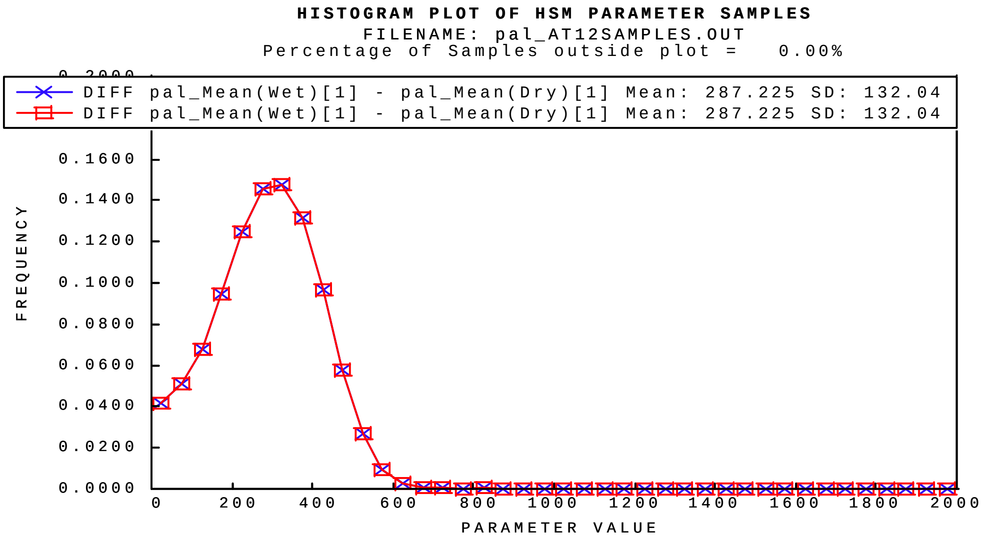
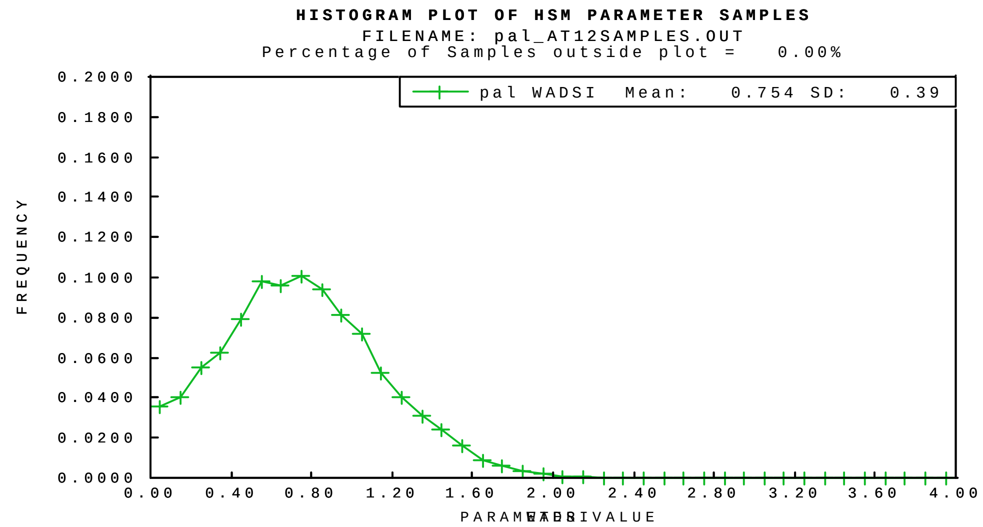
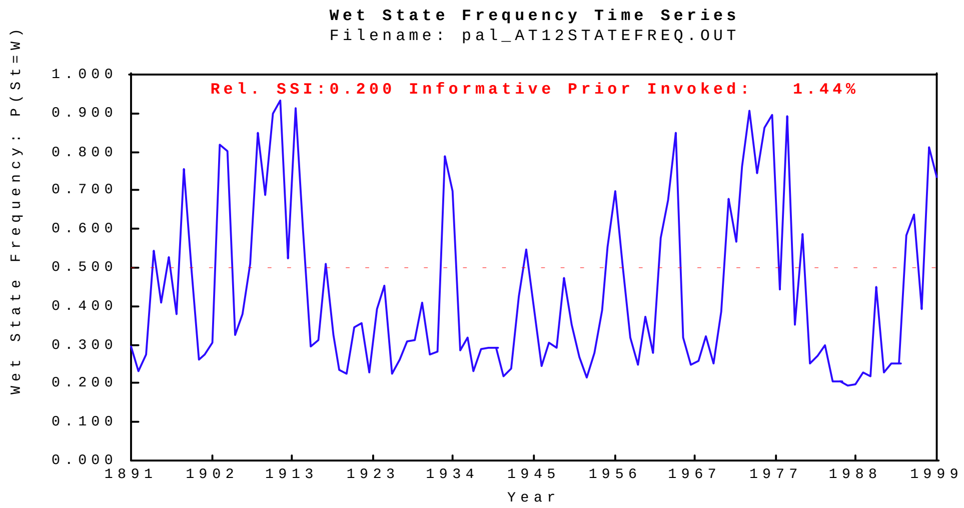


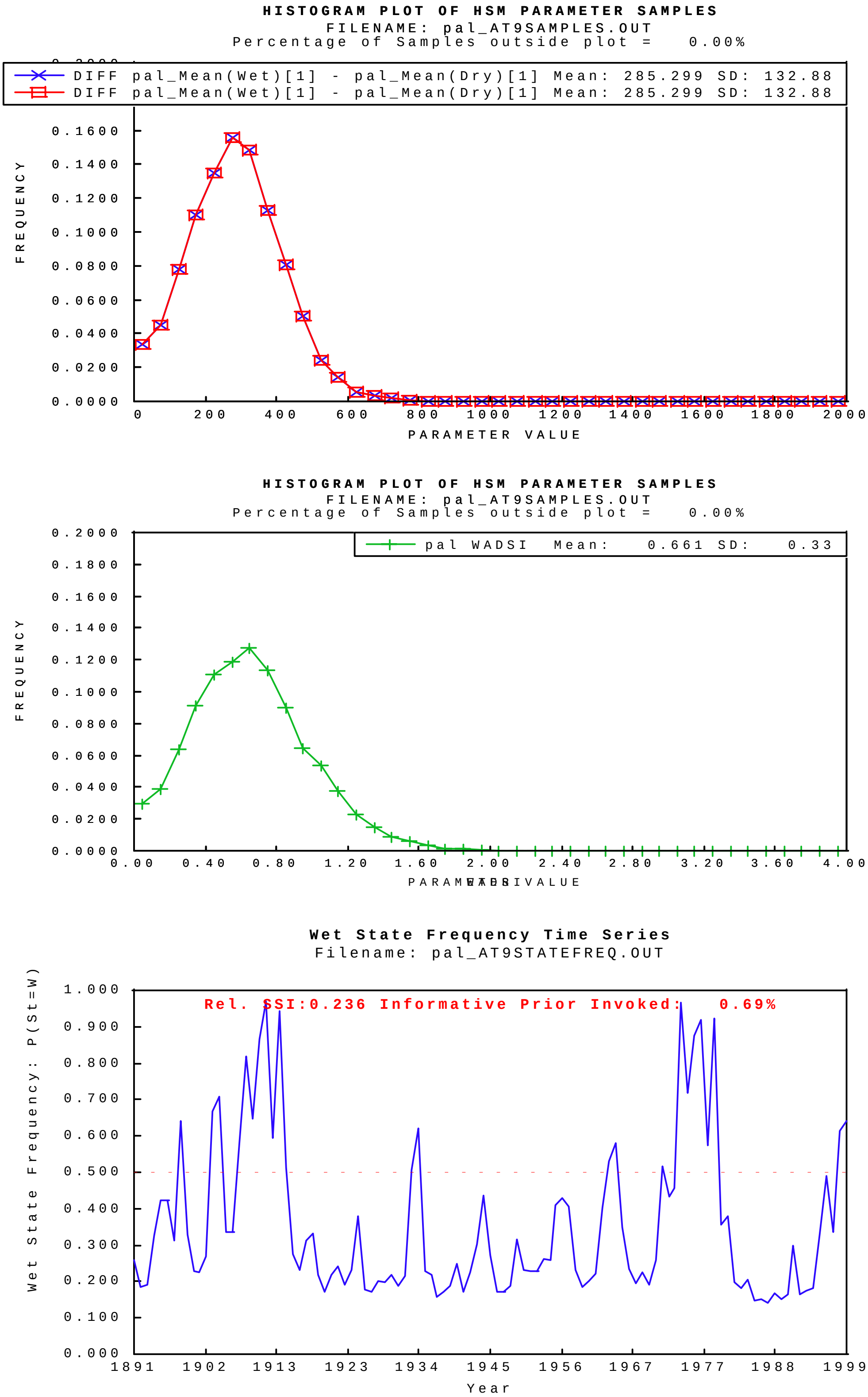
Figure C10. Calibration plots for Eudunda





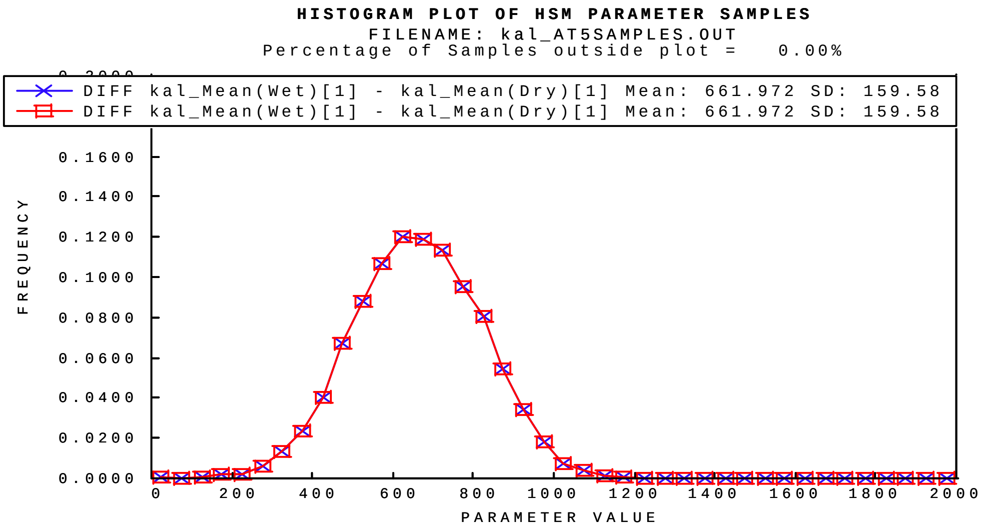


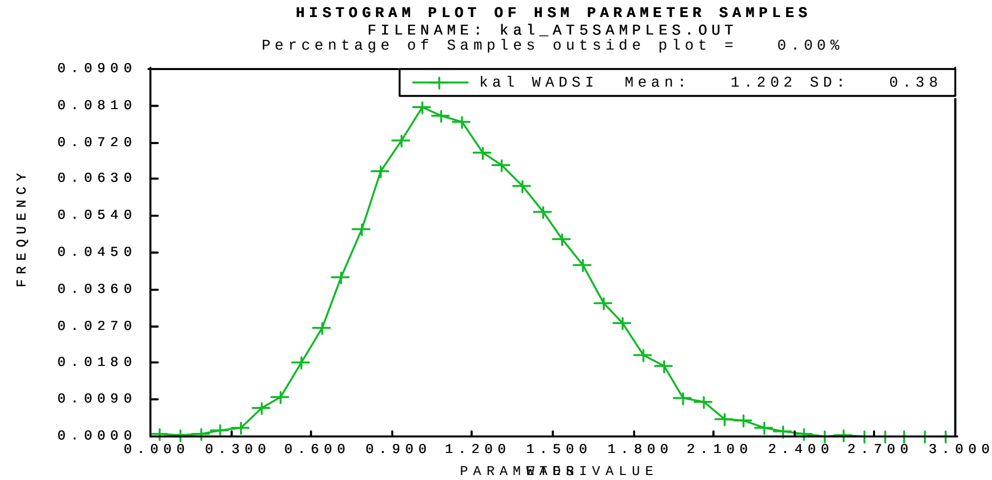
(a) Starting month December

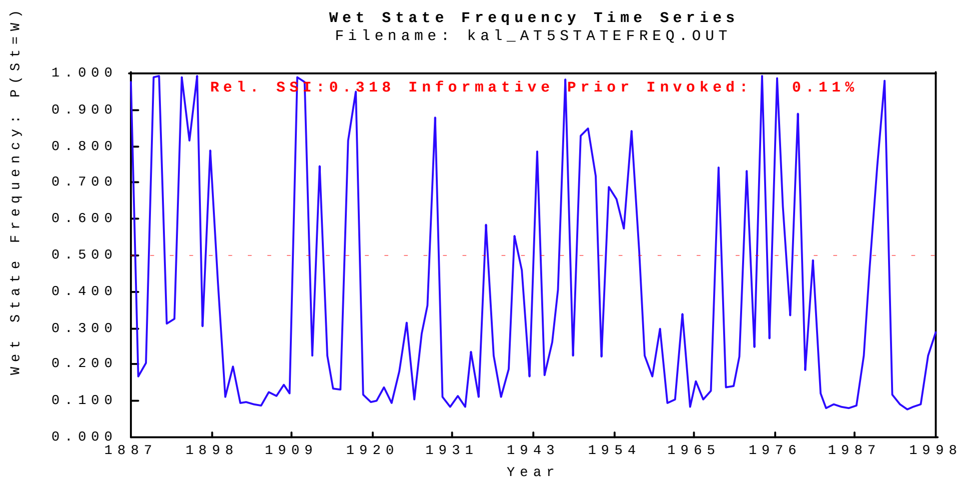


(b) Starting month September

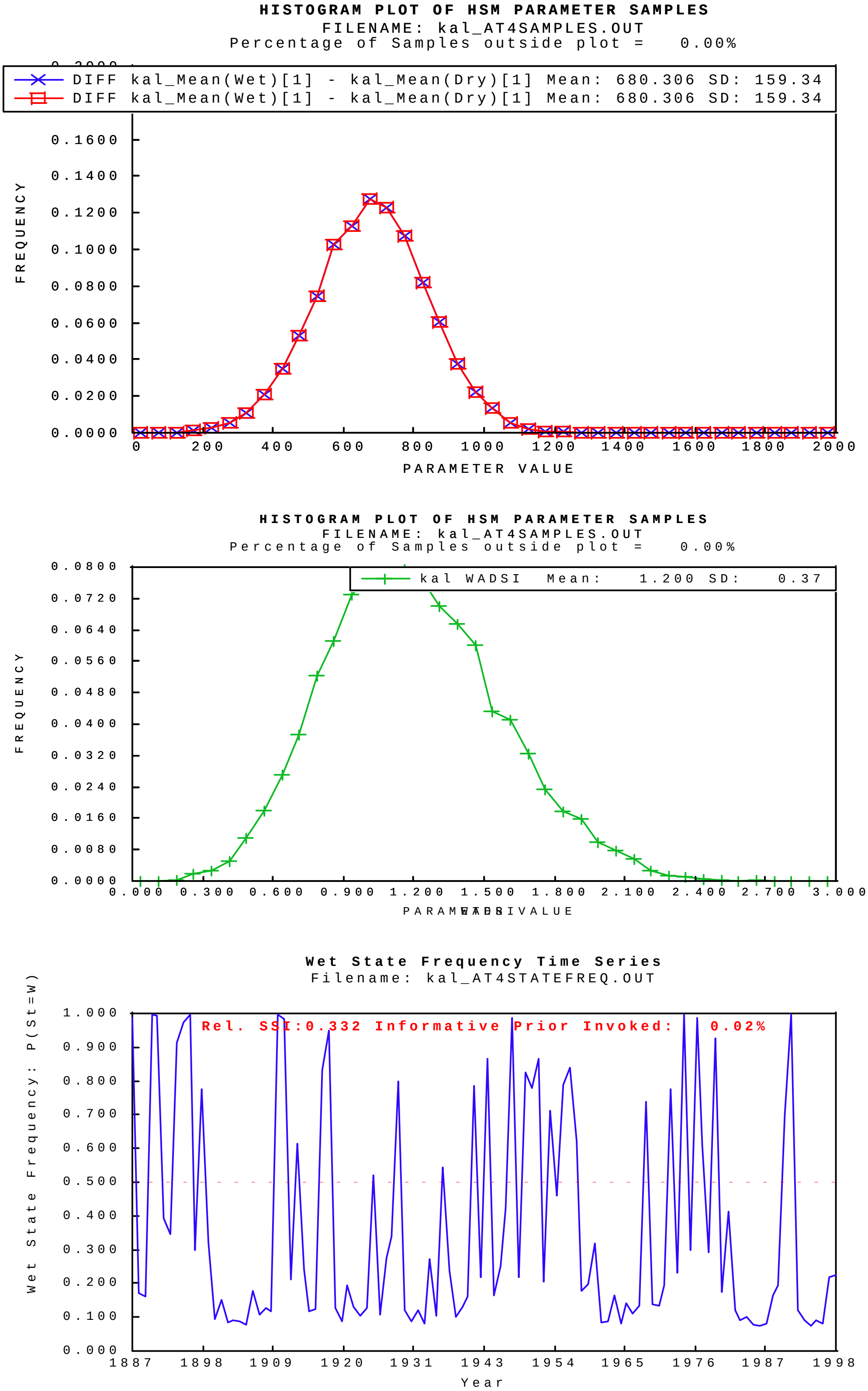
Figure C11. Calibration plots for Palmerville







(a) Starting month May



(b) Starting month April

Figure C12. Calibration plots for Kalamia

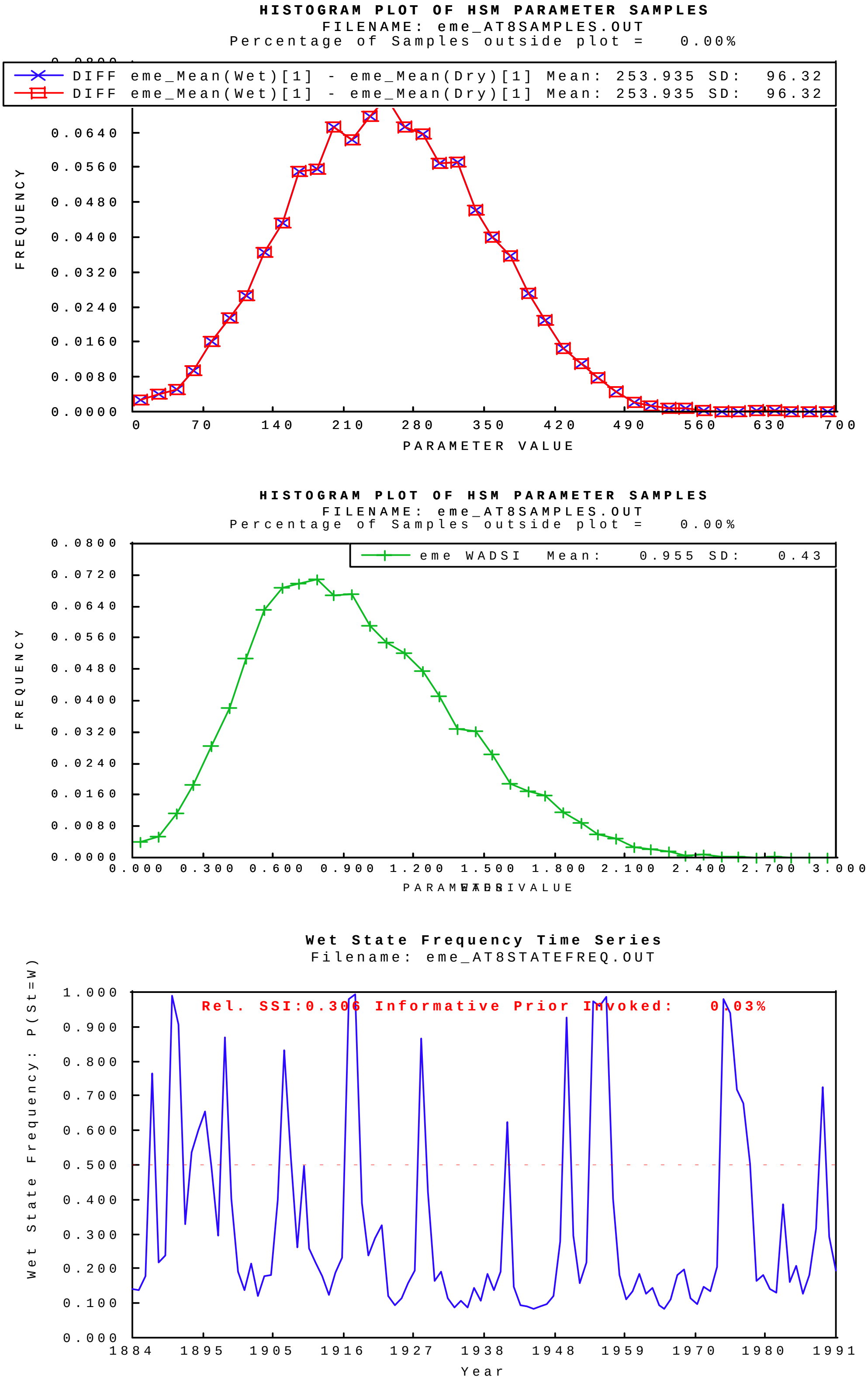
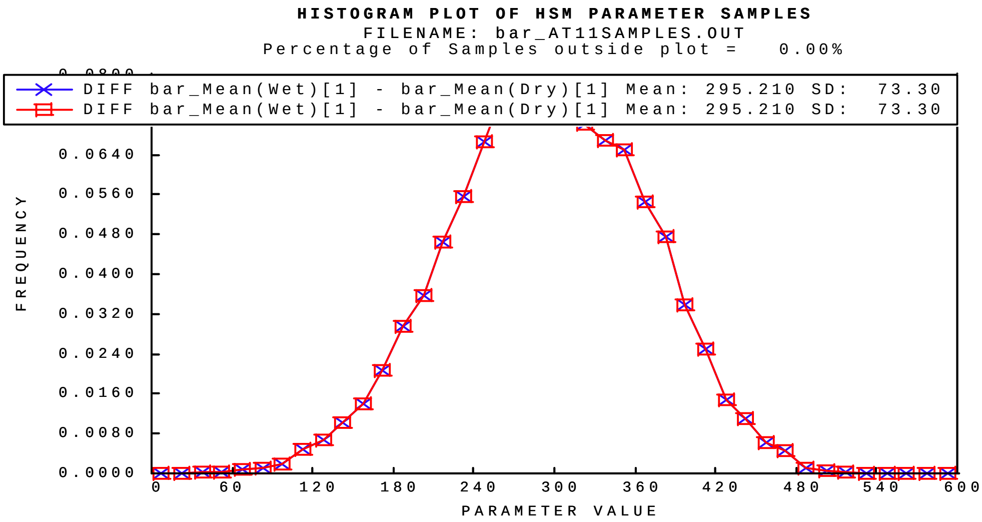
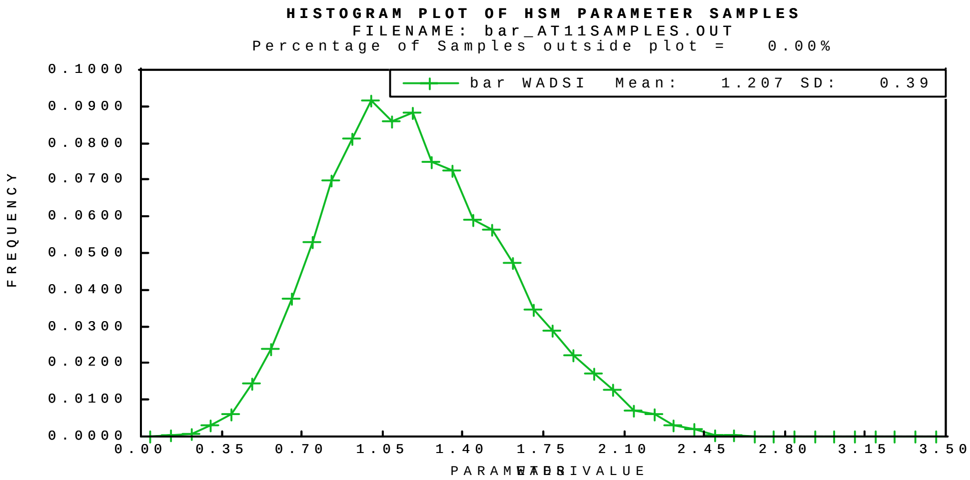


Figure C13. Calibration plots for Emerald





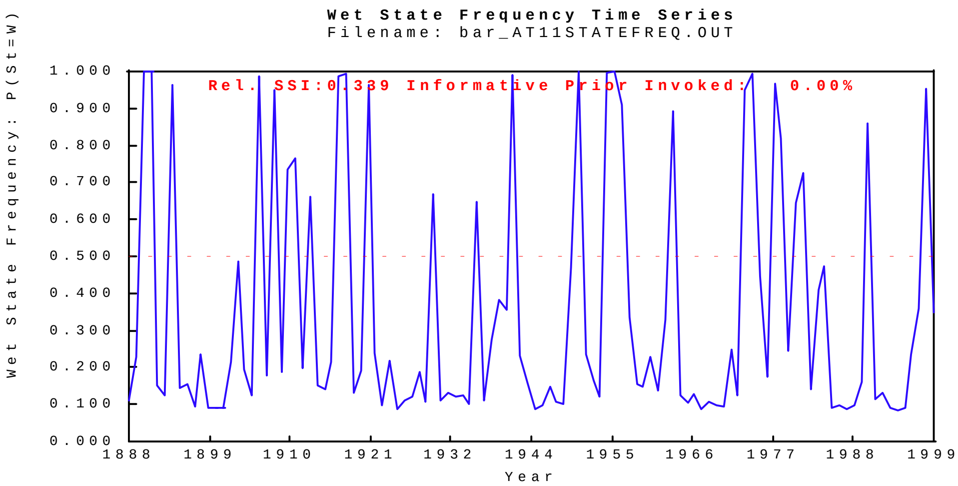


Figure C14. Calibration plots for Barcaldine

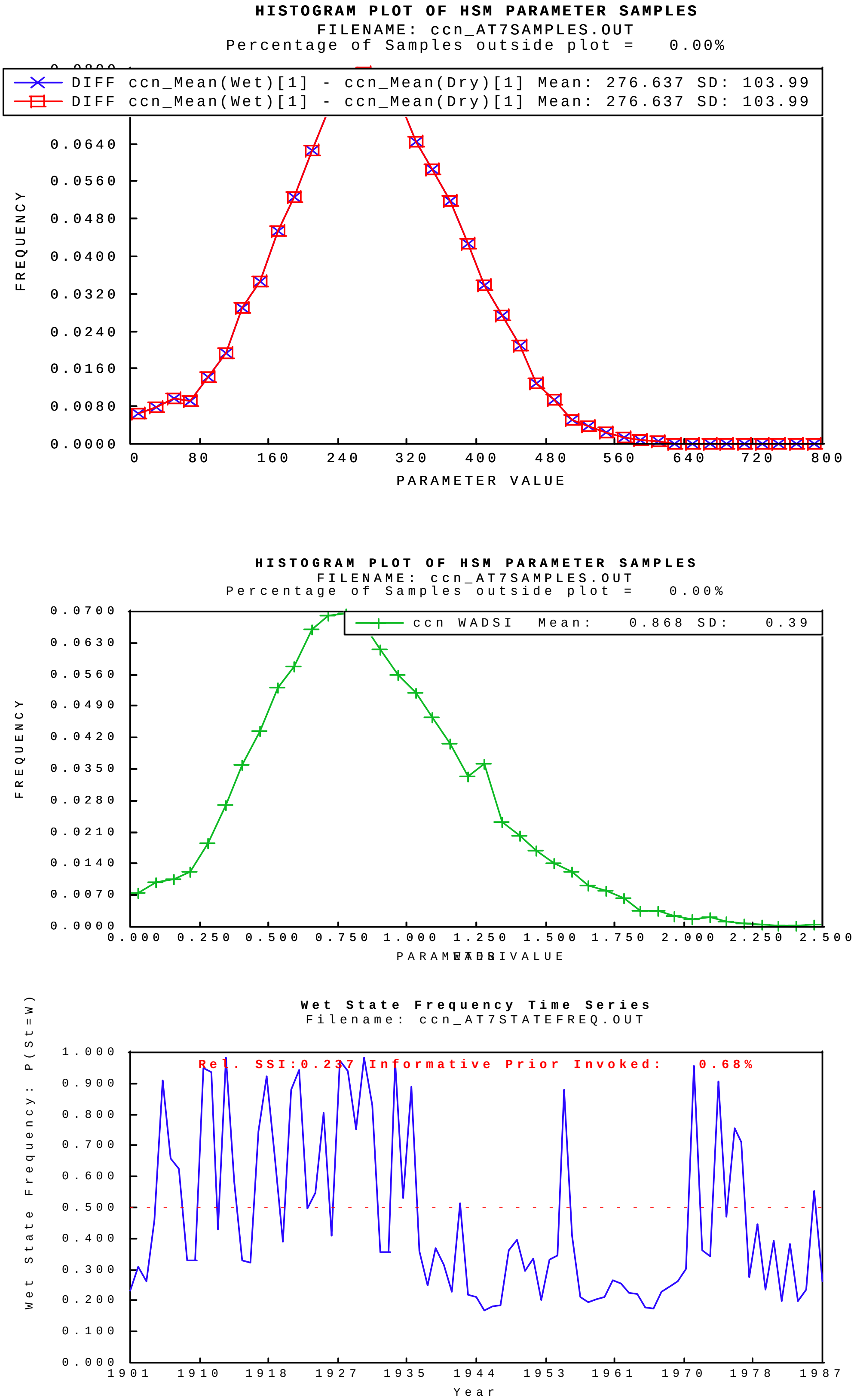
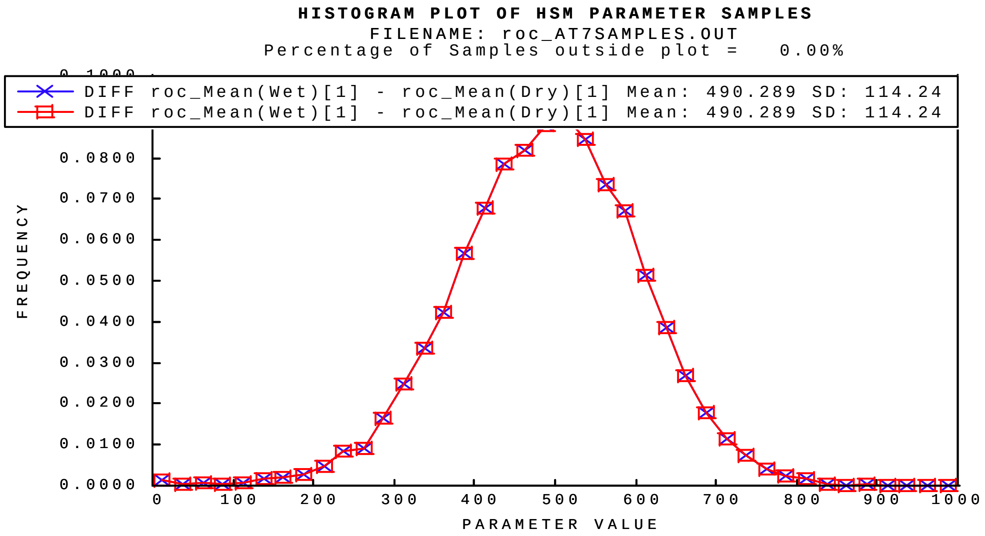
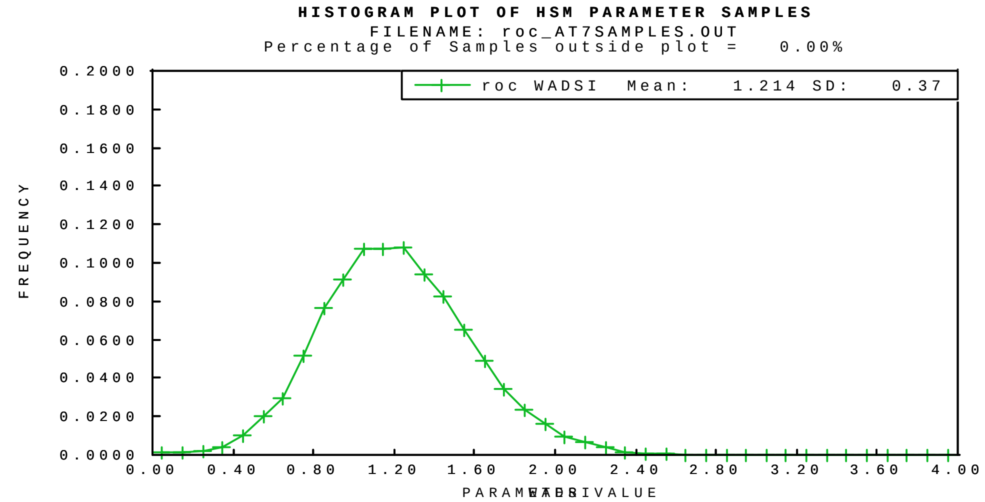
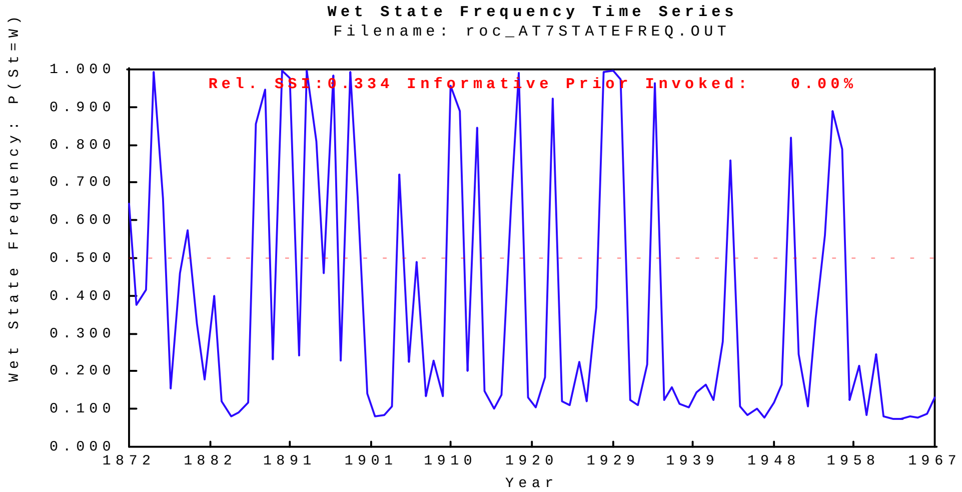


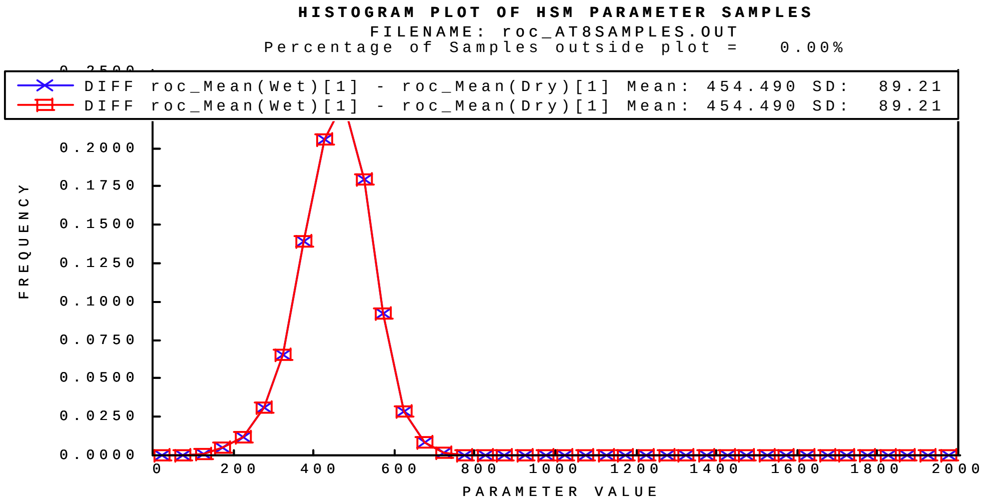
Figure C15. Calibration plots for Cape Capricorn

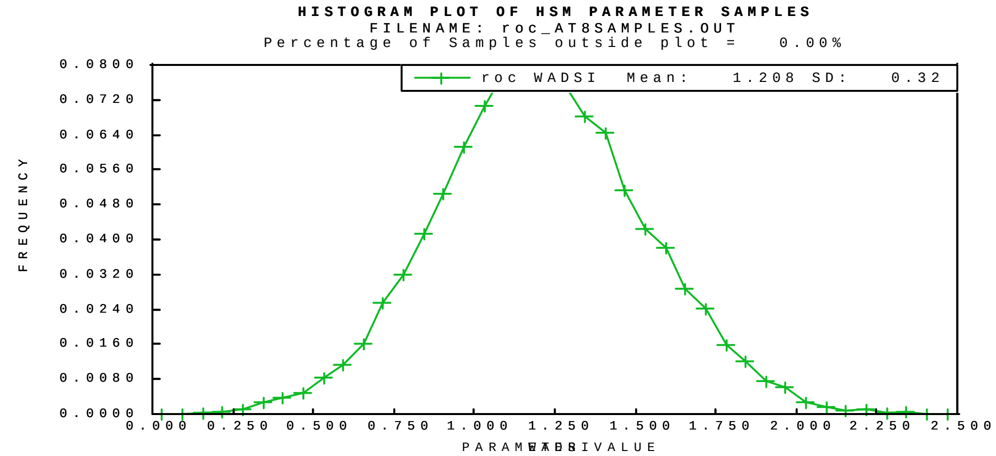


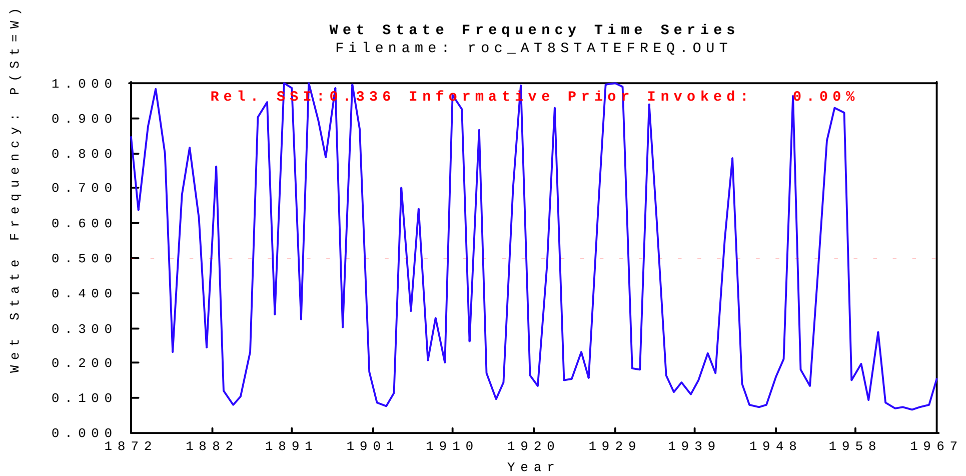




(a) Starting month July

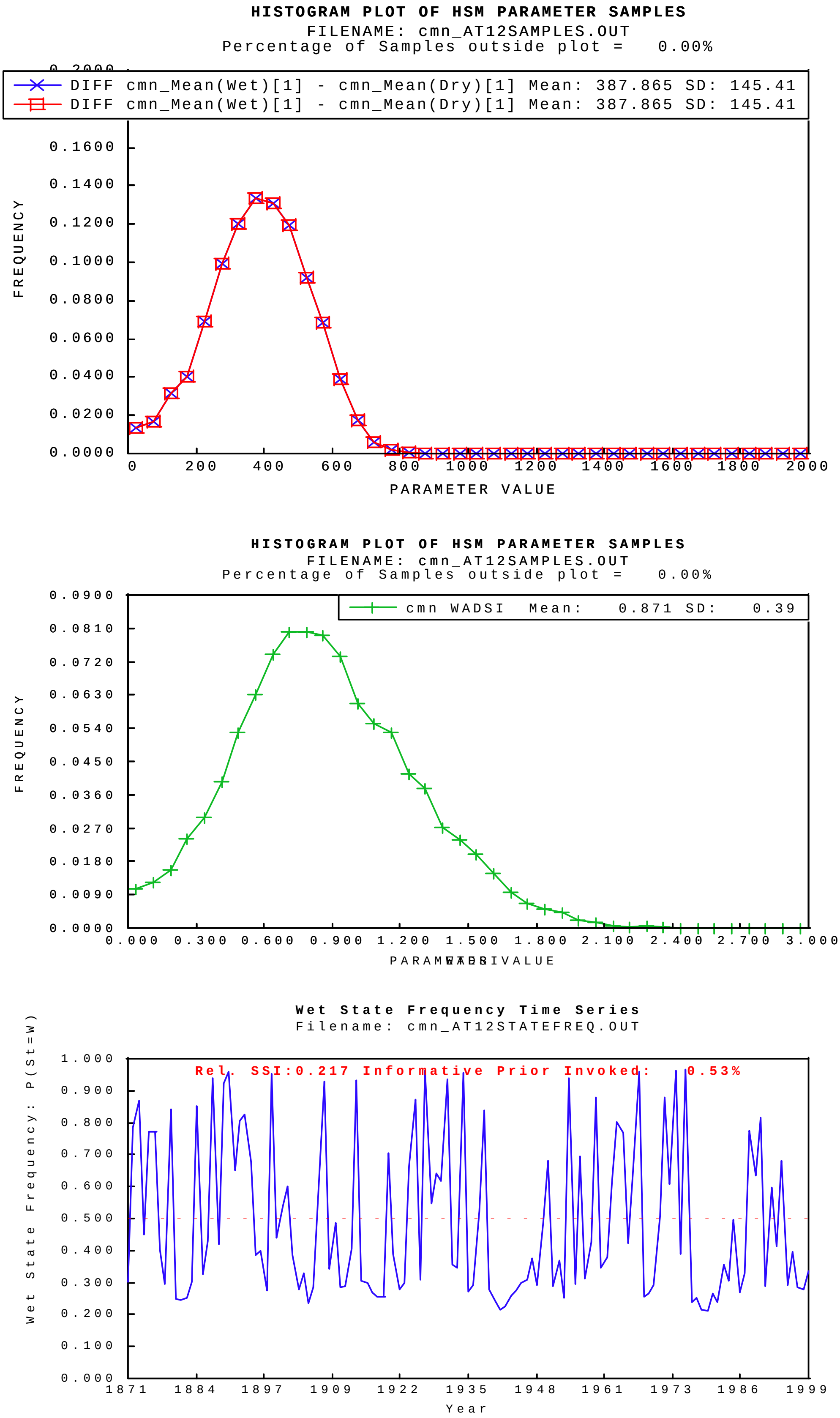




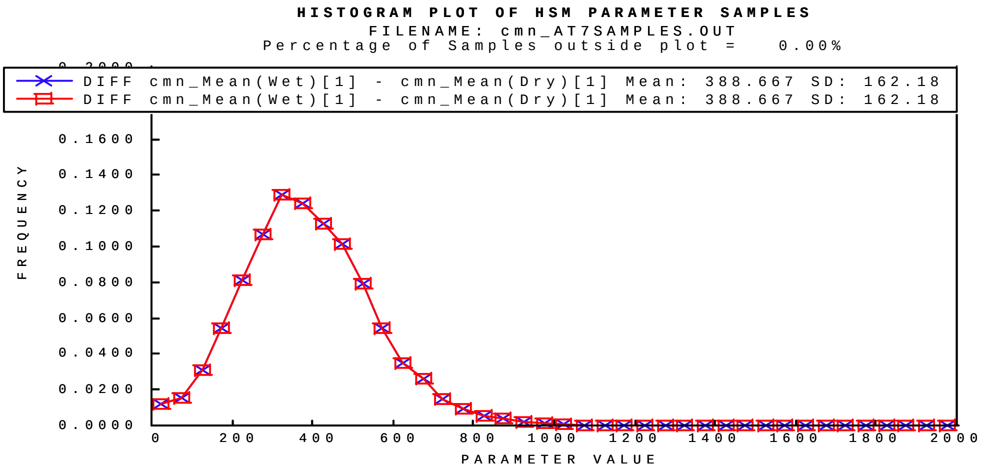


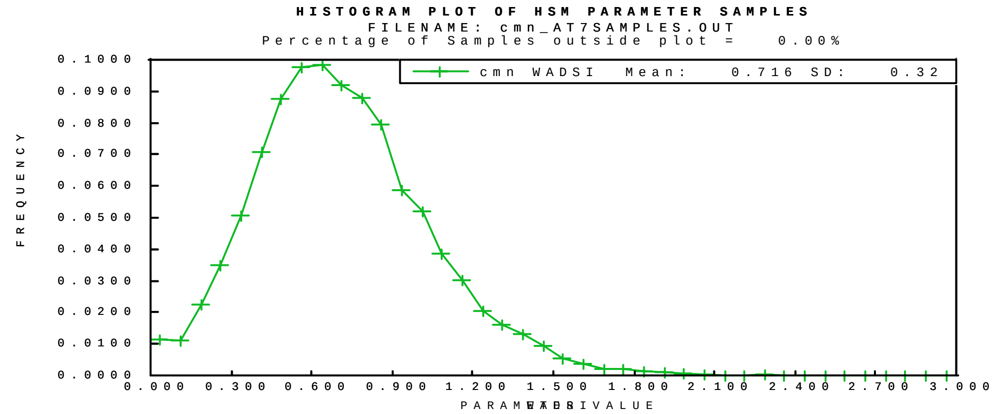
(b) Starting month August

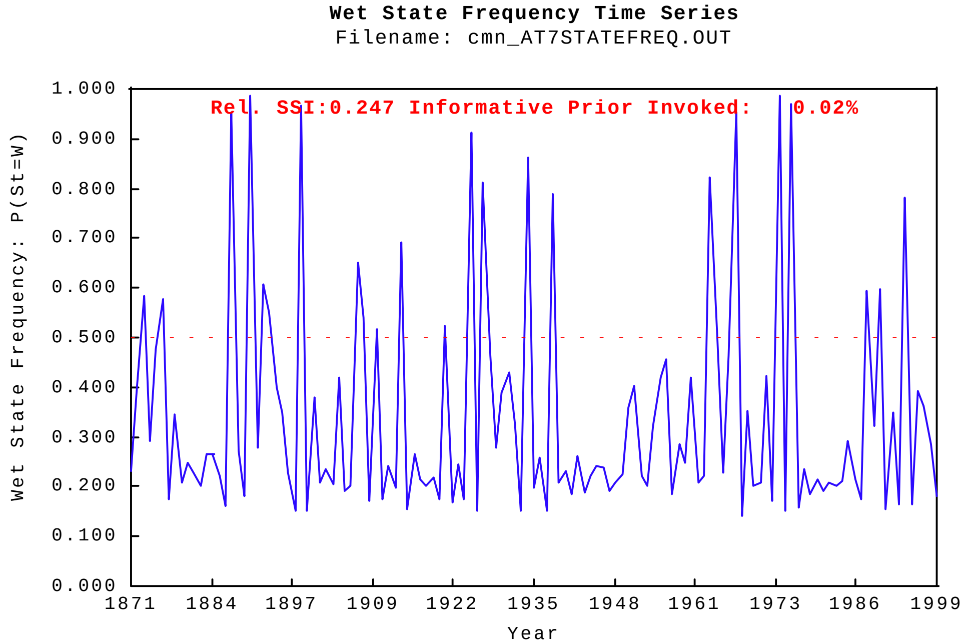
Figure C16. Calibration plots for Rockhampton



