

THE VARIABILITY OF AUSTRALIAN TANK EVAPORATION

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Abstract: Tests using the larger samples of monthly evaporation (\bar{E}) data (over 25 years) indicate that the distributions are not significantly different from normal. Estimates of standard deviation ($\hat{\sigma}_E$) and mean (\bar{E}), of monthly evaporation have been computed for a large number of Australian stations and monthly maps showing the geographical distribution of $\hat{\sigma}_E$ have been constructed. Values are a minimum over the south-east of the continent and a maximum over central and northern interior.

Variability is directly proportional to mean evaporation (\bar{E}) but at individual stations $\hat{\sigma}_E$ has a climatic dependence. For example, both Alice Springs and Merredin have December values of \bar{E} of about 12 in. but the respective sample standard deviations are 2.0 and 1.1 in.

1. INTRODUCTION

The total number of stations for which reasonably reliable evaporation records are available is less than a hundred and, of these, very few have records extending beyond 50 years. Average monthly totals are available for stations having 5 years of record or more, and from these data smoothed isopleths have been constructed (Bur. of Met. 1963).

Although their usefulness is limited in the direct measurement of evaporation, average values of tank evaporation can serve a useful purpose in climatic assessments, in making approximate estimates of transpiration from crops not suffering water stress, or evaporation from large water surfaces where the pan coefficient is known.

In view of these and other applications of average values, and the considerably greater labour involved in applying monthly data for individual years in applied meteorology, it is of interest to examine the variability of tank evaporation data. Here the standard deviation of monthly totals is looked at.

Where the standard deviation is relatively small it should be possible in some studies in applied meteorology to substitute the monthly mean for individual totals with little loss of accuracy.

Consideration of the areal variation of the standard deviation may also be helpful in assessing evaporation network requirements.

2. NORMALITY OF TANK EVAPORATION DATA

Significance tests based on sample values of skewness and kurtosis for monthly totals of evaporation have been carried out for stations having relatively long records. Ten of these stations in different climatic zones are shown in Table 1. Values of γ_1 (skewness coefficient) and γ_2 (excess of kurtosis coefficient) are shown in lines 5 and 6 respectively.

Table 1. Mean Monthly Evaporation in inches, Standard Deviation of monthly totals together with 95% confidence levels and coefficients of Skewness and Kurtosis for selected stations.

Line	Symbol	Description
Line 1	\bar{E}	= mean monthly evaporation in inches