(a) Starting month December

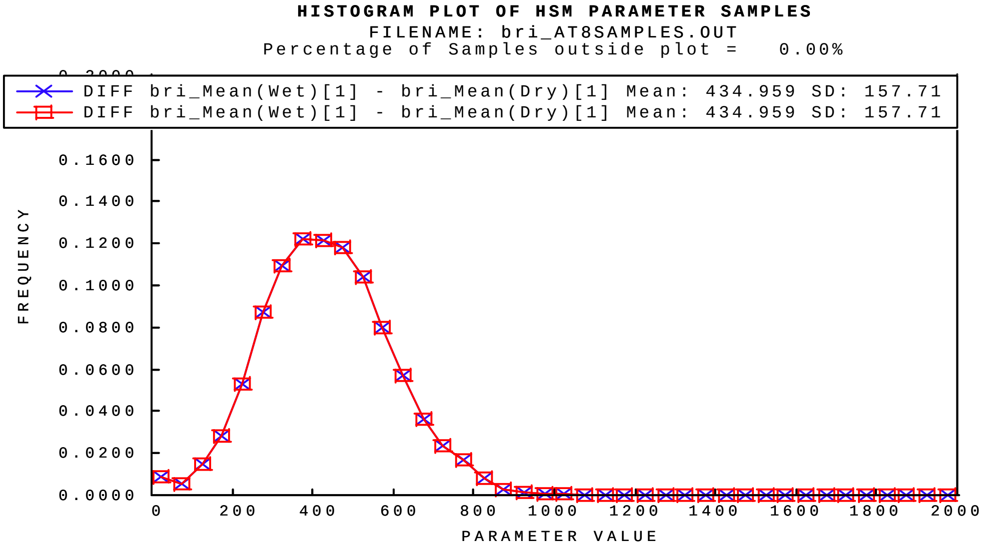


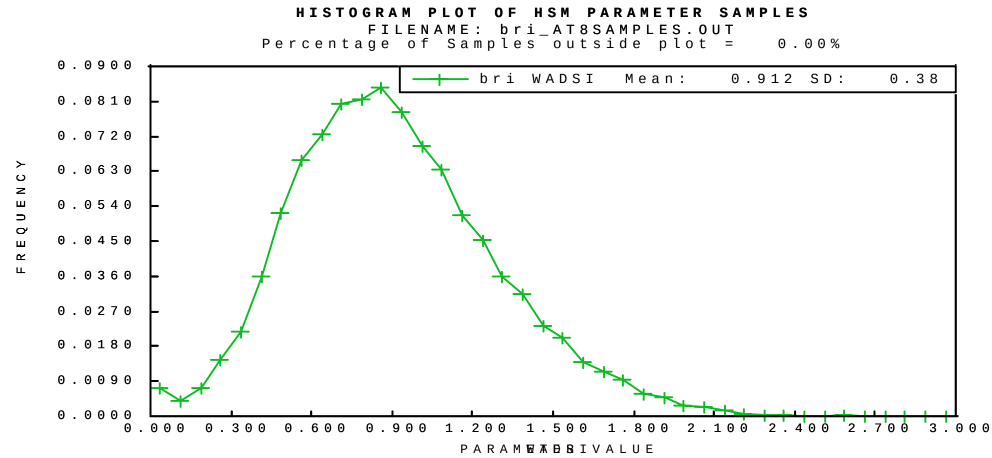


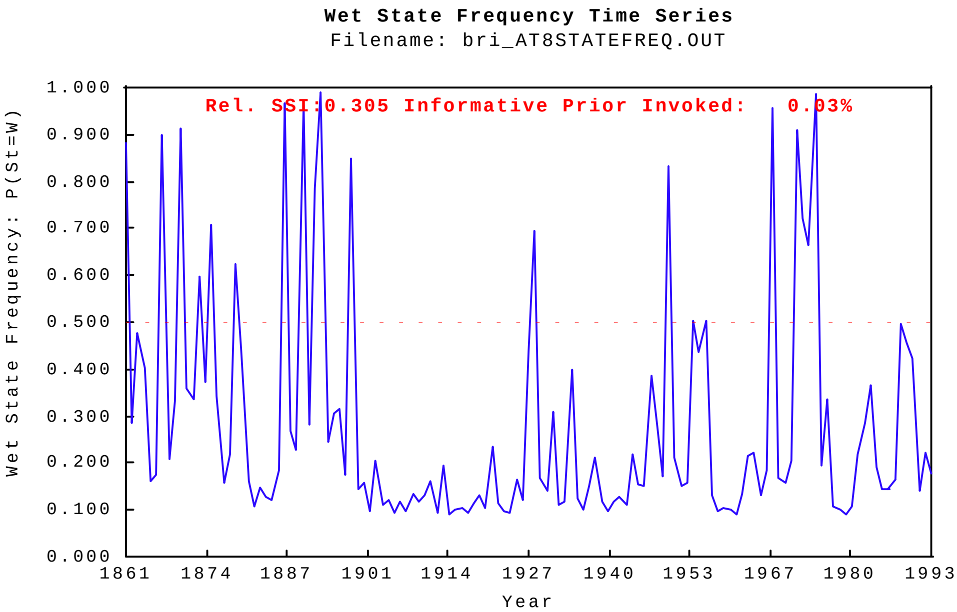


(b) Starting month July

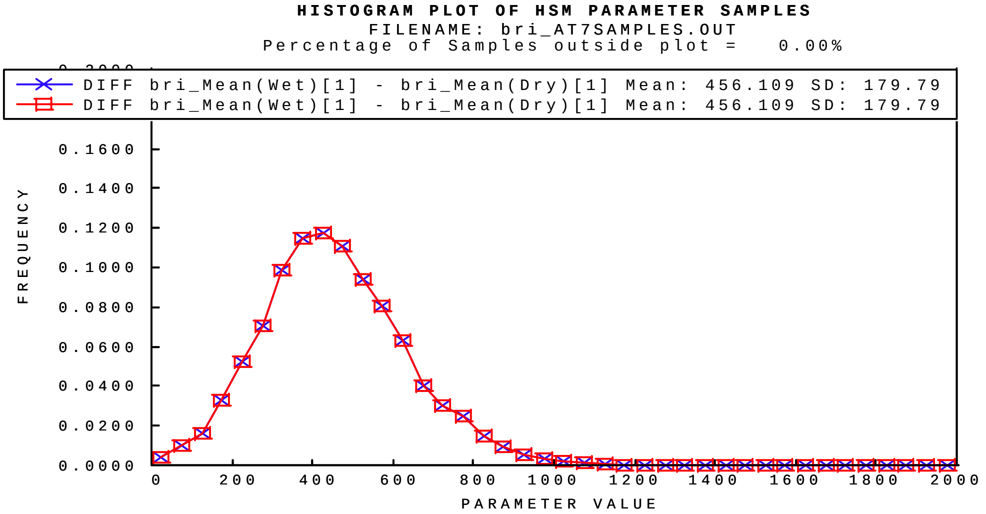
Figure C17. Calibration plots for Cape Moreton

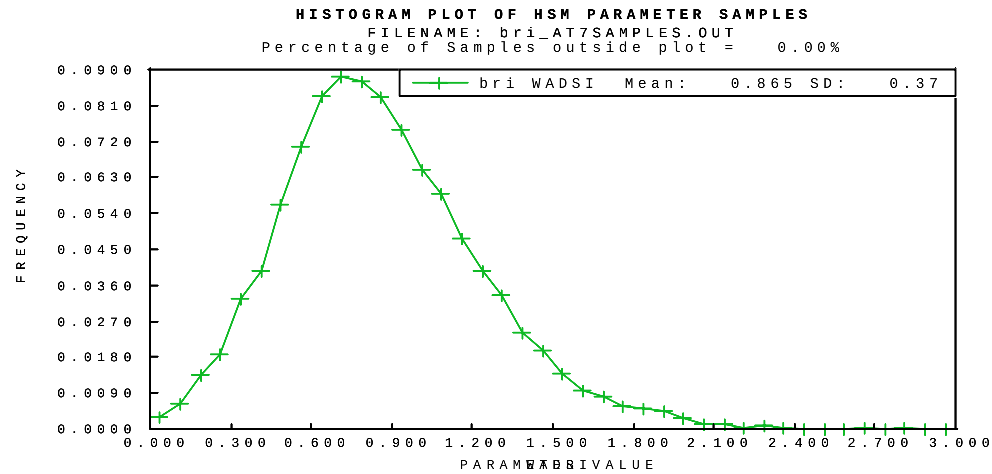


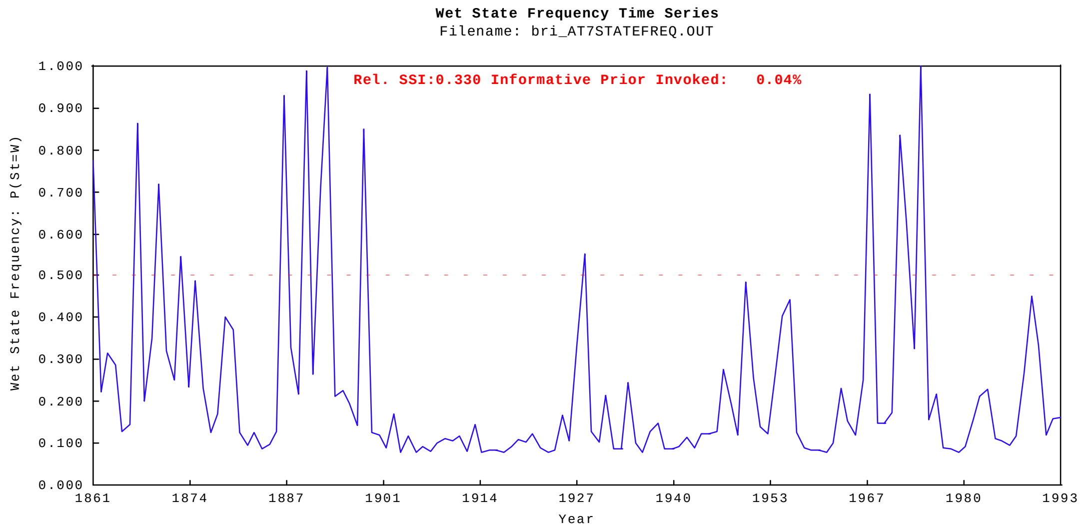




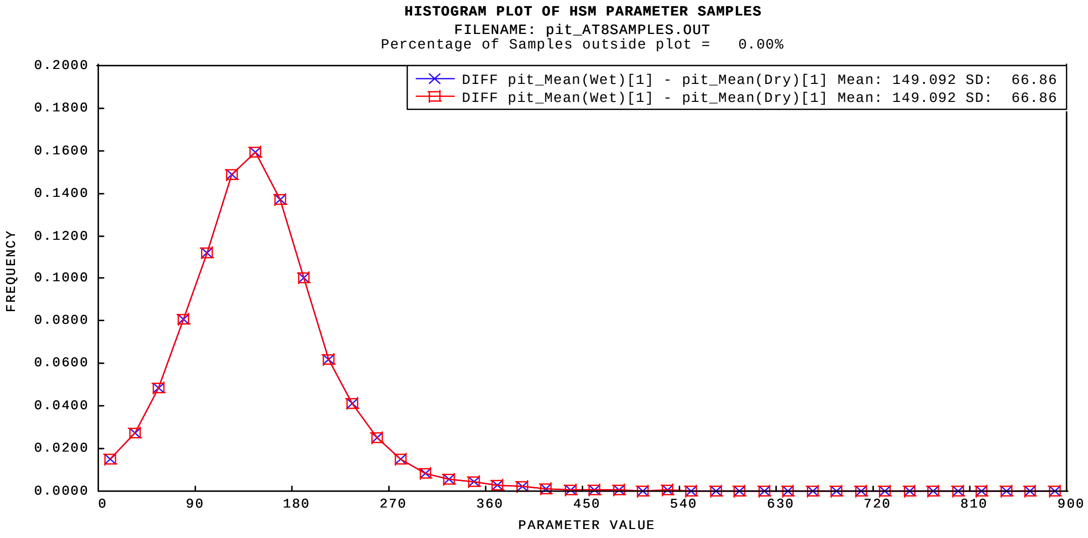
(a) Starting month July

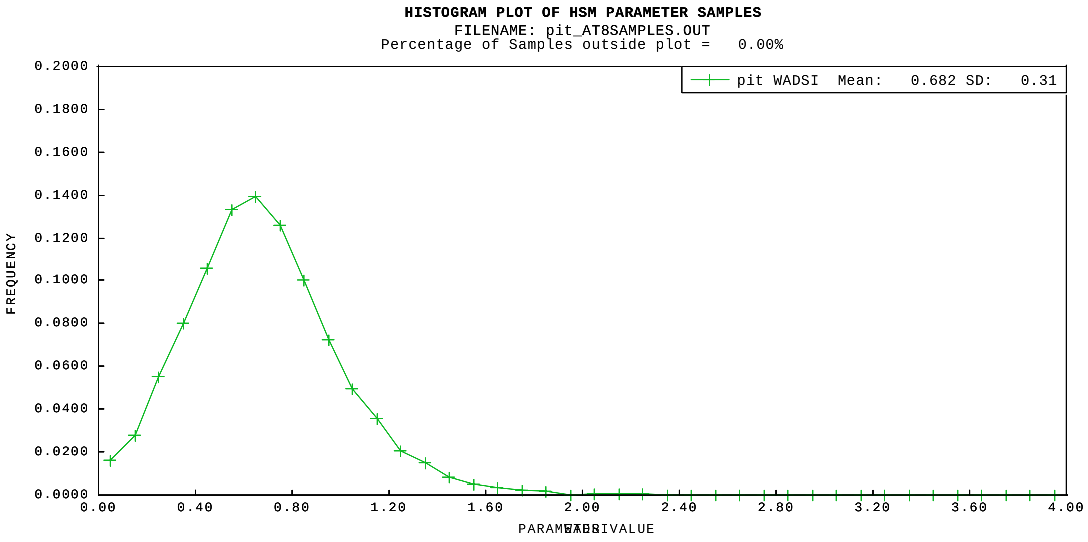


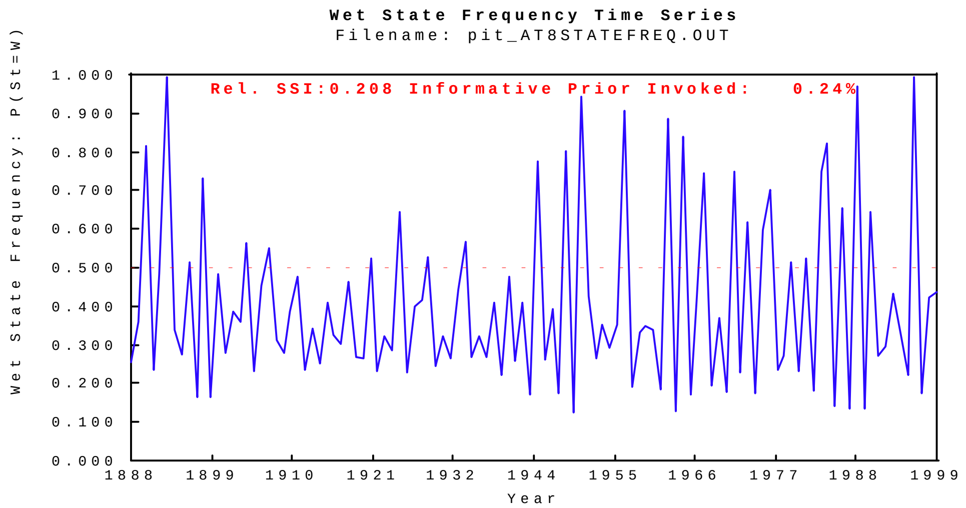




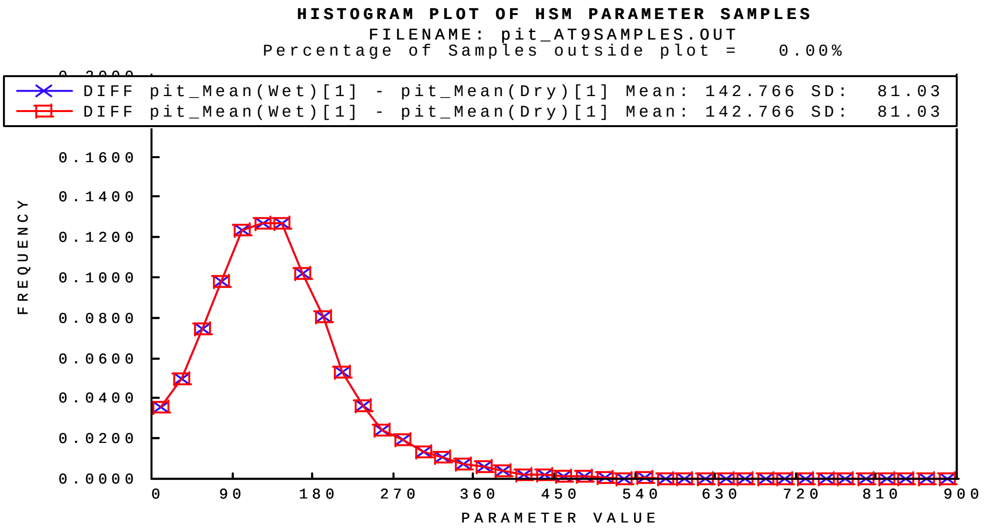
(b) Starting month July

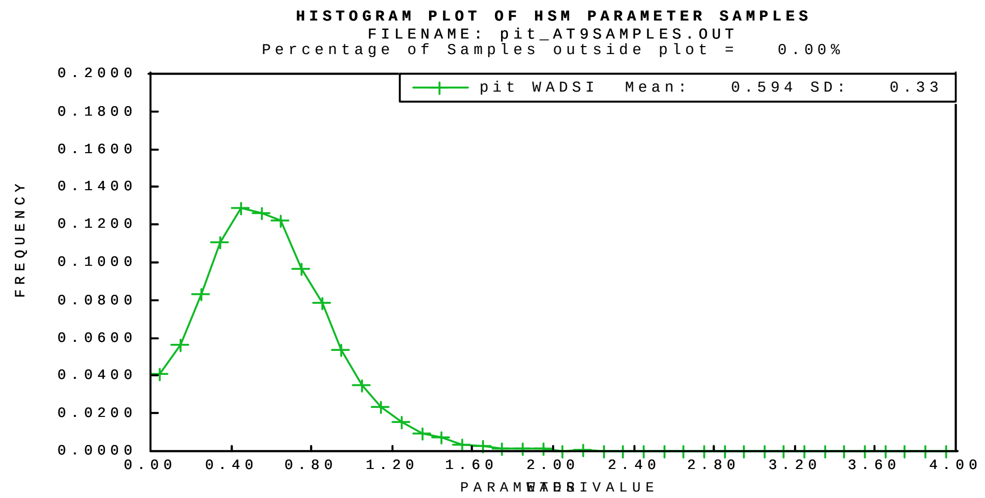


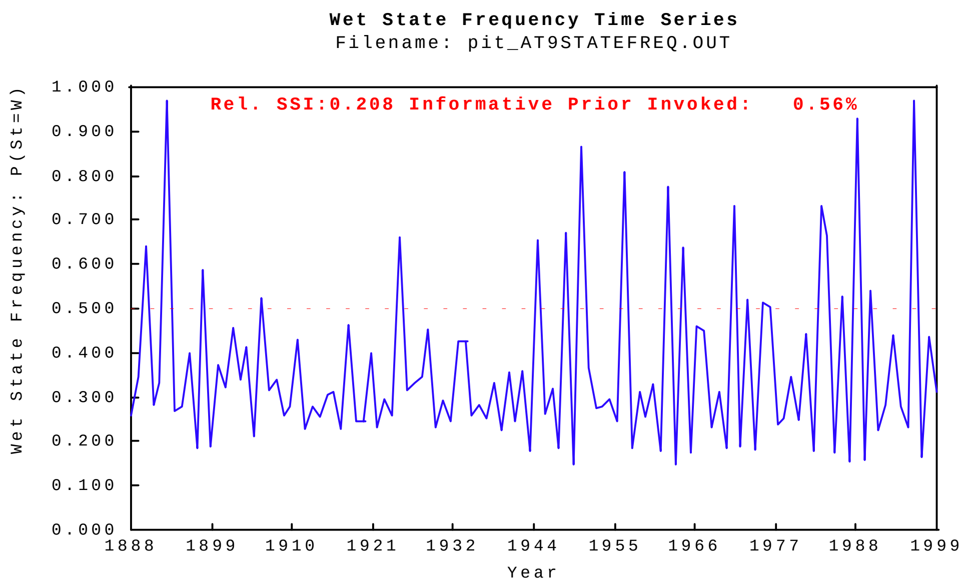




(a) Starting month August

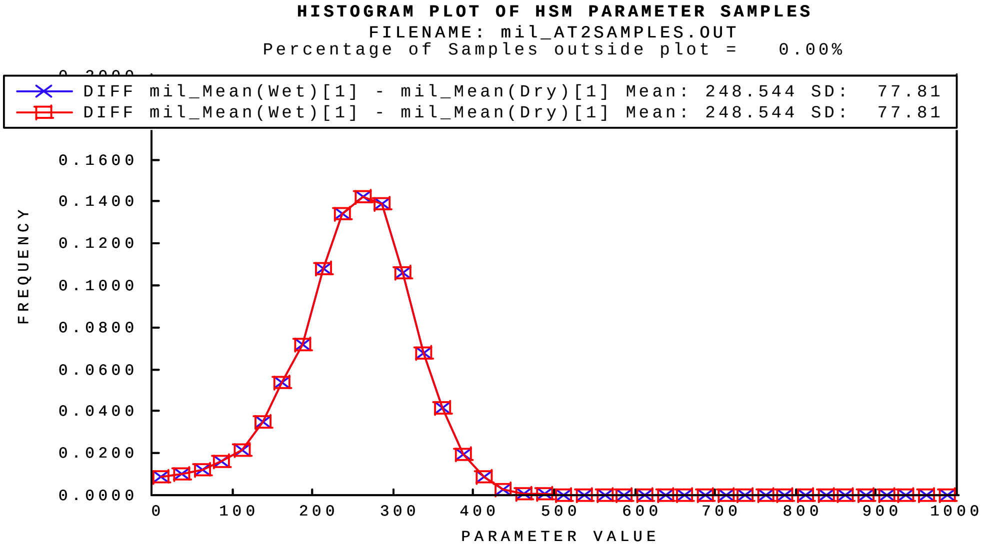


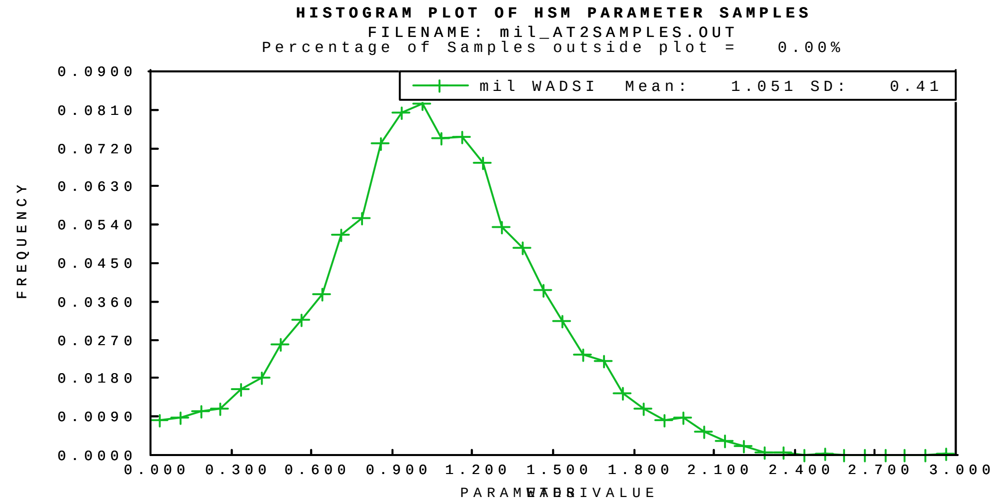


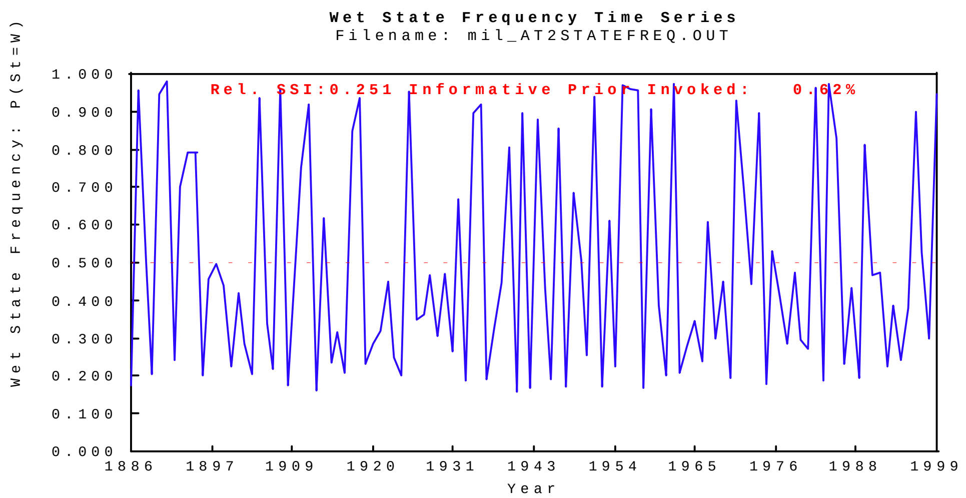


(b) Starting month September

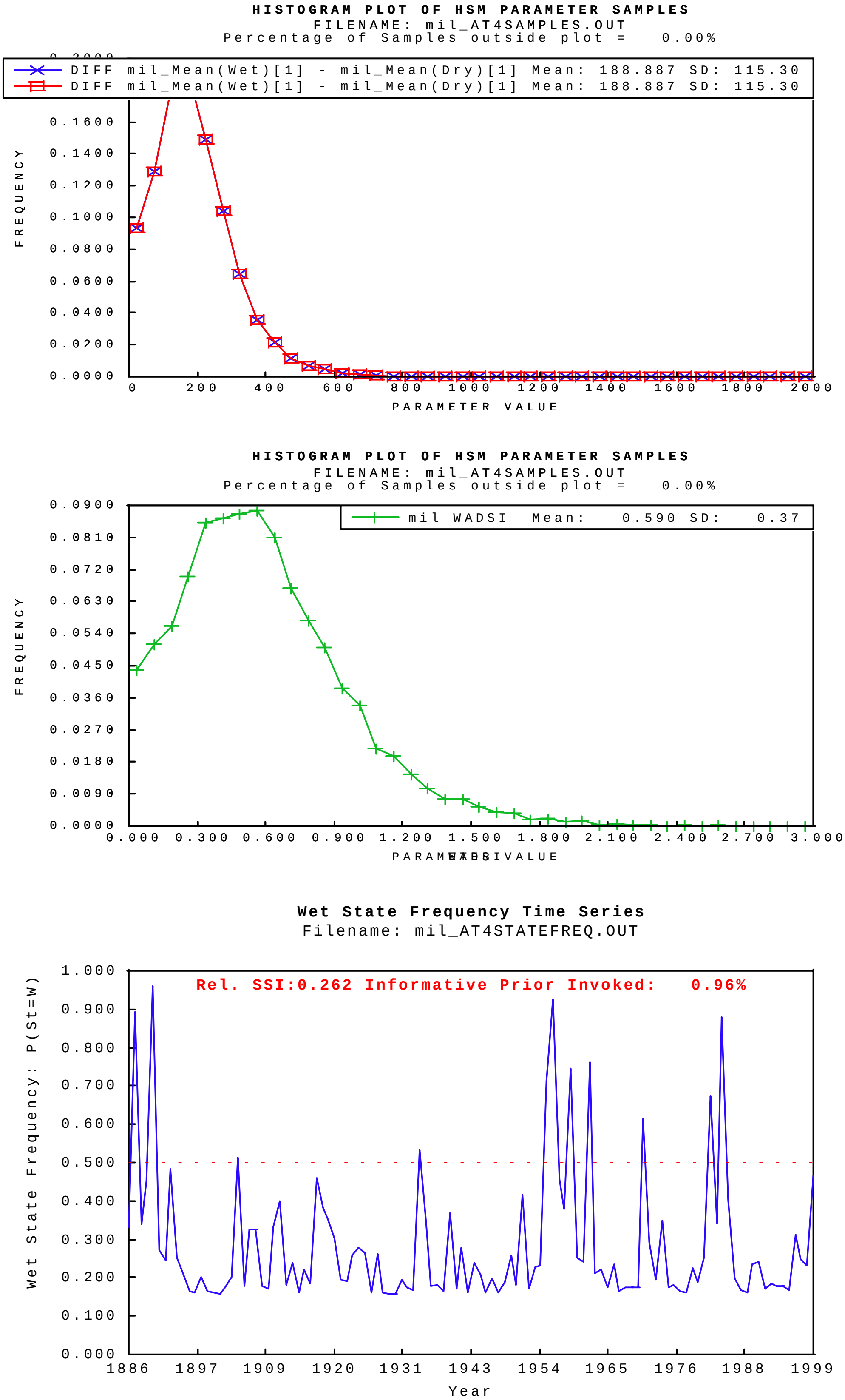
Figure C19. Calibration plots for Pittsworth







(a) Starting month April



(b) Starting month April

Figure C20. Calibration plots for Miles PO

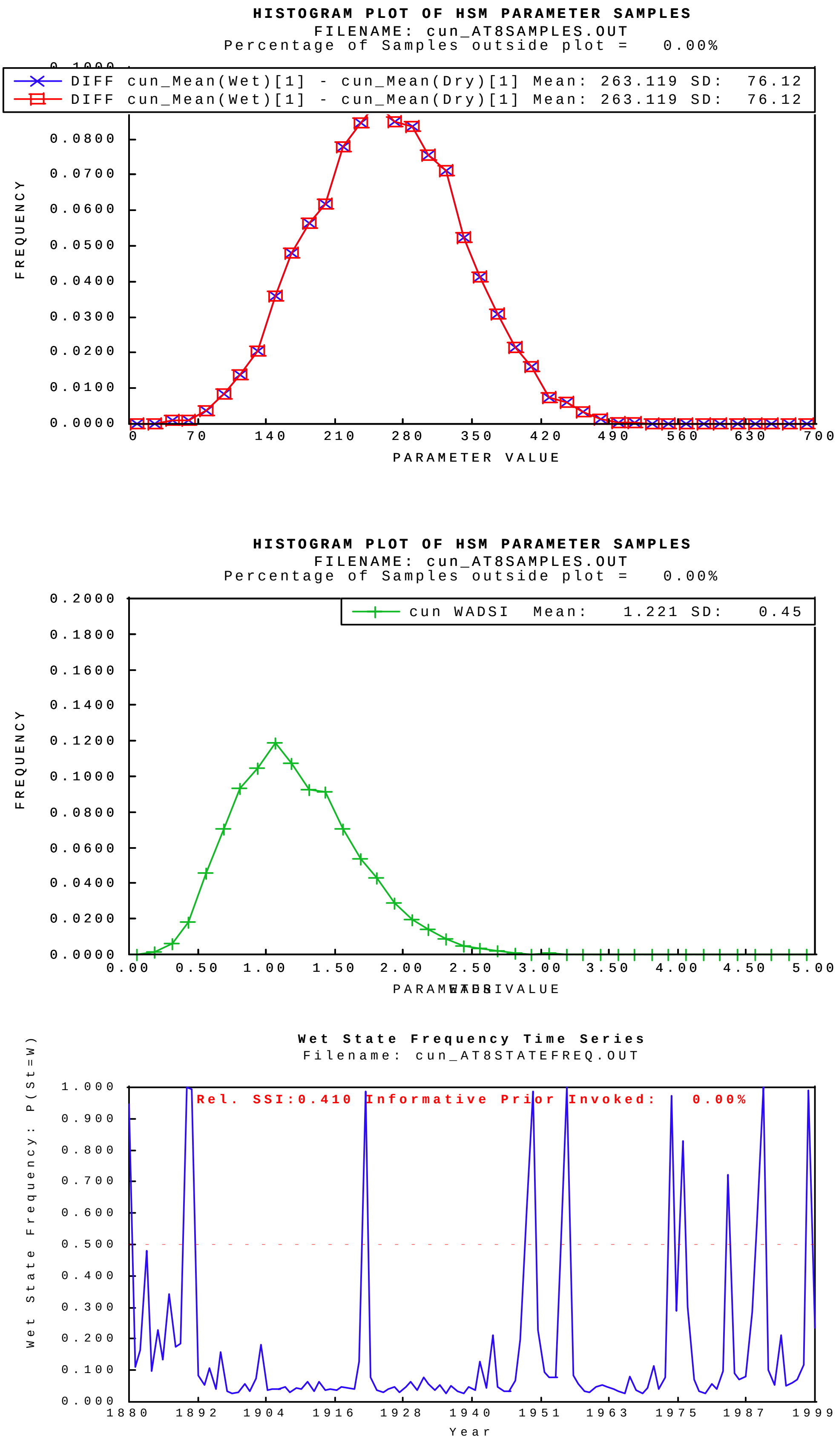
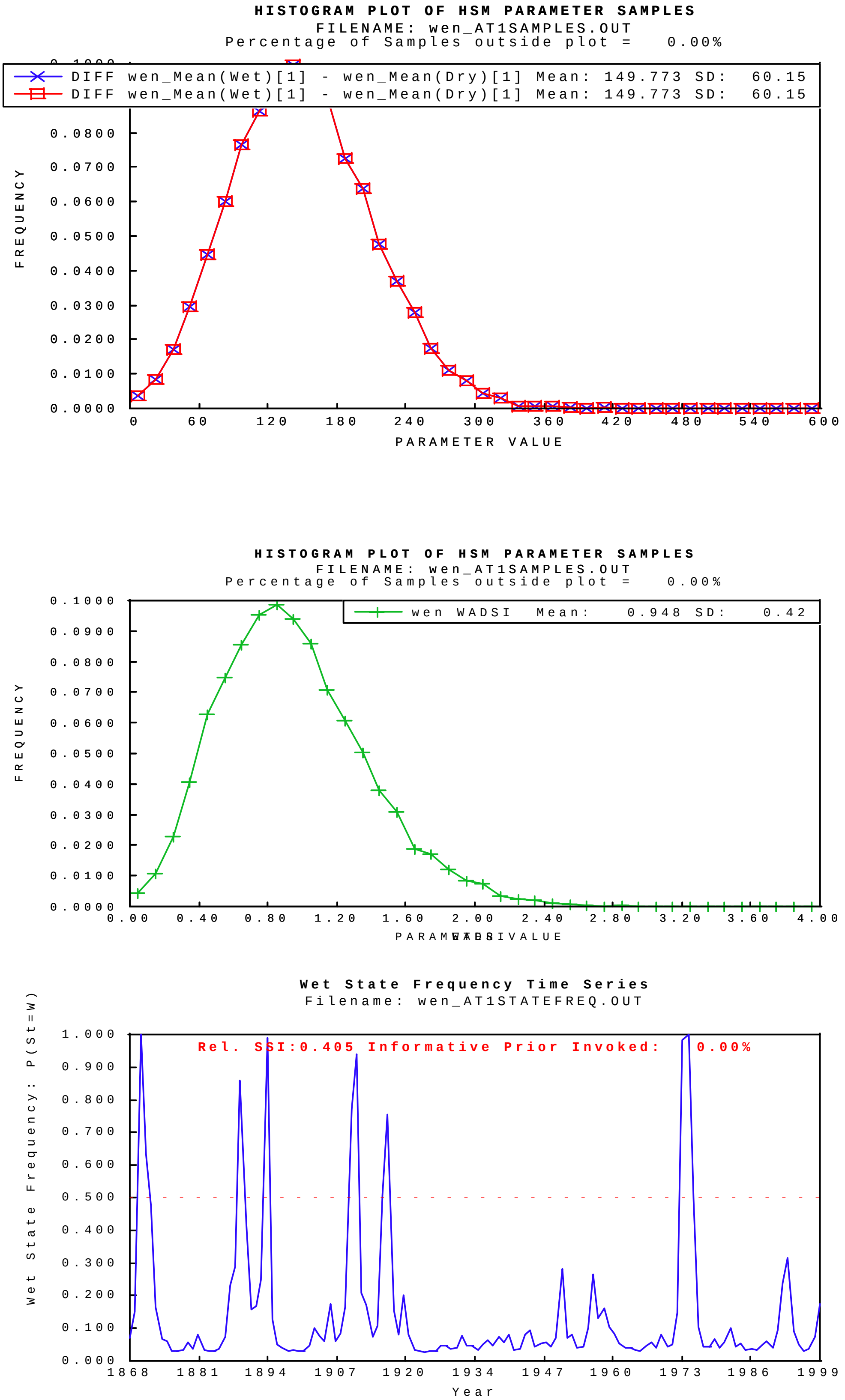
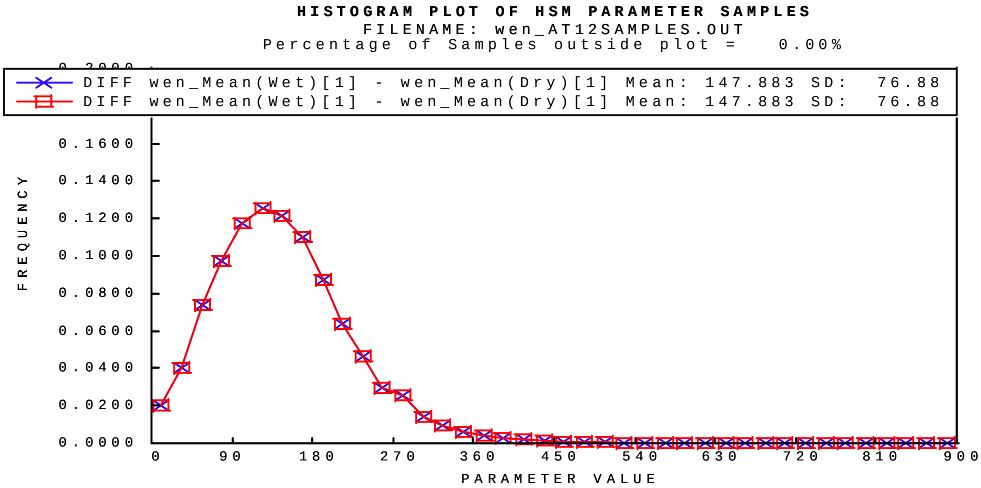
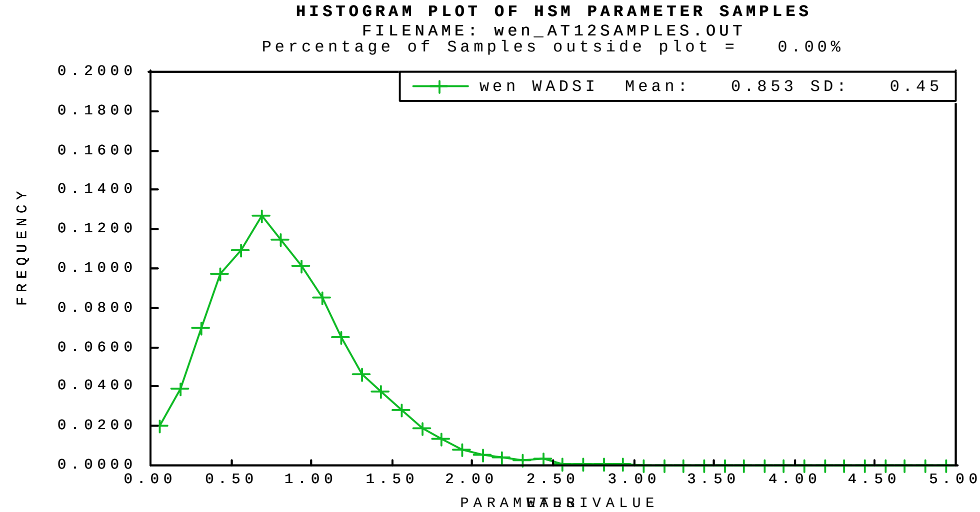


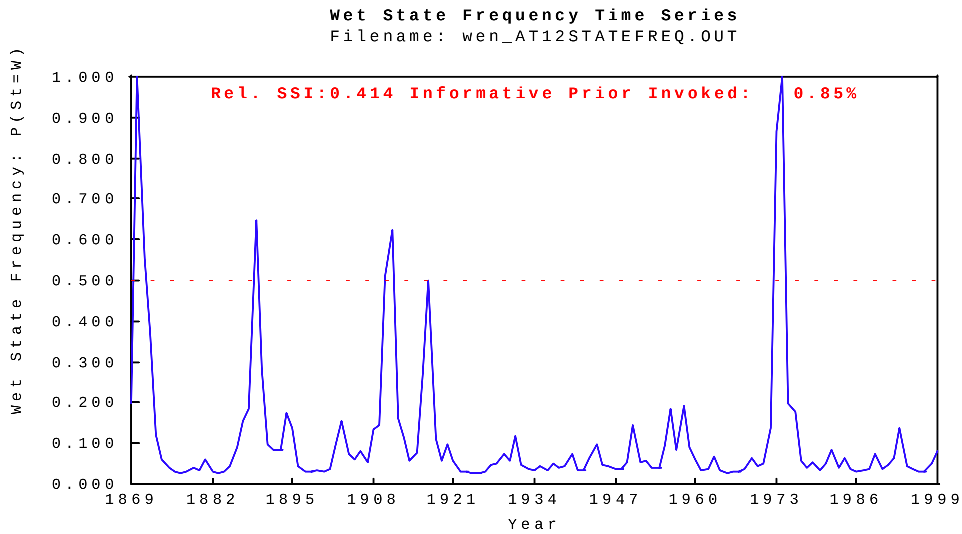
Figure C21. Calibration plots for Cunnamulla



(a) Starting month January

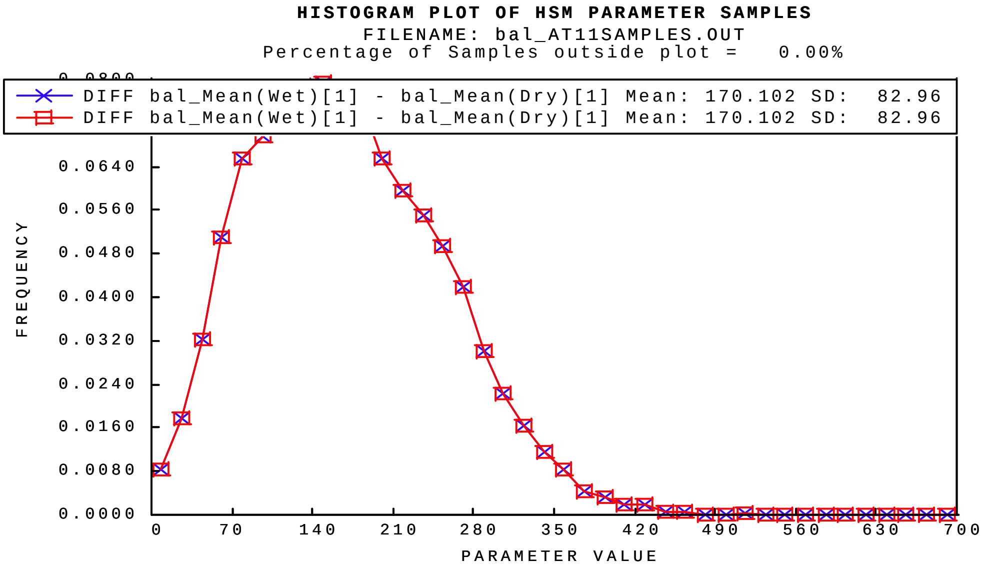


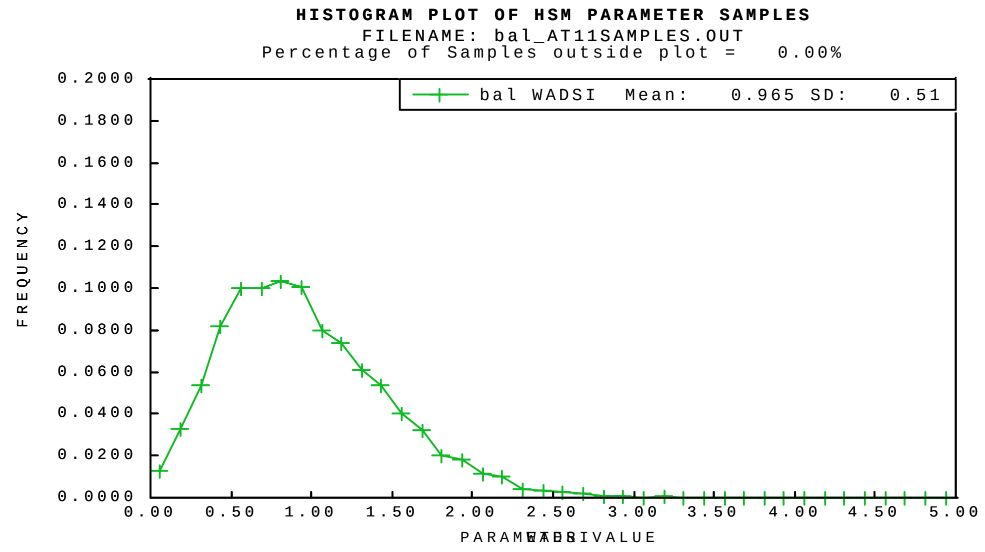




(b) Starting month December

Figure C22. Calibration plots for Wentworth





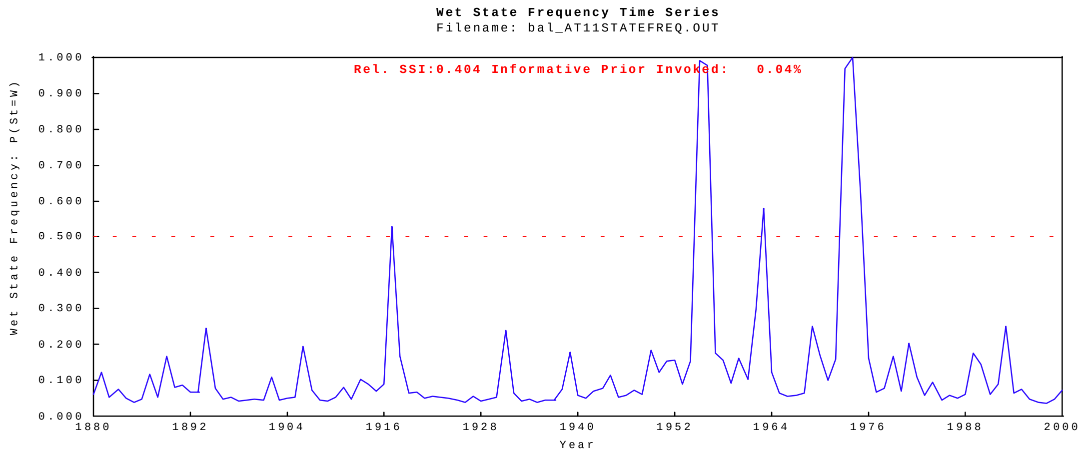
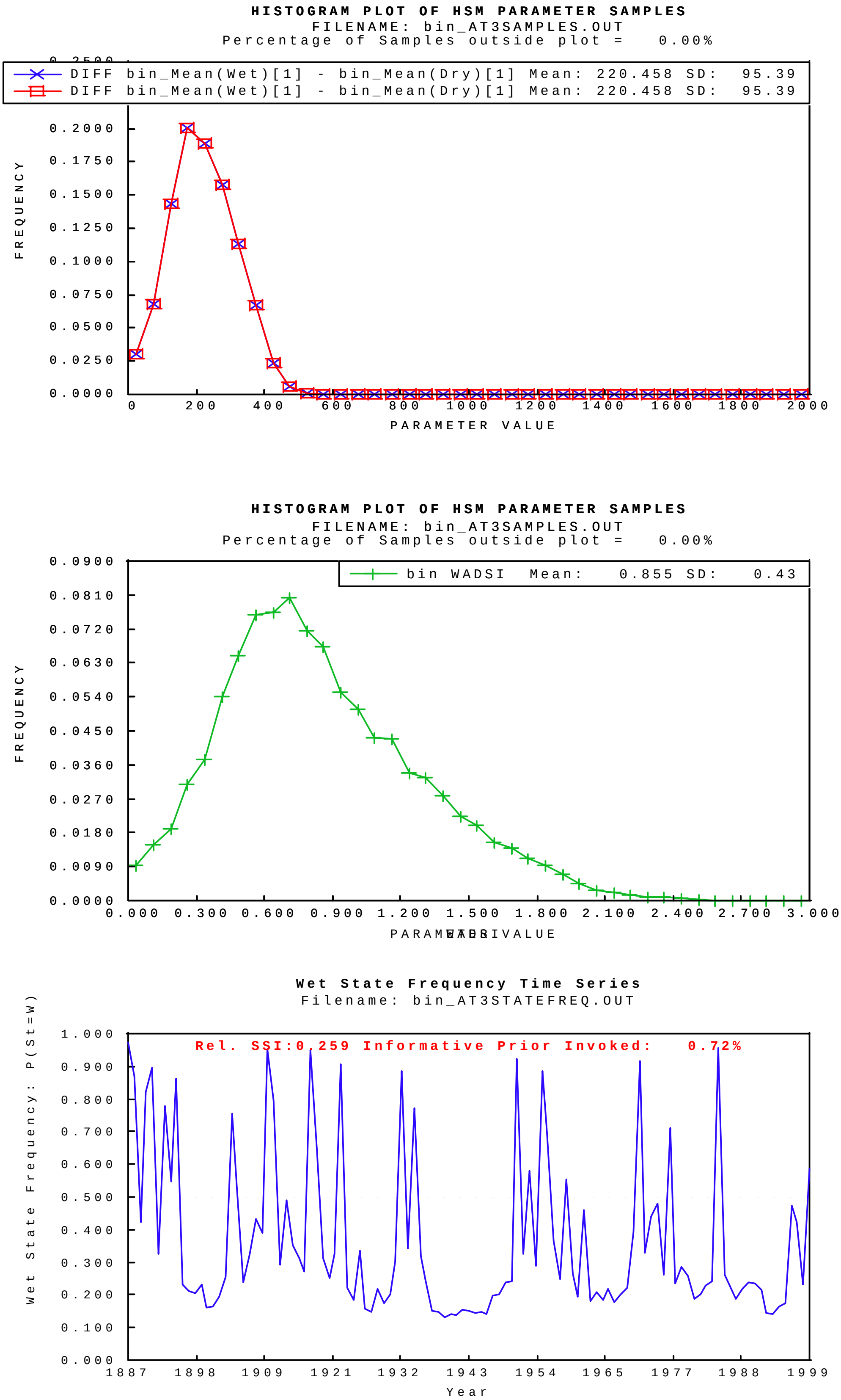
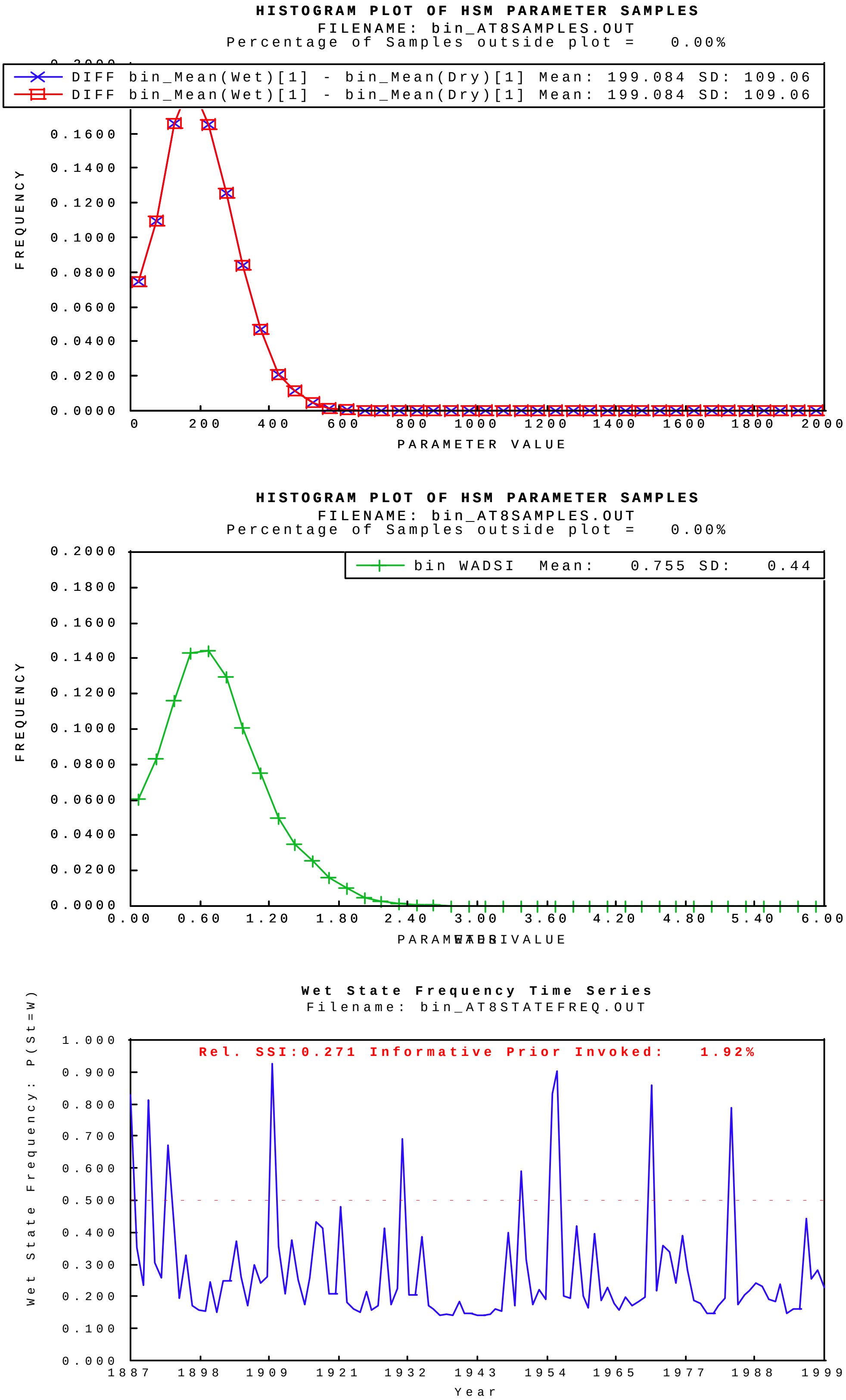


Figure C23. Calibration plots for Balranald

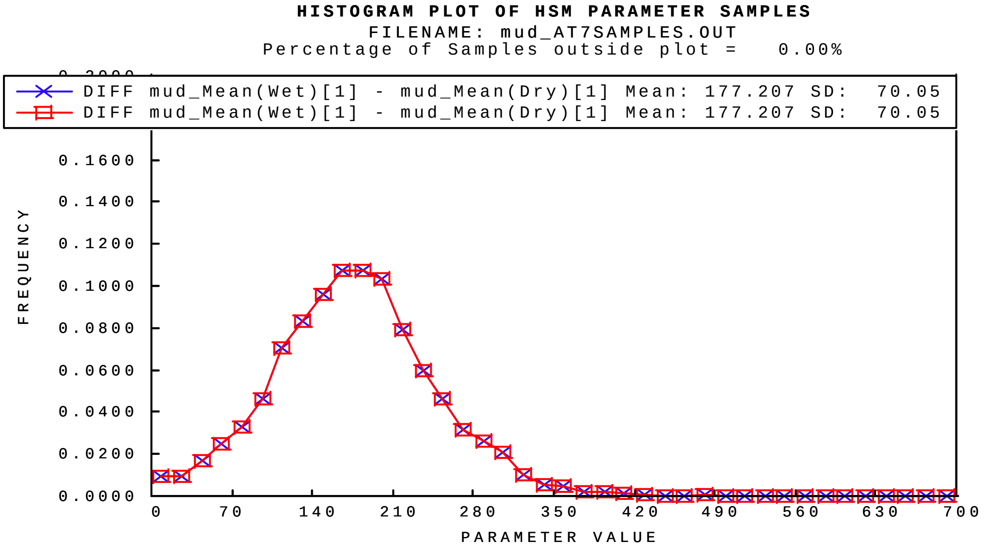


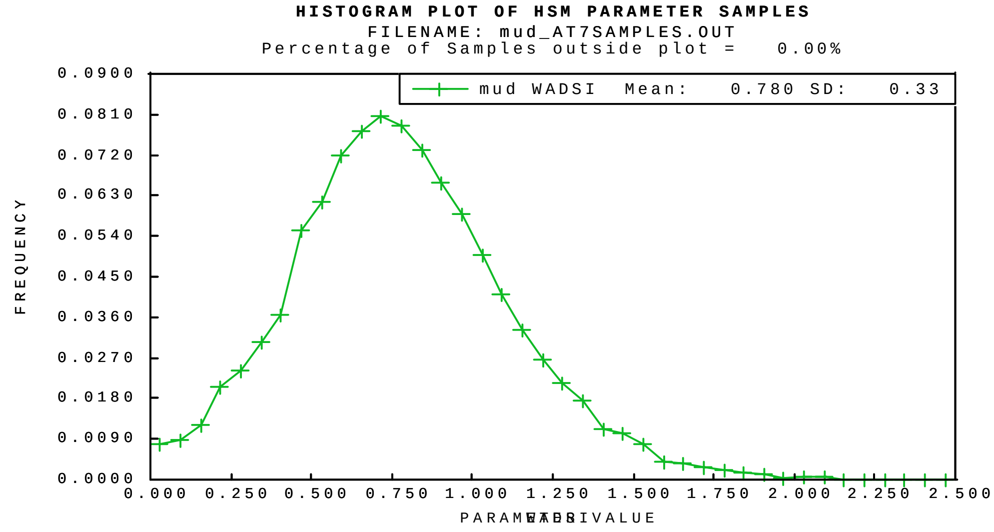
(a) Starting month March

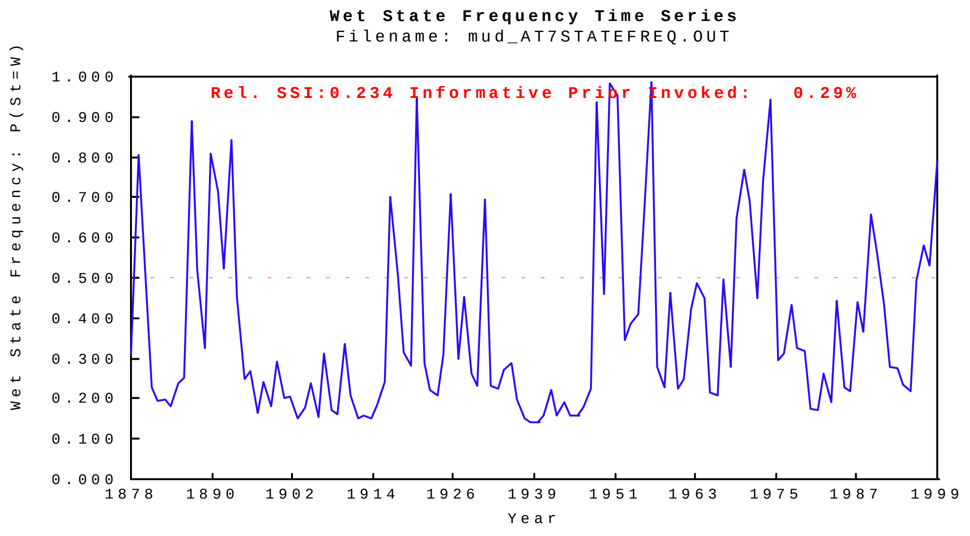


(b) Starting month August

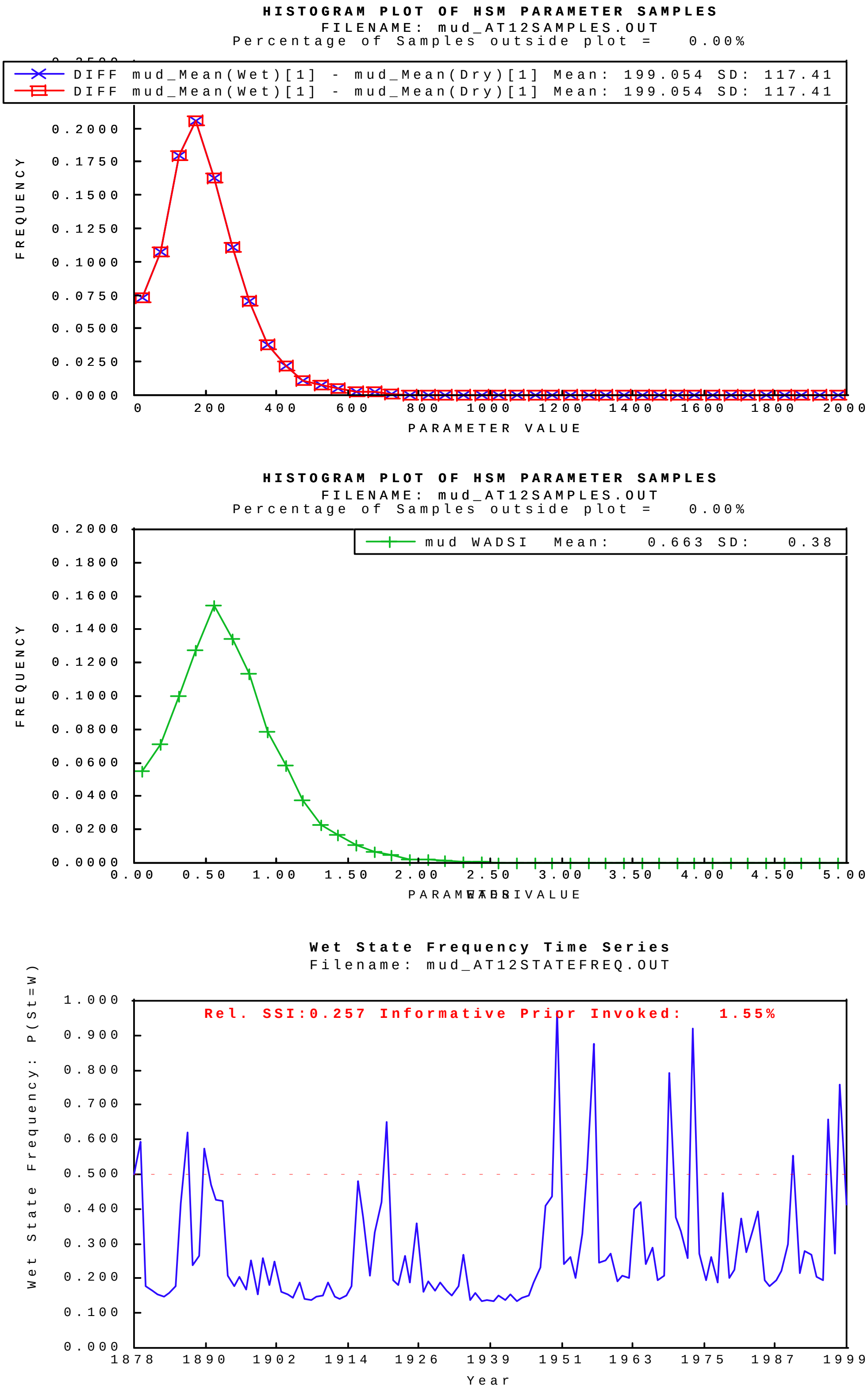
Figure C24. Calibration plots for Bingara





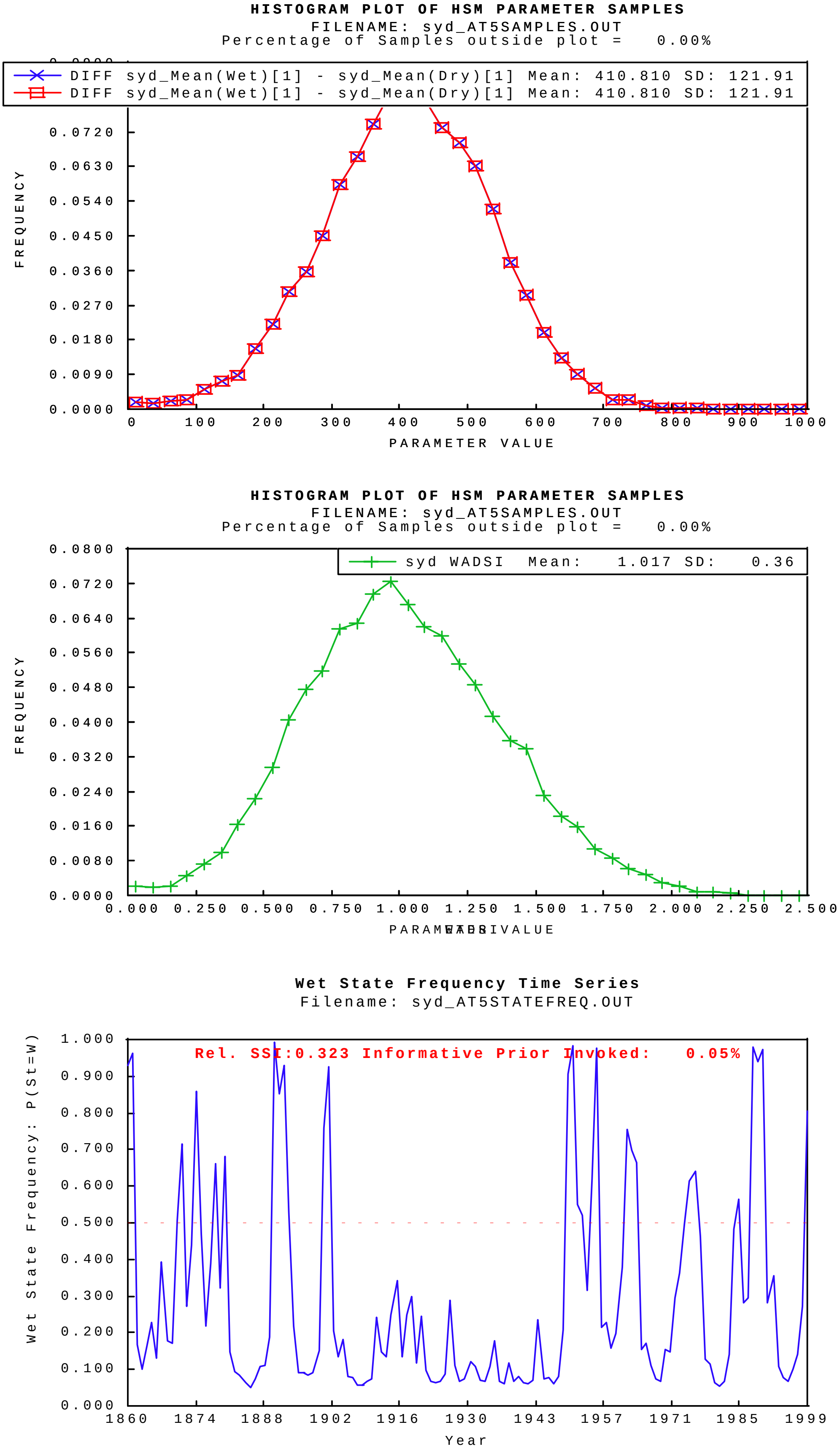


(a) Starting month July

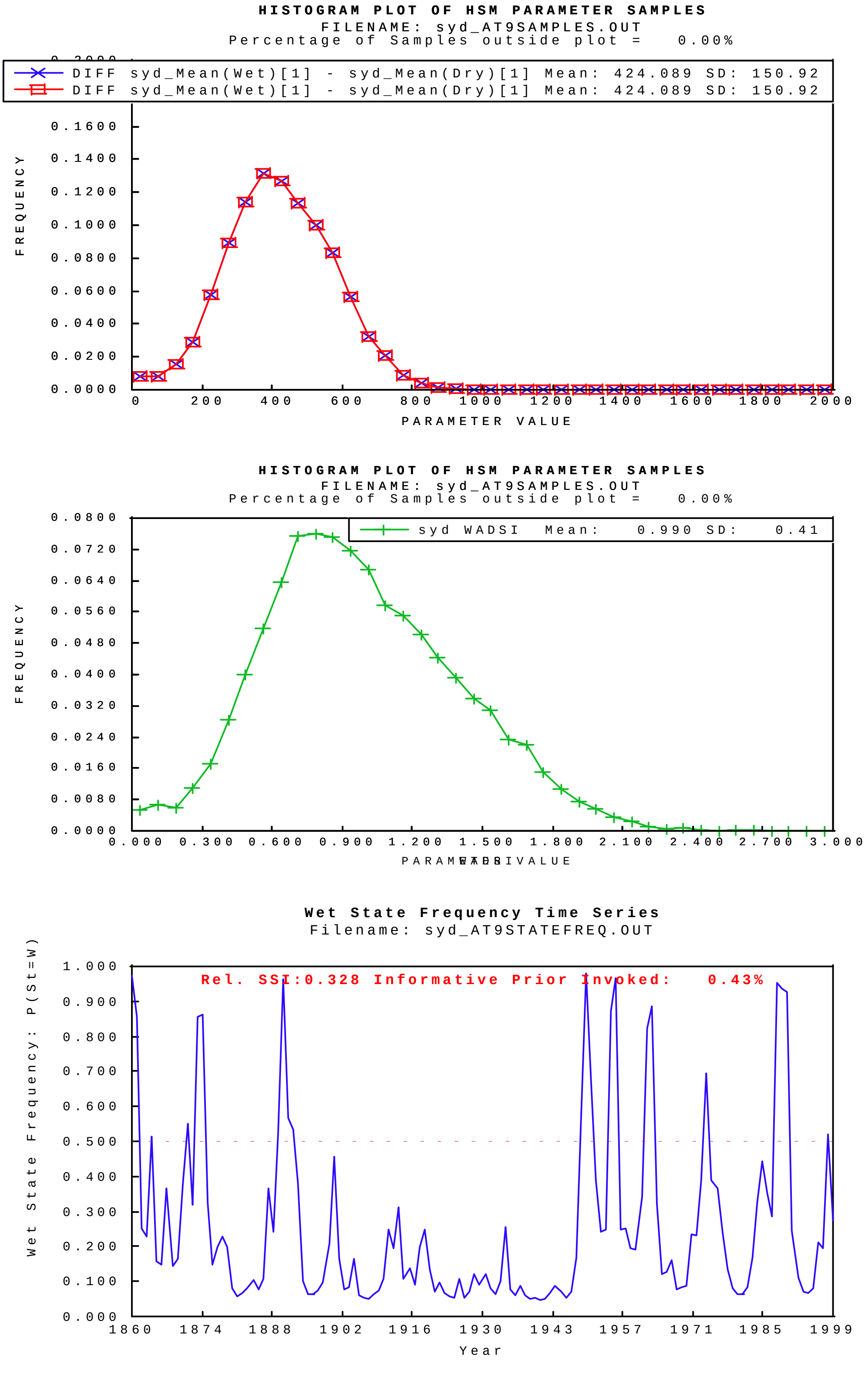


(b) Starting month December

Figure C25. Calibration plots for mudgee

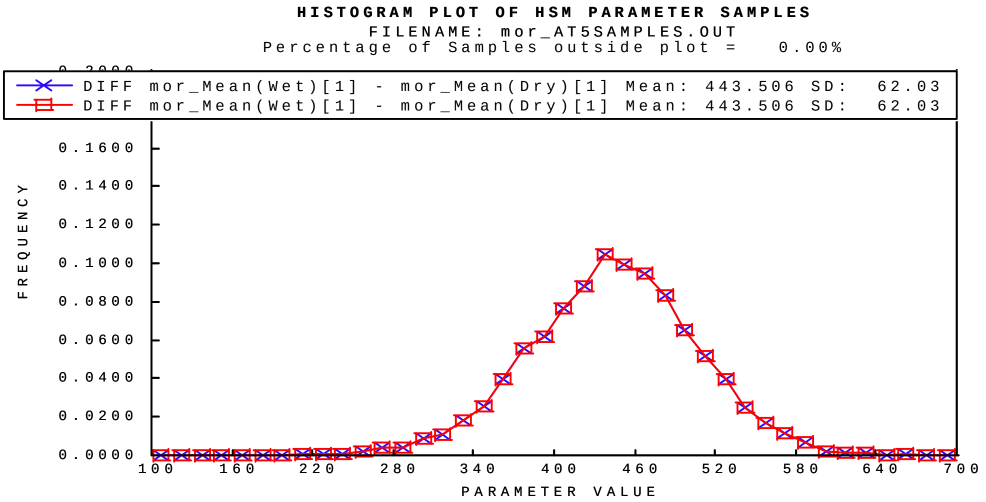


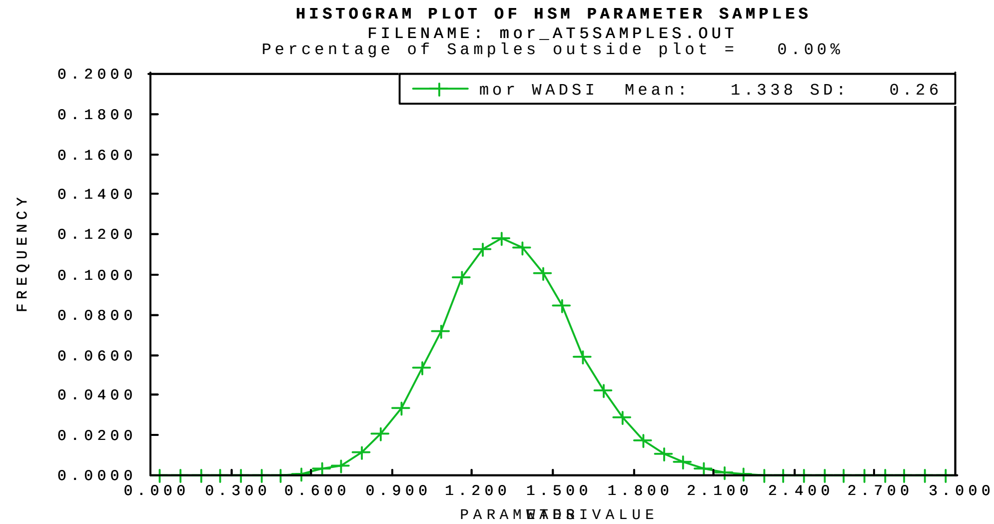
(a) Starting month May



(b) Starting month September

Figure C26. Calibration plots for Sydney





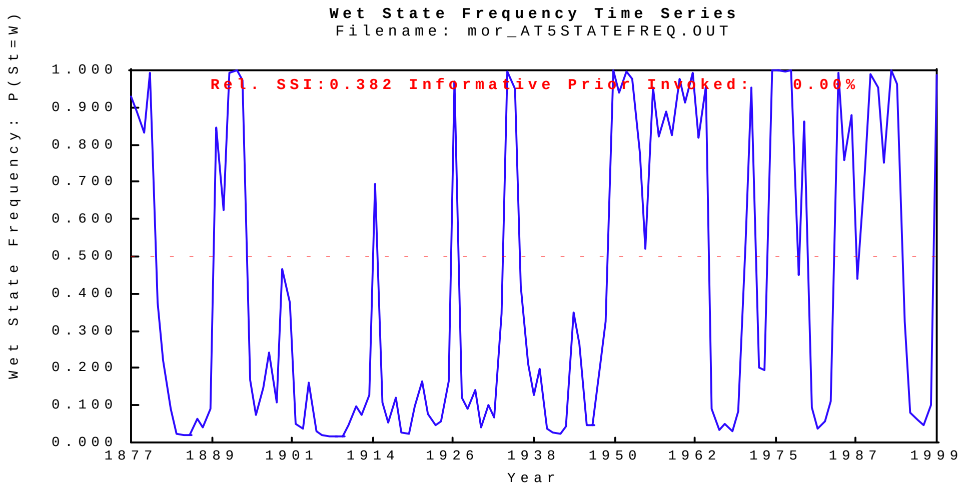
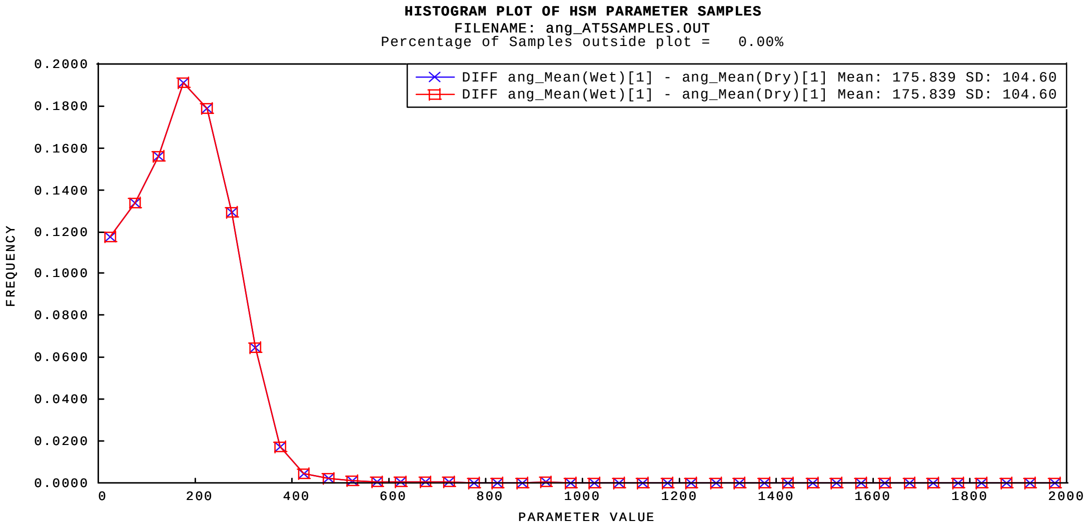
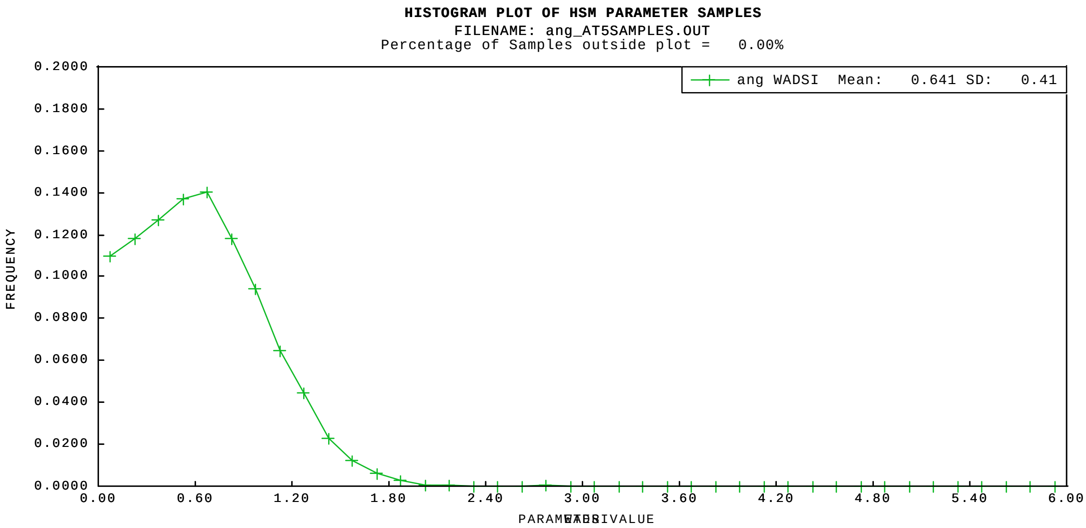
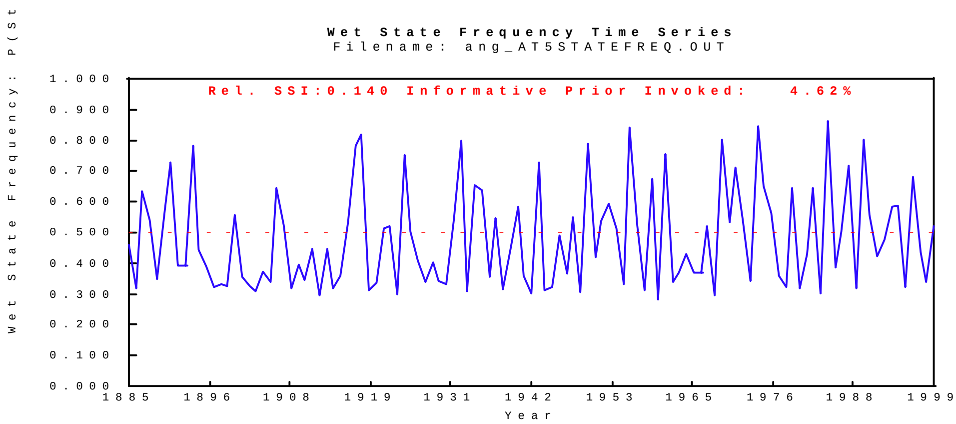


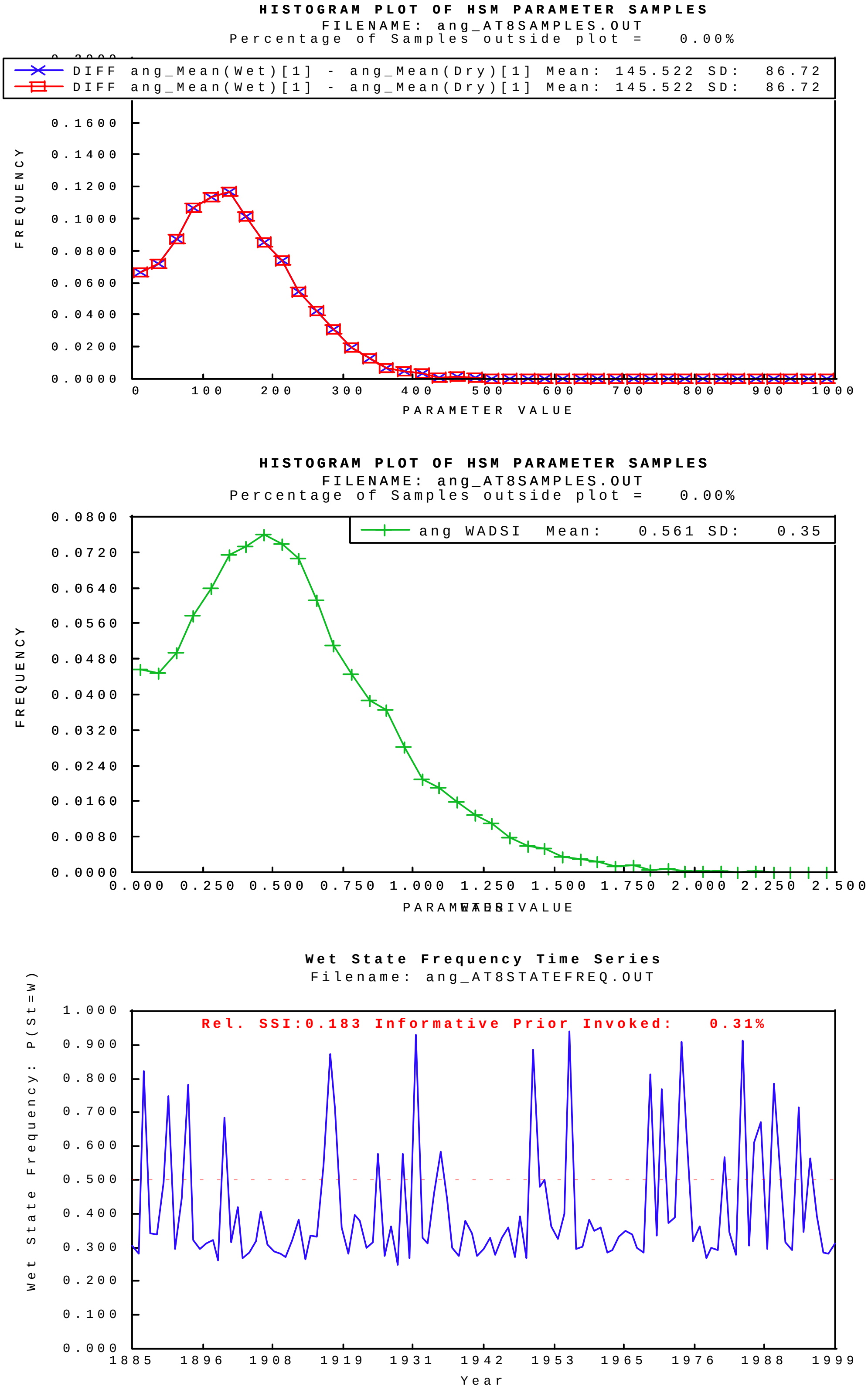
Figure C27. Calibration plots for Moruya Heads







(a) Starting month May



(b) Starting month August

Figure C28. Calibration plots for Adelong

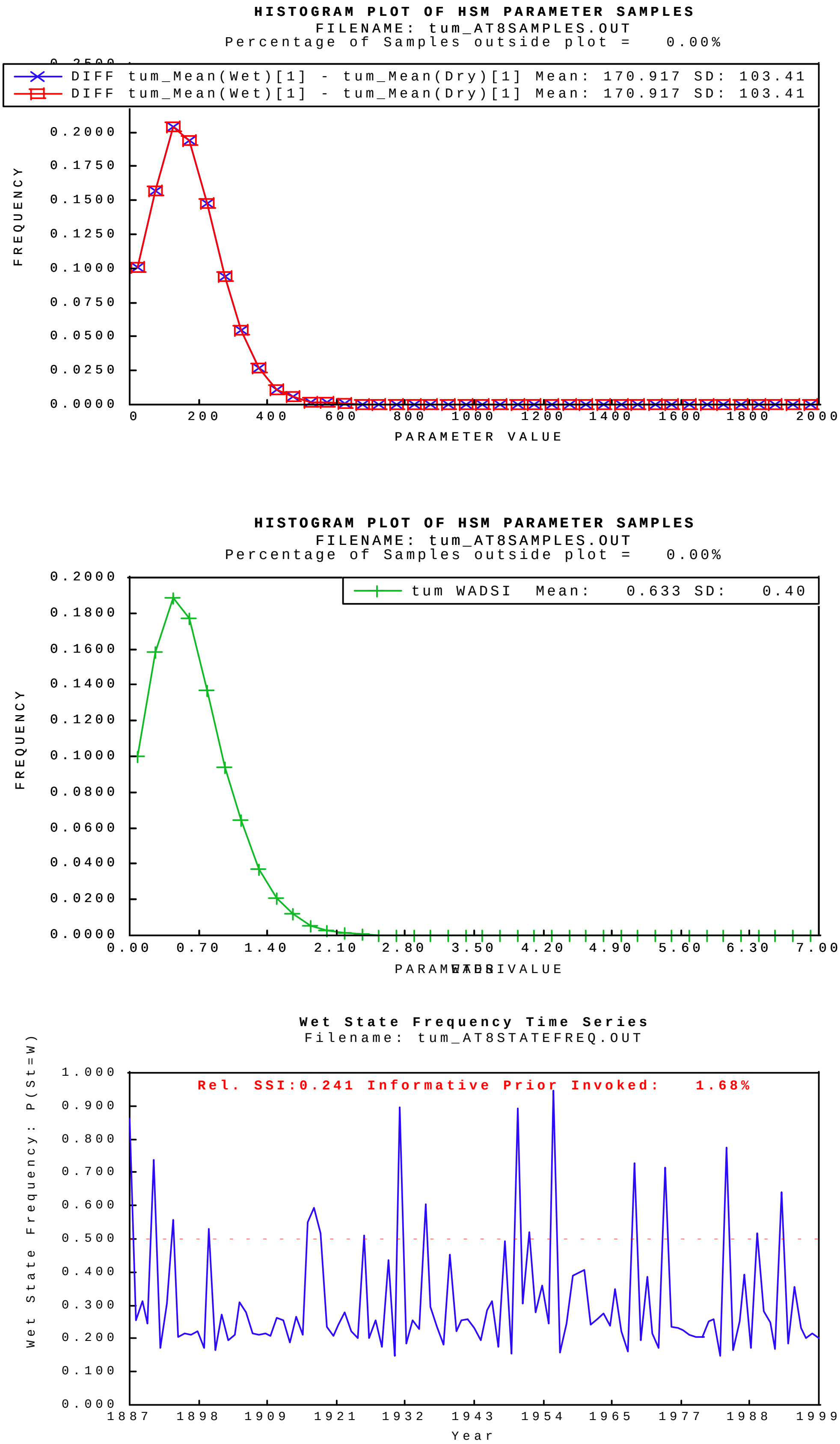


Figure C29. Calibration plots for Tumut

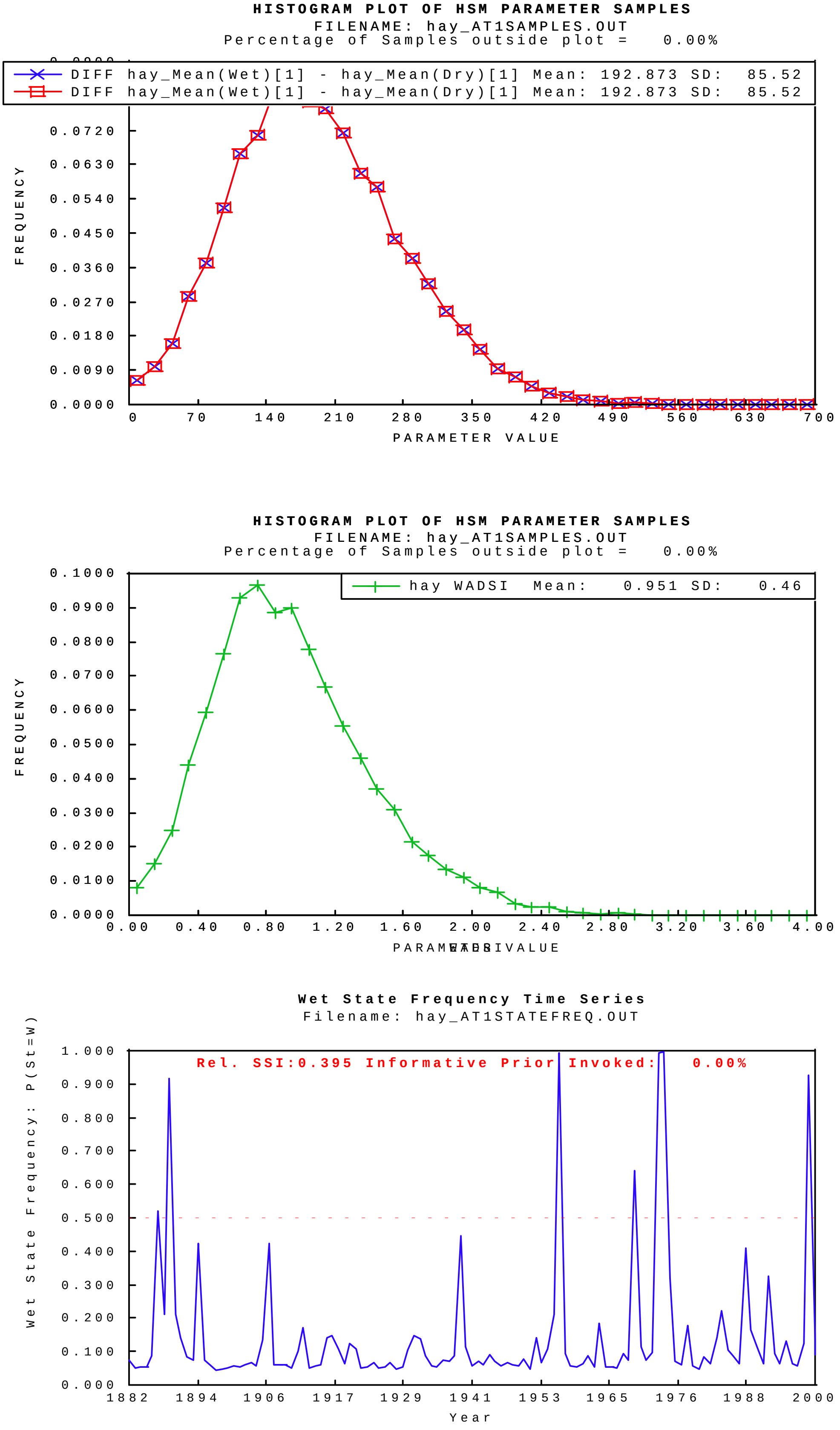
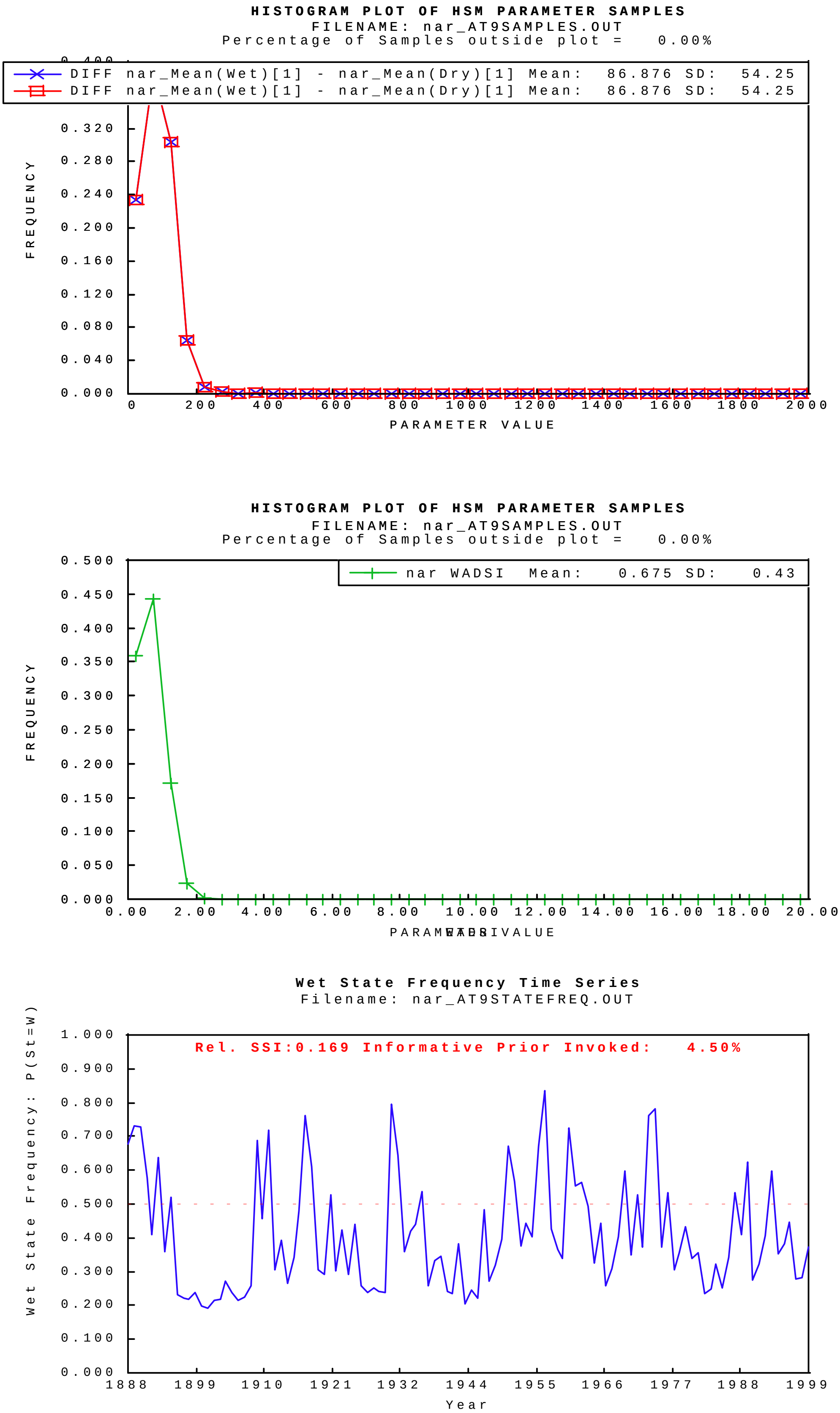
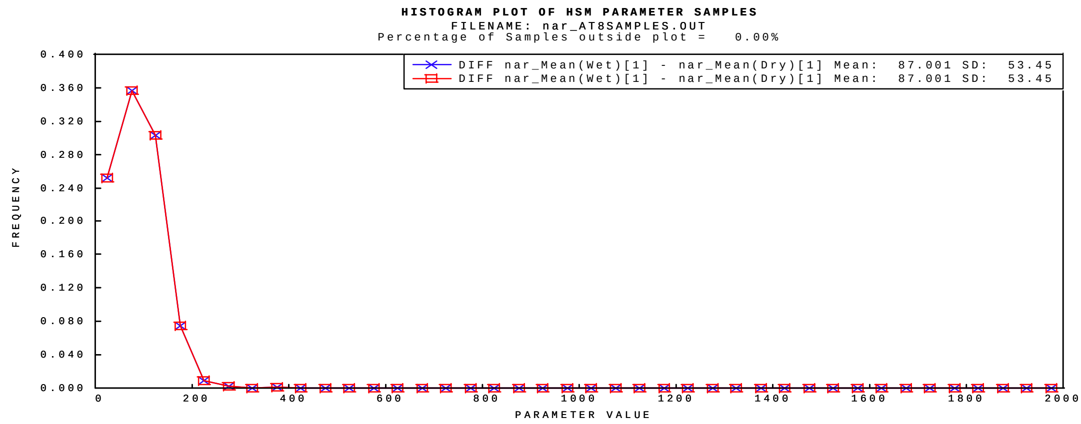
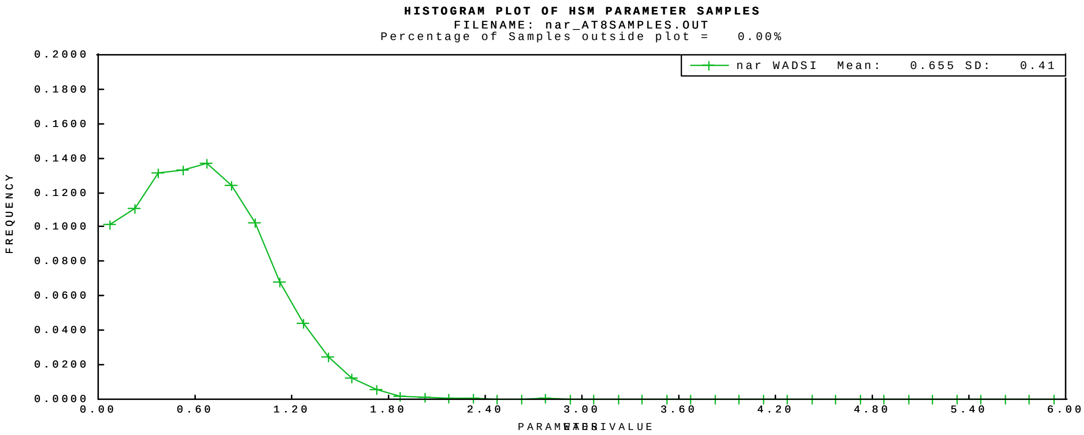