Line 2	$\hat{\sigma}_E$	= standard deviation in inches
Line 3	$\hat{\sigma}_{EL}$	= lower limit
Line 4	$\hat{\sigma}_{EU}$	= upper limit
} of 95% confidence level of σ_E		
Line 5	$\hat{\gamma}_1$	= skewness co-efficient
Line 6	$\hat{\gamma}_2$	= excess of kurtosis co-efficient
(In cases where skewness and kurtosis are significant, values of $\hat{\gamma}_1$ or $\hat{\gamma}_2$ are underlined)		
Line 7	n	= number of observations

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
MERRREDIN													
\bar{E}	13.14	10.89	9.35	5.99	3.73	2.36	2.12	2.73	4.21	6.75	9.83	12.39	83.19
$\hat{\sigma}_E$	1.11	1.04	1.29	0.85	0.65	0.46	0.42	0.44	0.62	0.74	1.06	1.09	5.40
$\hat{\sigma}_{EL}$	0.93	0.86	1.07	0.70	0.54	0.38	0.35	0.36	0.51	0.62	0.88	0.91	4.47
$\hat{\sigma}_{EU}$	1.40	1.30	1.62	1.06	0.82	0.57	0.53	0.55	0.78	0.93	1.33	1.37	6.85
$\hat{\gamma}_1$	0.15	-0.70	-0.62	-0.28	0.34	0.65	<u>0.73</u>	0.22	0.55	-0.10	<u>-0.77</u>	0.03	<u>-0.83</u>
$\hat{\gamma}_2$	-0.14	0.24	0.96	-0.73	0.56	0.64	<u>0.39</u>	0.00	0.07	-0.42	<u>0.66</u>	-0.36	<u>1.03</u>
n	47	47	47	47	46	47	46	45	47	47	47	47	44
ALICE SPRINGS													
\bar{E}	12.15	10.29	9.62	6.95	4.83	3.40	3.63	5.04	7.20	9.36	10.53	11.62	94.47
$\hat{\sigma}_E$	1.82	1.92	1.48	0.91	0.62	0.43	0.52	0.67	0.91	1.37	1.29	1.96	8.00
$\hat{\sigma}_{EL}$	1.46	1.55	1.19	0.73	0.50	0.35	0.42	0.54	0.73	1.10	1.04	1.58	6.42
$\hat{\sigma}_{EU}$	2.41	2.56	1.96	1.20	0.82	0.58	0.69	0.89	1.21	1.82	1.72	2.61	10.65
$\hat{\gamma}_1$	-0.16	0.08	-0.15	-0.33	0.59	0.04	0.01	0.39	-0.12	-0.37	-0.30	-0.64	-0.22
$\hat{\gamma}_2$	-0.77	-0.82	0.06	-0.58	1.46	-0.70	0.30	0.40	-0.18	-0.42	-0.20	-0.41	-0.93
n	33	33	33	33	33	32	32	32	33	33	33	33	32
WAITE INSTITUTE													
\bar{E}	8.45	6.92	6.25	3.93	2.45	1.72	1.65	2.24	3.20	4.54	5.83	7.42	54.51
$\hat{\sigma}_E$	0.88	0.80	0.65	0.52	0.34	0.30	0.17	0.32	0.42	0.54	0.69	0.79	3.01
$\hat{\sigma}_{EL}$	0.69	0.63	0.51	0.41	0.27	0.24	0.13	0.25	0.33	0.43	0.54	0.62	2.36
$\hat{\sigma}_{EU}$	1.20	1.10	0.89	0.71	0.47	0.42	0.23	0.43	0.57	0.74	0.94	1.07	4.15
$\hat{\gamma}_1$	0.49	-0.10	-0.10	0.30	<u>1.13</u>	0.79	-0.25	0.19	0.09	0.53	0.31	0.47	0.48
$\hat{\gamma}_2$	-0.31	-0.20	0.45	0.13	<u>0.82</u>	0.00	-0.61	-0.65	-0.53	0.04	0.07	-0.17	-0.06
n	27	27	27	27	27	27	28	28	28	28	27	28	26
BRISBANE													
\bar{E}	7.05	5.48	5.35	4.45	3.62	2.93	3.07	4.06	4.88	6.00	6.65	7.43	60.66
$\hat{\sigma}_E$	1.38	0.99	0.97	0.75	0.67	0.60	0.72	0.82	0.82	1.02	1.27	1.31	6.08
$\hat{\sigma}_{EL}$	1.13	0.82	0.80	0.62	0.54	0.49	0.59	0.67	0.67	0.84	1.04	1.08	4.97
$\hat{\sigma}_{EU}$	1.76	1.27	1.24	0.96	0.86	0.76	0.93	1.04	1.05	1.31	1.62	1.67	7.83
$\hat{\gamma}_1$	0.11	0.00	0.19	0.28	0.30	<u>1.28</u>	<u>0.83</u>	<u>0.81</u>	<u>0.93</u>	0.26	-0.50	-0.27	0.11
$\hat{\gamma}_2$	-1.01	-0.60	-0.53	0.57	-0.23	<u>2.08</u>	<u>0.85</u>	<u>0.79</u>	<u>1.21</u>	-0.36	-0.86	-0.74	-0.23
n	41	41	41	41	40	41	40	41	41	41	41	41	40