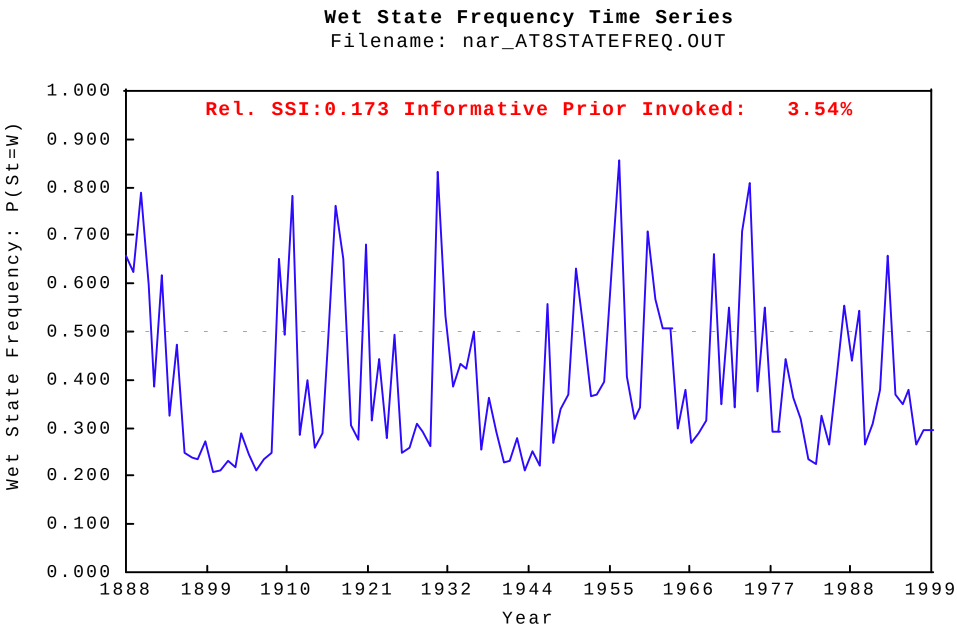
Figure C30. Calibration plots for Hay



(a) Starting month September







(b) Starting month August

Figure C31. Calibration plots for Narraport

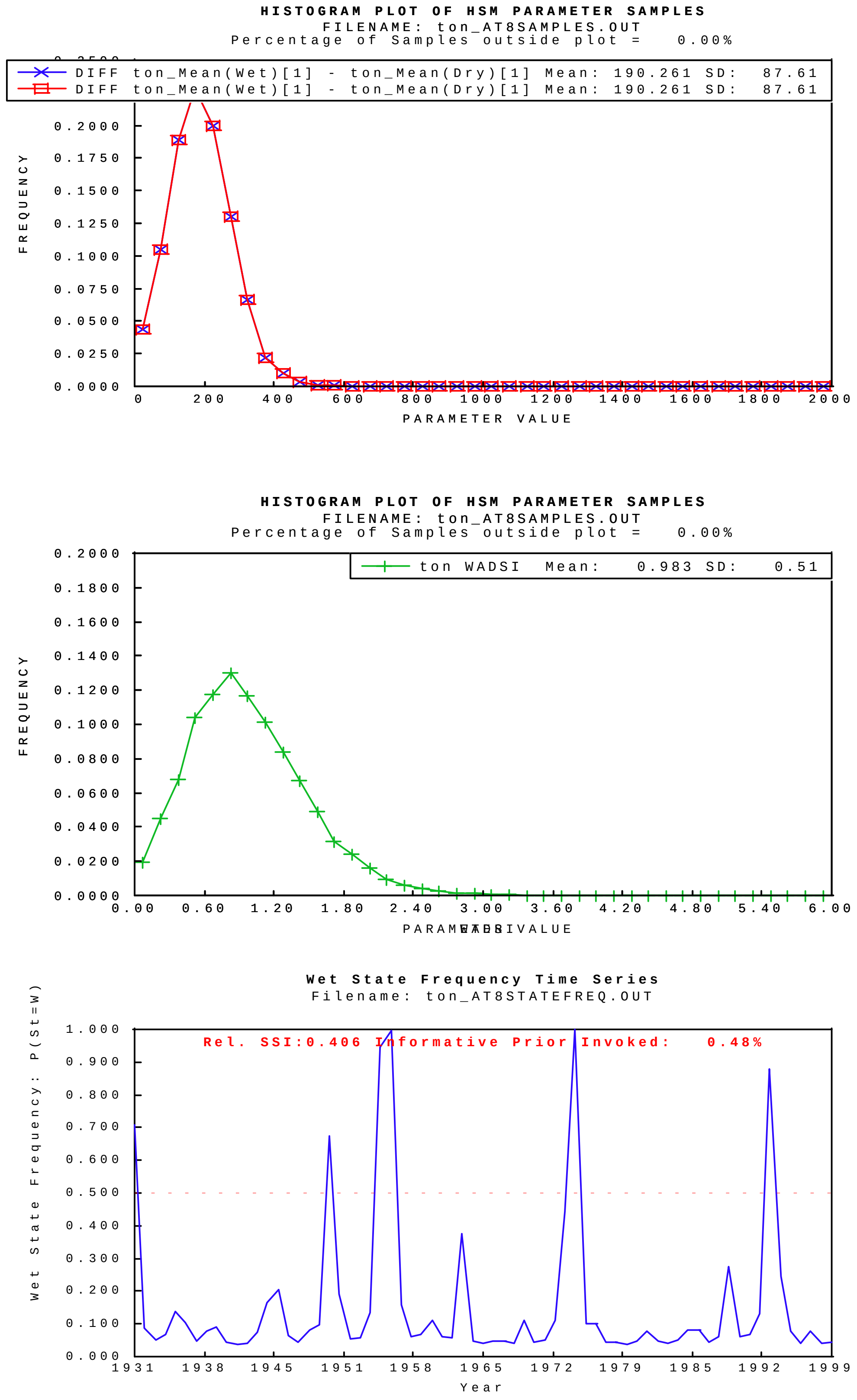
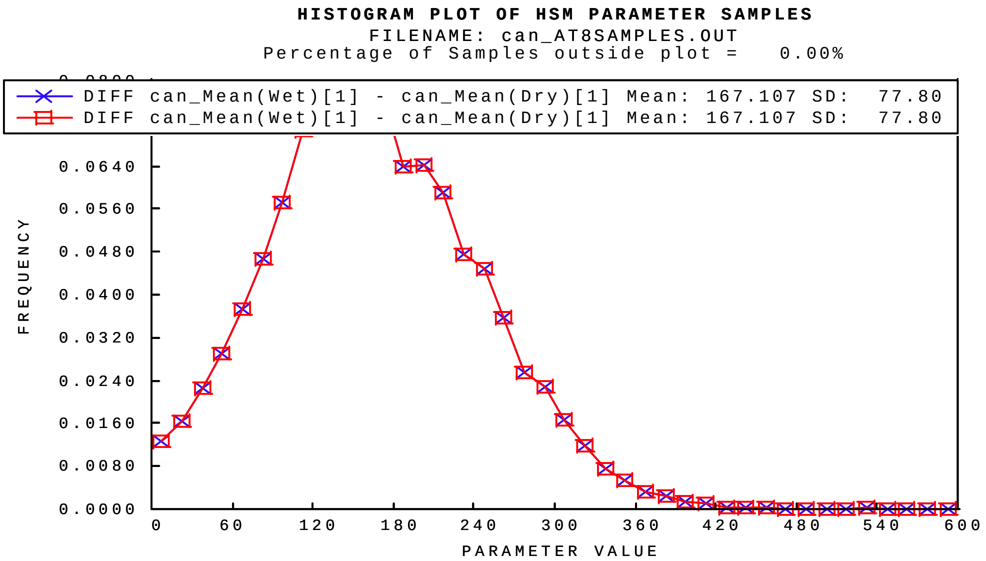
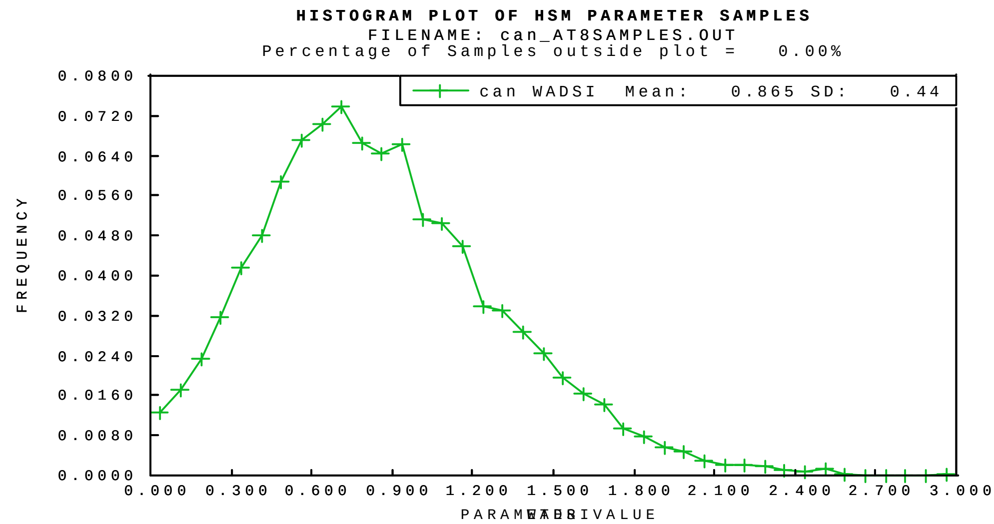


Figure C32. Calibration plots for Tongala





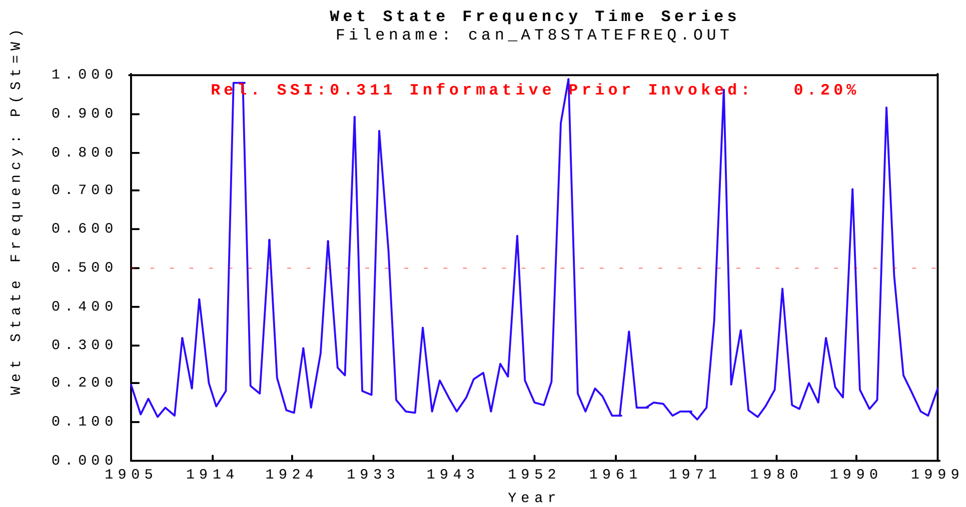
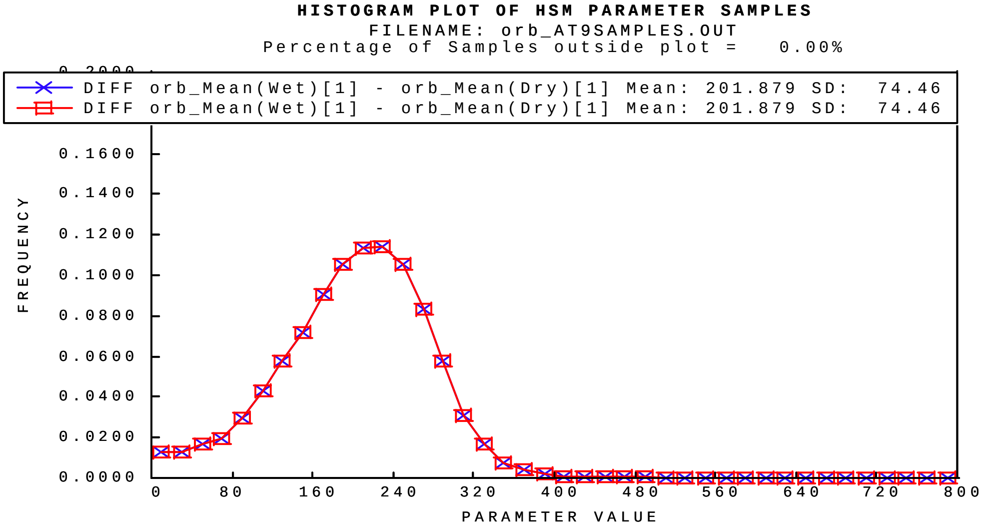
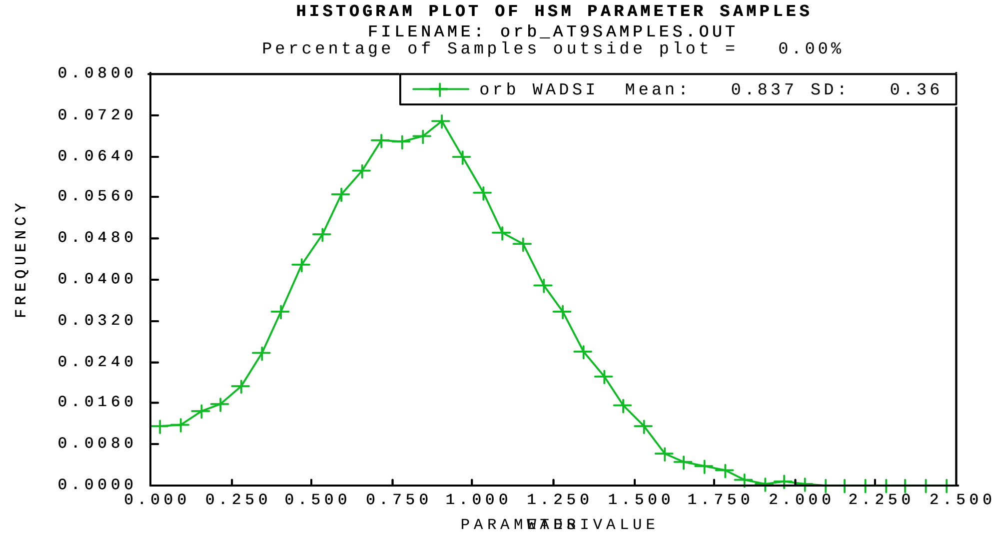
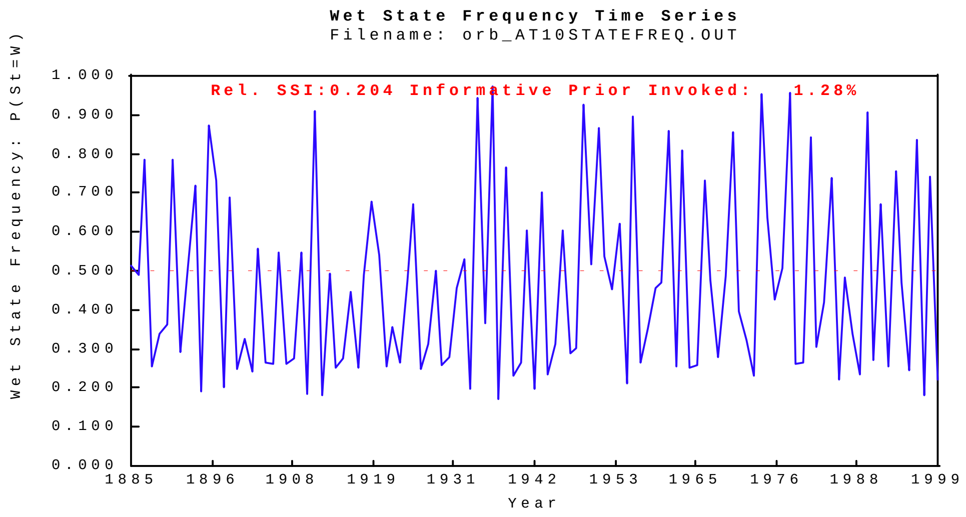


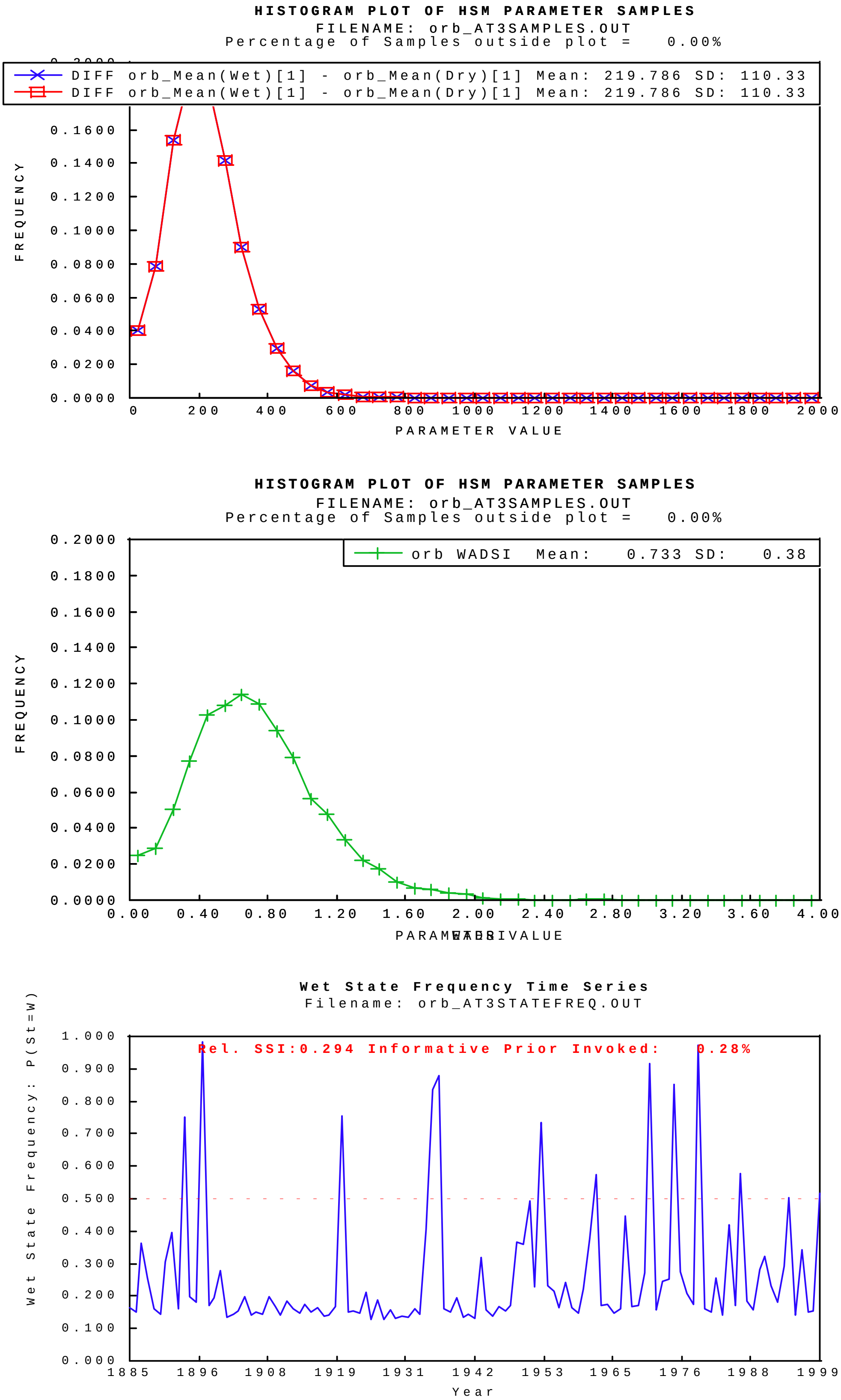
Figure C33. Calibration plots for Caniambo







(a) Starting month October



(b) Starting month March

Figure C34. Calibration plots for Orbost

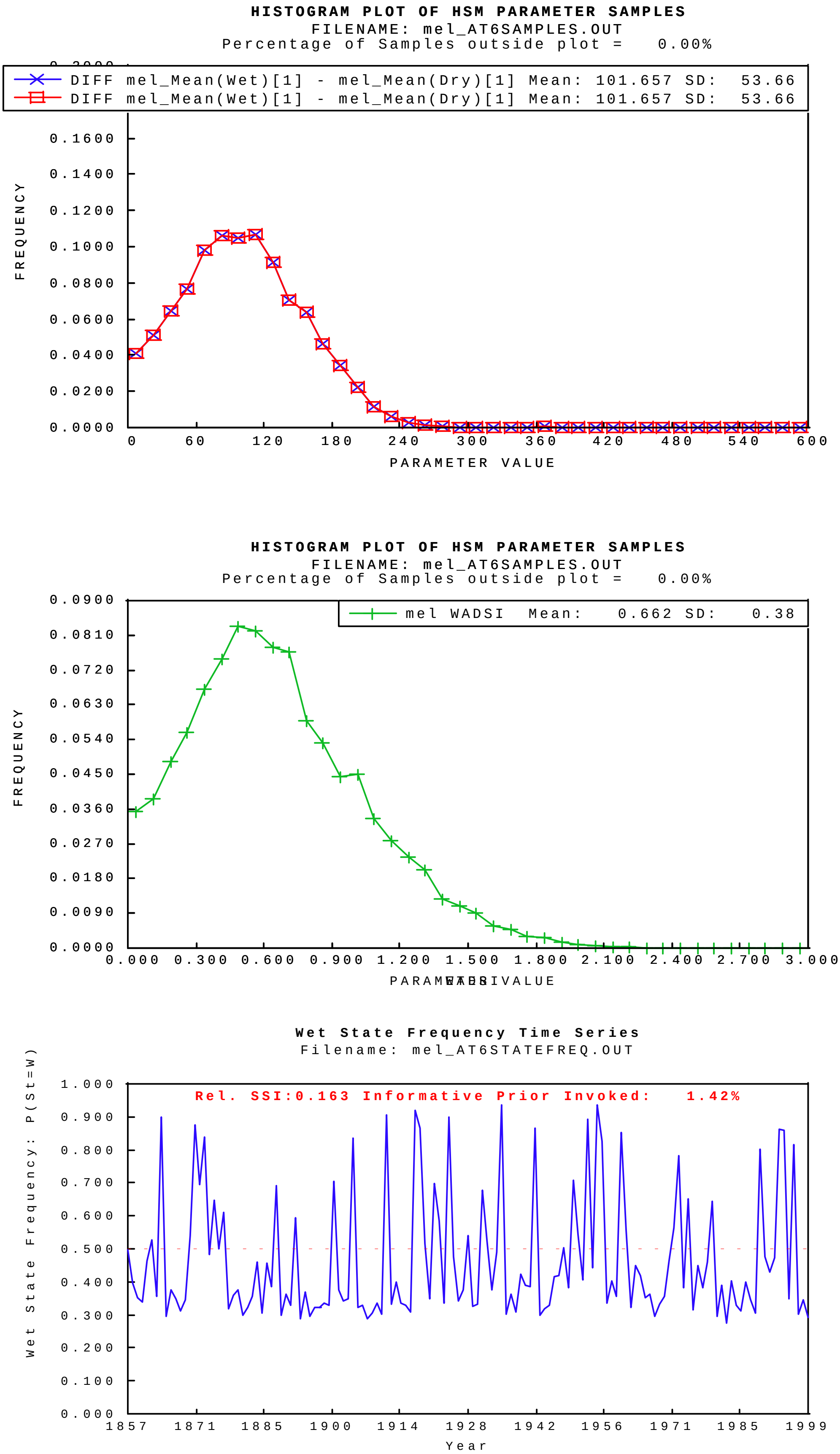


Figure C35. Calibration plots for Melbourne

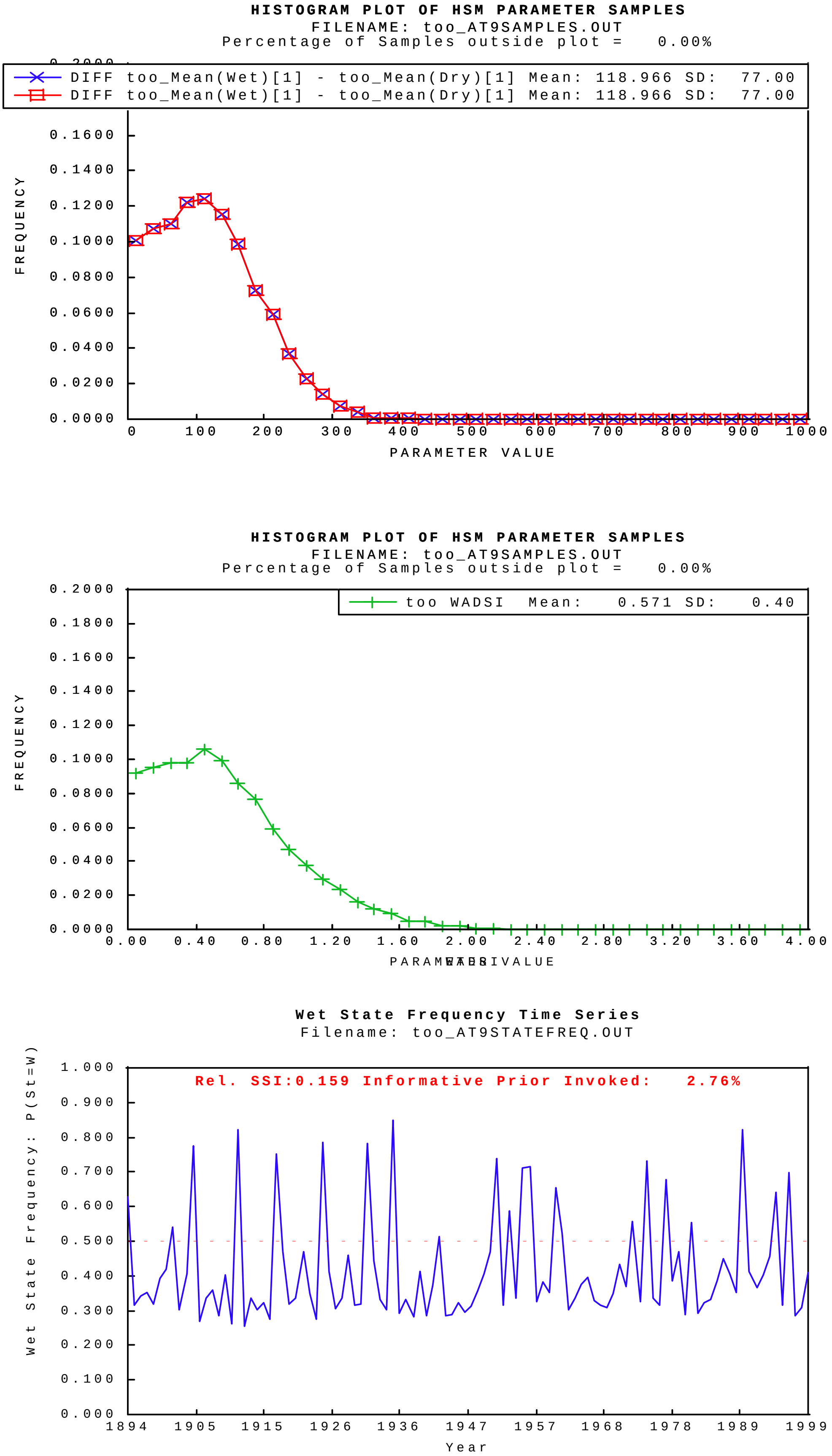


Figure C36. Calibration plots for Toorourrong

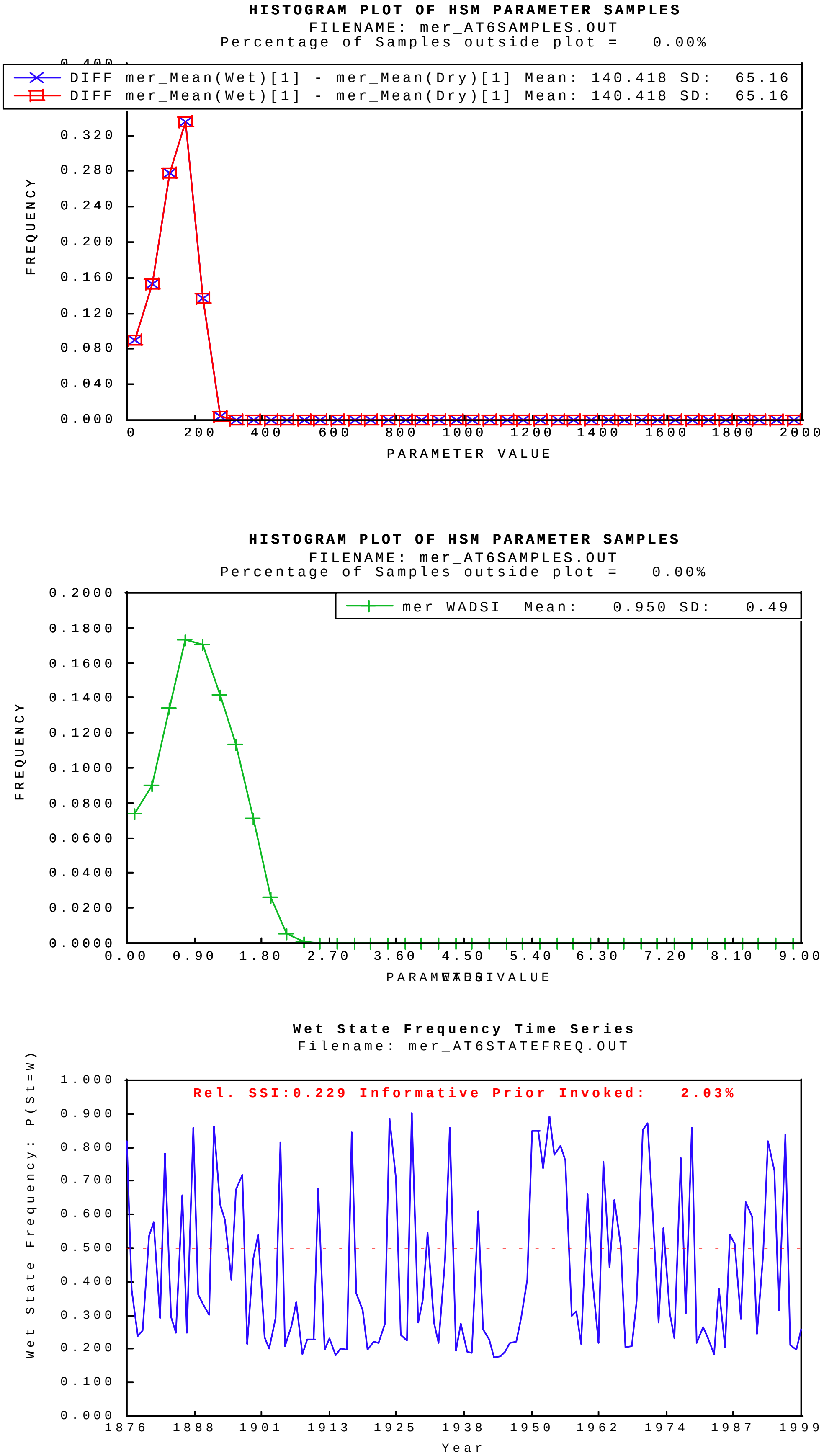
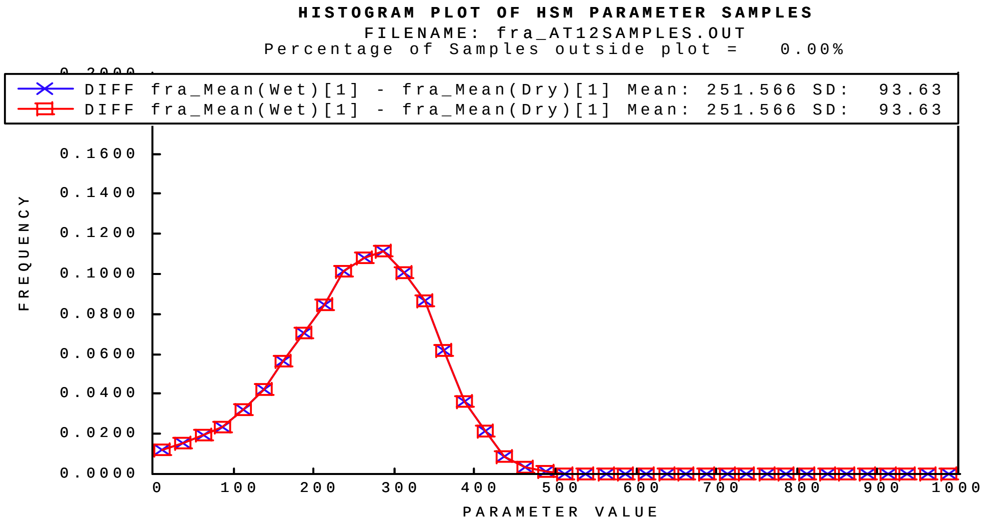
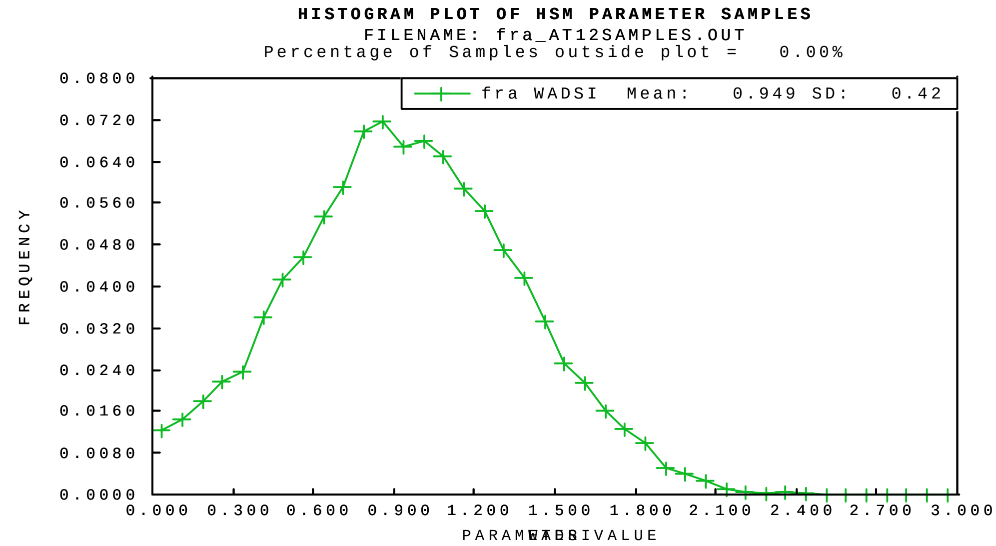


Figure C37. Calibration plots for Meredith





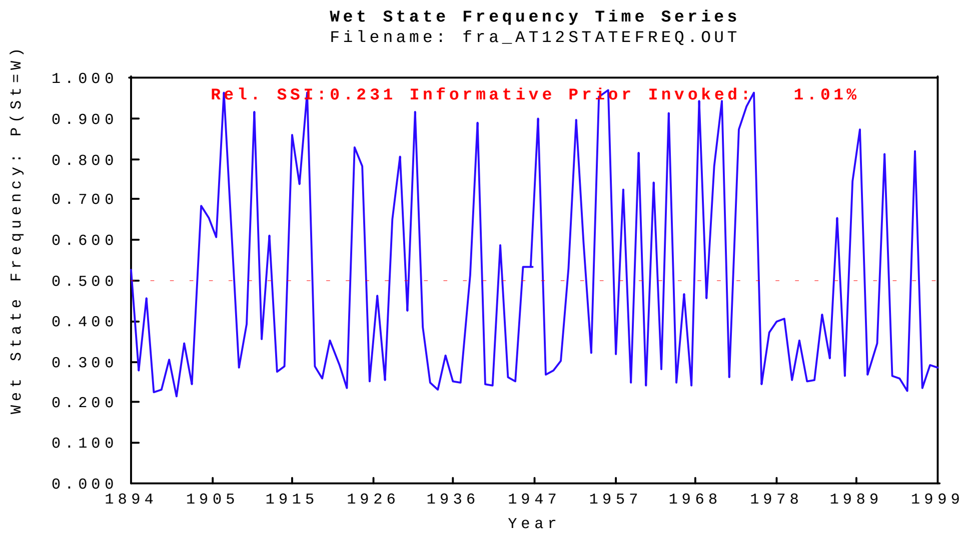
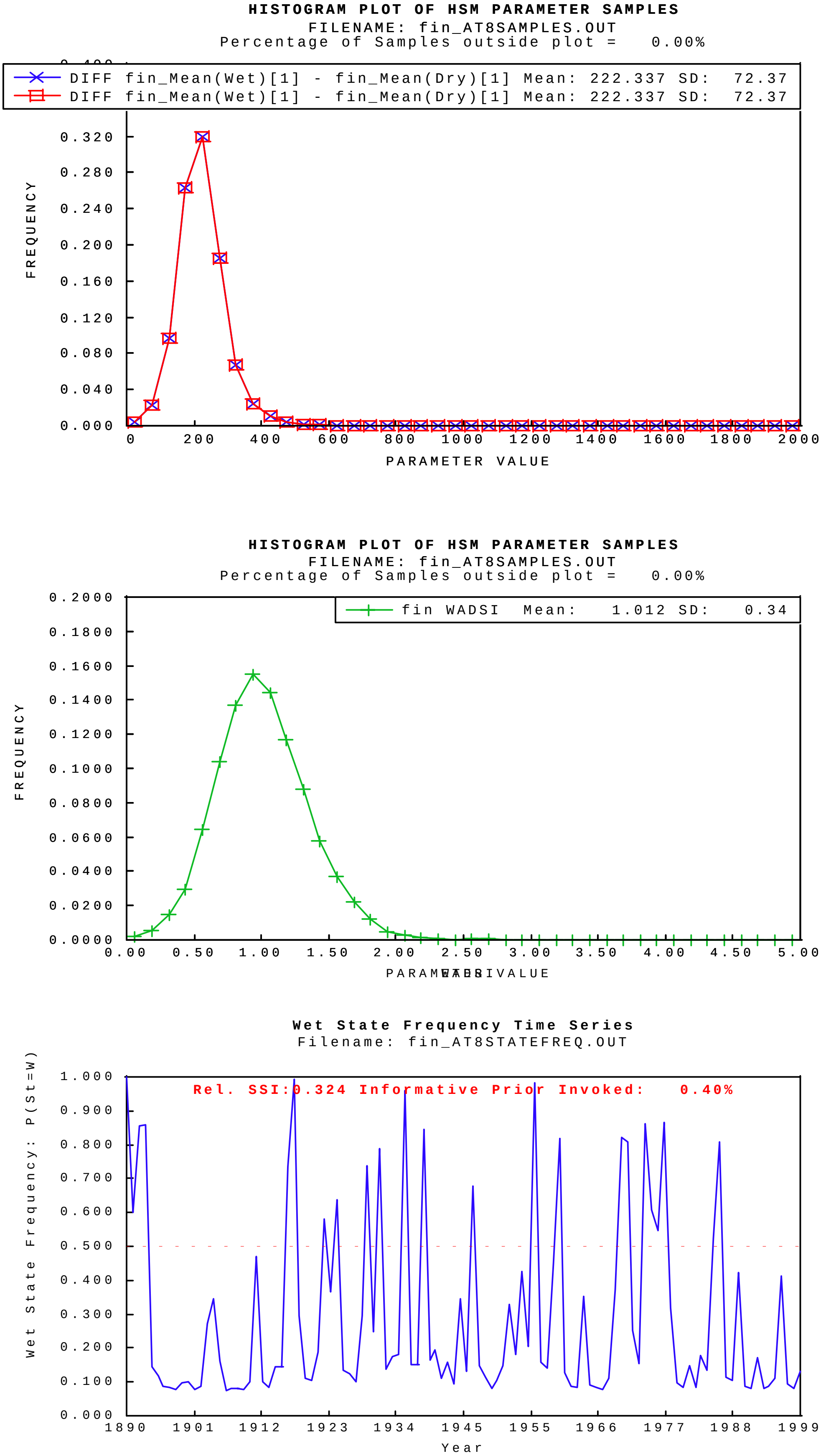
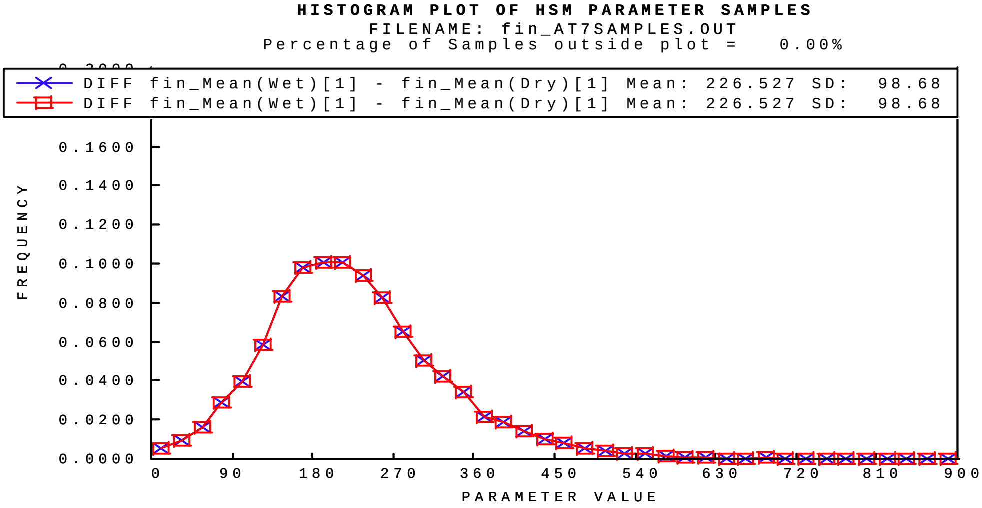
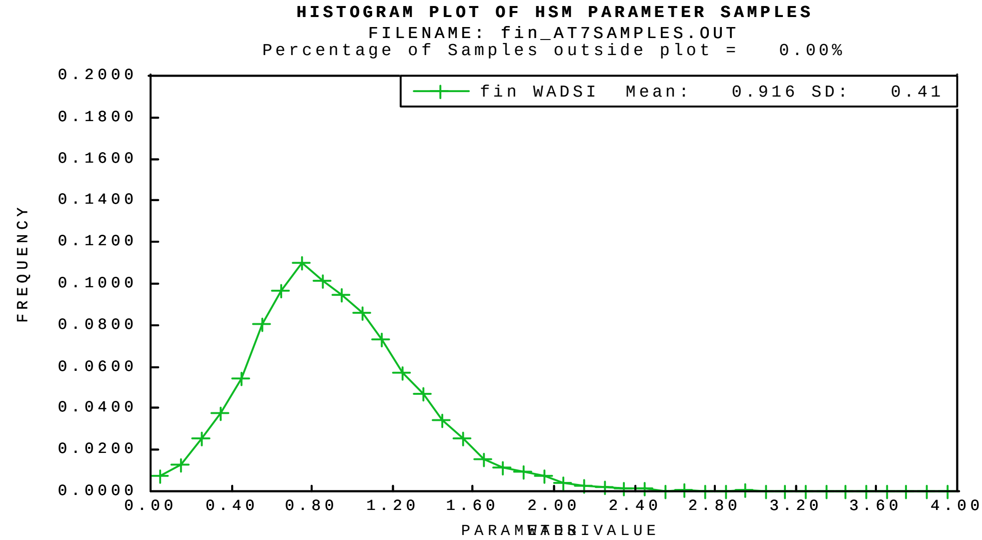


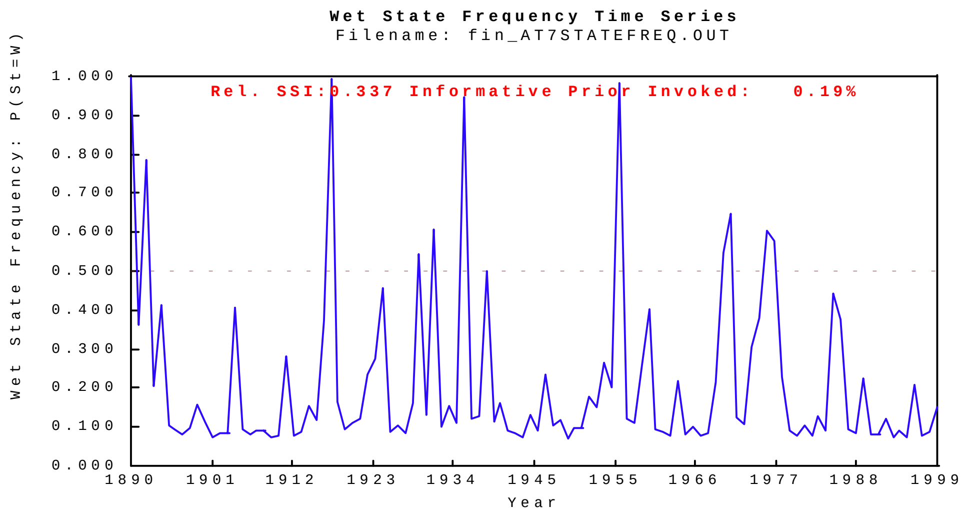
Figure C38. Calibration plots for Frankford



(a) Starting month August

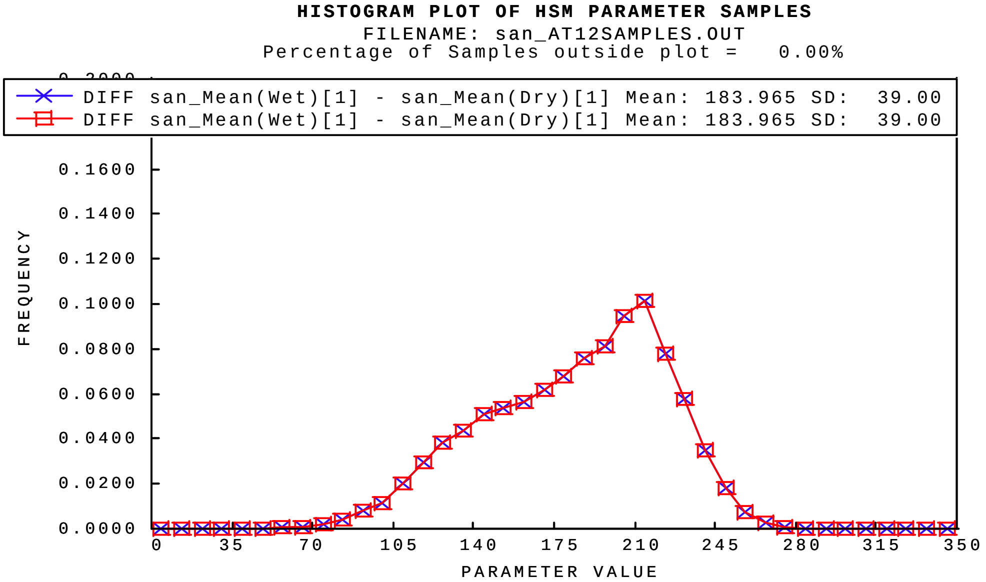


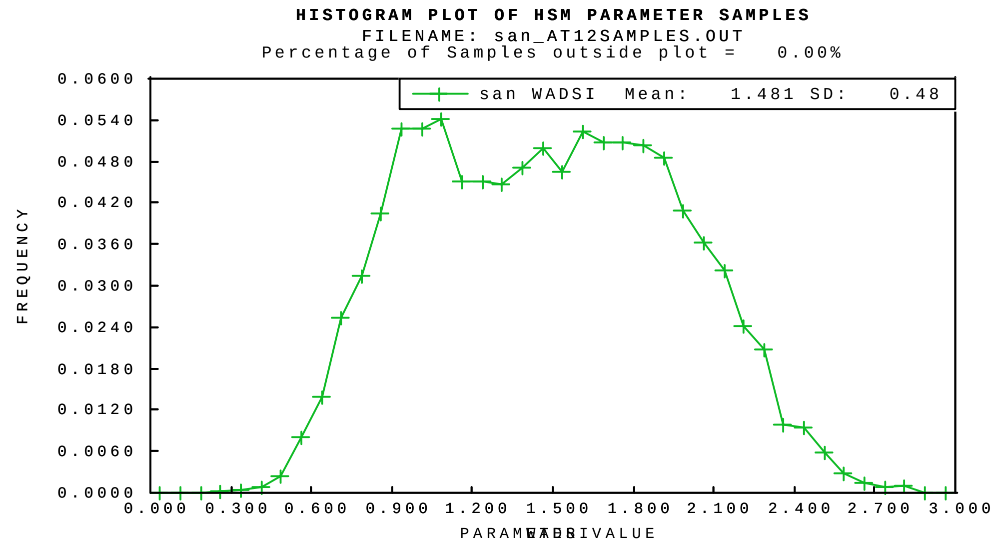


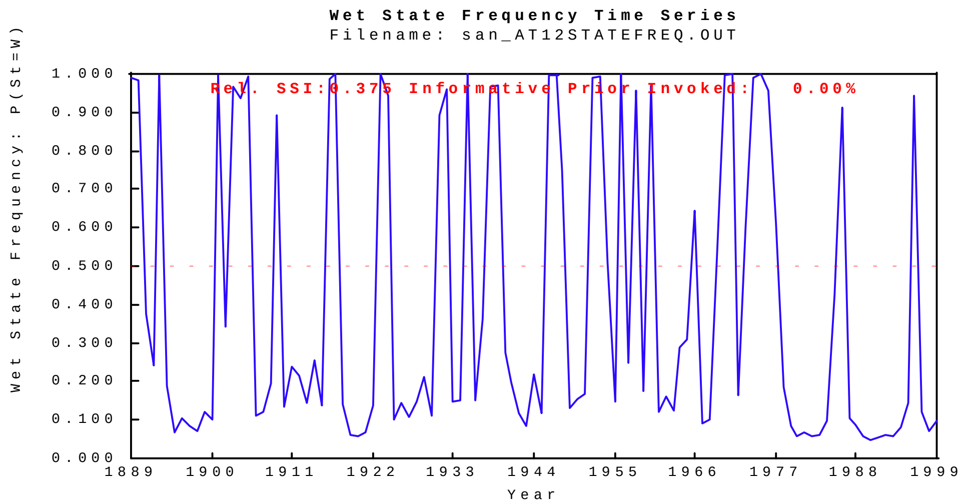


(b) Starting month July

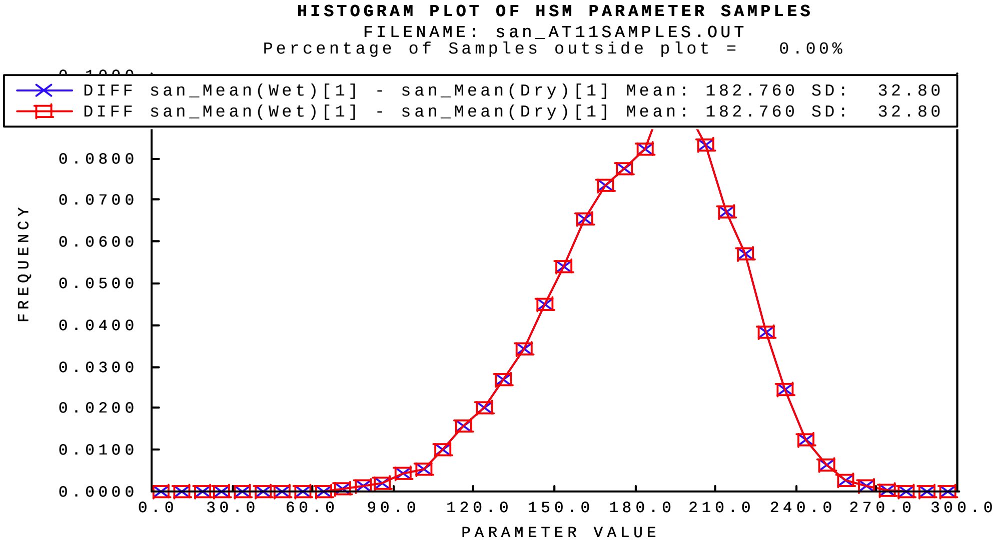
Figure C39. Calibration plots for Fingal

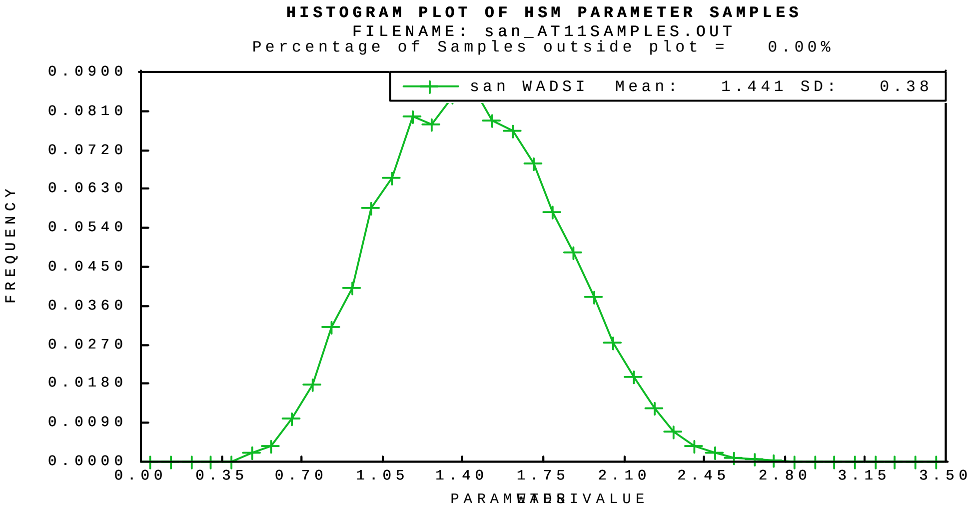


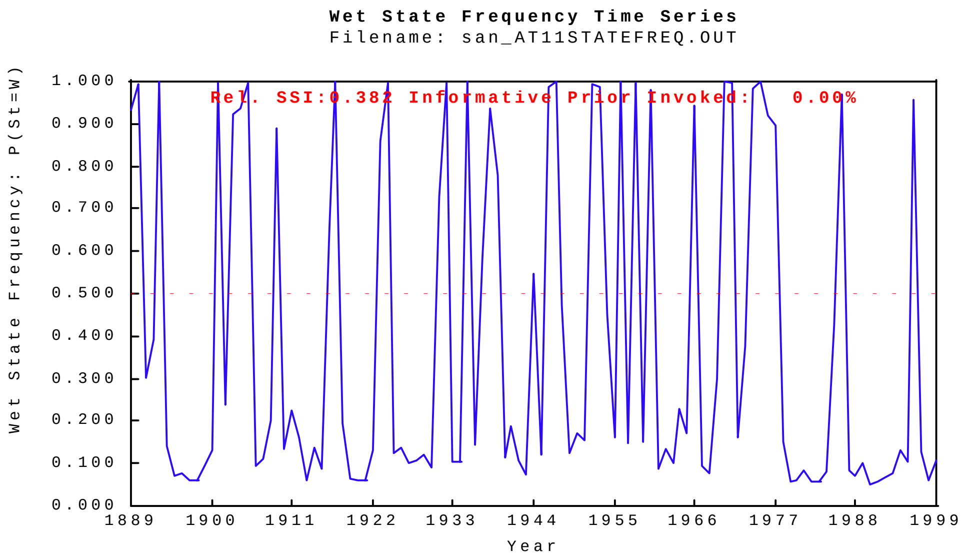




(a) Starting month December

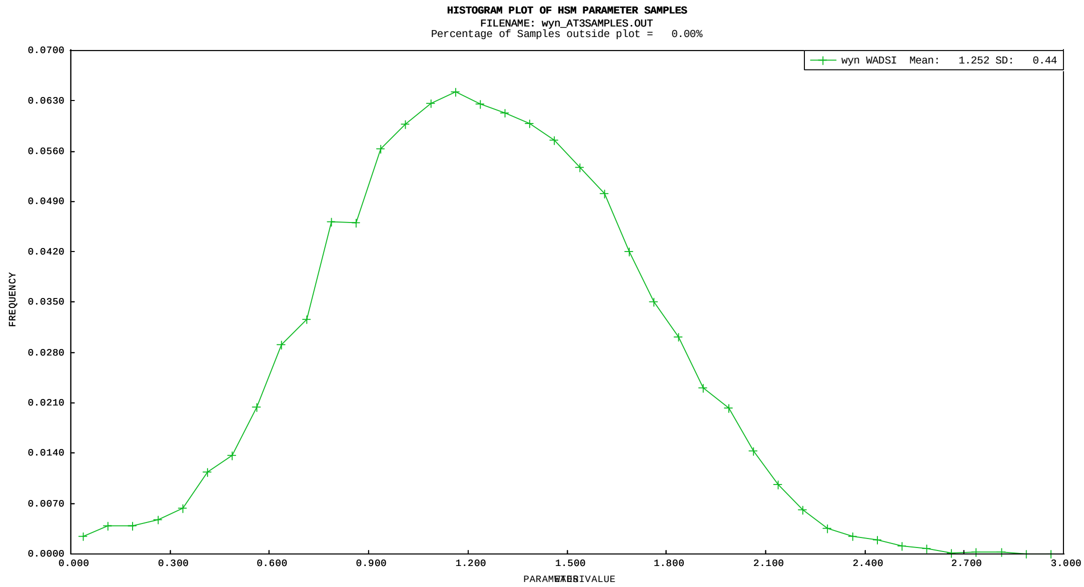






(b) Starting month November

Figure C40. Calibration plots for Sandford



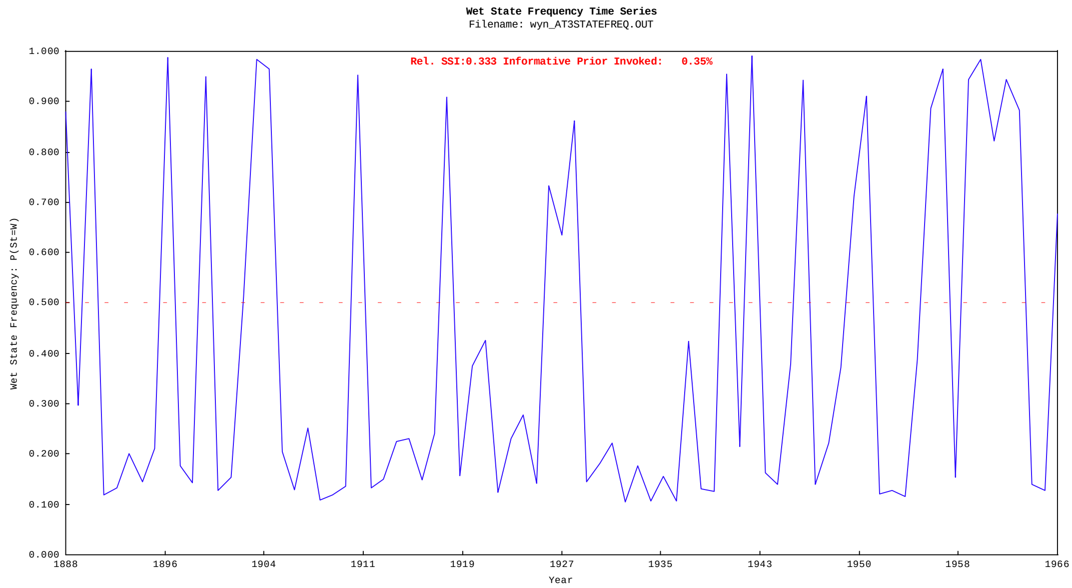
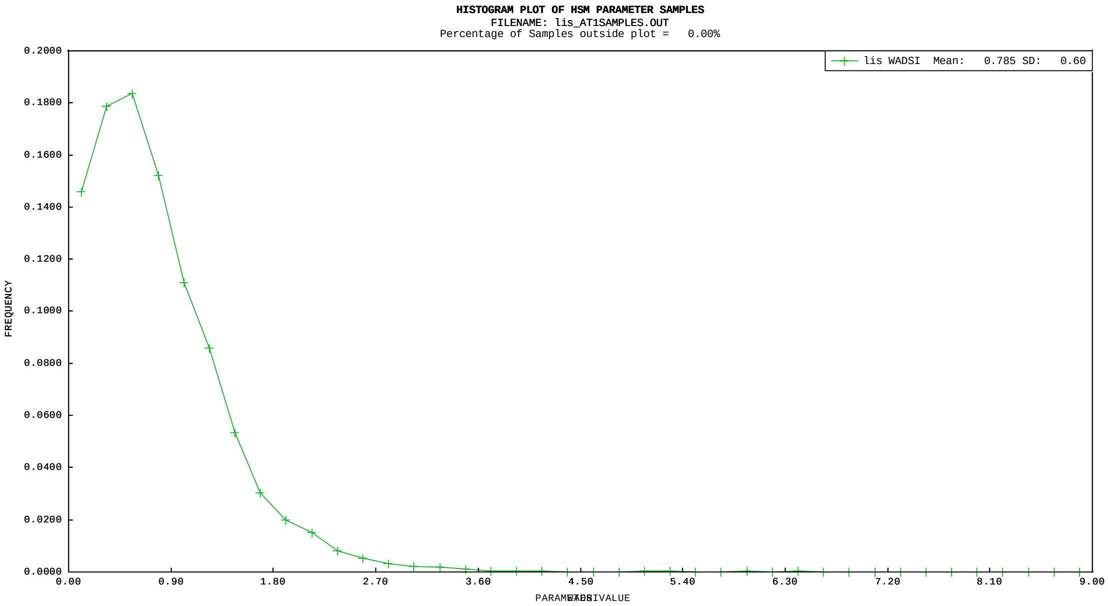


Figure C41. Calibration plots for Wyndham



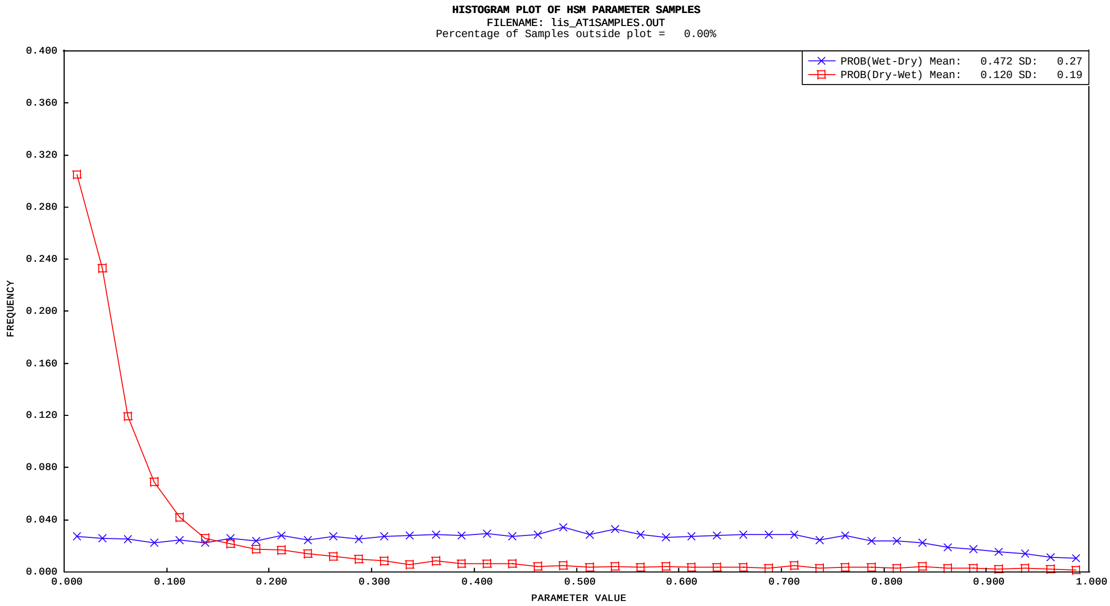
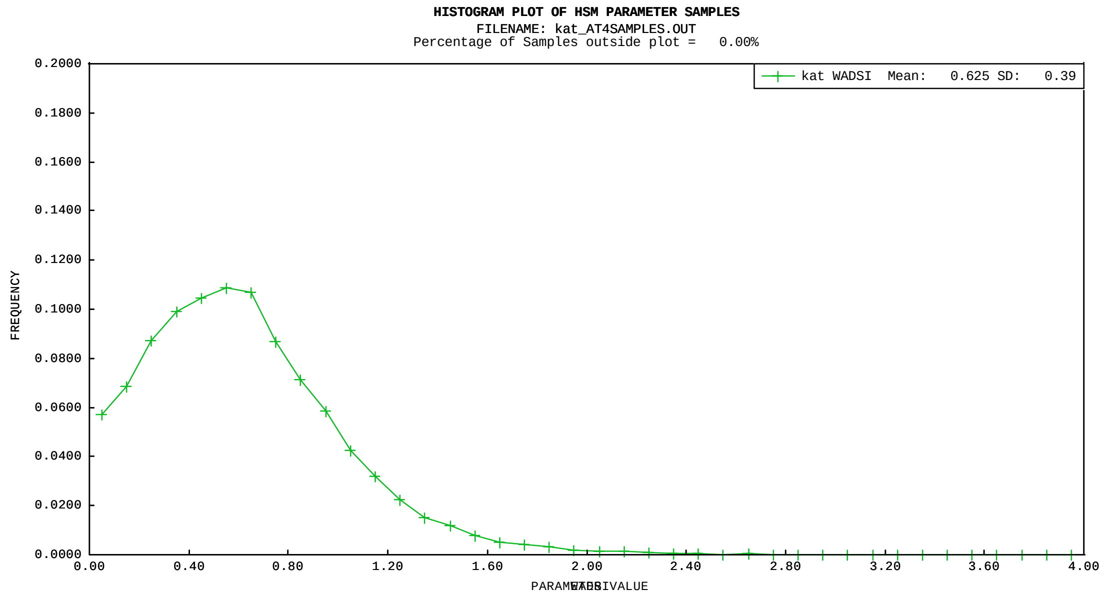
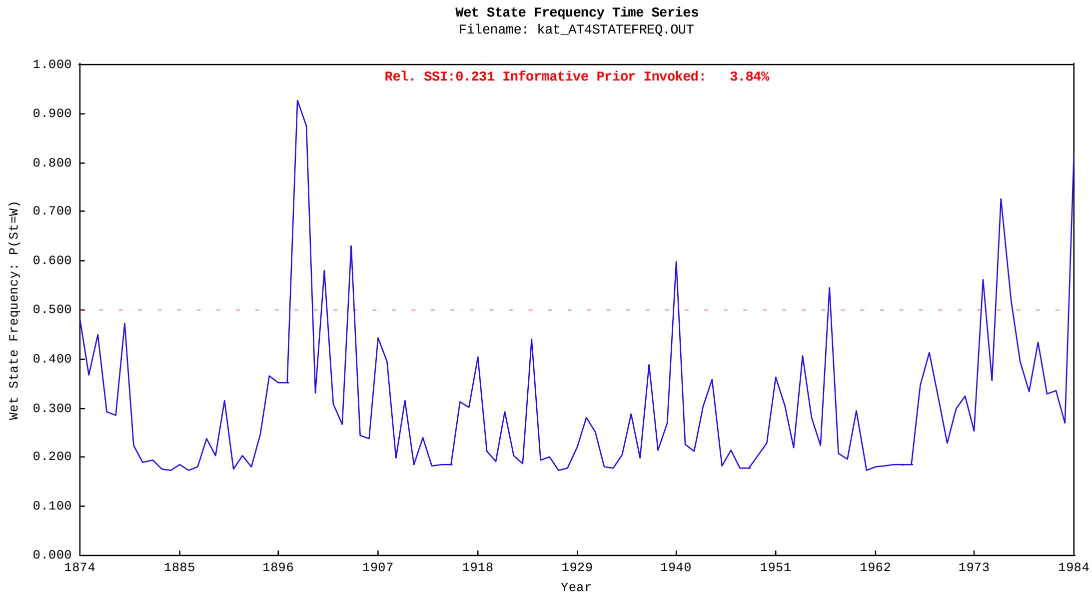
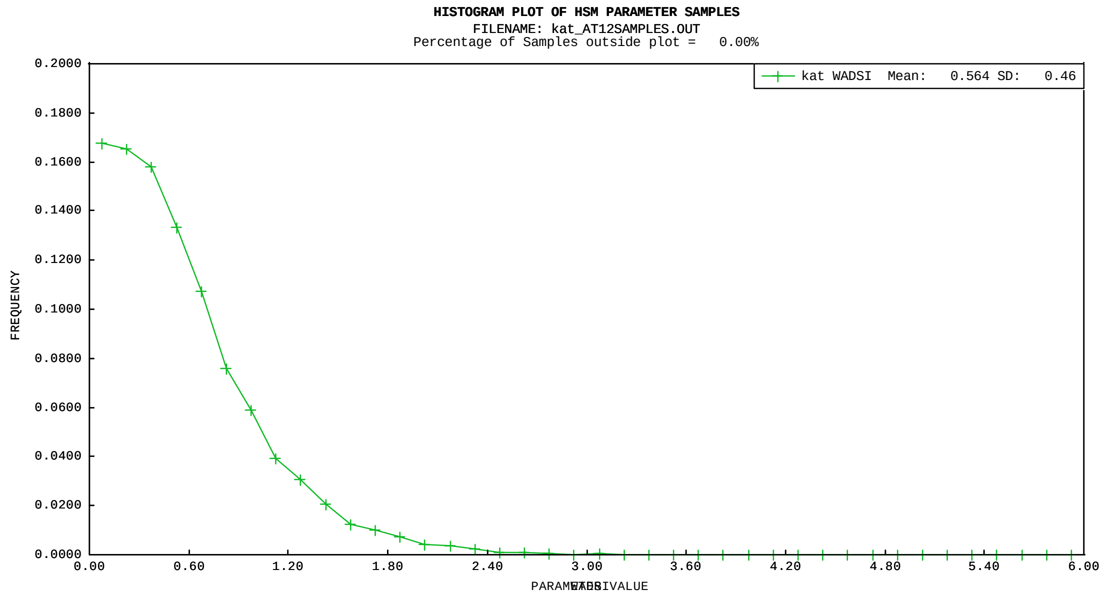


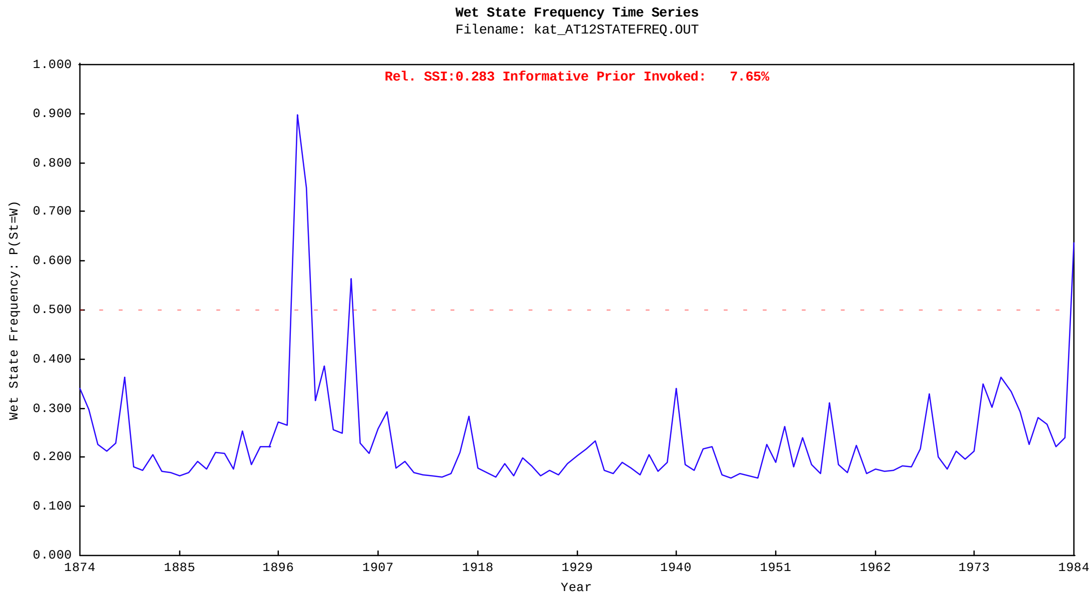
Figure C42.Calibration plots for Lissadell





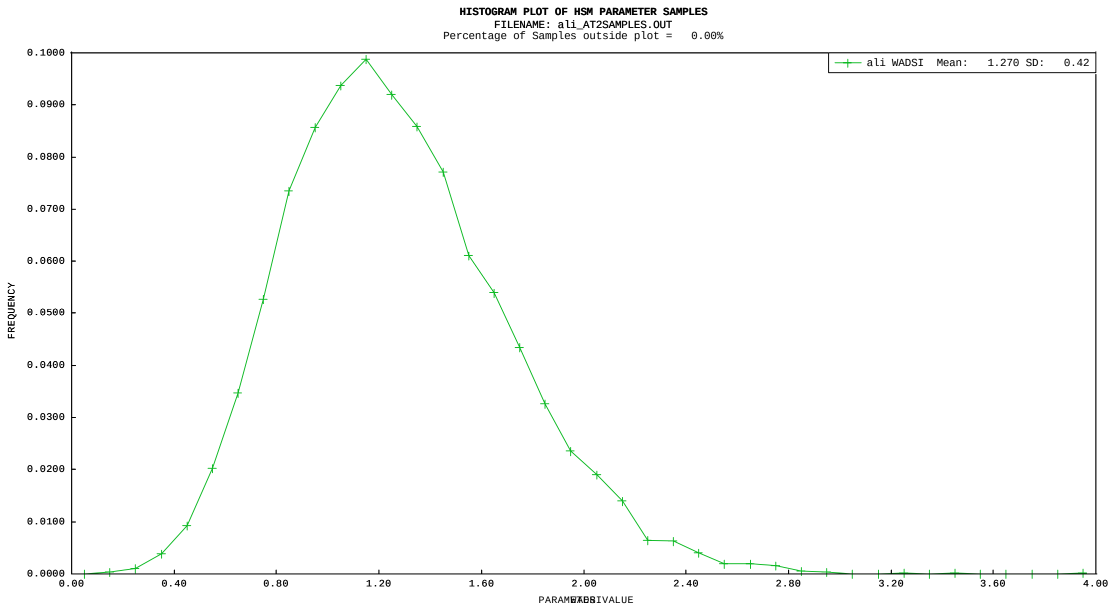
(a) Starting month April

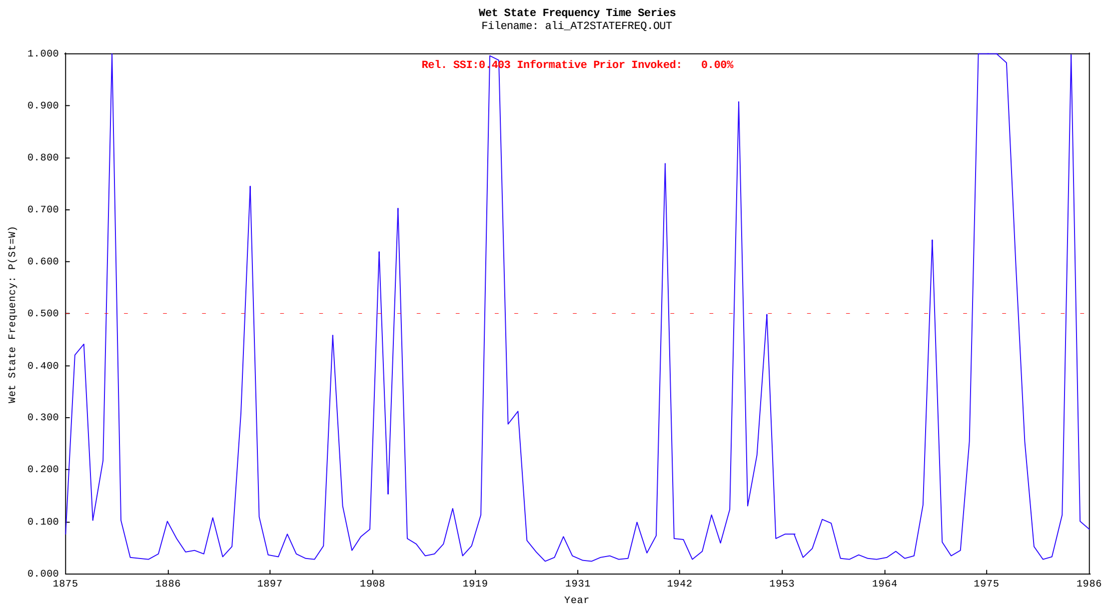




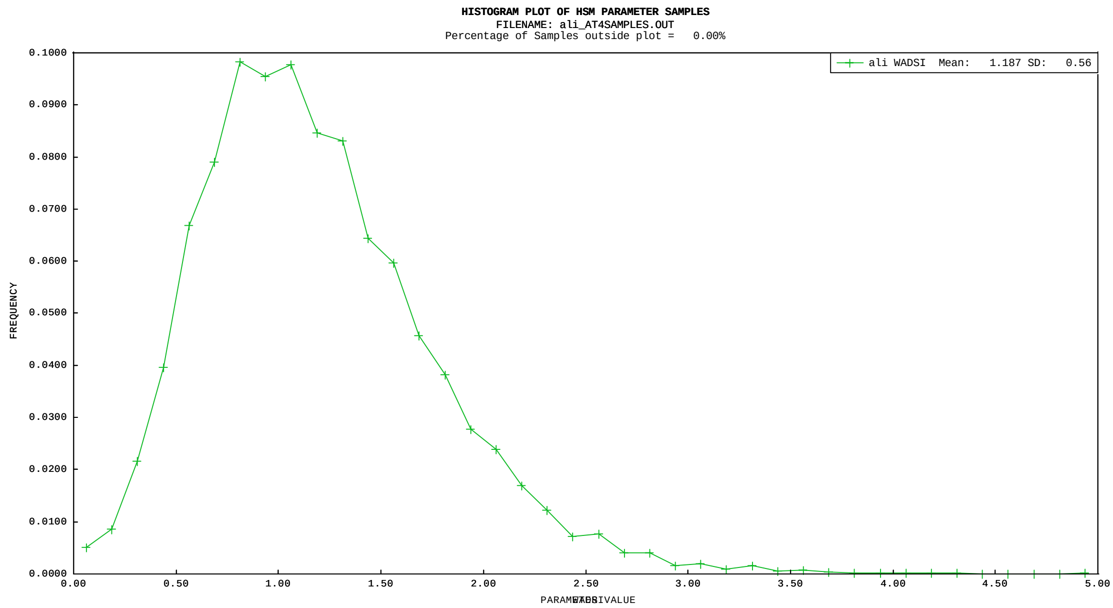
(b) Starting month December

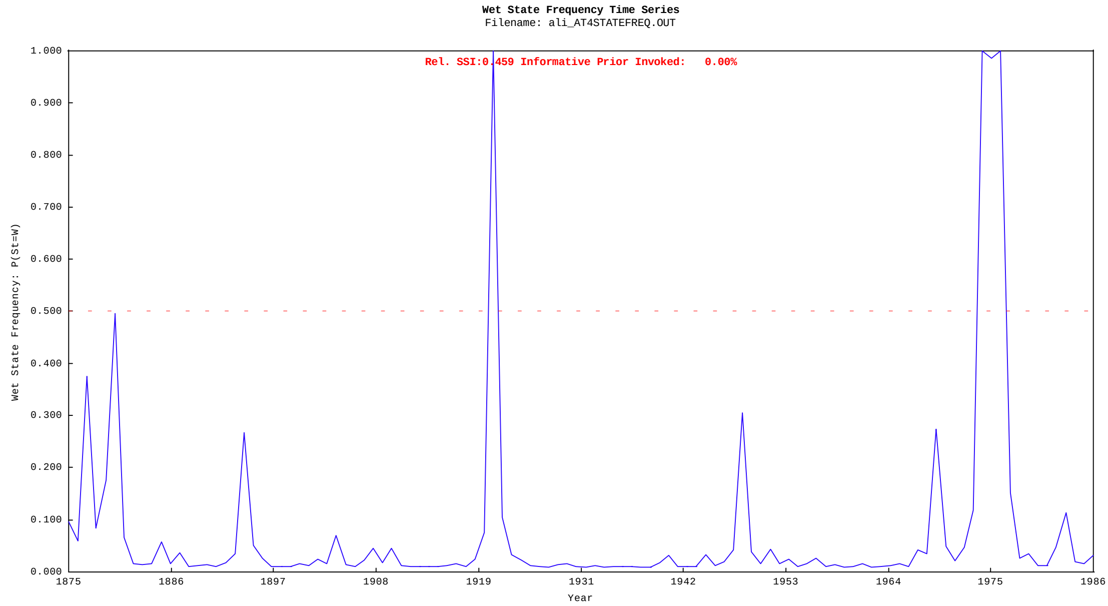
Figure C43. Calibration plots for Katherine





(a) Starting month February





(b) Starting month April

Figure C44. Calibration plots for Alice Springs

In the following plots, lines with crosses represents P(W→D) and squares P(D→W)

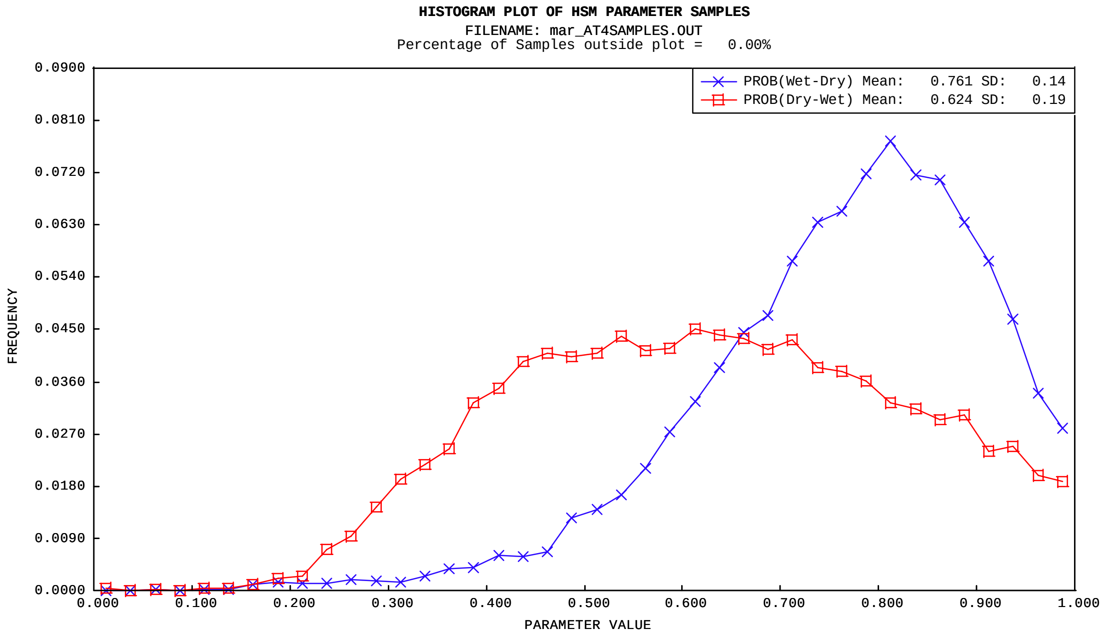


Figure C45. The posterior probability distributions of P(W→D) and P(D→W) for Mardie

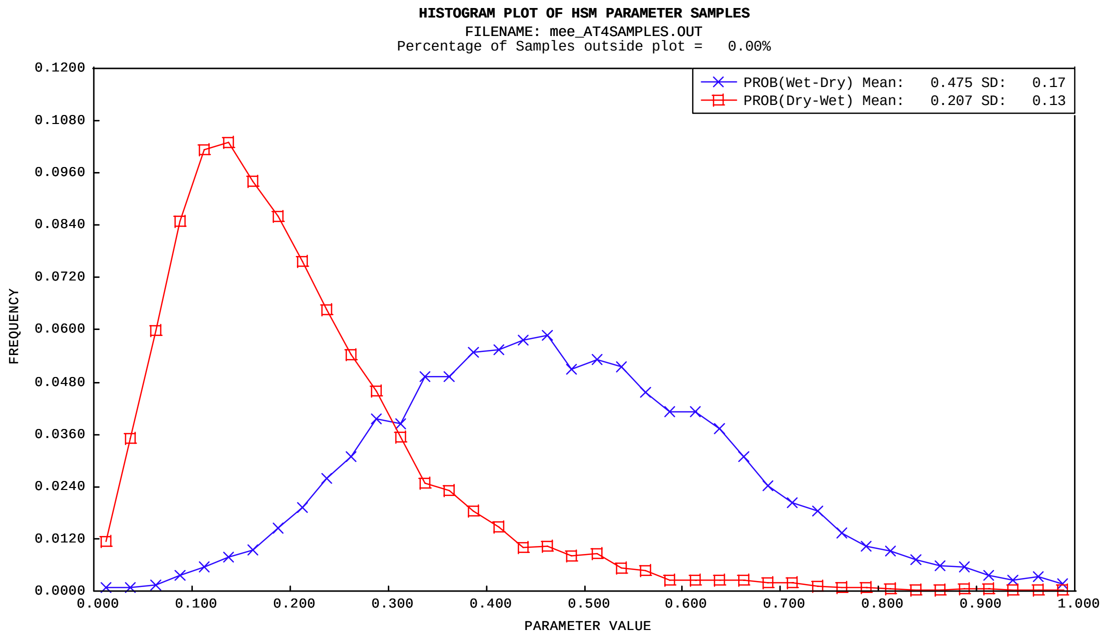


Figure C46. The posterior probability distributions of P(W→D) and P(D→W) for Meedo.
X - P(W→D) and - P(D→W)

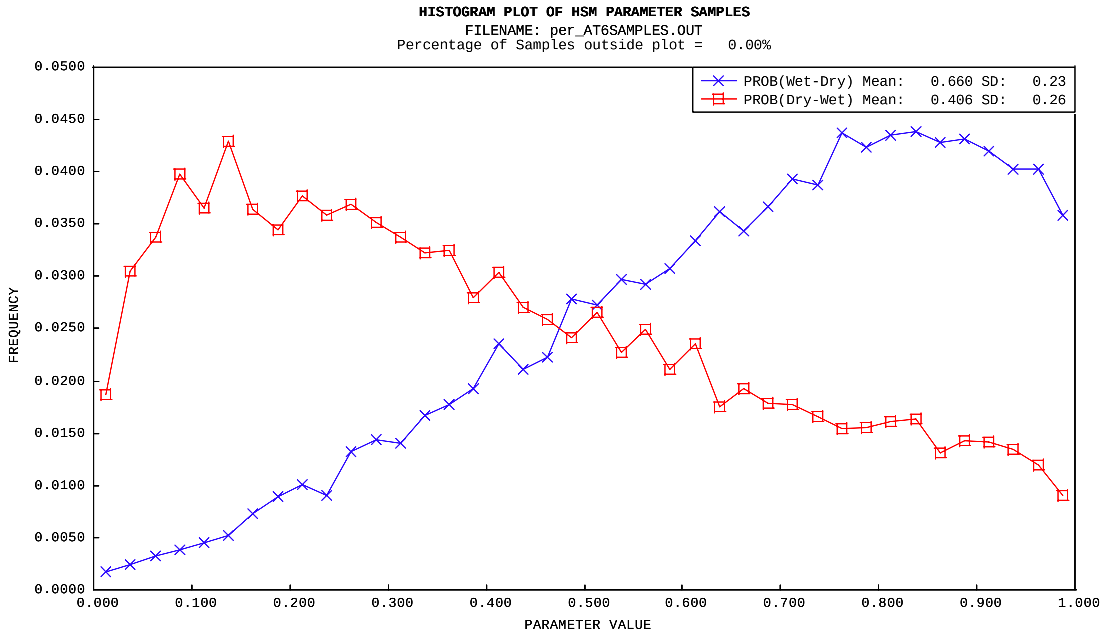


Figure C47. The posterior probability distributions of P(W→D) and P(D→W) for Perth

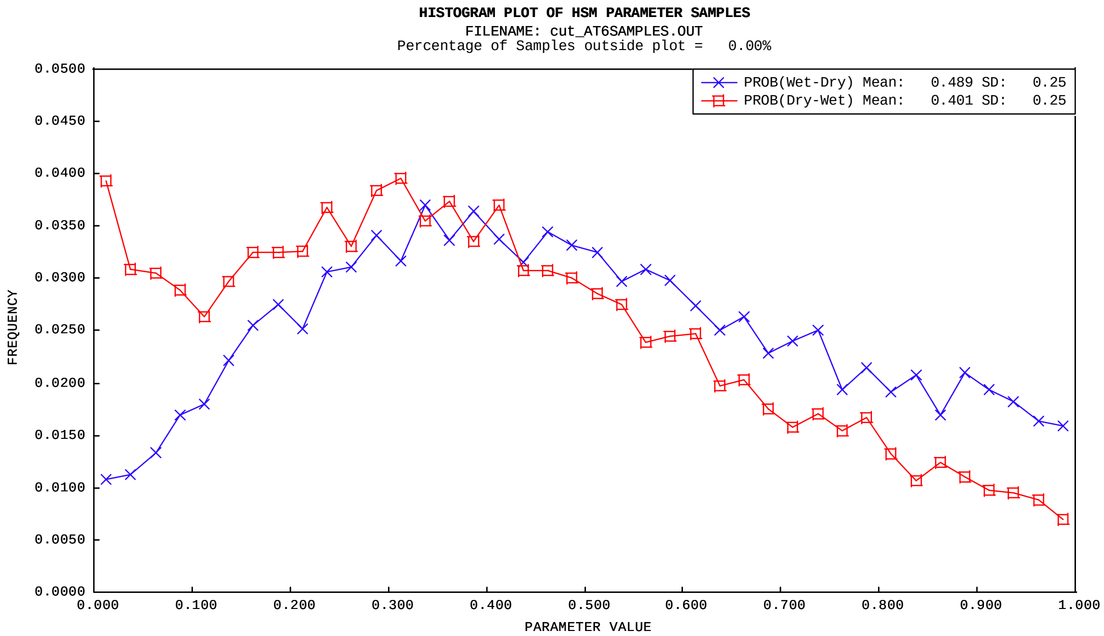


Figure C48. The posterior probability distributions of P(W→D) and P(D→W) for Cuttening

X - P(W→D) and - P(D→W)

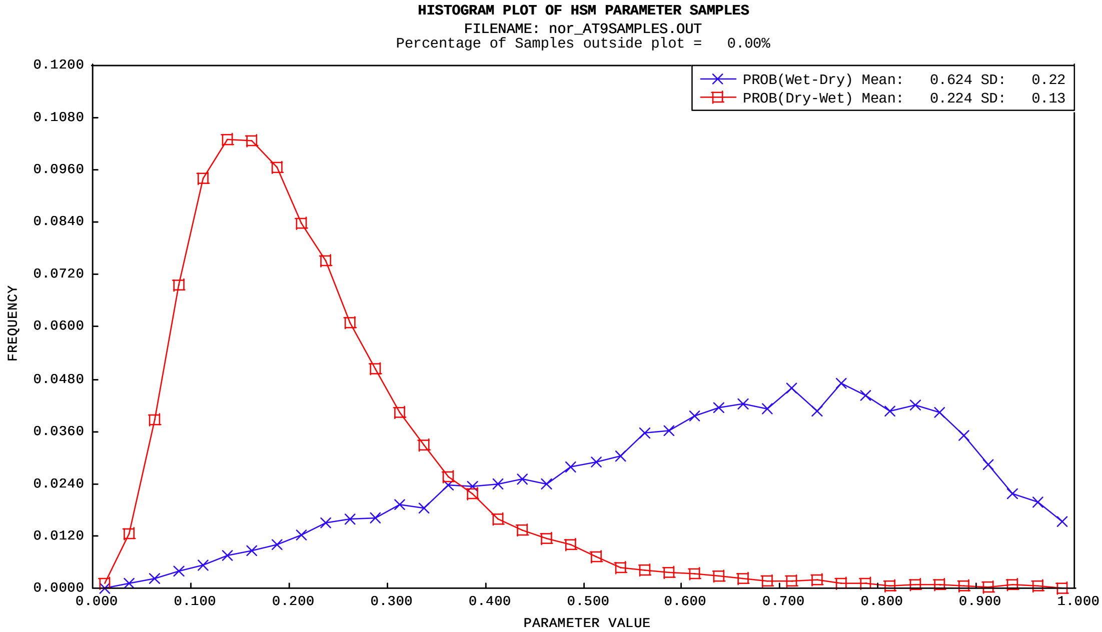


Figure C49. The posterior probability distributions of P(W→D) and P(D→W) for Norseman

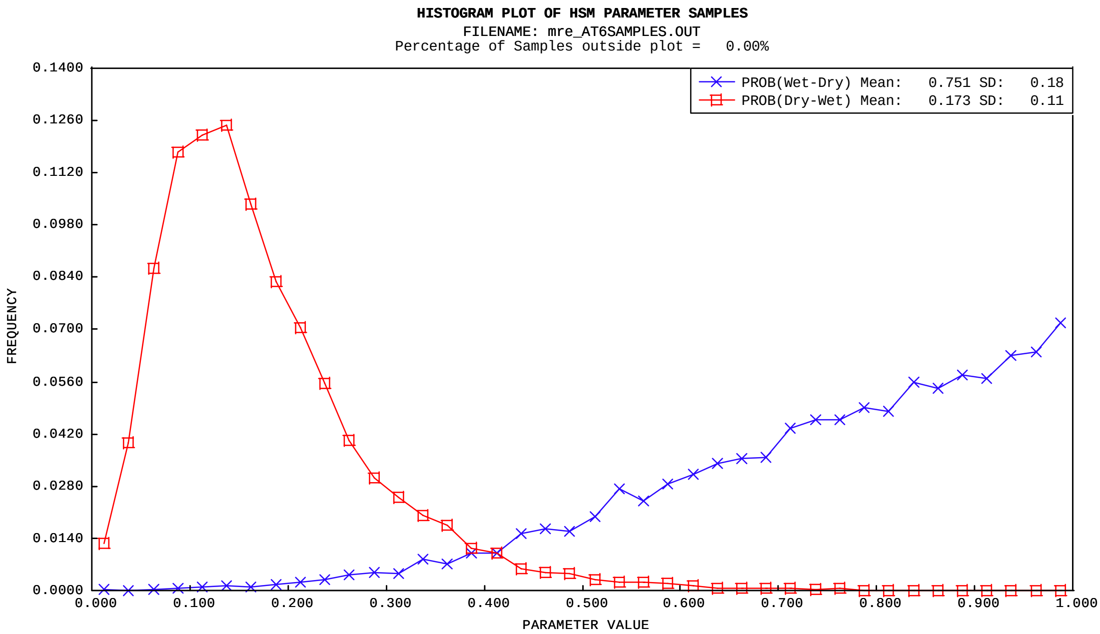


Figure C50. The posterior probability distributions of P(W→D) and P(D→W) for Marree

X - P(W→D) and - P(D→W)

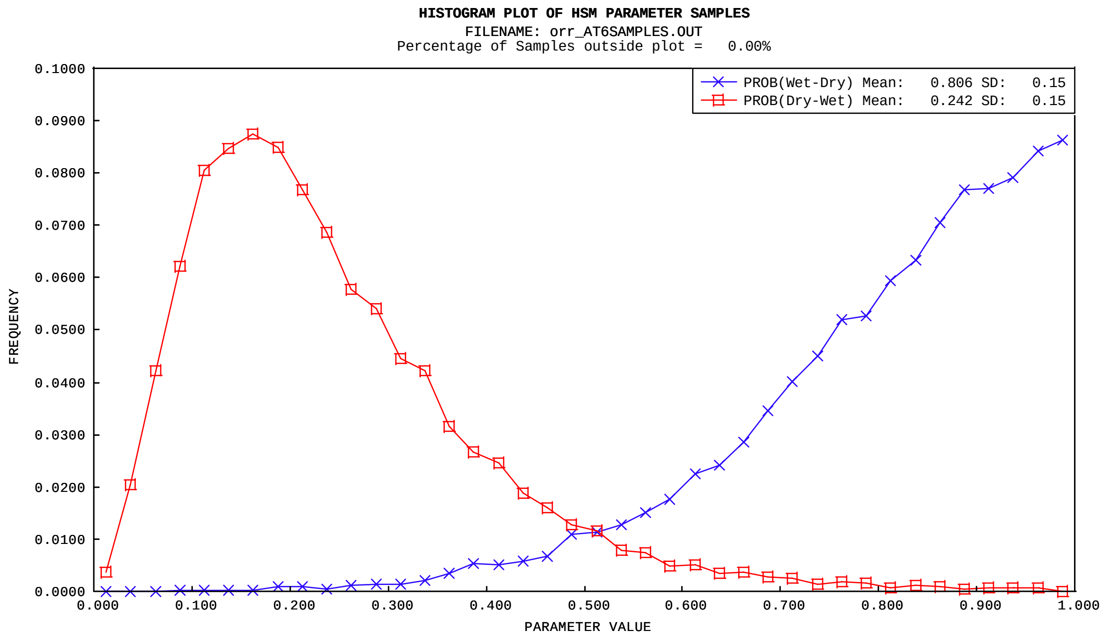


Figure C51. The posterior probability distributions of P(W→D) and P(D→W) for Orroroo

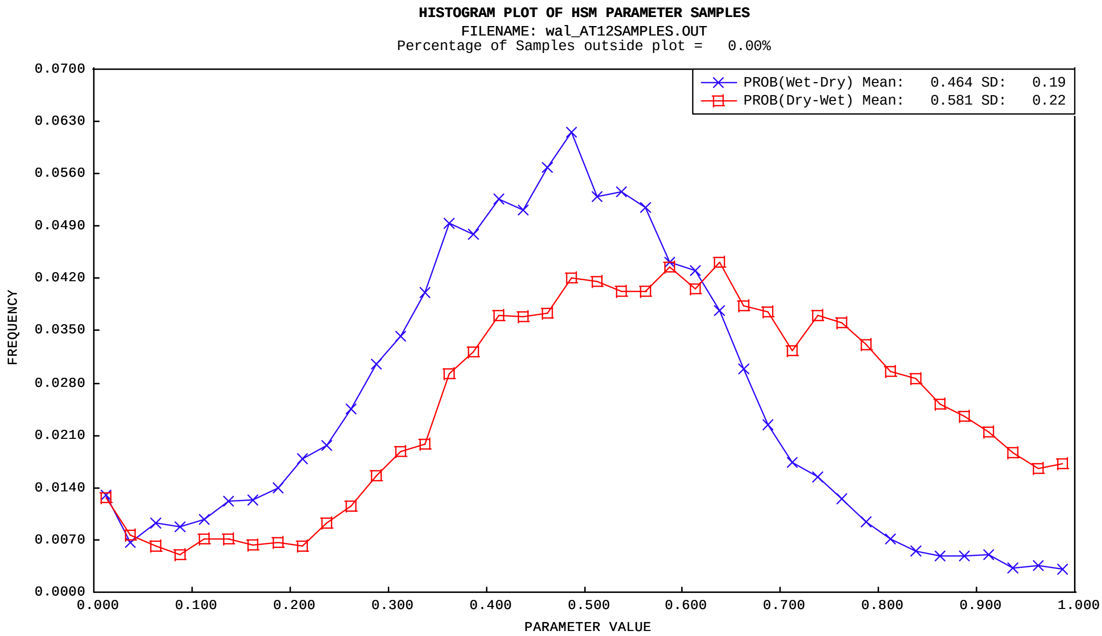


Figure C52. The posterior probability distributions of P(W→D) and P(D→W) for Wallaroo.
X - P(W→D) and - P(D→W)

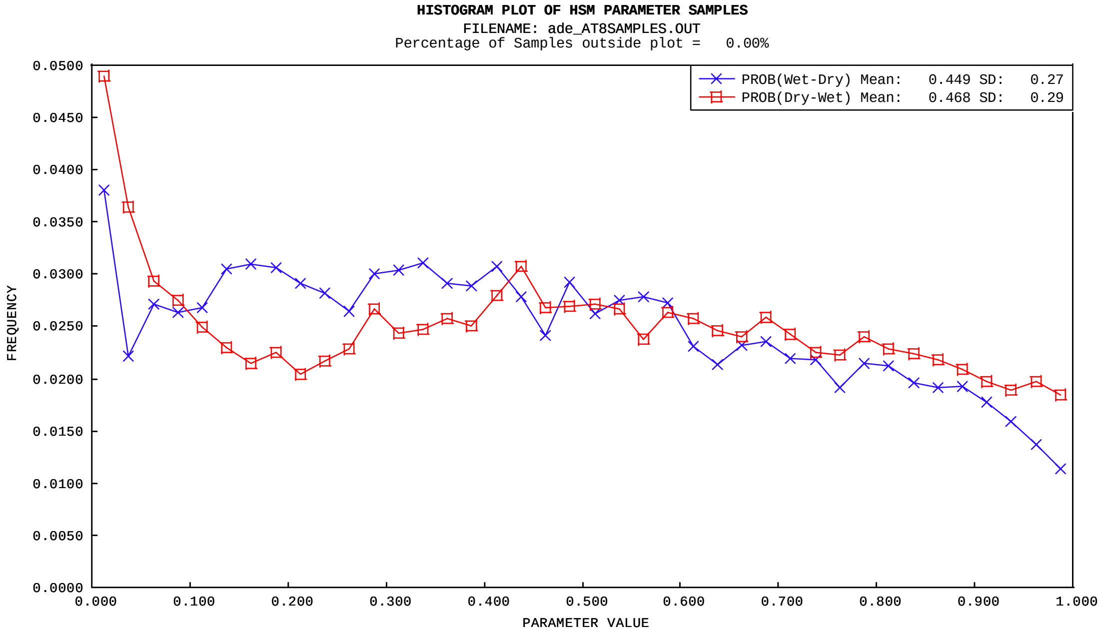


Figure C53. The posterior probability distributions of P(W→D) and P(D→W) for Adelaide