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
SYDNEY													
\bar{E}	5.12	3.87	3.59	2.87	2.17	1.57	1.55	2.09	2.68	4.02	4.82	5.24	39.59
$\hat{\sigma}_E$	0.61	0.47	0.59	0.41	0.46	0.41	0.37	0.45	0.34	0.43	0.79	0.72	3.32
$\hat{\sigma}_{EL}$	0.46	0.36	0.44	0.31	0.35	0.31	0.26	0.34	0.26	0.32	0.59	0.54	2.50
$\hat{\sigma}_{EU}$	0.90	0.70	0.87	0.60	0.69	0.60	0.54	0.66	0.50	0.63	1.16	1.06	4.90
$\hat{\gamma}_1$	0.28	-0.19	-0.19	0.16	0.99	0.63	0.29	0.32	-0.31	0.71	0.10	0.21	0.11
$\hat{\gamma}_2$	-0.99	-0.95	-0.65	-0.40	0.50	-0.17	-0.44	-1.06	0.25	-0.06	-0.90	-0.17	0.17
n	19	19	19	19	19	19	19	19	19	19	19	19	19
BATHURST													
\bar{E}	7.33	5.92	5.18	3.19	1.97	1.22	1.28	1.85	2.91	4.21	5.49	6.78	47.61
$\hat{\sigma}_E$	1.30	1.16	0.84	0.67	0.34	0.16	0.24	0.27	0.46	0.59	0.97	1.29	3.64
$\hat{\sigma}_{EL}$	1.03	0.92	0.66	0.53	0.27	0.13	0.19	0.21	0.36	0.47	0.77	1.02	2.88
$\hat{\sigma}_{EU}$	1.75	1.57	1.13	0.90	0.46	0.22	0.33	0.36	0.62	0.79	1.32	1.76	4.96
$\hat{\gamma}_1$	0.18	0.13	0.03	0.06	<u>1.35</u>	0.59	0.22	0.28	0.27	0.05	0.35	-0.14	0.23
$\hat{\gamma}_2$	-1.19	-1.01	-0.51	-0.69	<u>2.01</u>	0.46	-0.03	-0.29	-0.45	-0.48	-0.22	-0.23	0.13
n	29	29	29	29	29	29	29	29	29	29	29	28	28
UMBERUMBERKA													
\bar{E}	12.44	10.41	8.97	5.94	4.06	2.81	2.84	3.86	5.67	8.21	10.04	11.82	87.23
$\hat{\sigma}_E$	1.60	1.42	1.22	0.83	0.81	0.54	0.59	0.92	1.01	1.28	1.51	1.54	8.17
$\hat{\sigma}_{EL}$	1.33	1.18	1.00	0.68	0.67	0.45	0.49	0.76	0.84	1.06	1.25	1.28	6.73
$\hat{\sigma}_{EU}$	2.02	1.79	1.54	1.05	1.01	0.68	0.75	1.16	1.27	1.61	1.90	1.94	10.46
$\hat{\gamma}_1$	-0.44	-0.46	-0.26	-0.07	0.43	0.71	0.47	0.64	-0.66	0.02	0.05	-0.23	-0.36
$\hat{\gamma}_2$	-0.69	-0.41	-0.65	-0.57	-0.27	0.34	0.20	-0.20	-0.15	-0.16	0.26	-0.36	-0.54
n	47	47	45	44	47	45	46	46	45	46	46	46	42
MERBEIN													
\bar{E}	9.57	7.47	6.50	3.97	2.50	1.82	1.73	2.43	3.92	5.67	7.30	9.10	61.99
$\hat{\sigma}_E$	1.32	1.08	1.03	0.68	0.36	0.39	0.35	0.45	0.69	1.04	1.21	1.41	7.17
$\hat{\sigma}_{EL}$	1.06	0.87	0.83	0.55	0.29	0.31	0.29	0.36	0.55	0.84	0.98	1.13	5.69
$\hat{\sigma}_{EU}$	1.73	1.44	1.36	0.89	0.48	0.52	0.47	0.60	0.91	1.38	1.60	1.87	9.69
$\hat{\gamma}_1$	-0.37	-0.41	0.49	0.25	0.60	-0.02	0.27	<u>0.93</u>	0.40	0.84	0.80	0.19	0.73
$\hat{\gamma}_2$	-0.14	-0.58	-0.36	-0.80	0.74	-0.92	-0.17	<u>0.80</u>	-0.70	0.95	0.02	-0.57	-0.73
n	34	33	34	34	32	31	33	32	34	33	34	33	29
MELBOURNE													
\bar{E}	6.58	5.10	4.22	2.59	1.58	1.16	1.15	1.55	2.39	3.43	4.55	5.88	40.20
$\hat{\sigma}_E$	0.65	0.59	0.56	0.35	0.24	0.21	0.20	0.22	0.35	0.45	0.58	0.71	2.63
$\hat{\sigma}_{EL}$	0.64	0.59	0.51	0.33	0.22	0.22	0.18	0.21	0.31	0.38	0.51	0.68	2.55
$\hat{\sigma}_{EU}$	0.87	0.79	0.69	0.44	0.30	0.30	0.24	0.28	0.42	0.51	0.69	0.92	3.46
$\hat{\gamma}_1$	-0.43	0.03	0.27	0.13	0.25	0.28	0.09	0.03	0.26	0.59	-0.11	0.20	0.26
$\hat{\gamma}_2$	-0.37	-0.83	-0.35	-0.35	-0.48	-0.64	-0.74	-0.81	-0.03	0.43	-0.70	-0.27	-0.80
n	59	59	59	59	59	59	59	59	59	59	59	59	59
HOBART													
\bar{E}	4.97	3.82	3.17	2.04	1.39	0.95	0.93	1.27	1.98	3.09	3.84	4.45	31.91
$\hat{\sigma}_E$	0.79	0.71	0.50	0.39	0.26	0.24	0.27	0.25	0.36	0.62	0.76	0.70	3.51
$\hat{\sigma}_{EL}$	0.63	0.57	0.41	0.31	0.21	0.19	0.22	0.20	0.29	0.50	0.61	0.56	2.82
$\hat{\sigma}_{EU}$	1.05	0.94	0.67	0.51	0.35	0.32	0.37	0.34	0.48	0.83	1.01	0.93	4.67
$\hat{\gamma}_1$	0.47	0.09	0.47	0.33	0.58	<u>1.08</u>	<u>1.54</u>	<u>1.19</u>	0.07	<u>0.94</u>	0.14	0.12	0.25
$\hat{\gamma}_2$	-0.60	-0.65	-0.13	0.39	1.67	<u>0.93</u>	<u>4.07</u>	<u>0.83</u>	0.29	<u>0.65</u>	-1.14	-0.93	-0.71
n	33	33	33	33	33	32	33	33	33	33	33	33	33