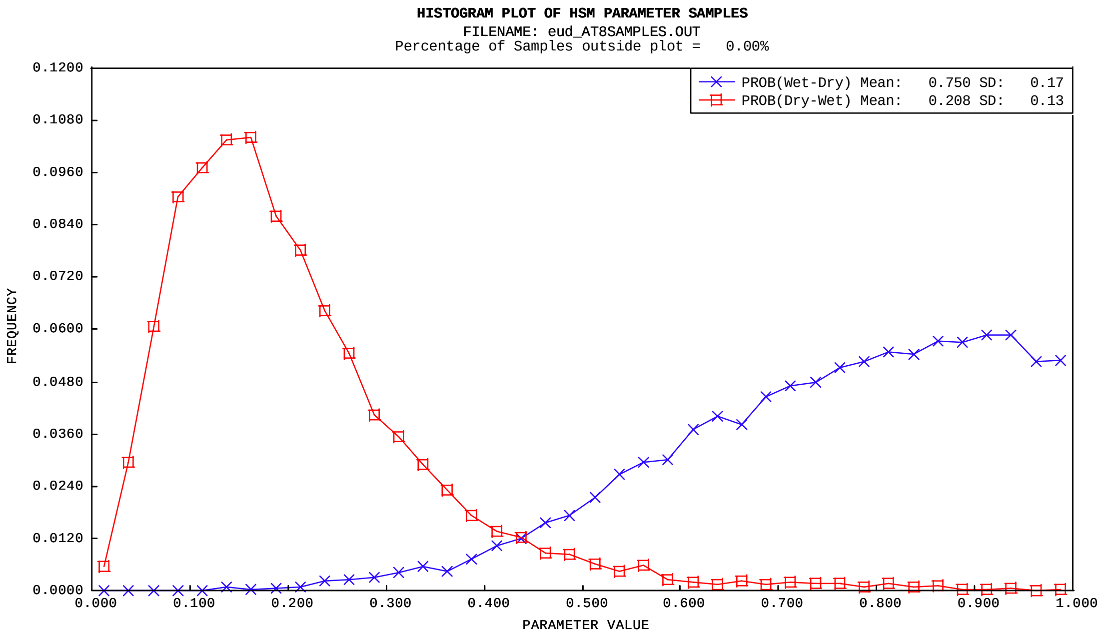


Figure C54. The posterior probability distributions of P(W→D) and P(D→W) for Eudunda

X - P(W→D) and - P(D→W)

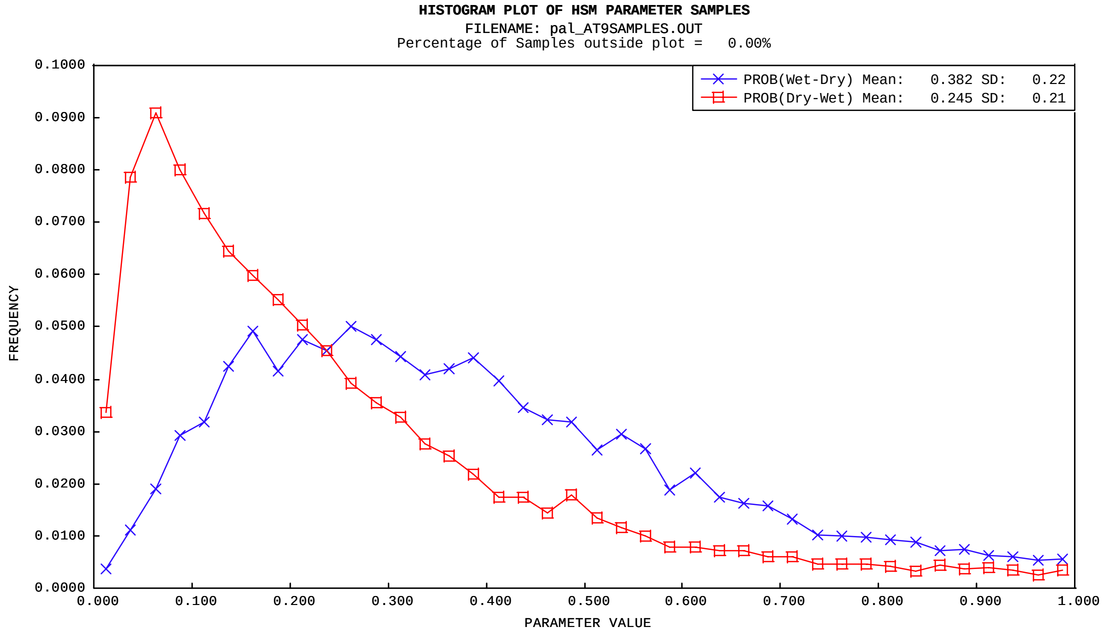


Figure C55. The posterior probability distributions of P(W→D) and P(D→W) for Palmerville

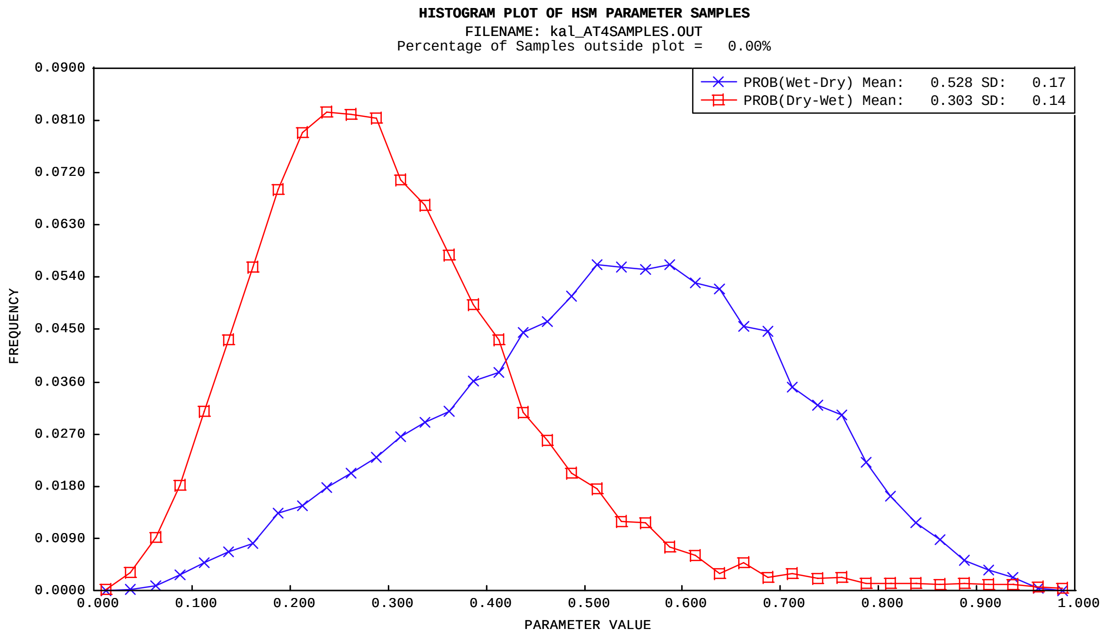


Figure C56. The posterior probability distributions of P(W→D) and P(D→W) for Kalamia

X - P(W→D) and - P(D→W)

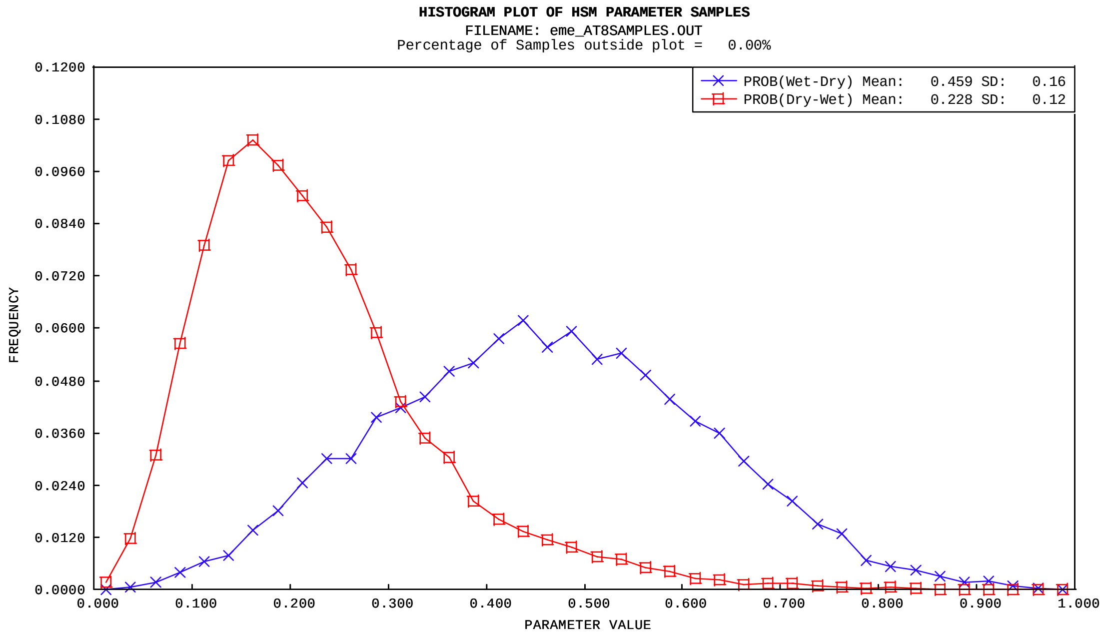


Figure C57. The posterior probability distributions of P(W→D) and P(D→W) for Emerald

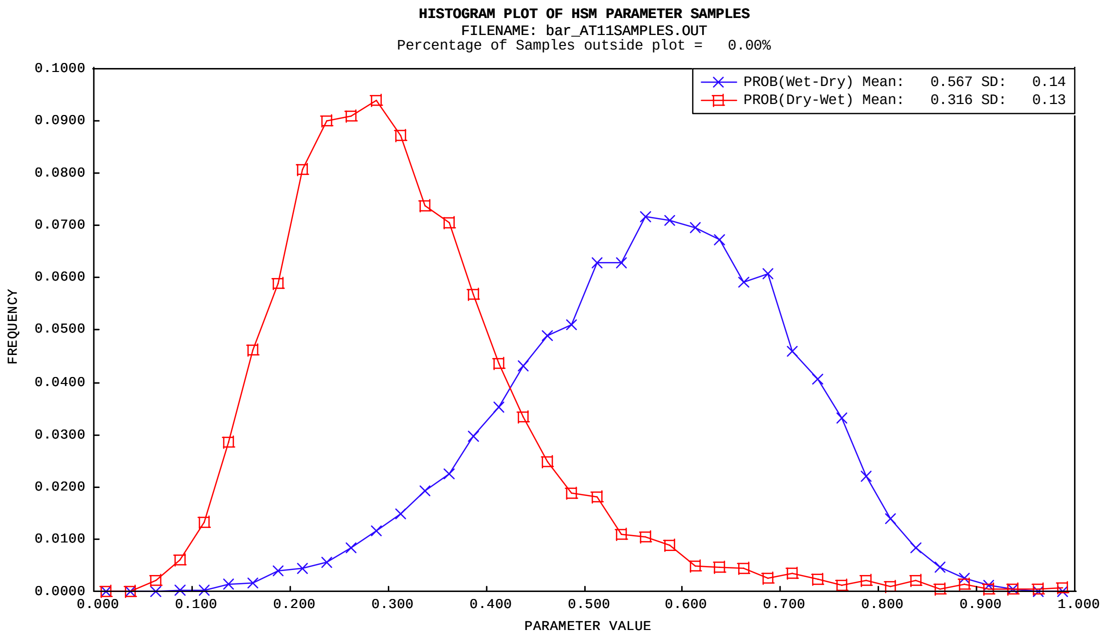


Figure C58. The posterior probability distributions of P(W→D) and P(D→W) for Barcaldine. X - P(W→D) and - P(D→W)

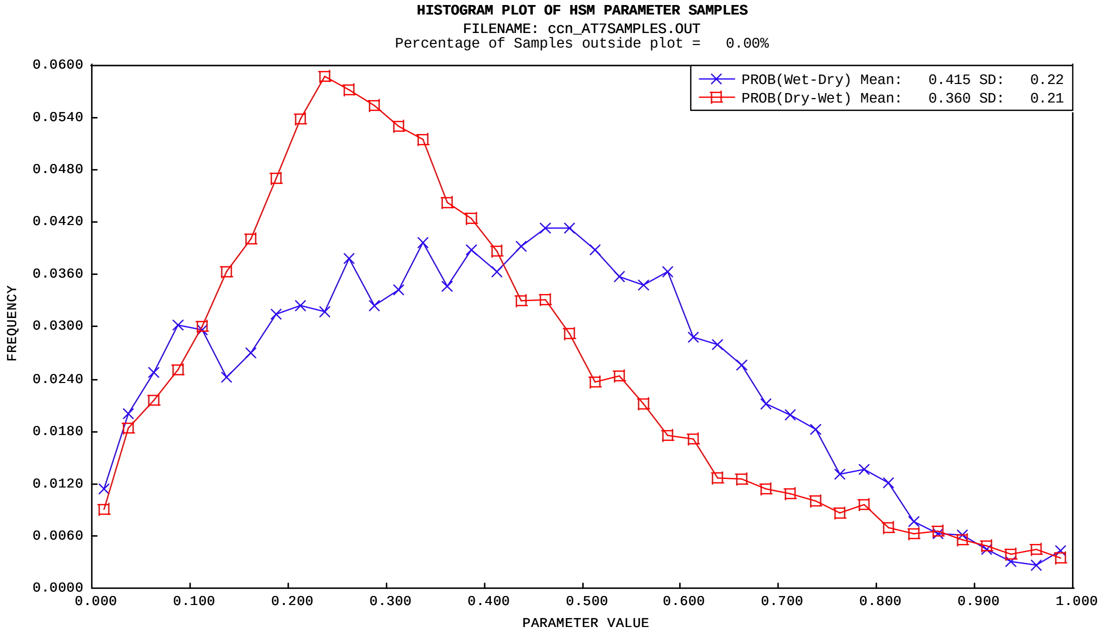


Figure C59. The posterior probability distributions of P(W→D) and P(D→W) for Cape Capricorn

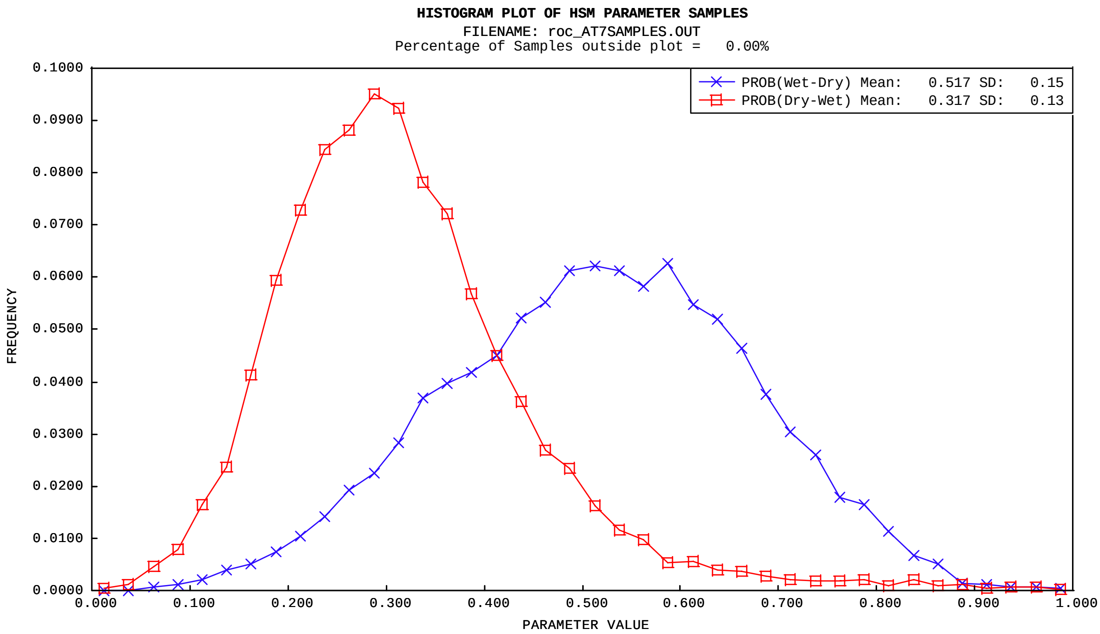


Figure C60. The posterior probability distributions of P(W→D) and P(D→W) for Rockhampton X - P(W→D) and - P(D→W)

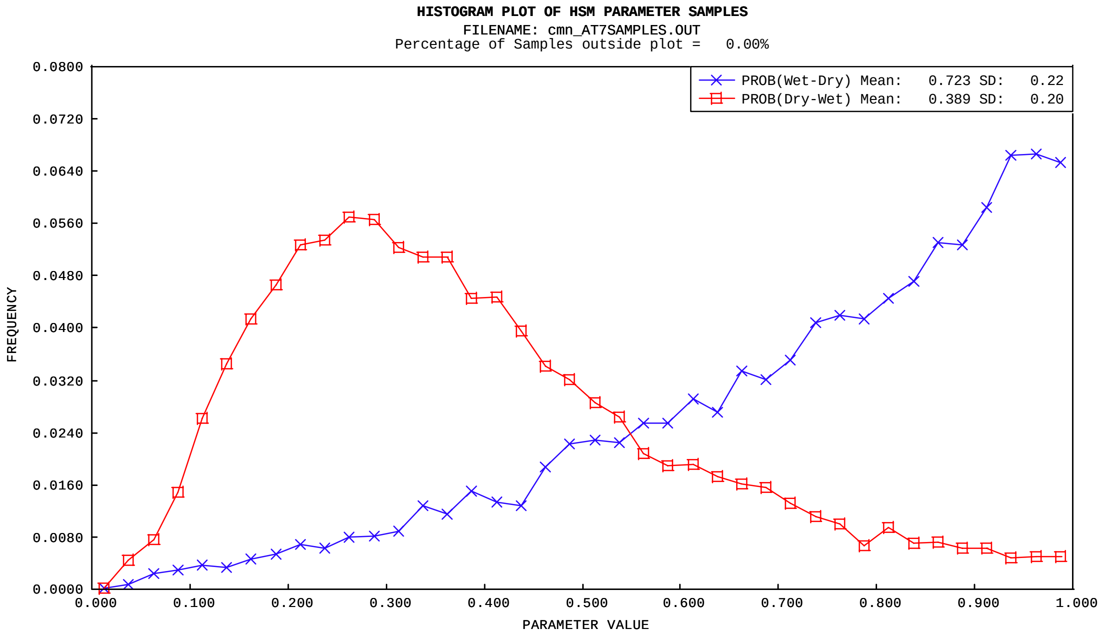


Figure C61. The posterior probability distributions of P(W→D) and P(D→W) for Cape Moreton

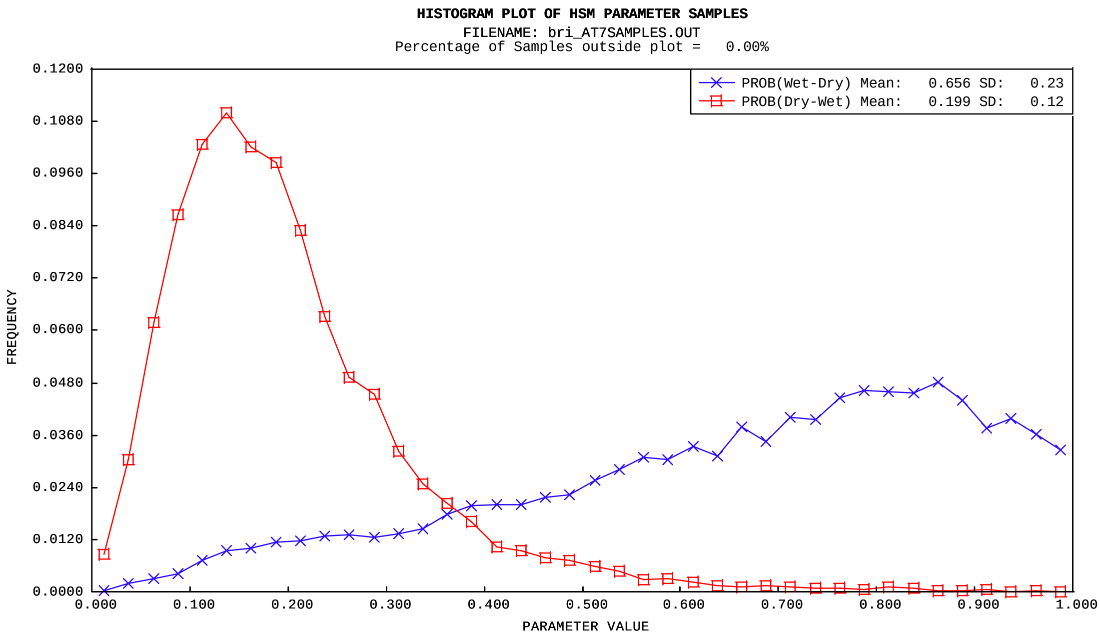


Figure C62. The posterior probability distributions of P(W→D) and P(D→W) for Brisbane
X - P(W→D) and - P(D→W)

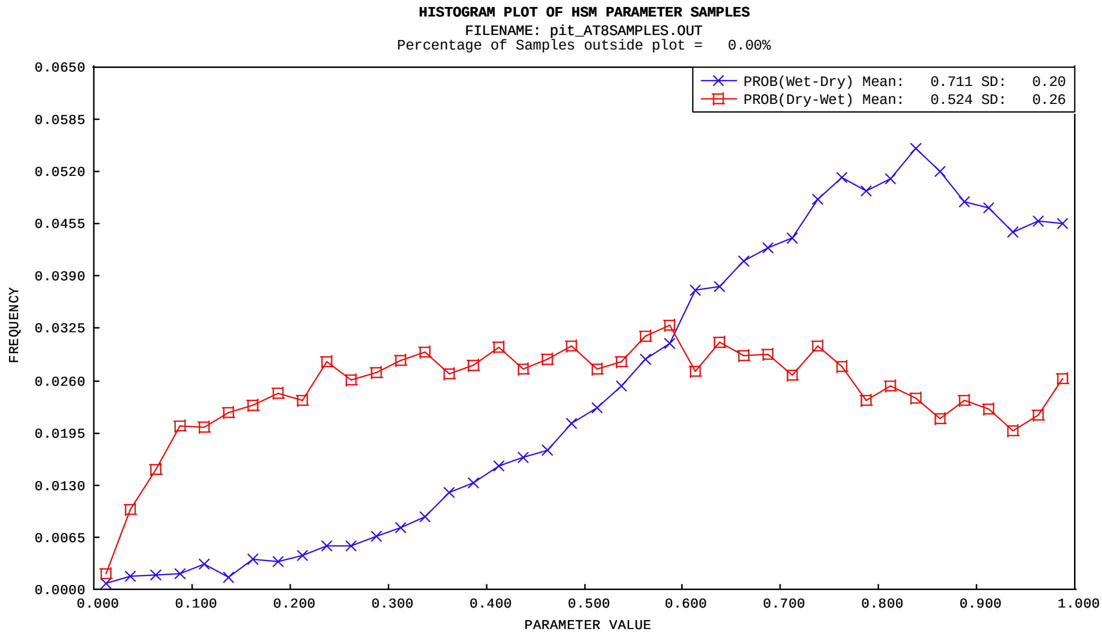


Figure C63. The posterior probability distributions of P(W→D) and P(D→W) for Pittsworth

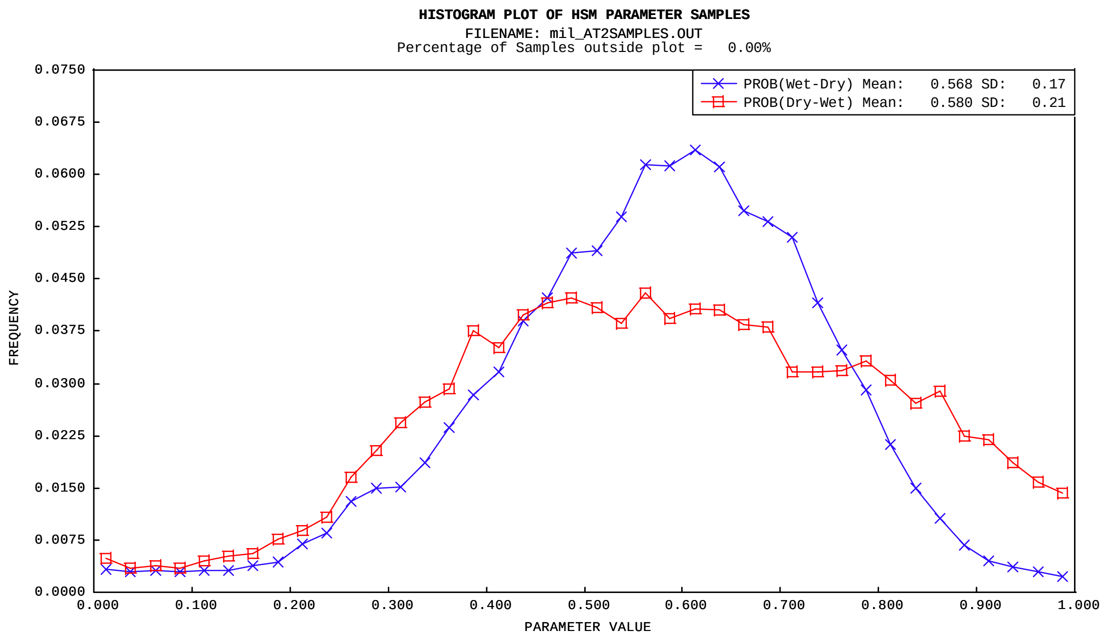


Figure C64. The posterior probability distributions of P(W→D) and P(D→W) for Miles Post Office X - P(W→D) and - P(D→W)

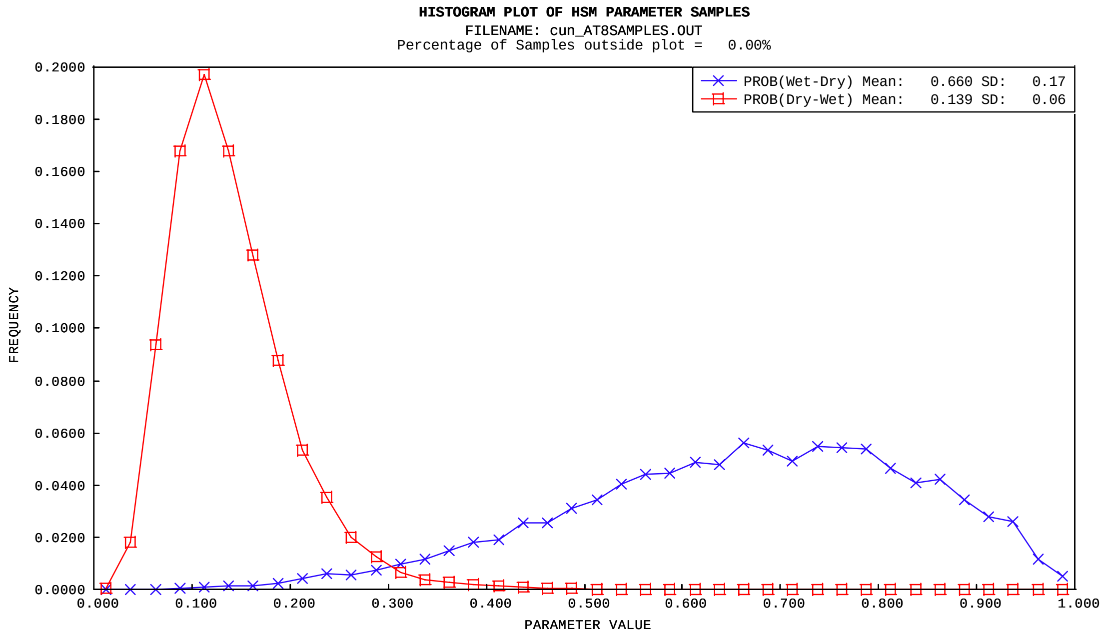


Figure C65. The posterior probability distributions of P(W→D) and P(D→W) for Cunnamulla.

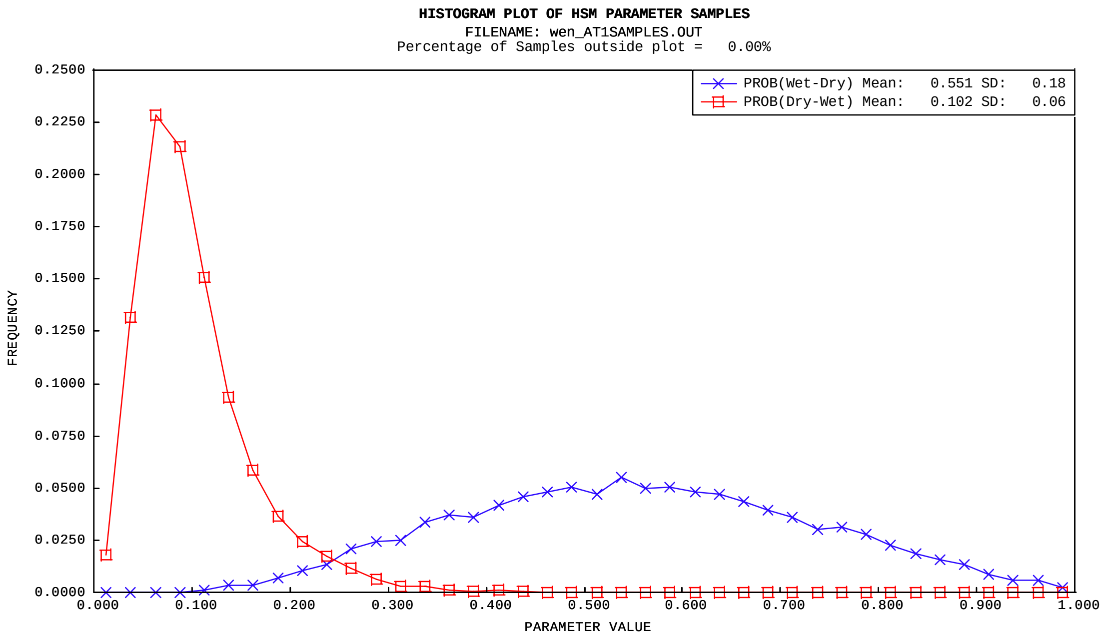


Figure C66. The posterior probability distributions of P(W→D) and P(D→W) for Wentworth X - P(W→D) and - P(D→W)

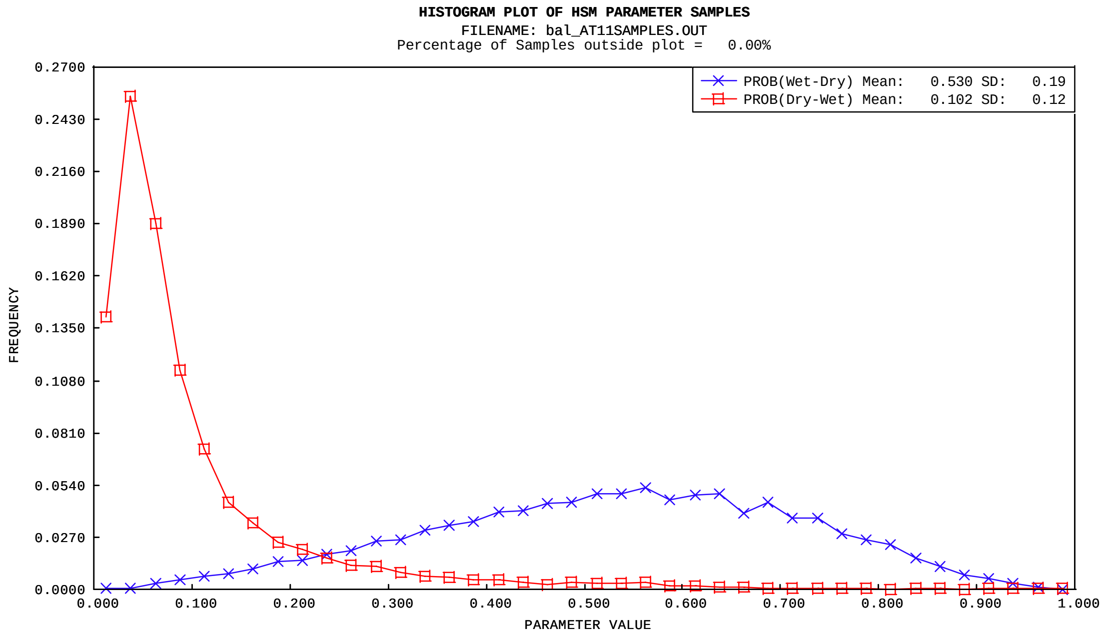


Figure C67. The posterior probability distributions of P(W→D) and P(D→W) for Balranald

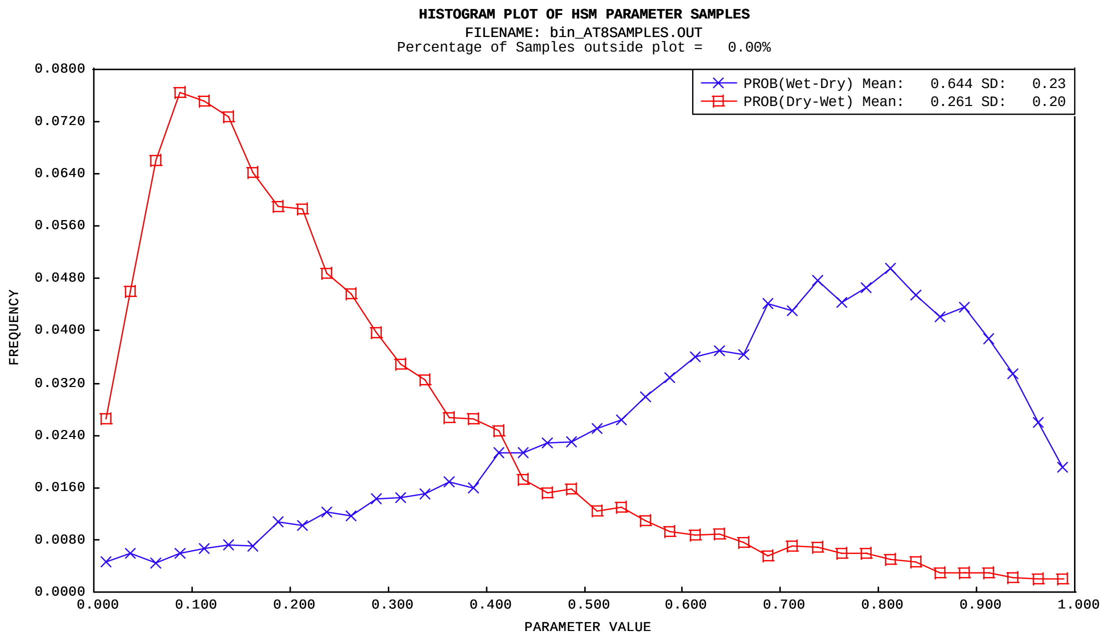


Figure C68. The posterior probability distributions of P(W→D) and P(D→W) for Bingara.
X - P(W→D) and - P(D→W)

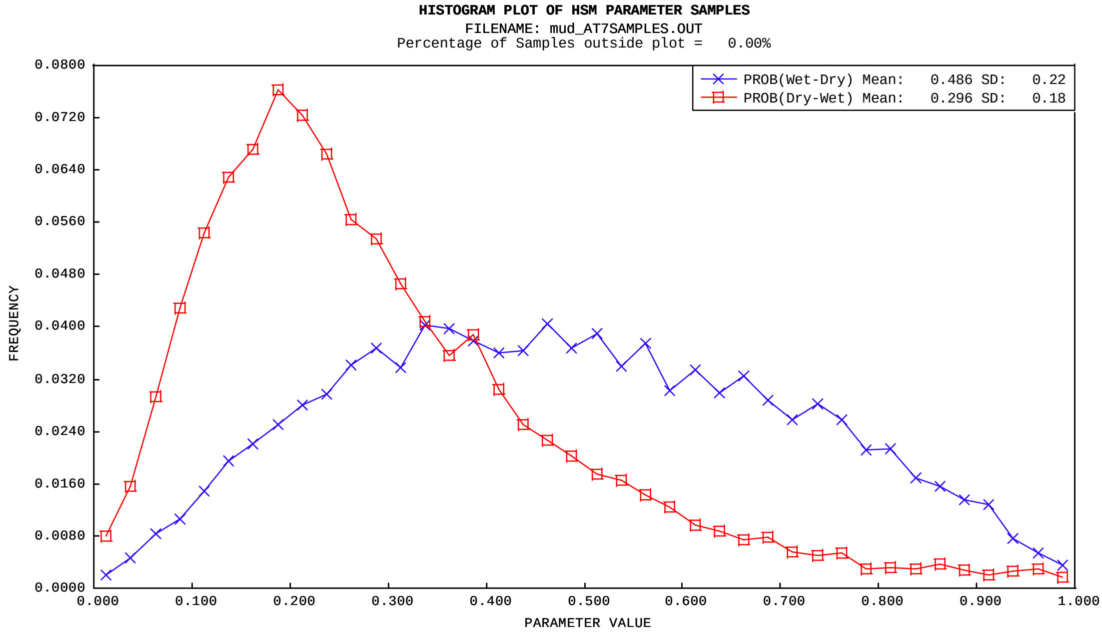


Figure C69. The posterior probability distributions of P(W→D) and P(D→W) for Mudgee

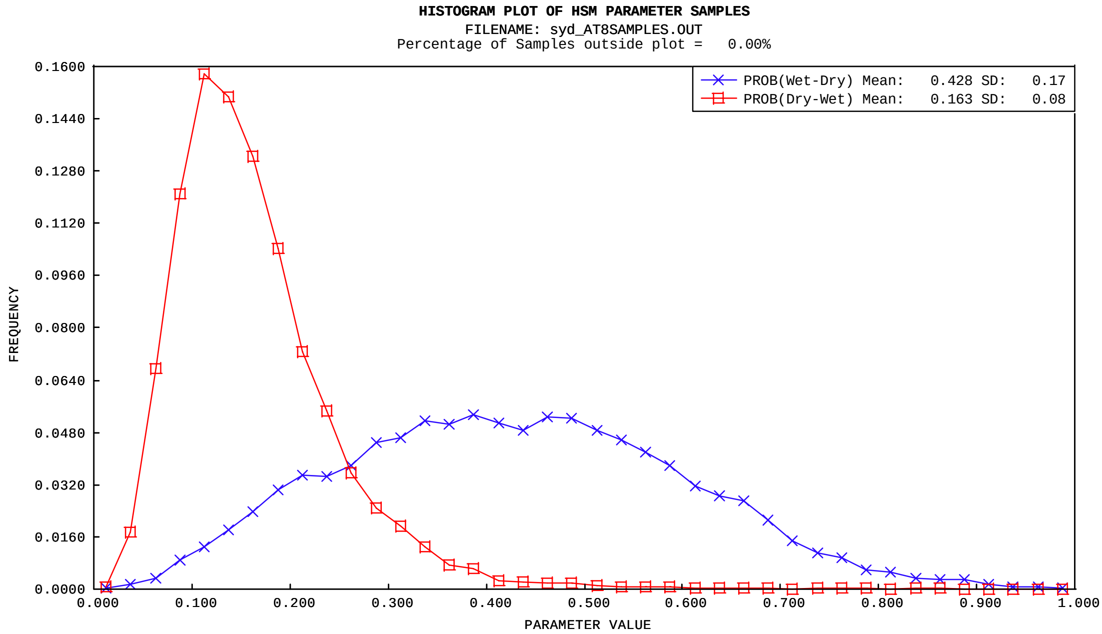


Figure C70. The posterior probability distributions of P(W→D) and P(D→W) for Sydney

X - P(W→D) and - P(D→W)

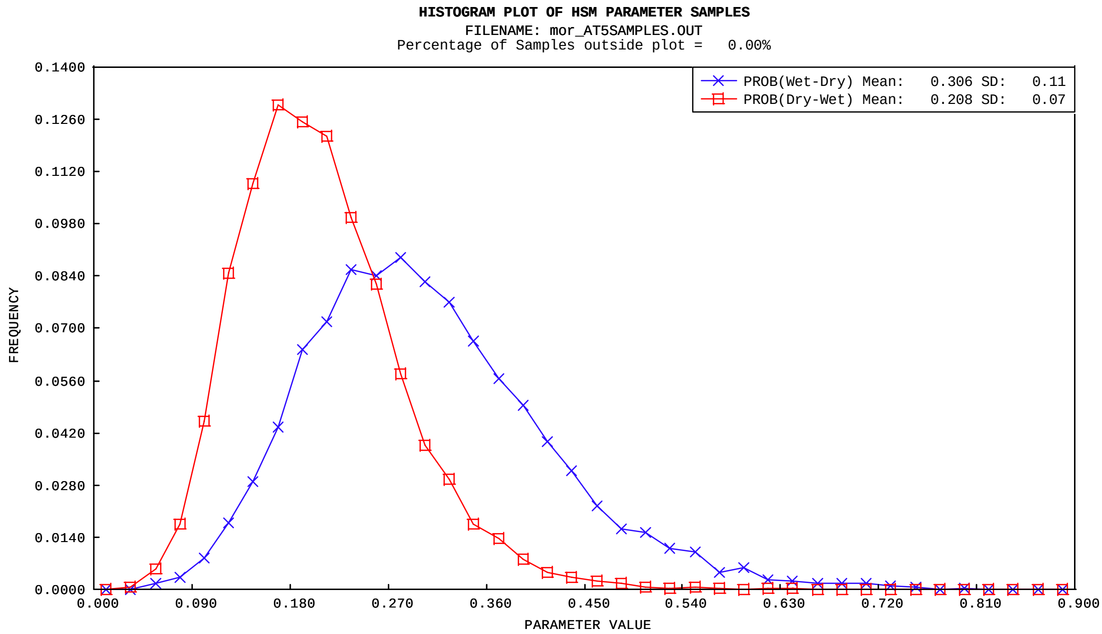


Figure C71. The posterior probability distributions of P(W→D) and P(D→W) for Moruya Heads.

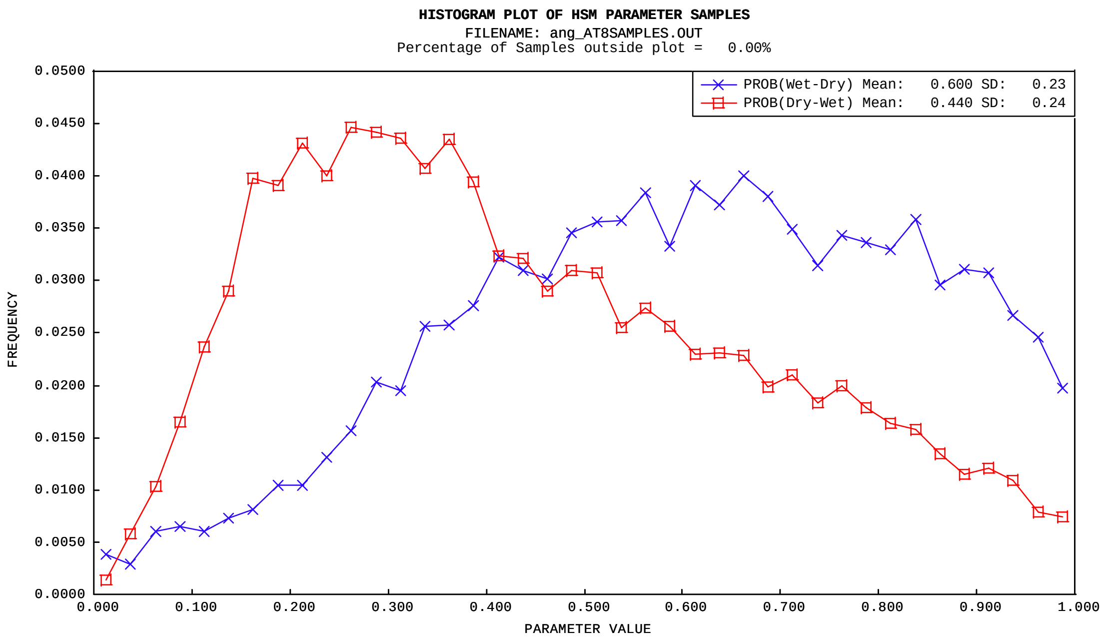


Figure C72. The posterior probability distributions of P(W→D) and P(D→W) for Adelong.

X - P(W→D) and - P(D→W)

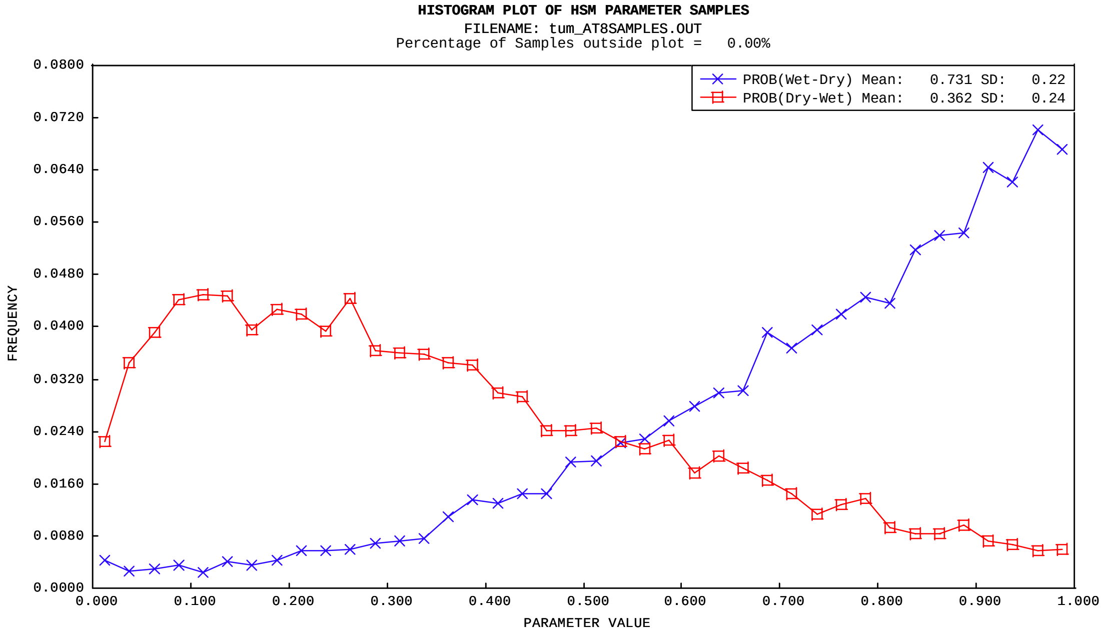


Figure C73. The posterior probability distributions of P(W→D) and P(D→W) for Tumut.

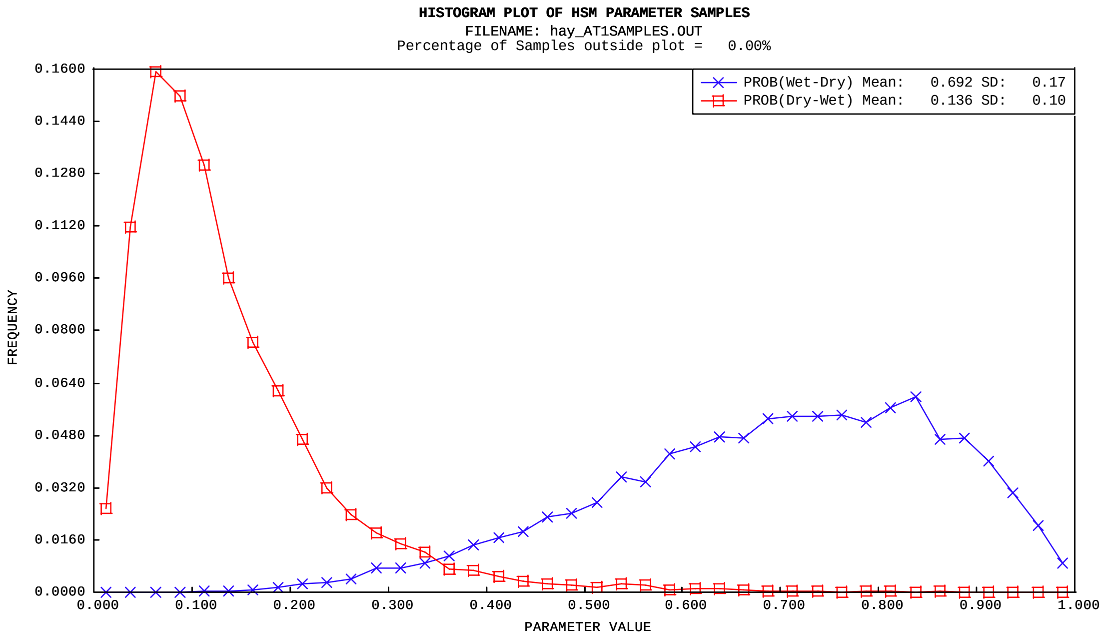


Figure C74. The posterior probability distributions of P(W→D) and P(D→W) for Hay

X - P(W→D) and - P(D→W)

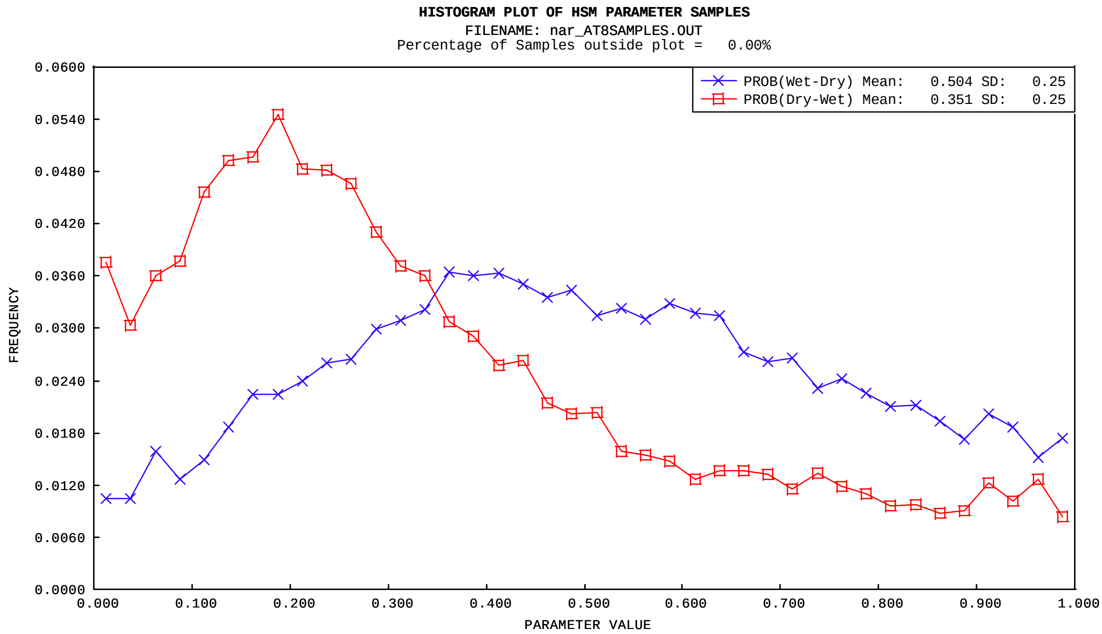


Figure C75. The posterior probability distributions of P(W→D) and P(D→W) for Narraport.

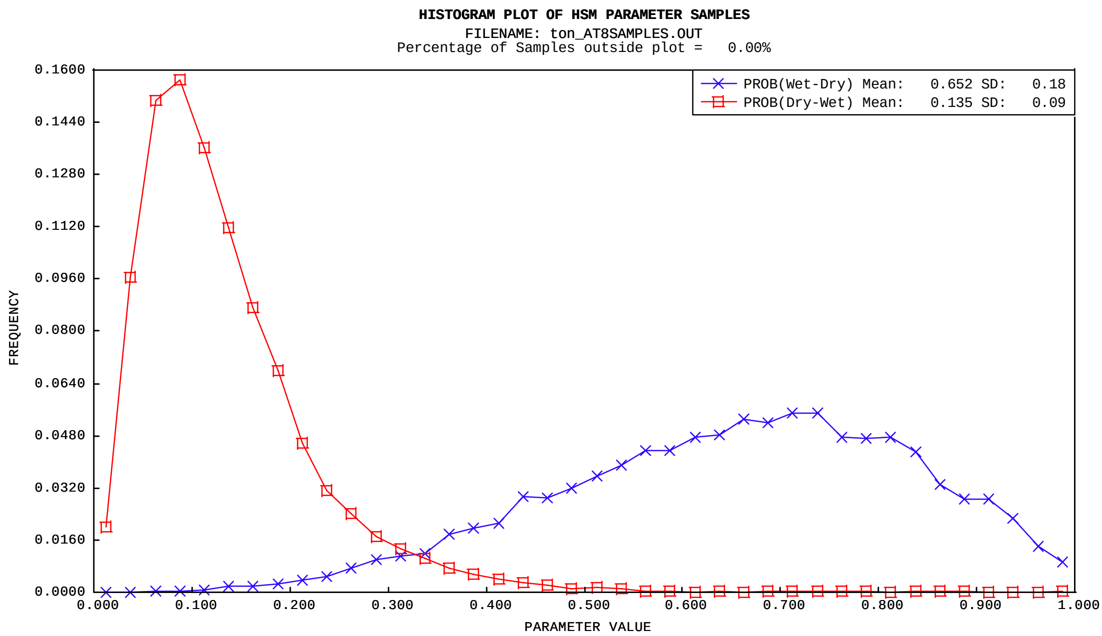


Figure C76. The posterior probability distributions of P(W→D) and P(D→W) for Tongala.

X - P(W→D) and - P(D→W)

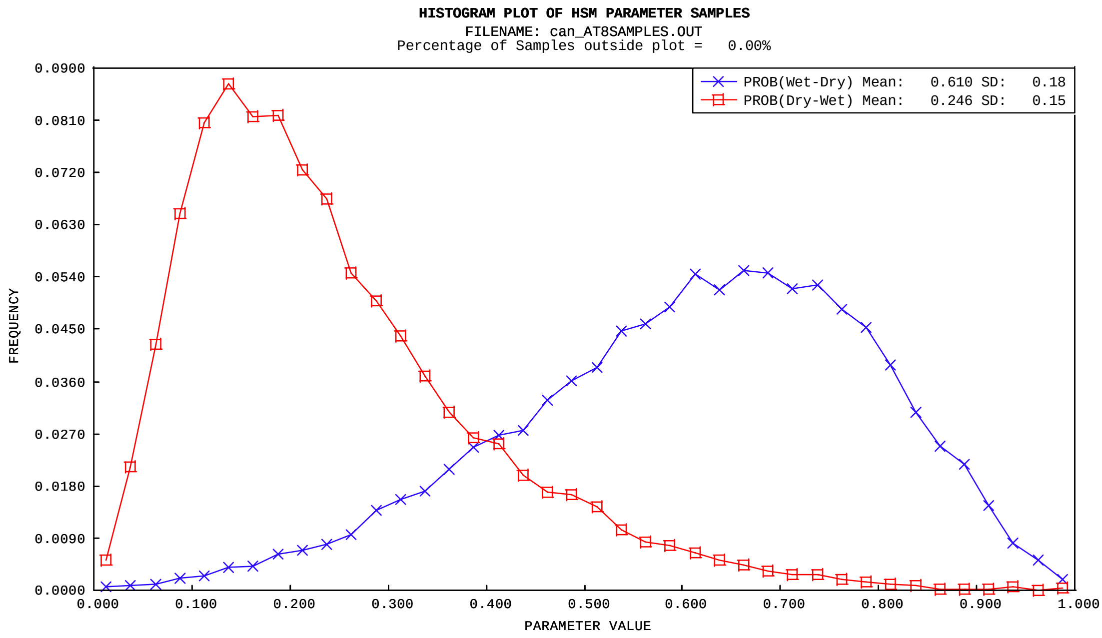


Figure C77. The posterior probability distributions of P(W→D) and P(D→W) for Caniambo.

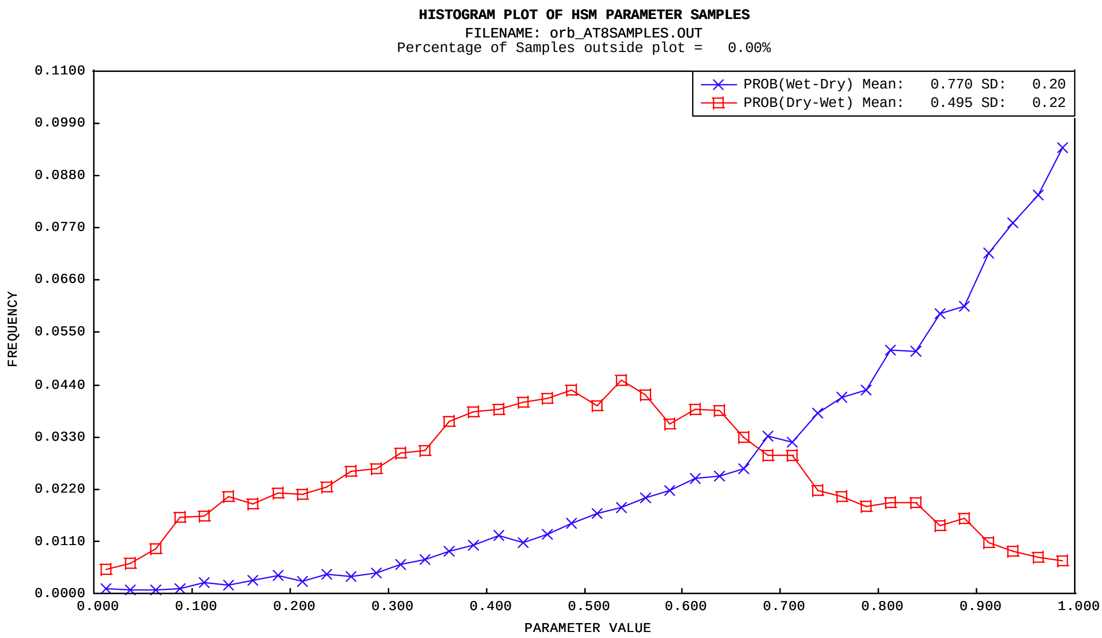


Figure C78. The posterior probability distributions of P(W→D) and P(D→W) for Orbost
X - P(W→D) and - P(D→W)

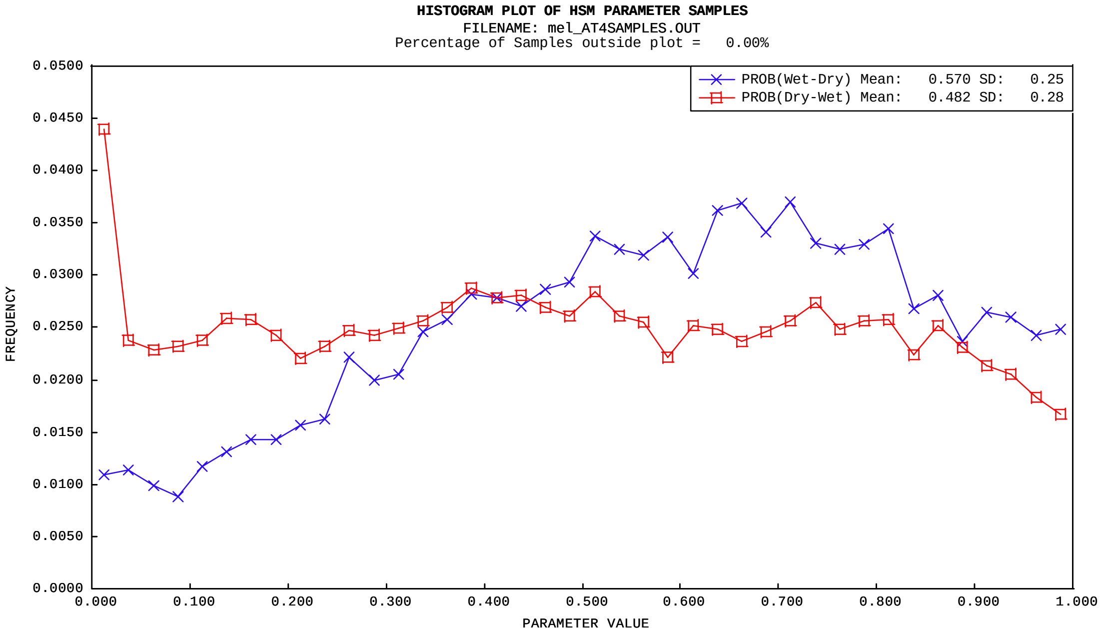


Figure C79. The posterior probability distributions of P(W→D) and P(D→W) for Melbourne

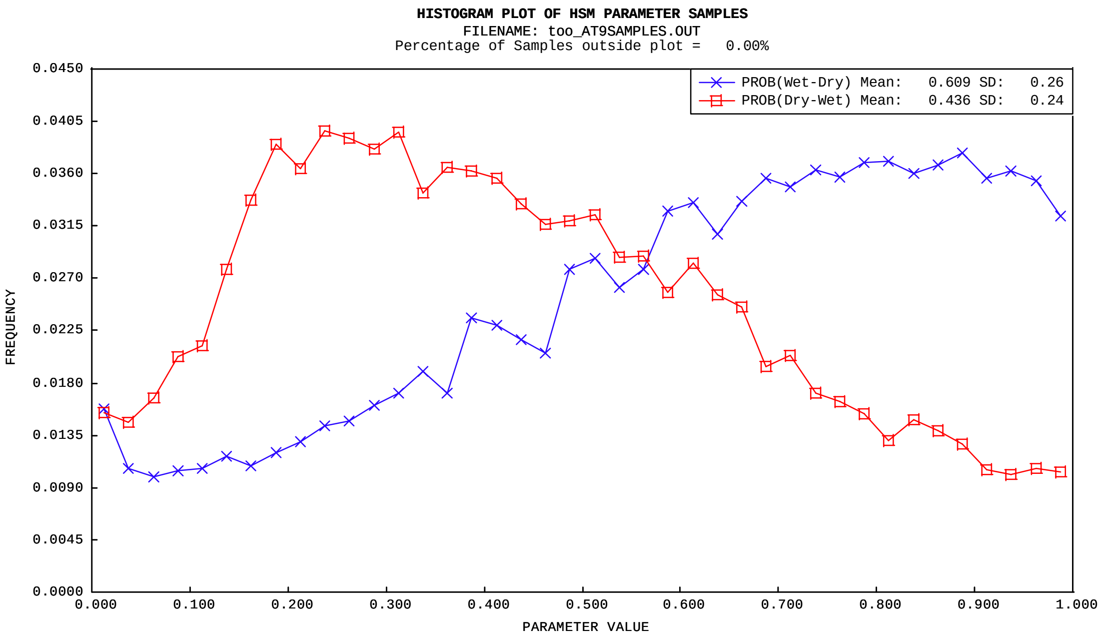


Figure C80. The posterior probability distributions of P(W→D) and P(D→W) for Toorourrong. X - P(W→D) and - P(D→W)

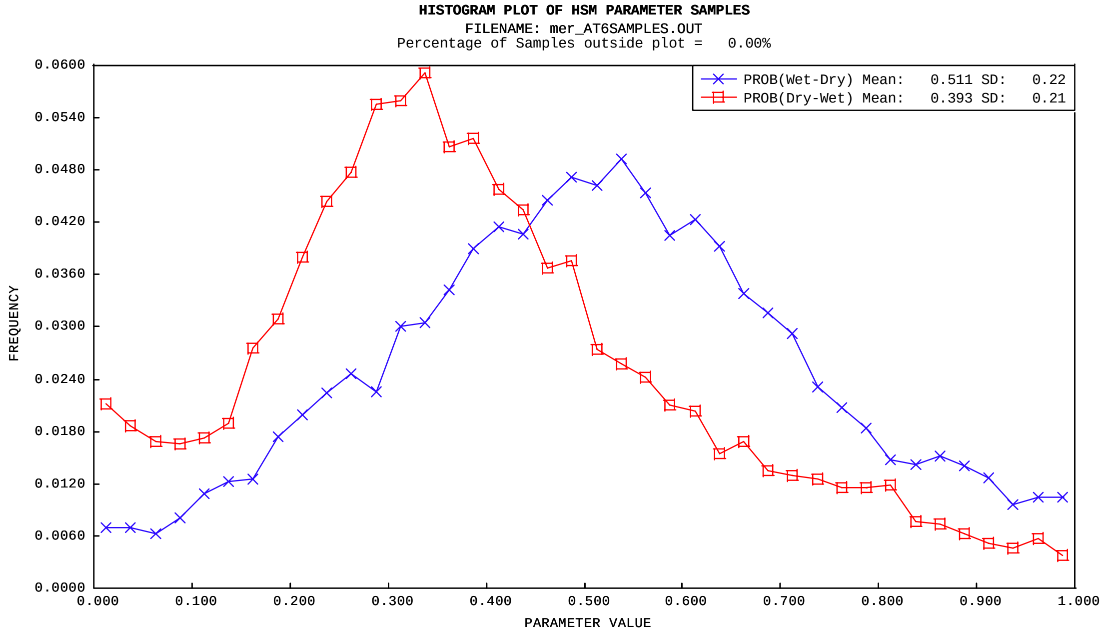


Figure C81. The posterior probability distributions of P(W→D) and P(D→W) for Meredith

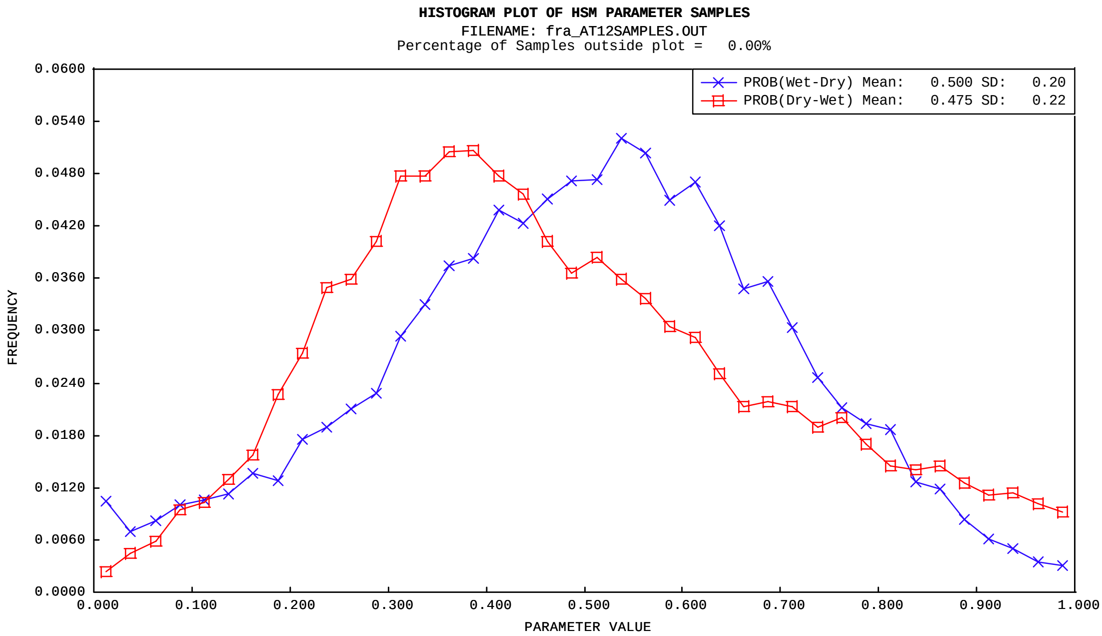


Figure C82. The posterior probability distributions of P(W→D) and P(D→W) for Frankford X - P(W→D) and - P(D→W)

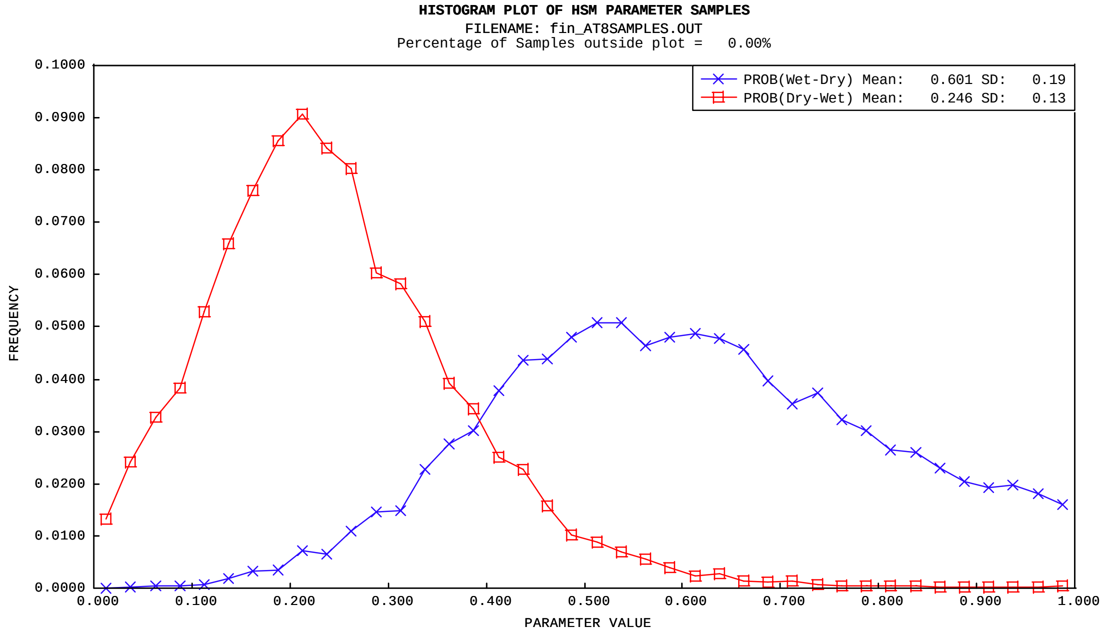


Figure C83. The posterior probability distributions of P(W→D) and P(D→W) for Fingal

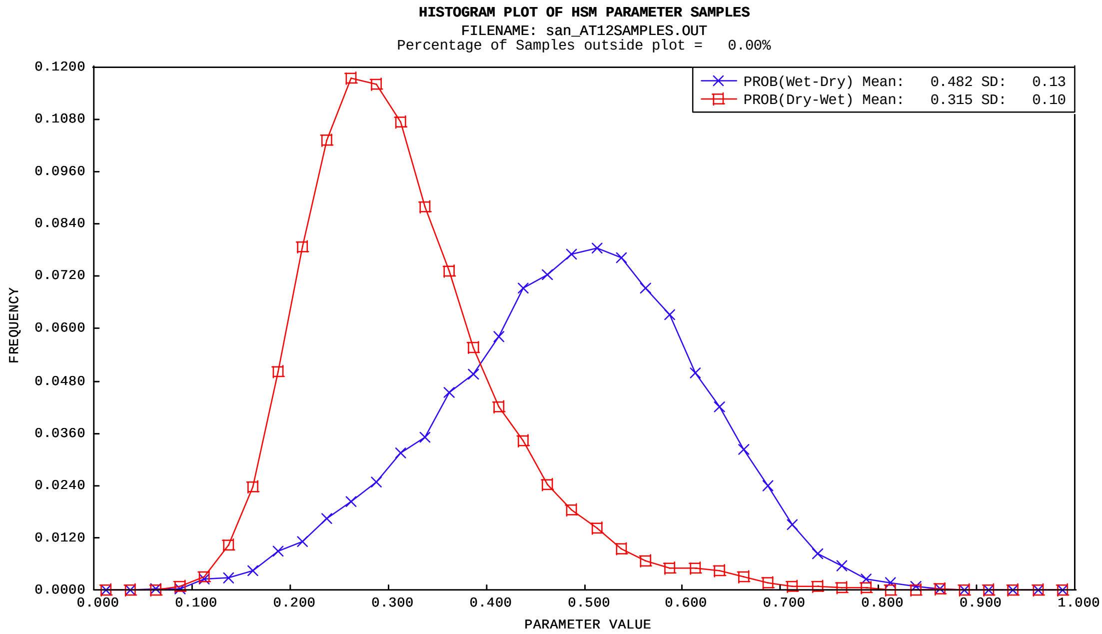


Figure C84. The posterior probability distributions of P(W→D) and P(D→W) for Sandford

X - P(W→D) and - P(D→W)

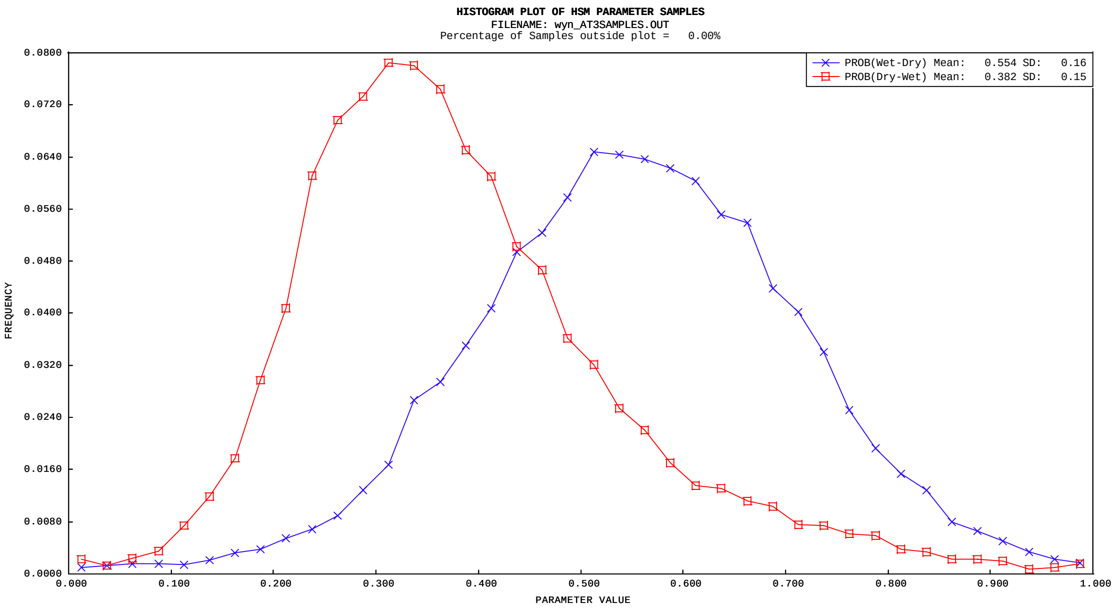


Figure C85. The posterior probability distributions of P(W→D) and P(D→W) for Wyndham.

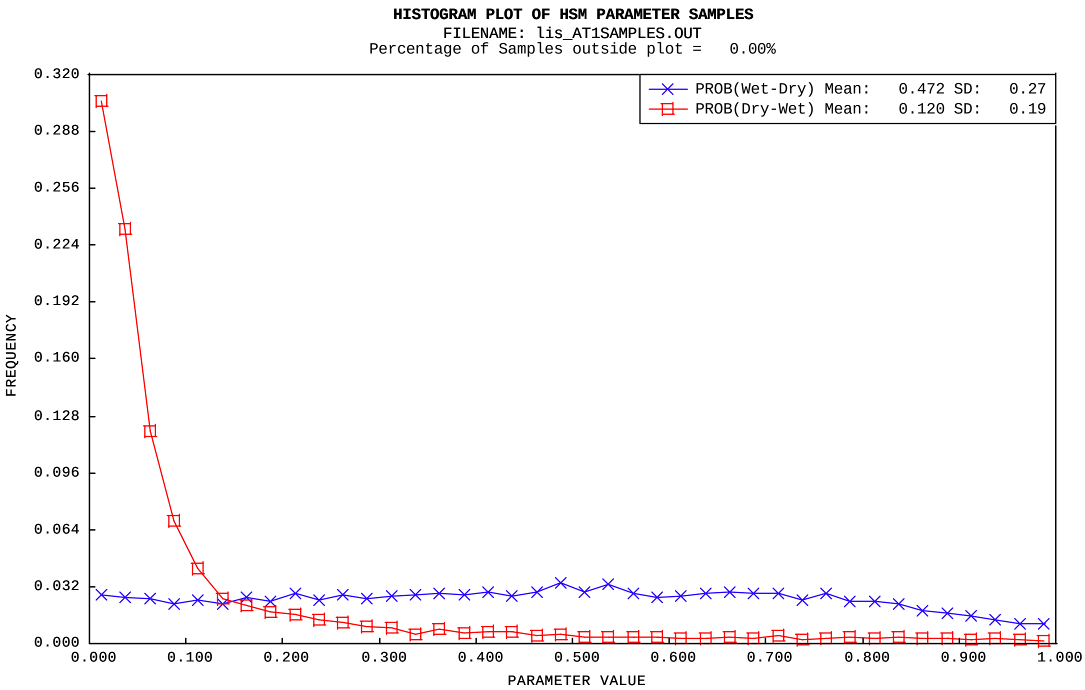


Figure C86. The posterior probability distributions of P(W→D) and P(D→W) for Lissadell. X - P(W→D) and - P(D→W)

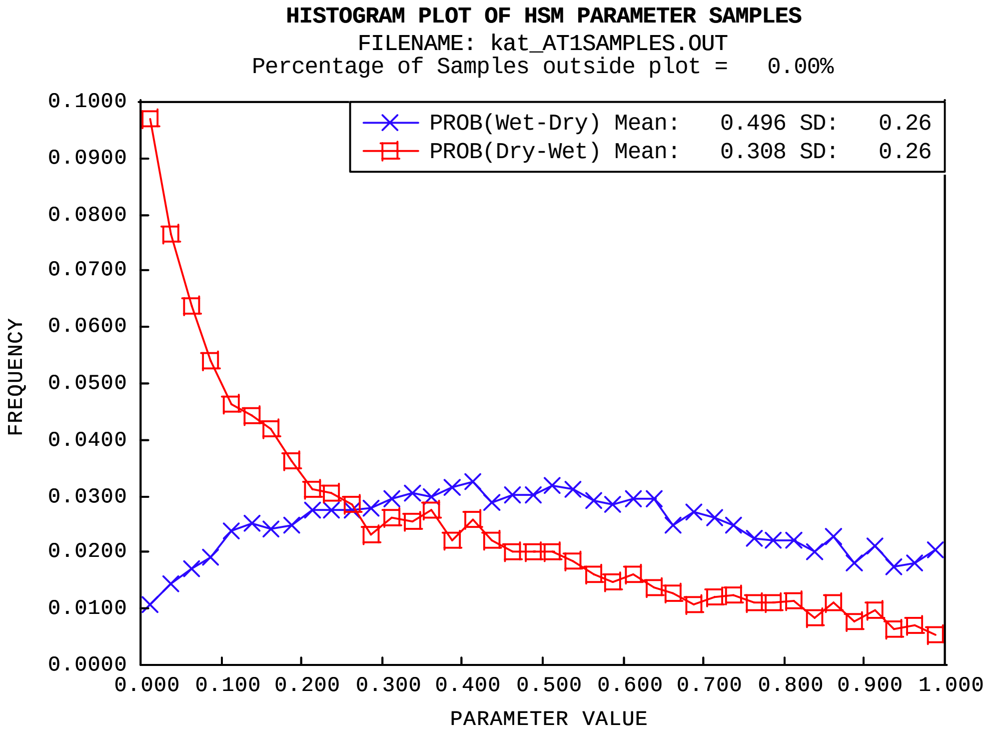


Figure C87. The posterior probability distributions of P(W→D) and P(D→W) for Katherine.

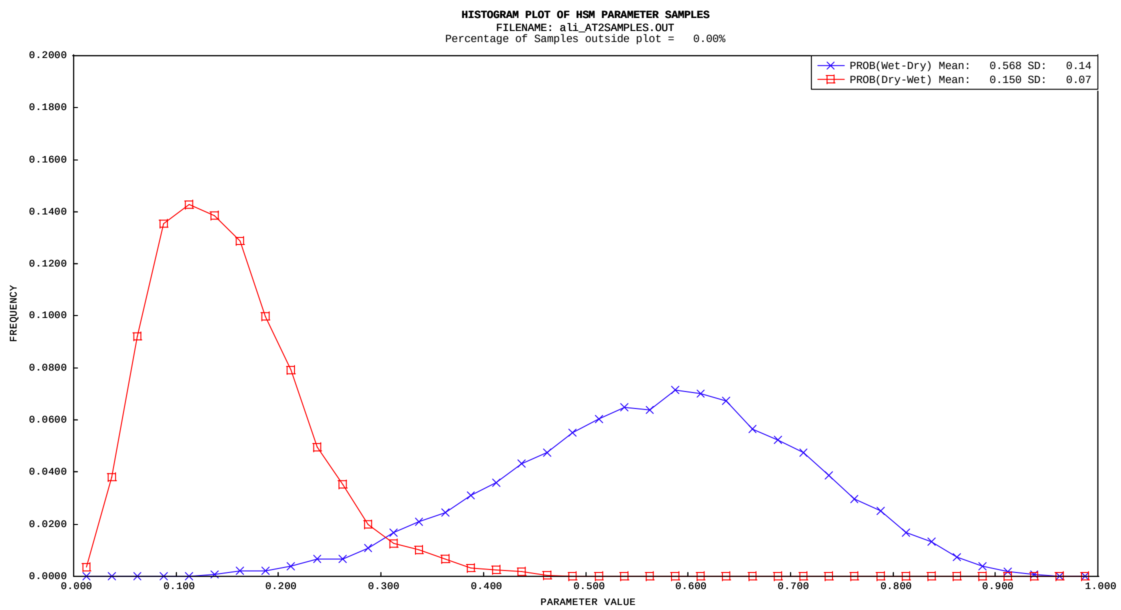


Figure C88. The posterior probability distributions of P(W→D) and P(D→W) for Alice Springs. X - P(W→D) and - P(D→W)

Table C1 . The mean and standard deviation of the transition probabilities.

Name	p(W → D)		p(D → W)	
	Mean	Std dev	Mean	Std dev
Mardie	0.761	0.145	0.624	0.192
Meedo	0.494	0.170	0.239	0.151
Perth	0.660	0.228	0.406	0.264
Cuttening	0.489	0.254	0.401	0.252
Norseman	0.624	0.218	0.224	0.131
Marree	0.751	0.184	0.173	0.106
Orroroo	0.806	0.151	0.242	0.146
Wallaroo	0.464	0.187	0.581	0.222
Adelaide	0.586	0.241	0.284	0.237
Eudunda	0.750	0.169	0.208	0.132
Palmerville	0.382	0.218	0.245	0.207
Kalamia Estate	0.528	0.173	0.303	0.138
Emerald	0.459	0.162	0.228	0.119
Barcaldine	0.567	0.139	0.316	0.127
Cape Capricorn	0.415	0.222	0.360	0.207
Rockhampton	0.517	0.154	0.317	0.127
Cape Moreton	0.723	0.217	0.389	0.204
Brisbane	0.656	0.232	0.199	0.123
Pittsworth	0.711	0.199	0.524	0.262
Miles	0.568	0.170	0.580	0.214
Cunnamulla	0.660	0.174	0.139	0.061
Wentworth	0.551	0.178	0.102	0.059
Balranald RSL	0.530	0.187	0.102	0.119
Bingara	0.644	0.230	0.261	0.201
Mudgee	0.486	0.223	0.296	0.184
Sydney	0.428	0.172	0.163	0.208
Moruya Heads	0.306	0.109	0.208	0.074
Adelong	0.600	0.229	0.440	0.239
Tumut	0.731	0.217	0.362	0.243
Hay	0.692	0.170	0.136	0.100
Narraport	0.504	0.250	0.351	0.253
Tongala	0.652	0.178	0.135	0.092
Caniambo	0.610	0.181	0.246	0.152
Orbost	0.770	0.197	0.495	0.224
Melbourne	0.508	0.231	0.445	0.241
Toorourrong	0.609	0.261	0.436	0.244
Meredith	0.511	0.216	0.393	0.211
Frankford	0.500	0.203	0.475	0.217
Fingal	0.601	0.188	0.246	0.129
Sandford	0.482	0.129	0.315	0.101
Wyndhem	0.554	0.156	0.382	0.154
Lissadell	0.472	0.267	0.120	0.188
Katherine	0.526	0.254	0.255	0.233
Alice Springs	0.568	0.141	0.150	0.072

APPENDIX D – DISTRIBUTION OF ANNUAL FLOWS

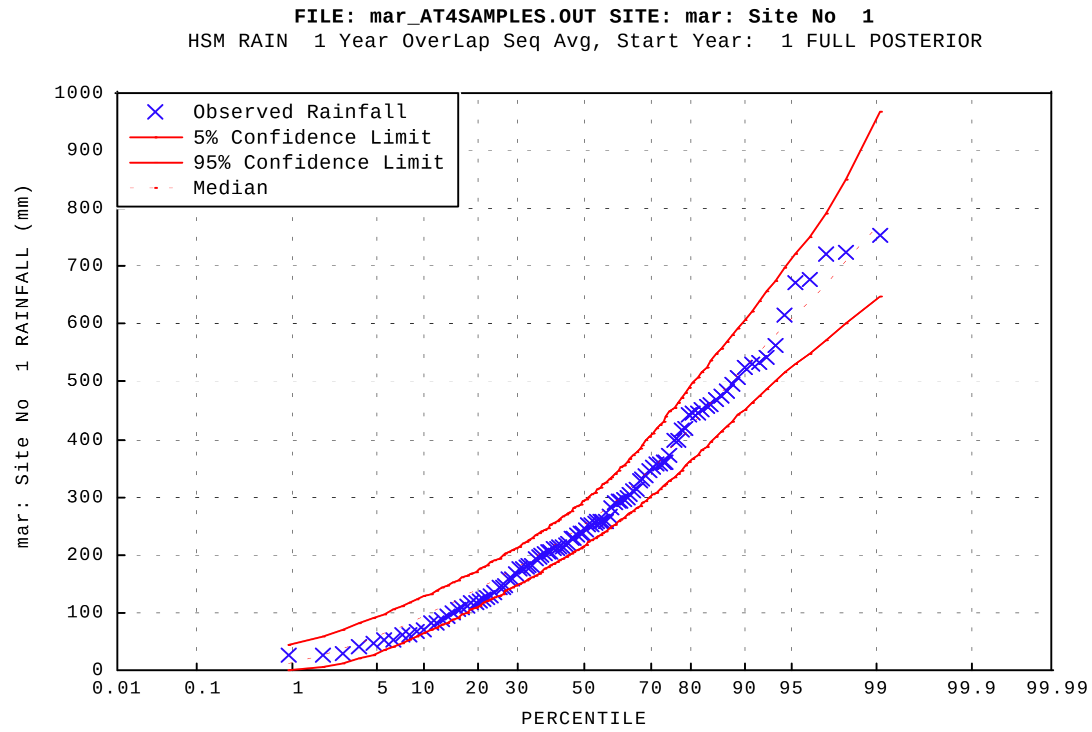


Figure D1. Comparison of the distribution of observed and generated annual rainfall for Mardie

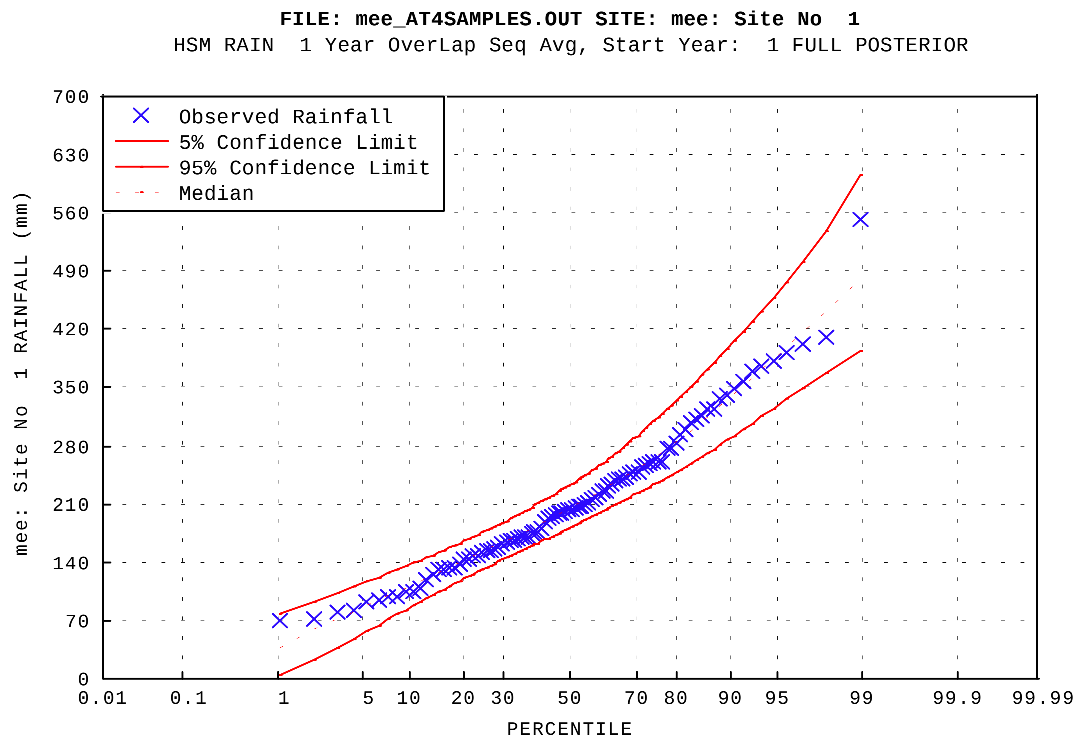


Figure D2. Comparison of the distribution of observed and generated annual rainfall for Meedo

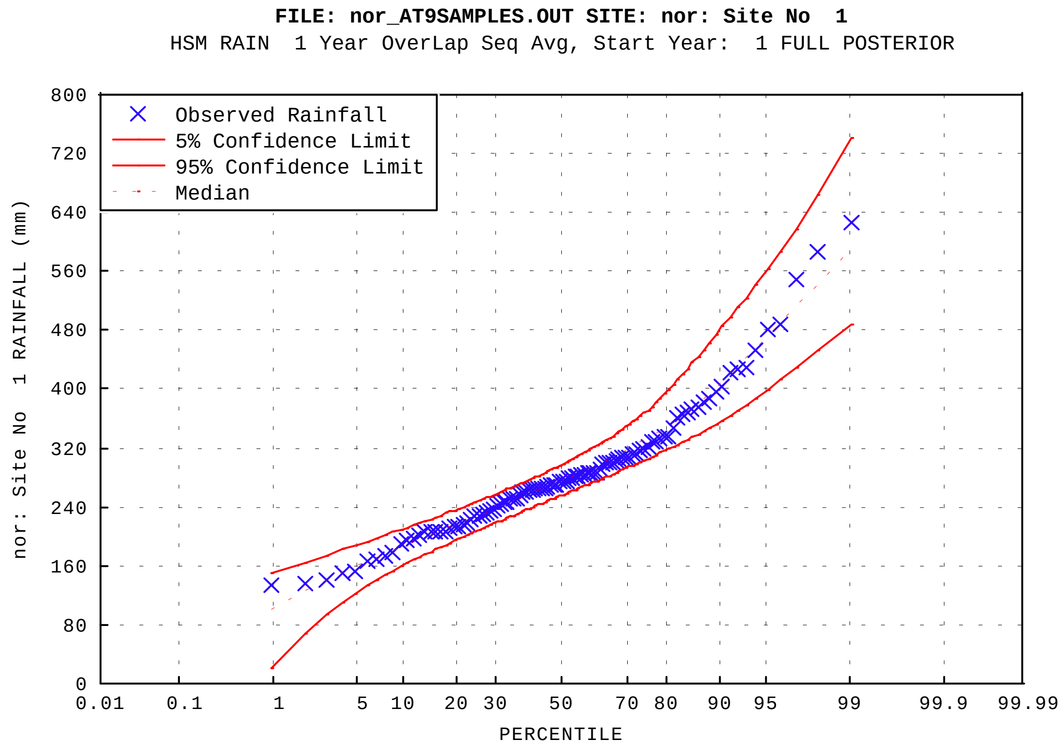


Figure D3. Comparison of the distribution of observed and generated annual rainfall for Norseman.

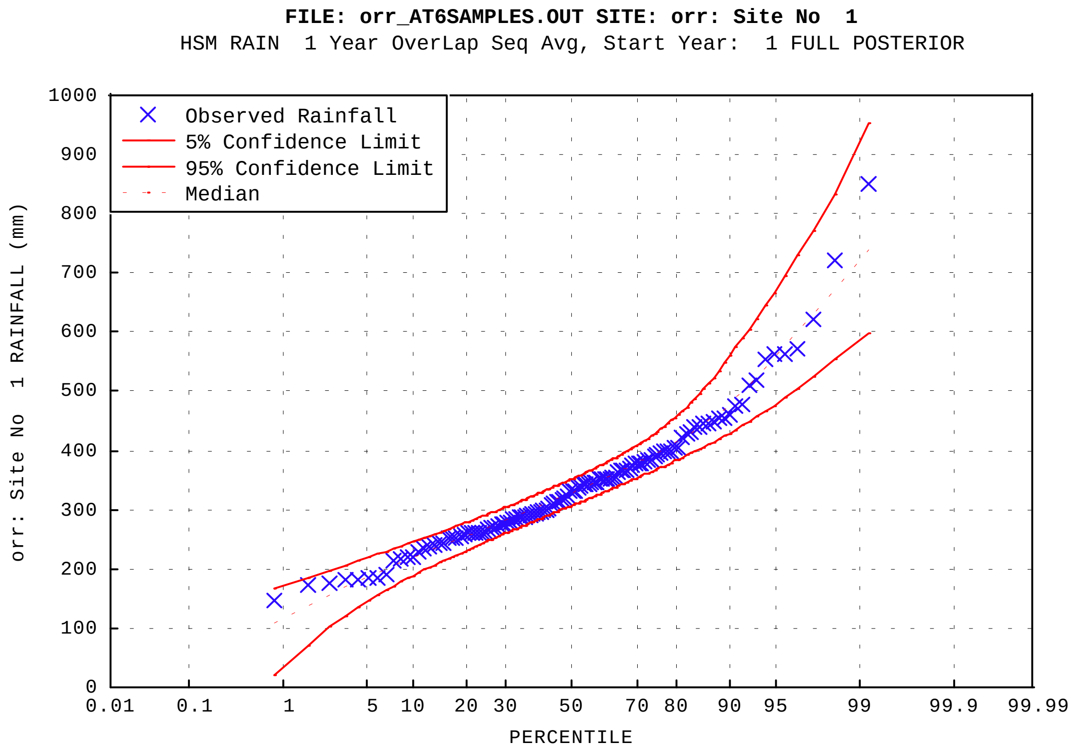


Figure D4. Comparison of the distribution of observed and generated annual rainfall for Orroroo.

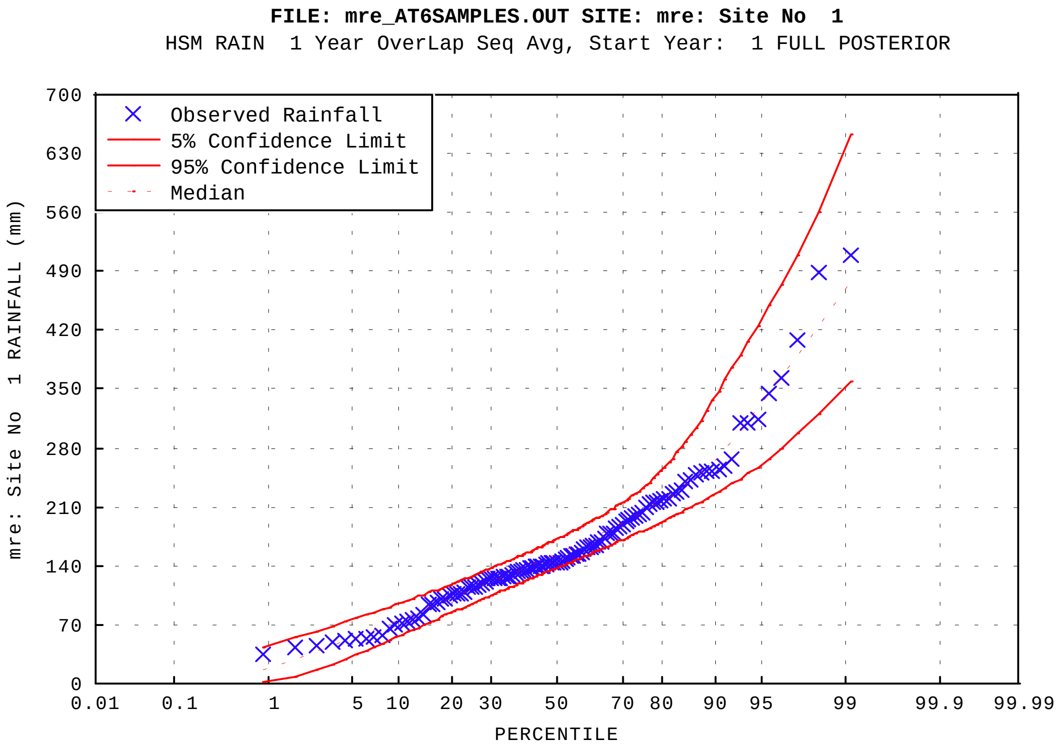


Figure D5. Comparison of the distribution of observed and generated annual rainfall for Marree.