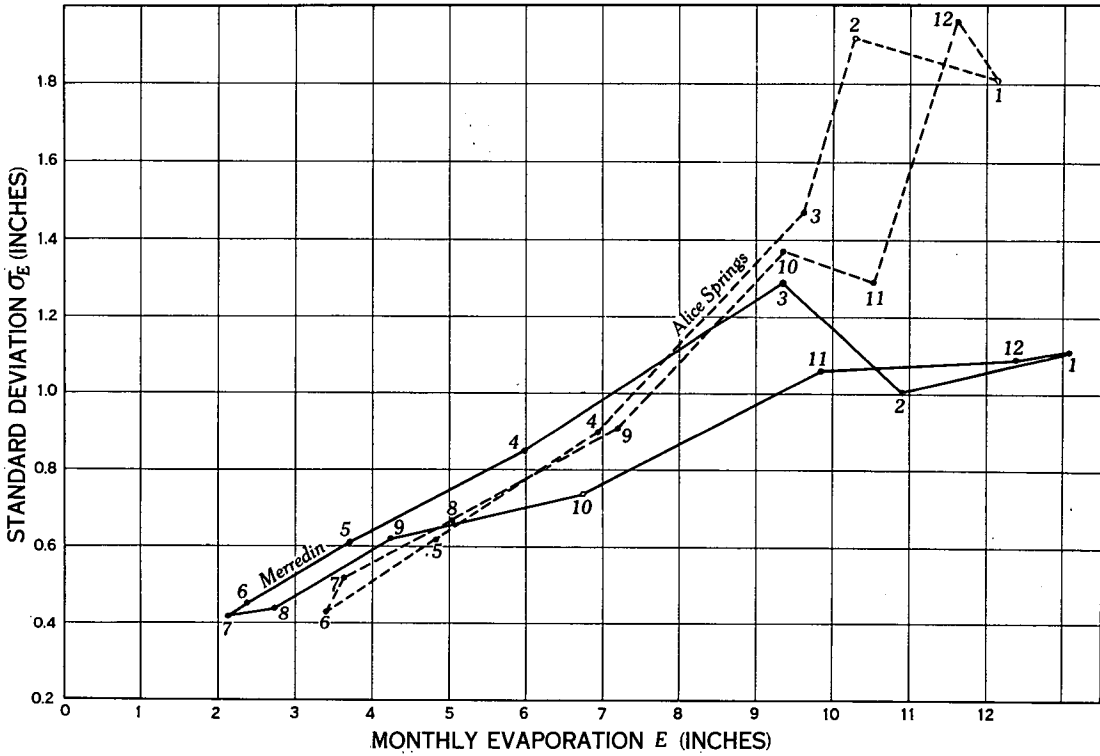


Fig. 1(a) Showing relationship between average monthly E and σ_E

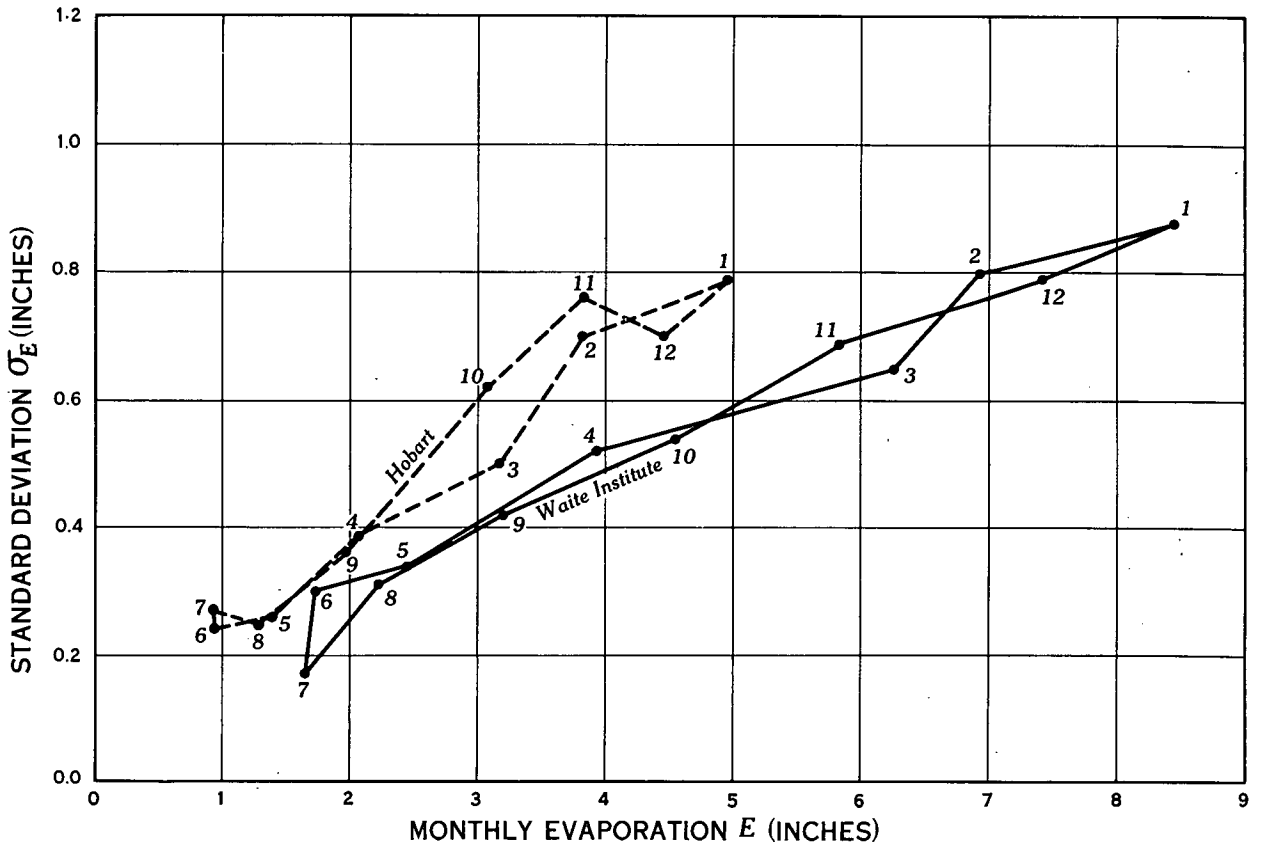


Fig. 1(b) Showing relationship between average monthly E and σ_E

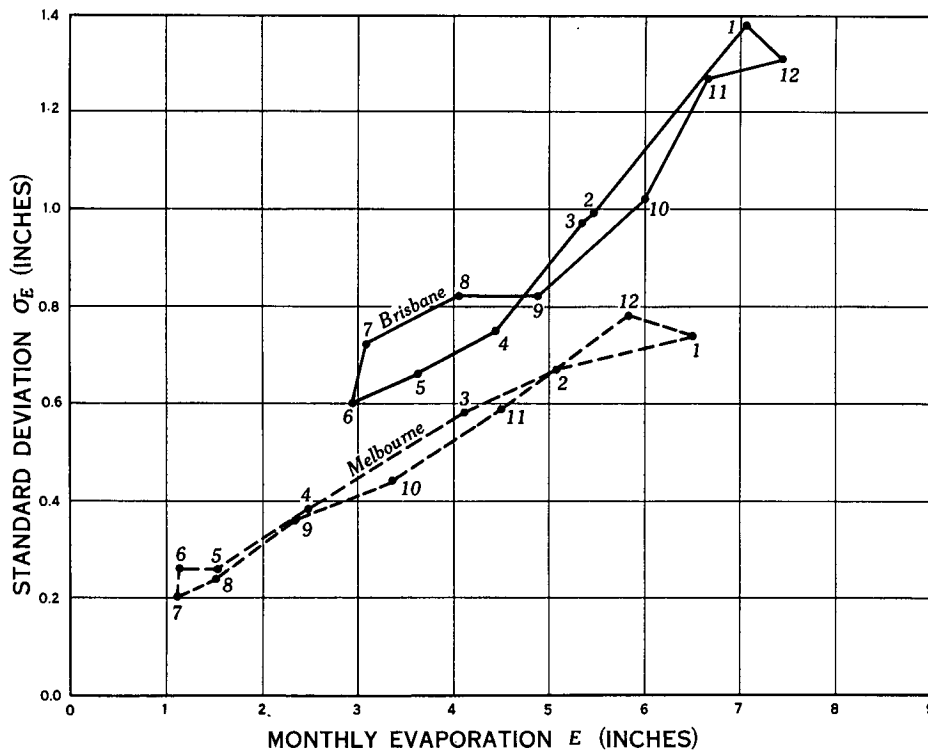


Fig. 1(c) Showing relationship between average monthly E and σ_E

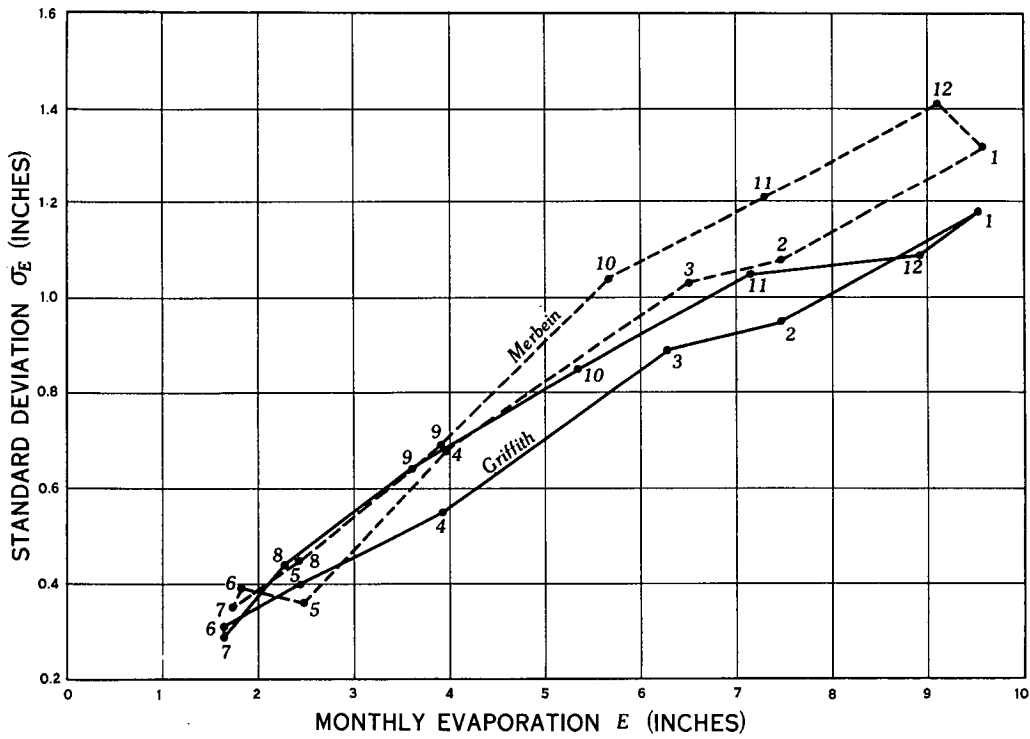


Fig. 1(d) Showing relationship between average monthly E and σ_E

In most cases the tests indicate that the distributions of monthly totals are probably normal, but in view of the low value of n (less than 50 years in most cases) they are not conclusive.

3. STANDARD DEVIATION $\hat{\sigma}_E$ OF MONTHLY EVAPORATION

The values of \bar{E} and $\hat{\sigma}_E$ for selected stations are shown in Table 1.

In view of the relatively short period of record for many stations it is pertinent to have some knowledge of the reliability of the estimates and for this purpose the upper and lower 95% confidence limits of $\hat{\sigma}_E$ have been computed and are also shown in Table 1. Some of these are quite wide and were even wider for a number of stations not shown in the table. The need for longer periods of record at many stations is indicated.

The relationship between E and σ_E is of interest and has been referred to previously (Hounam 1963). The examination is here extended to a greater number of stations and Fig. 1(a-d) shows the relationship for selected stations in different climatic zones.

4. VARIABILITY OF METEOROLOGICAL PARAMETERS CONTROLLING EVAPORATION

Fig. 1 immediately suggests the climatic dependance of σ_E and it is of interest to look at the variability of a meteorological parameter on which evaporation is dependent. Radiation would be the first choice but lengths of record are inadequate for such an examination; hence sunshine and cloudiness have been substituted.