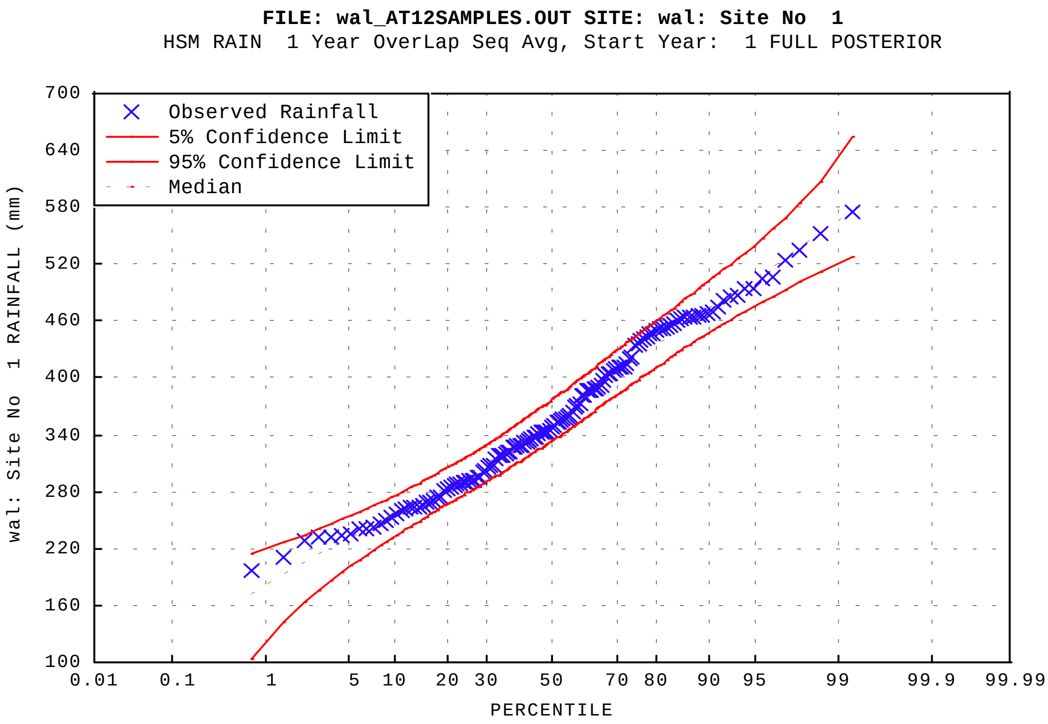


Figure D6. Comparison of the distribution of observed and generated annual rainfall for Wallaroo.

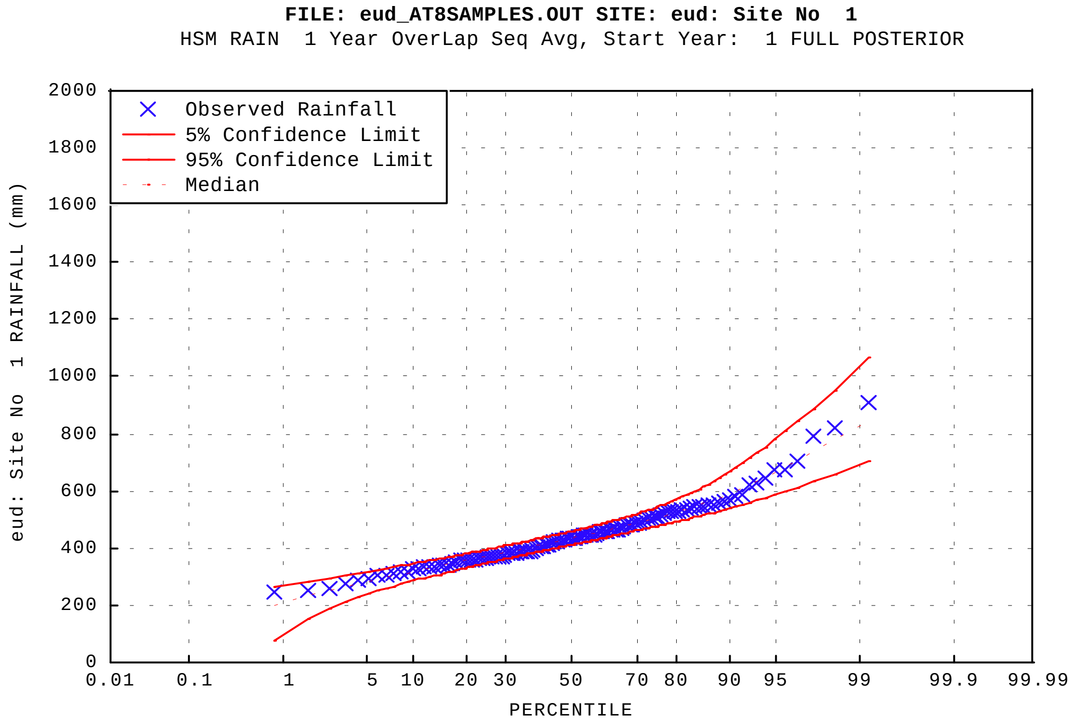


Figure D7. Comparison of the distribution of observed and generated annual rainfall for Eudunda.

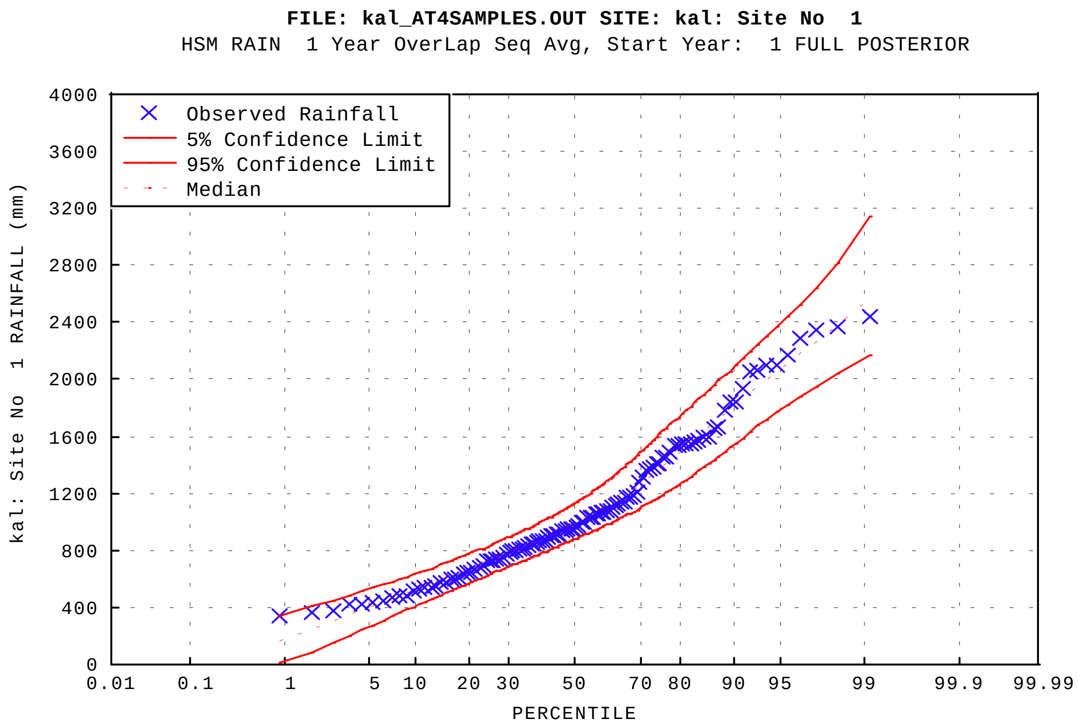


Figure D8. Comparison of the distribution of observed and generated annual rainfall for Kalamia.

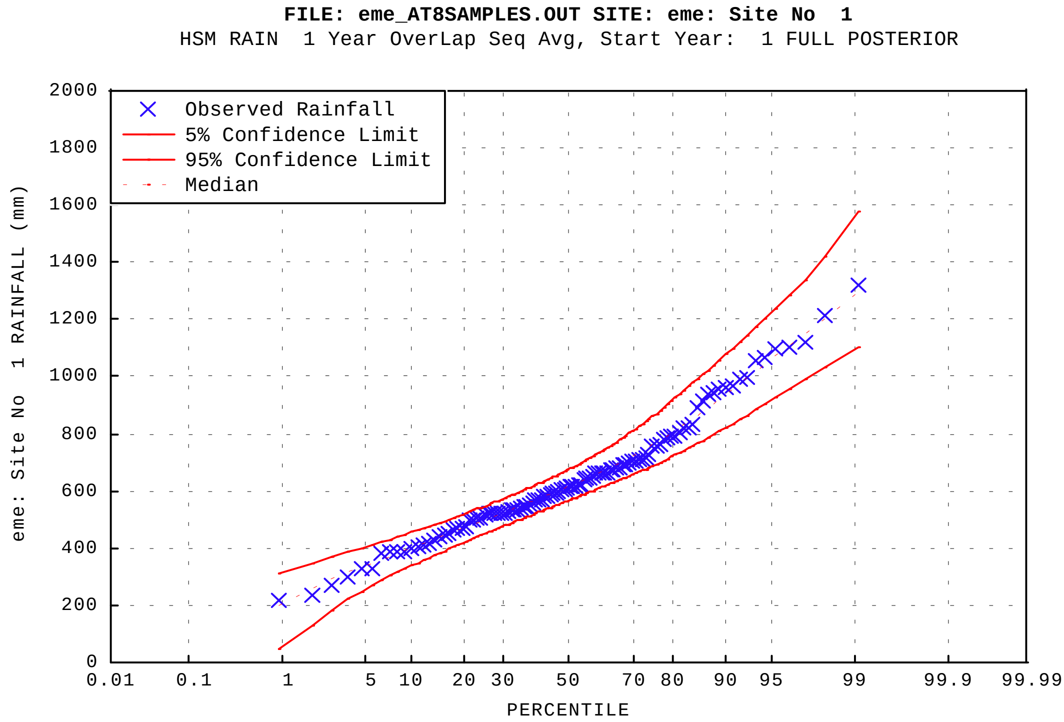


Figure D9. Comparison of the distribution of observed and generated annual rainfall for Emerald.

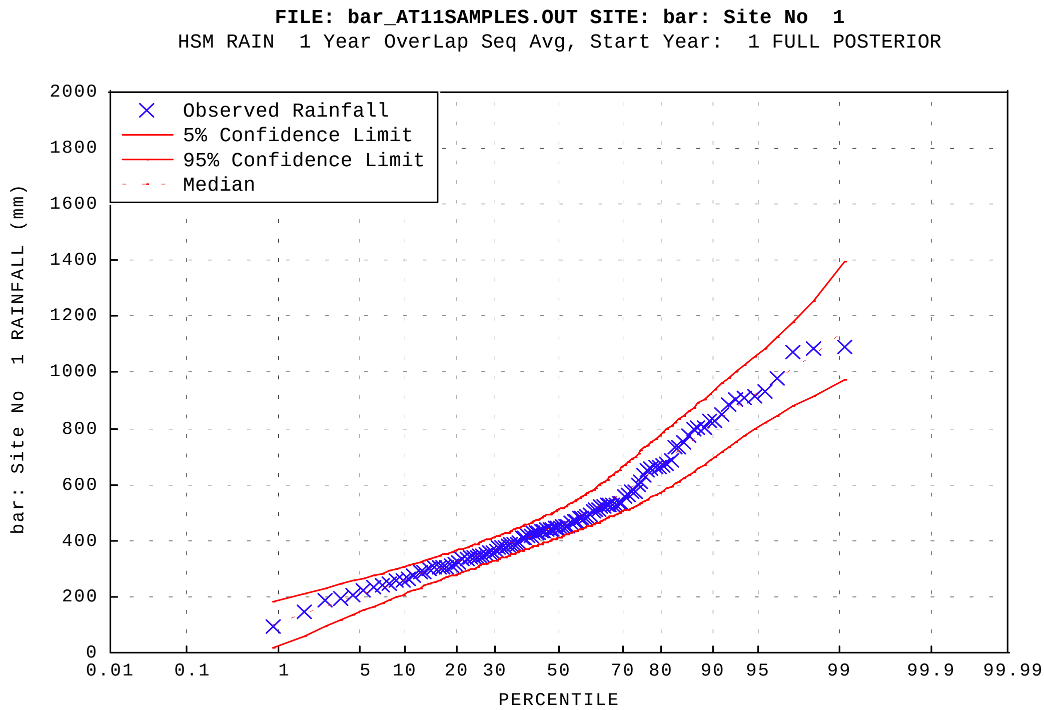


Figure D10. Comparison of the distribution of observed and generated annual rainfall for Barcaldine.

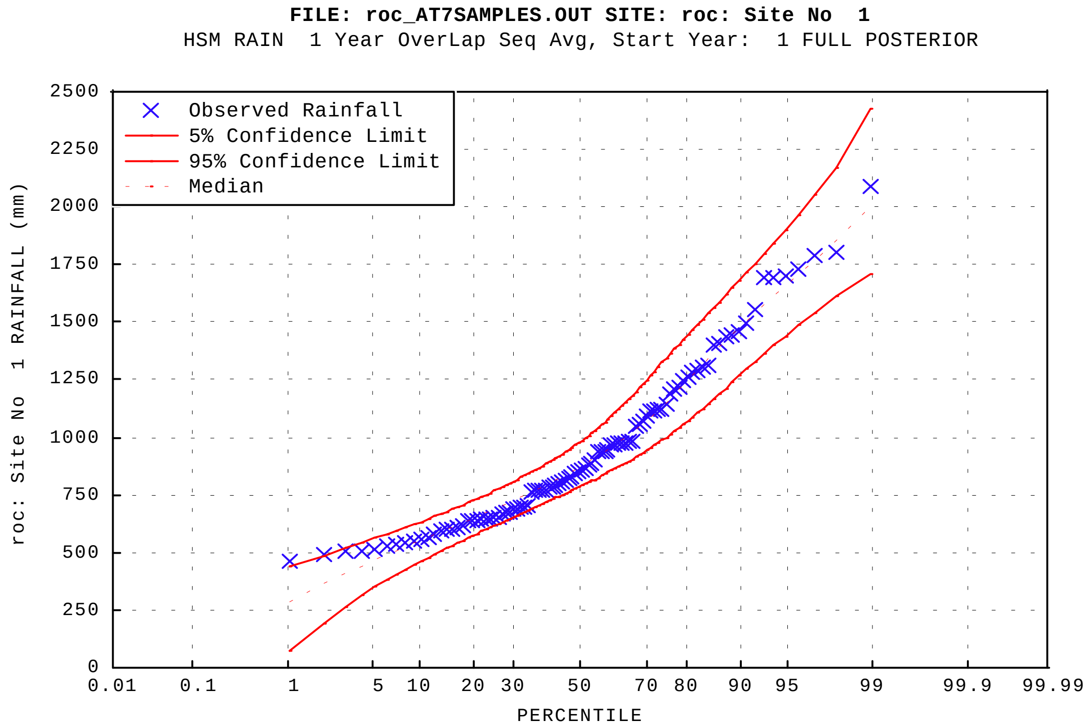


Figure D11. Comparison of the distribution of observed and generated annual rainfall for Rockhampton.

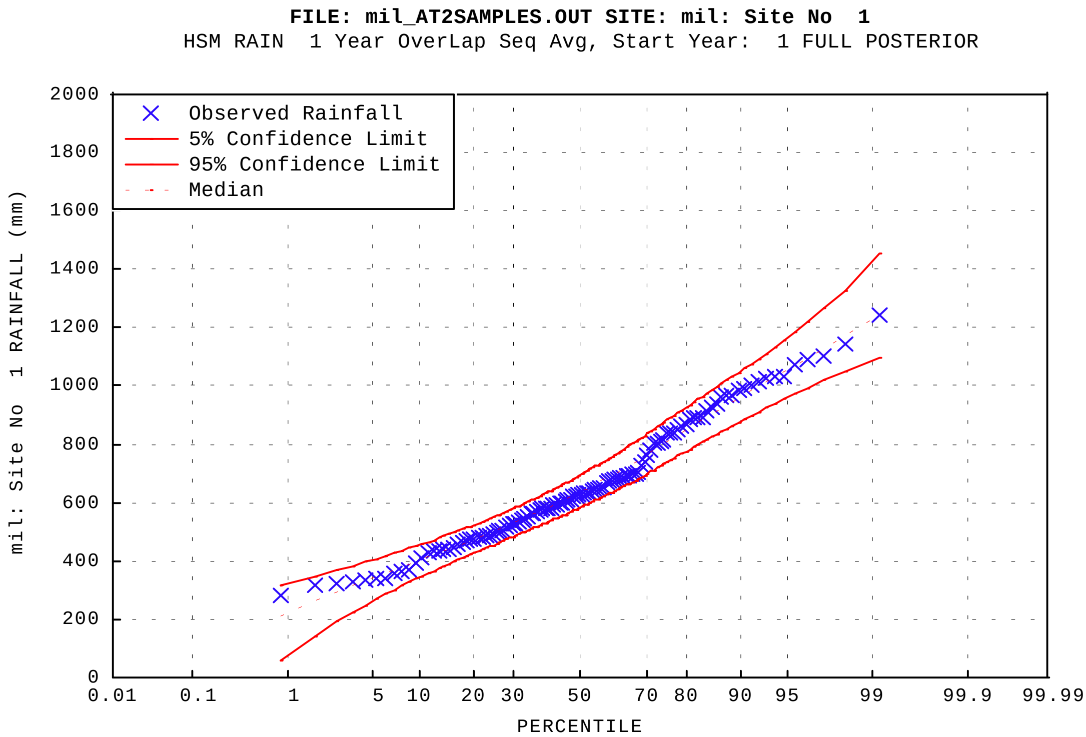


Figure D12. Comparison of the distribution of observed and generated annual rainfall for Miles Post Office.

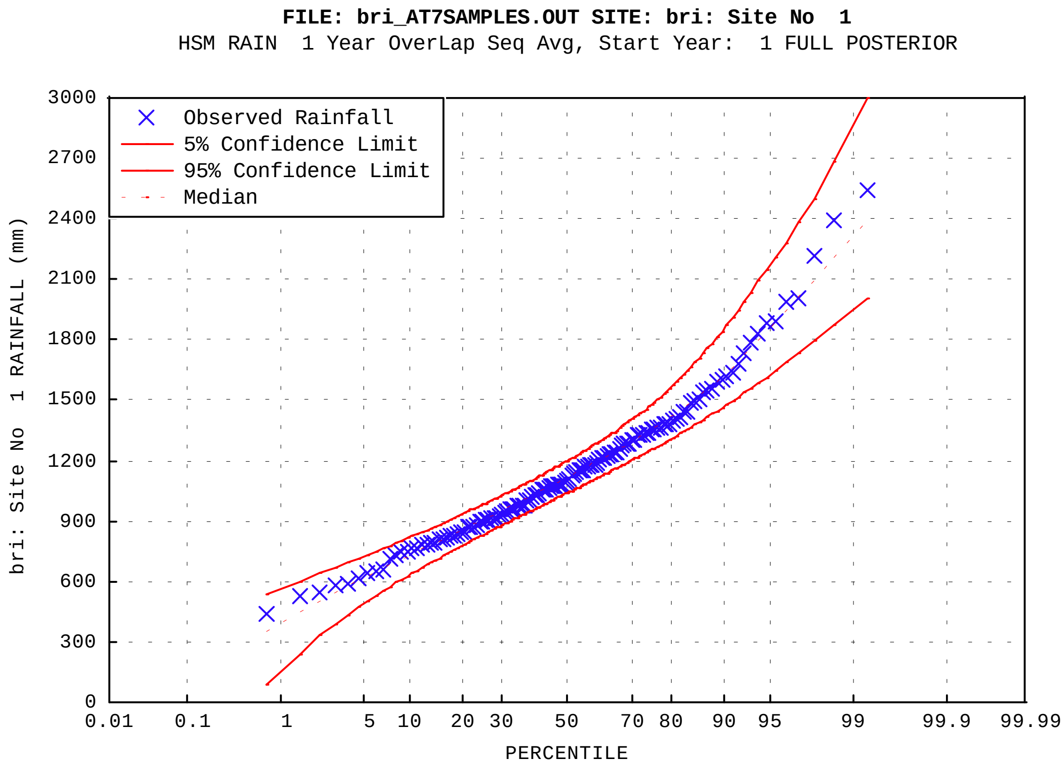


Figure D13. Comparison of the distribution of observed and generated annual rainfall for Brisbane.

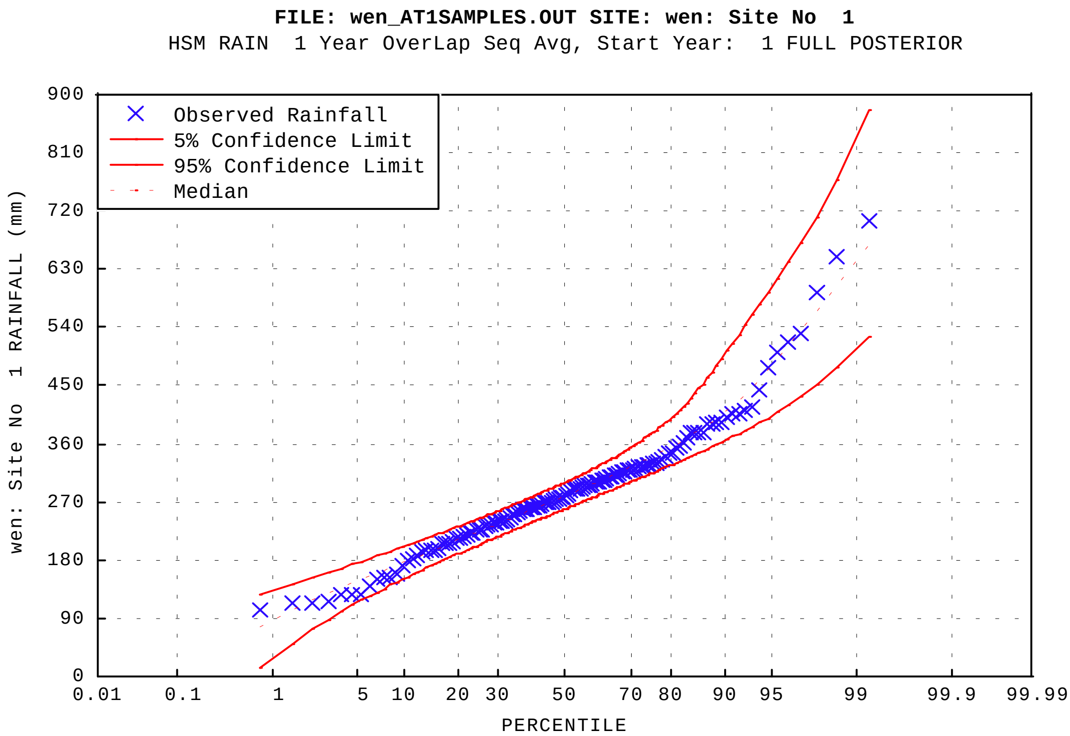


Figure D14. Comparison of the distribution of observed and generated annual rainfall for Wentworth.

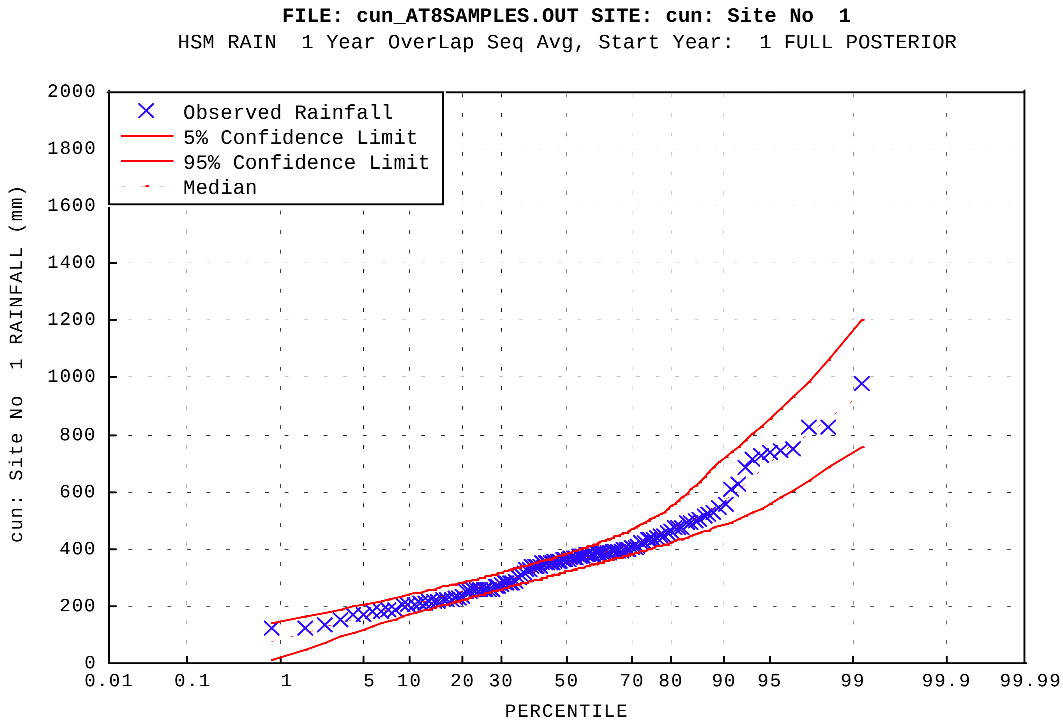


Figure D15. Comparison of the distribution of observed and generated annual rainfall for Cunnamulla.

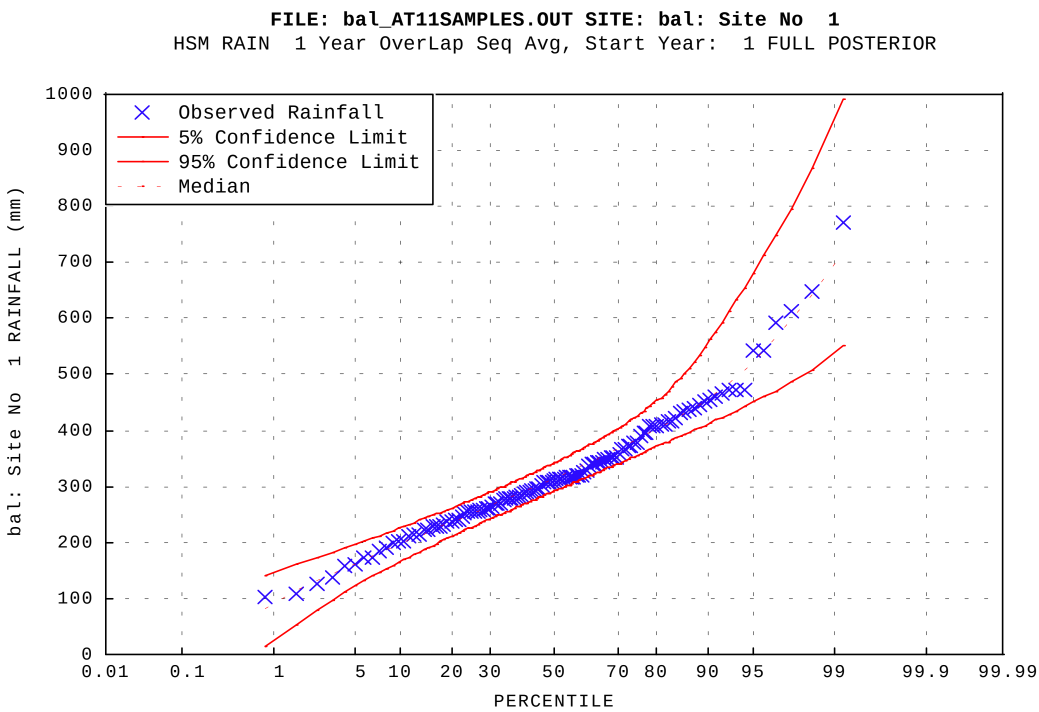


Figure D16. Comparison of the distribution of observed and generated annual rainfall for Balranald.

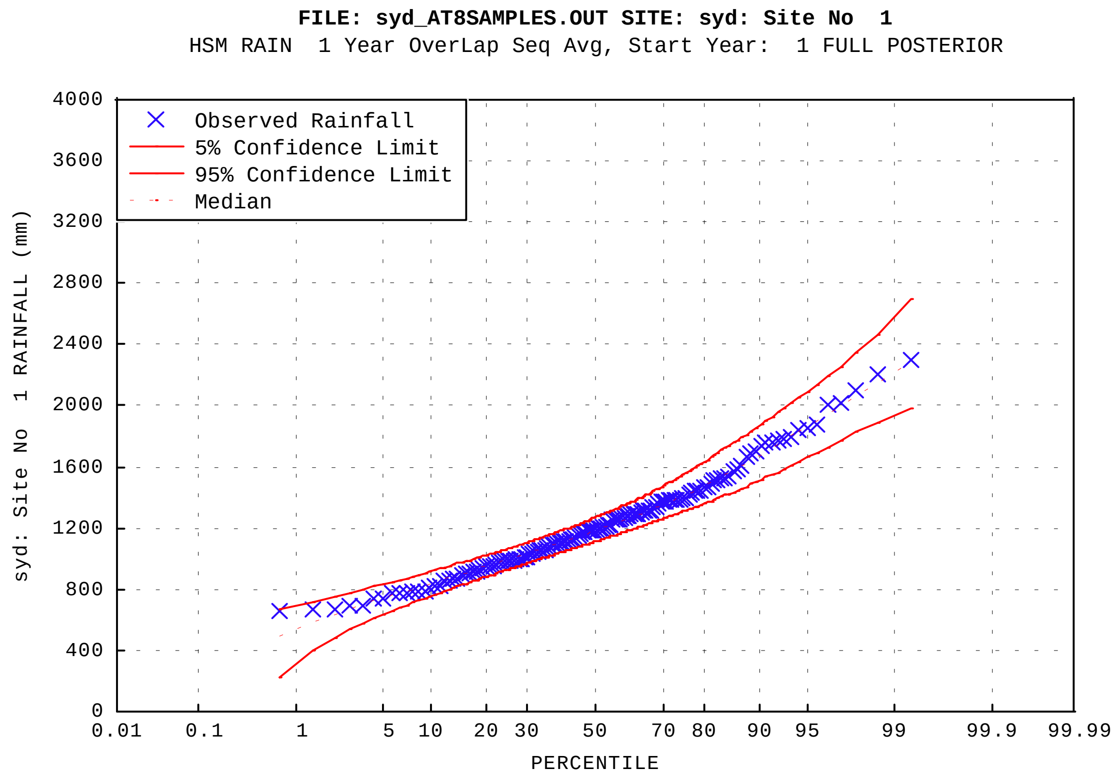


Figure D17. Comparison of the distribution of observed and generated annual rainfall for Sydney.

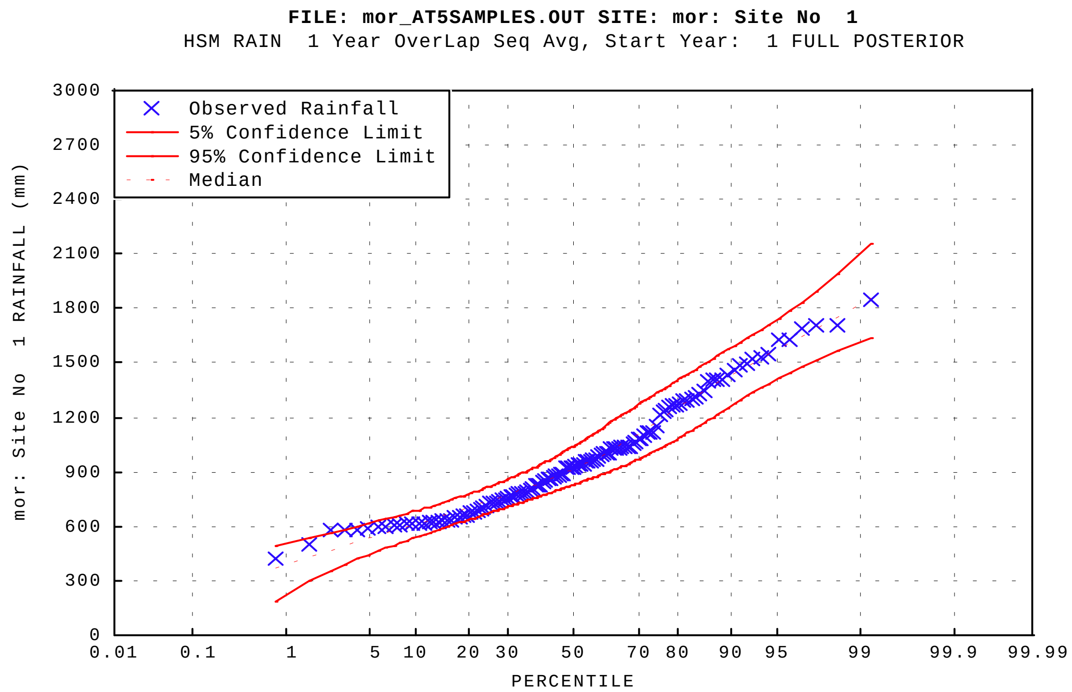


Figure D18. Comparison of the distribution of observed and generated annual rainfall for Moruya Heads.

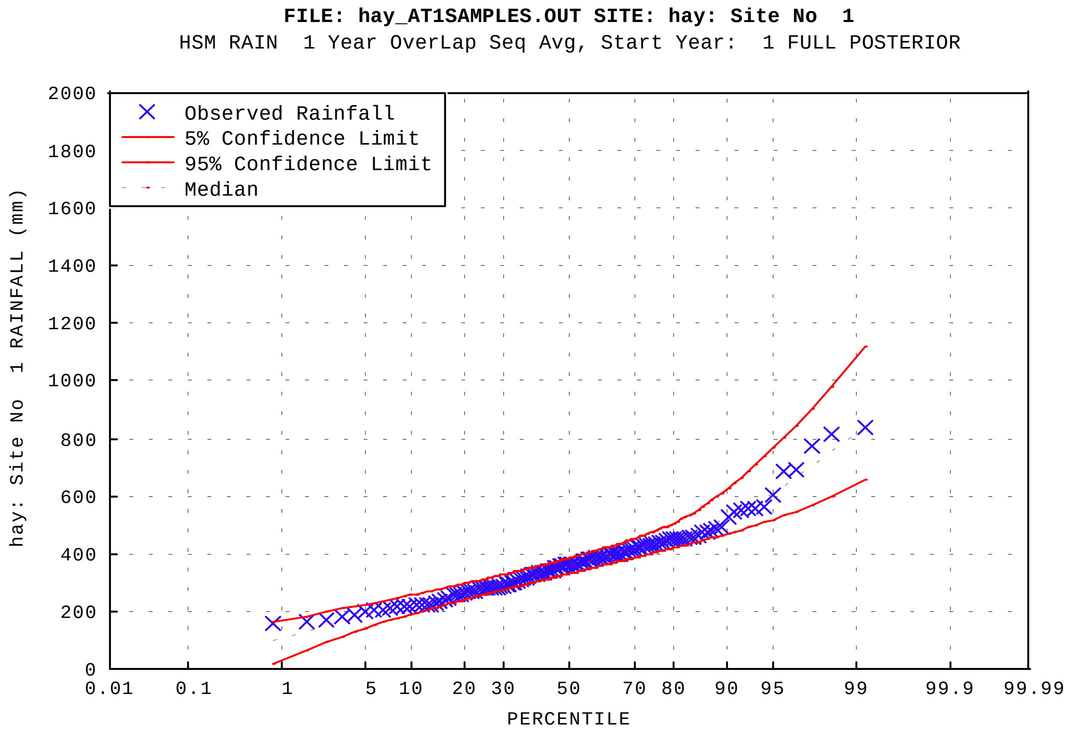


Figure D19. Comparison of the distribution of observed and generated annual rainfall for Hay.

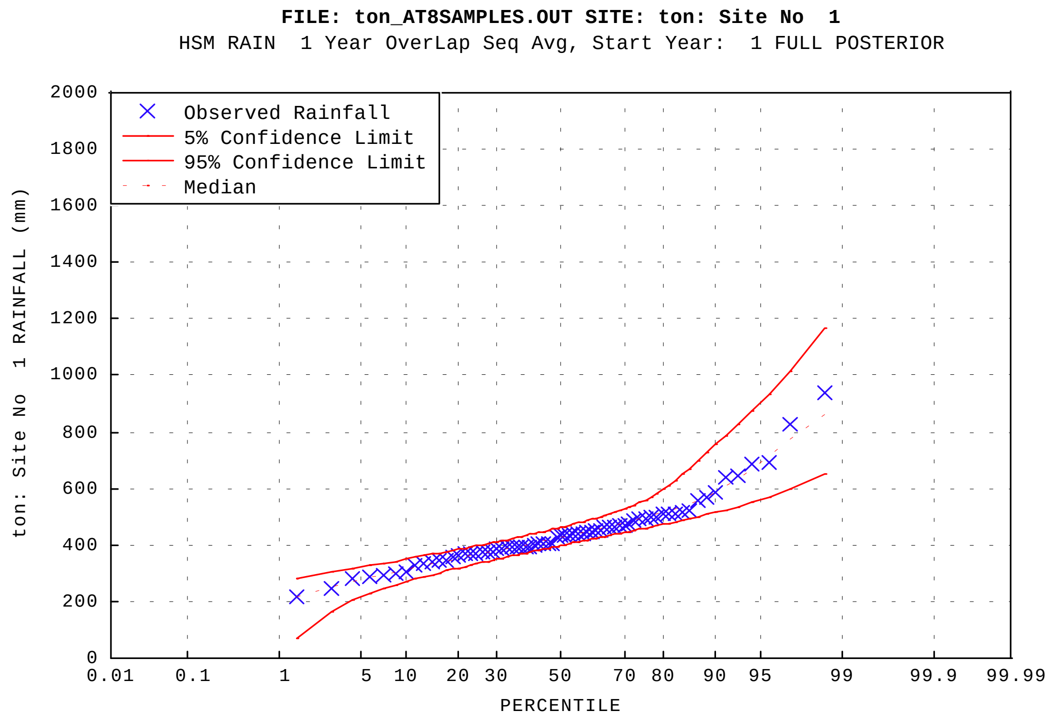


Figure D20. Comparison of the distribution of observed and generated annual rainfall for Tongala.

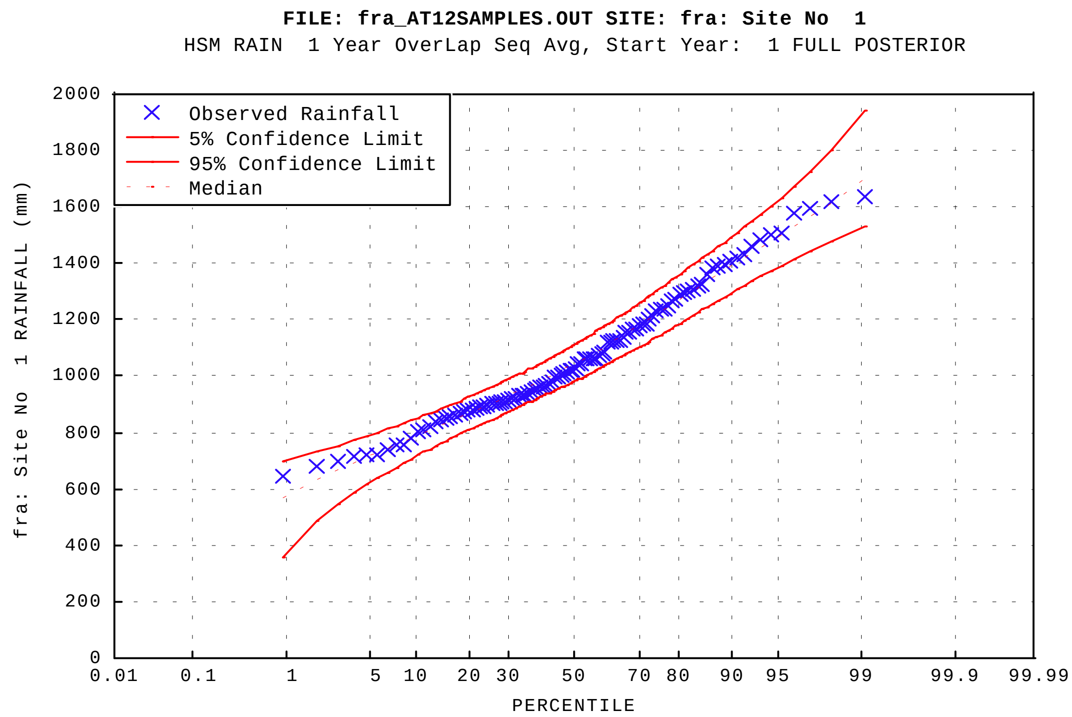


Figure D21. Comparison of the distribution of observed and generated annual rainfall for Frankford.

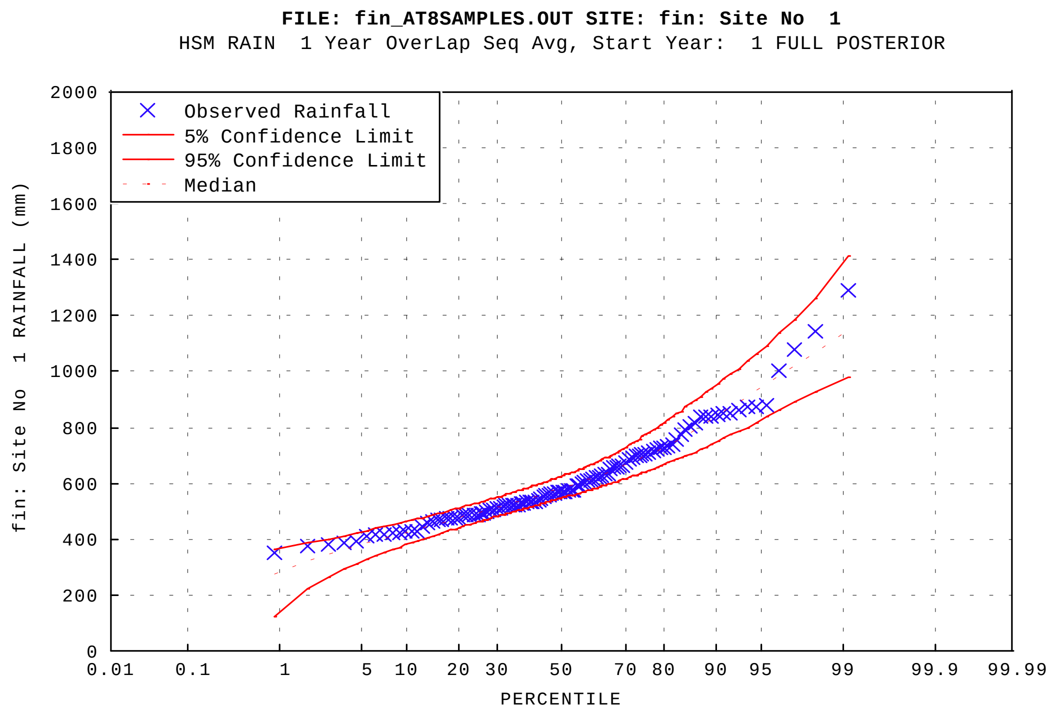


Figure D22. Comparison of the distribution of observed and generated annual rainfall for Fingal.

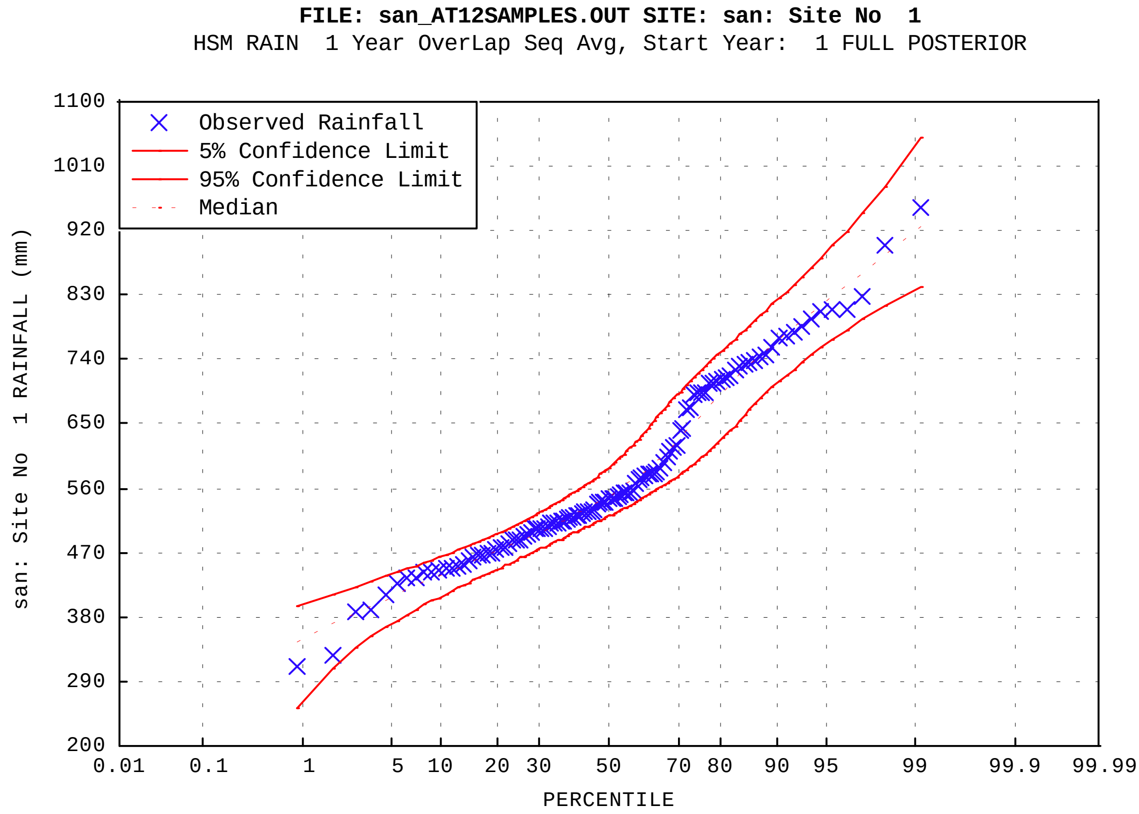


Figure D23. Comparison of the distribution of observed and generated annual rainfall for Sandford.

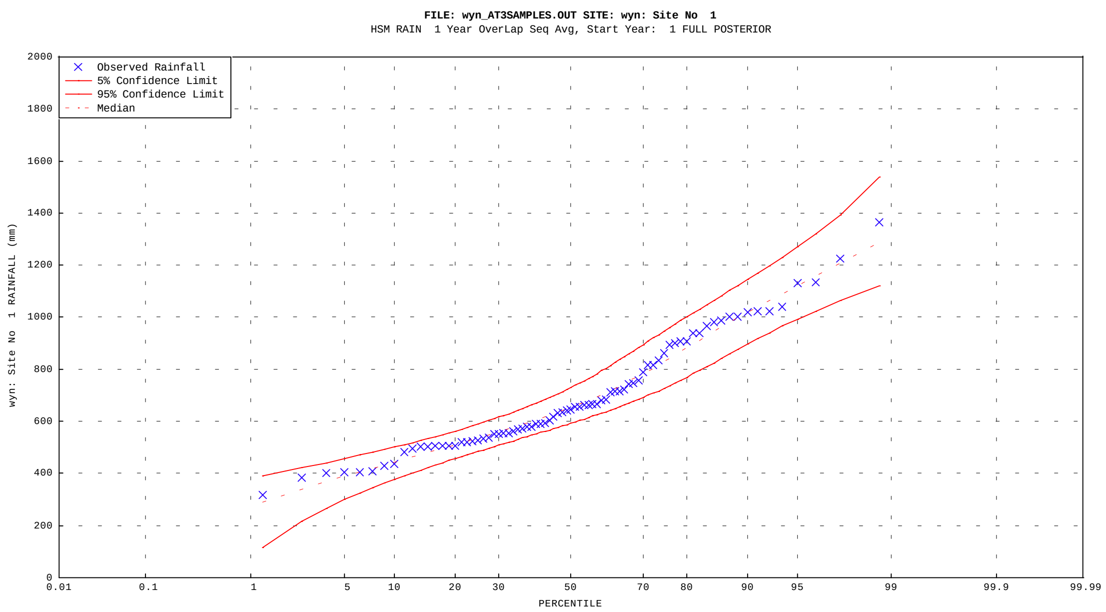


Figure D24. Comparison of the distribution of observed and generated annual rainfall for Wyndham.

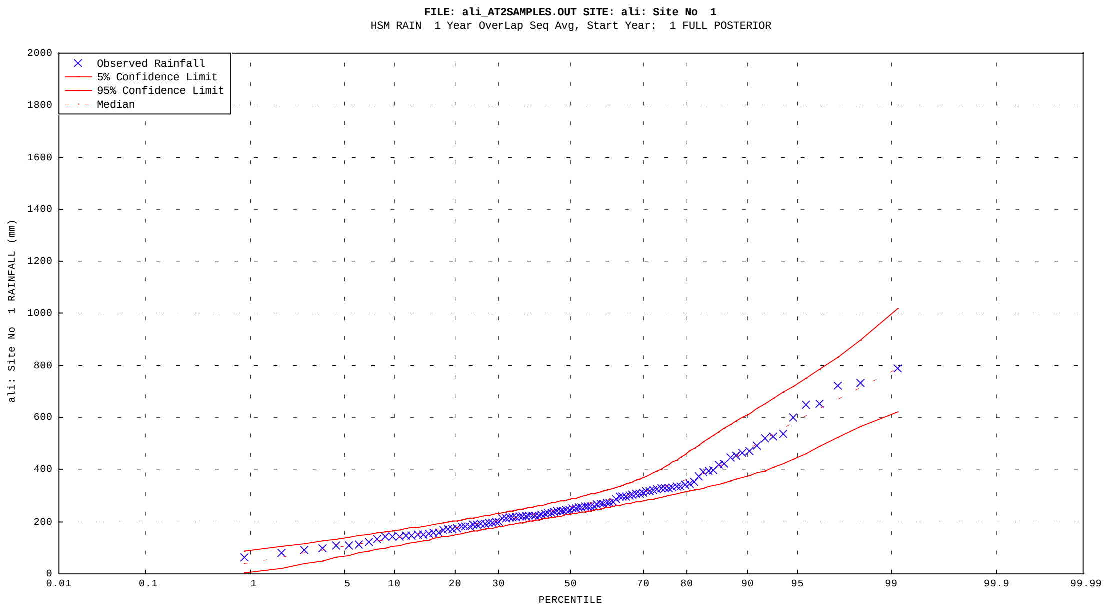


Figure D25. Comparison of the distribution of observed and generated annual rainfall for Alice Springs.

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

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