Melbourne and Brisbane were selected because both stations have average January evaporation approximating to 7 inches but rather different $\hat{\sigma}_E$ values (0.74 and 1.37 in. respectively).

The distributions of monthly sunshine for January are about normal and estimates of means and standard deviations are as follows:-

	Mean Sunshine (hours/day)	Standard Deviation (hours)
Melbourne	8.7	1.0
Brisbane	9.1	1.4

It can be inferred that the greater variability of monthly evaporation at Brisbane is related in part to the greater variability of monthly sunshine.

The same conclusion can be drawn from an examination of daily values of sunshine but in this case the distribution is not normal. Using mean deviation the variabilities of daily sunshine are 3.0 and 3.7 hours respectively at Melbourne and Brisbane.

In the arid summer climates at Alice Springs and Merredin, average evaporation totals for December approximate to 12 inches with $\hat{\sigma}_E$ values 1.96 and 1.09 in. respectively. As sunshine data are not available for Merredin, cloudiness is used here. The standard deviations of December monthly mean cloudiness expressed in tenths of sky covered, are 1.0 at Alice Springs and 0.7 at Merredin. The distribution of daily cloudiness is quite abnormal, as with sunshine, but the mean deviations are 2.3 and 1.2 tenths respectively at Alice Springs and Merredin, thus conforming with the variabilities of the respective evaporation means.

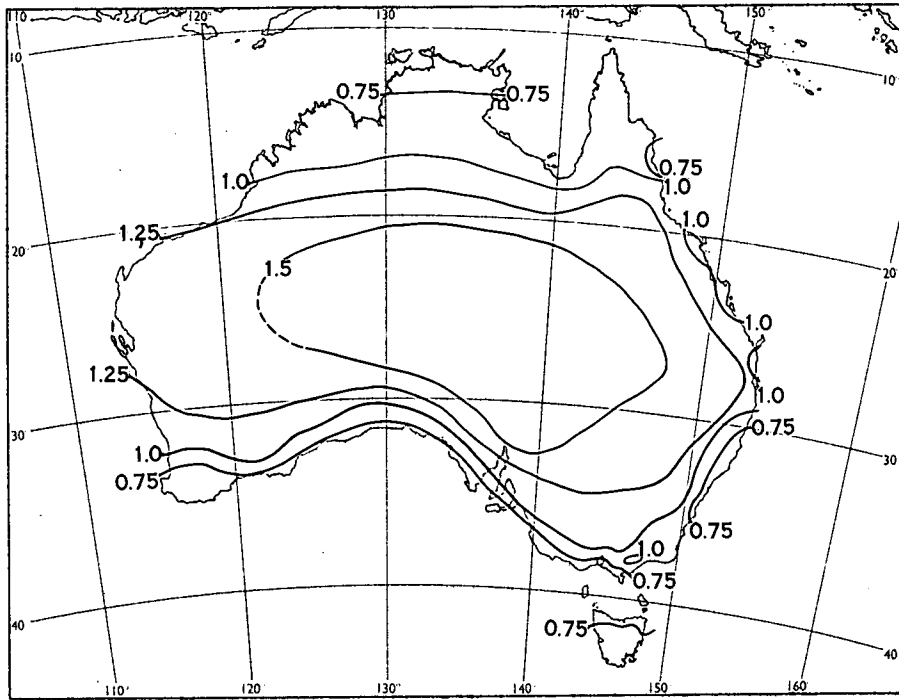


Fig. 2(a) Standard deviation of monthly evaporation for January (inches).

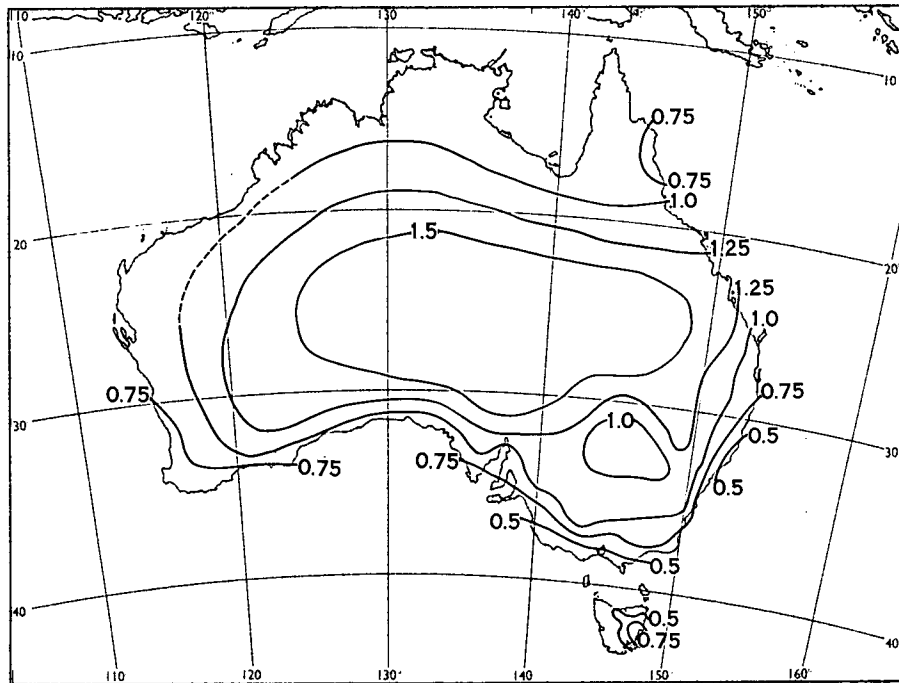


Fig. 2(b) Standard deviation of monthly evaporation for February (inches).

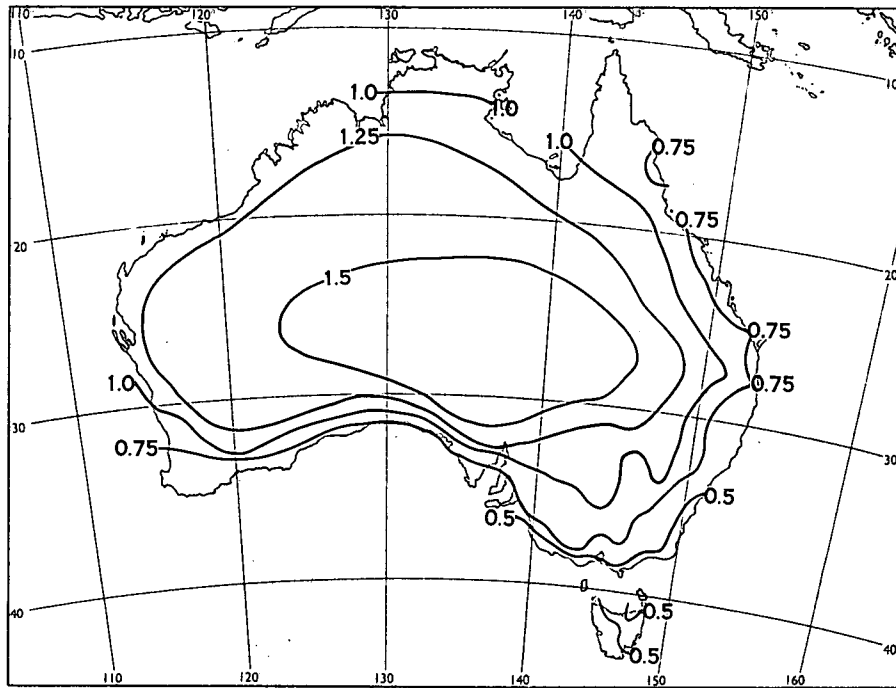


Fig. 2(c) Standard deviation of monthly evaporation for March (inches).

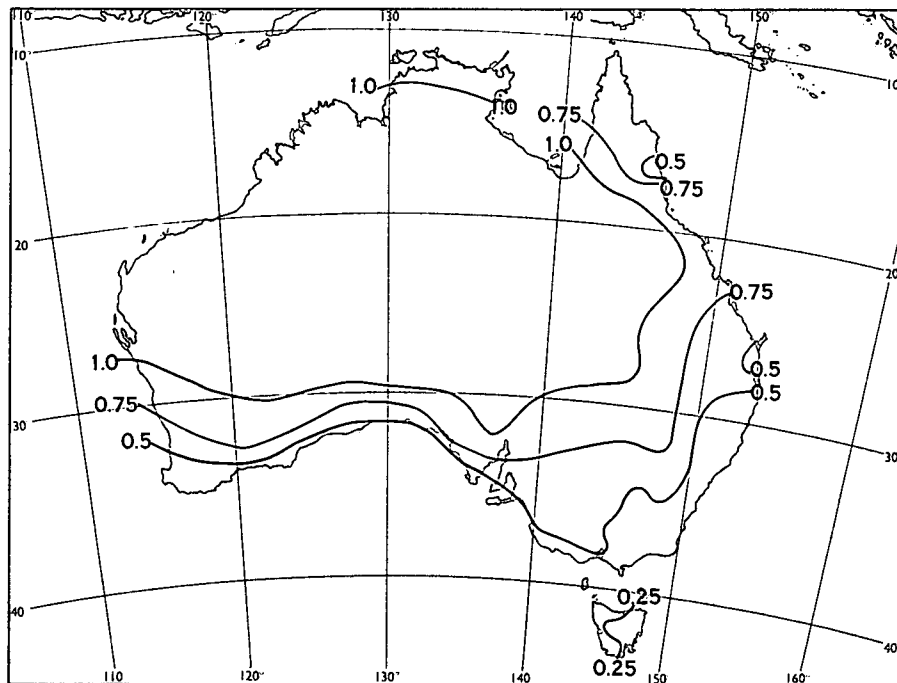


Fig. 2(d) Standard deviation of monthly evaporation for April (inches).

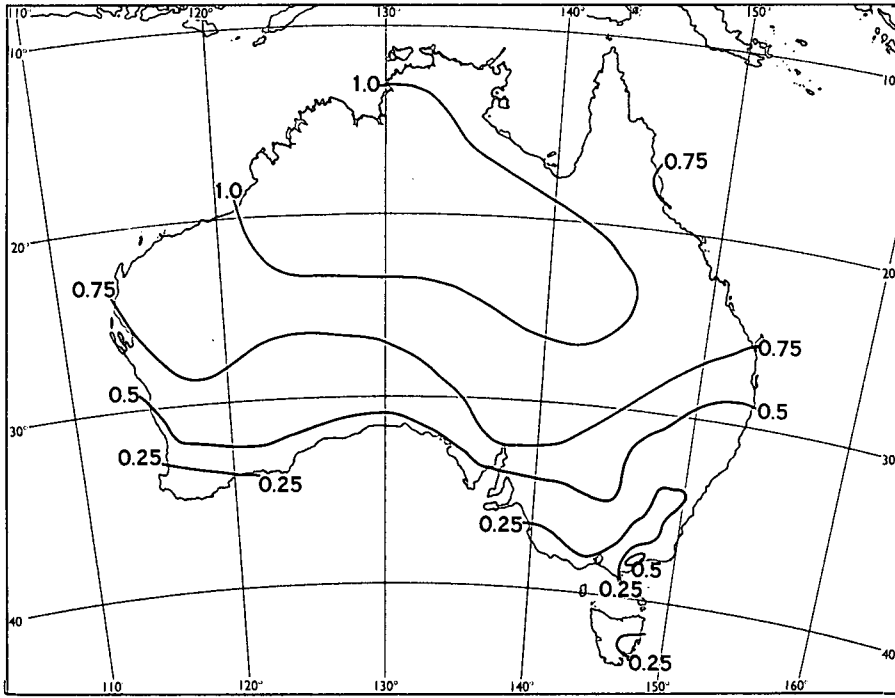


Fig. 2(e) Standard deviation of monthly evaporation for May (inches).

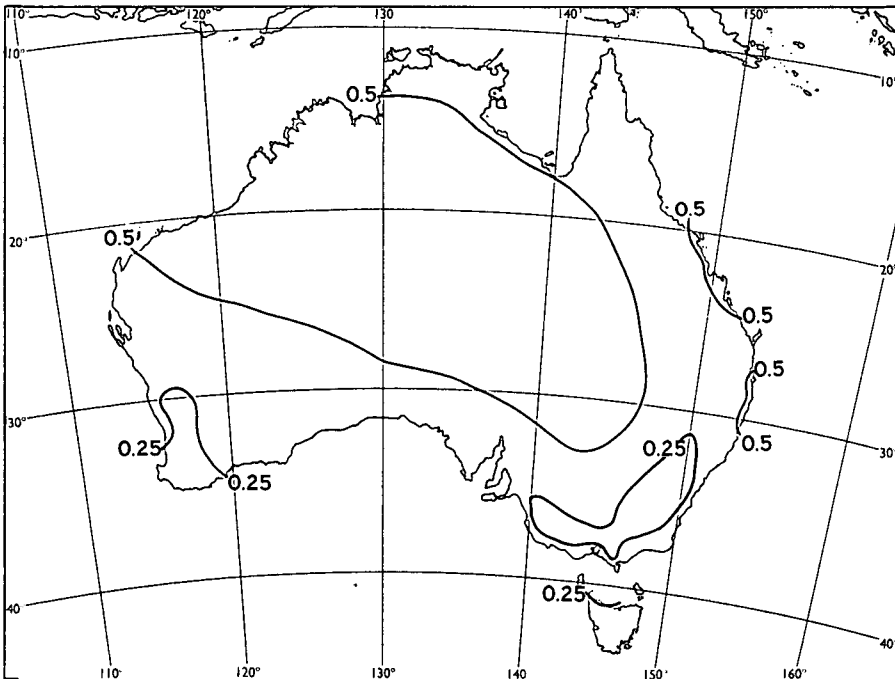


Fig. 2(f) Standard deviation of monthly evaporation for June (inches).

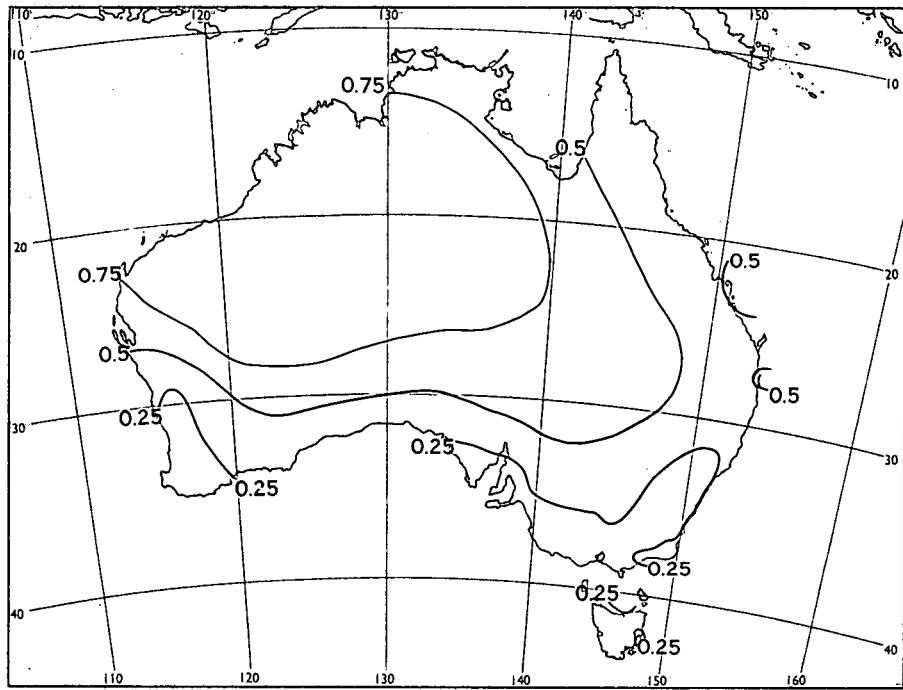


Fig. 2(g) Standard deviation of monthly evaporation for July (inches).

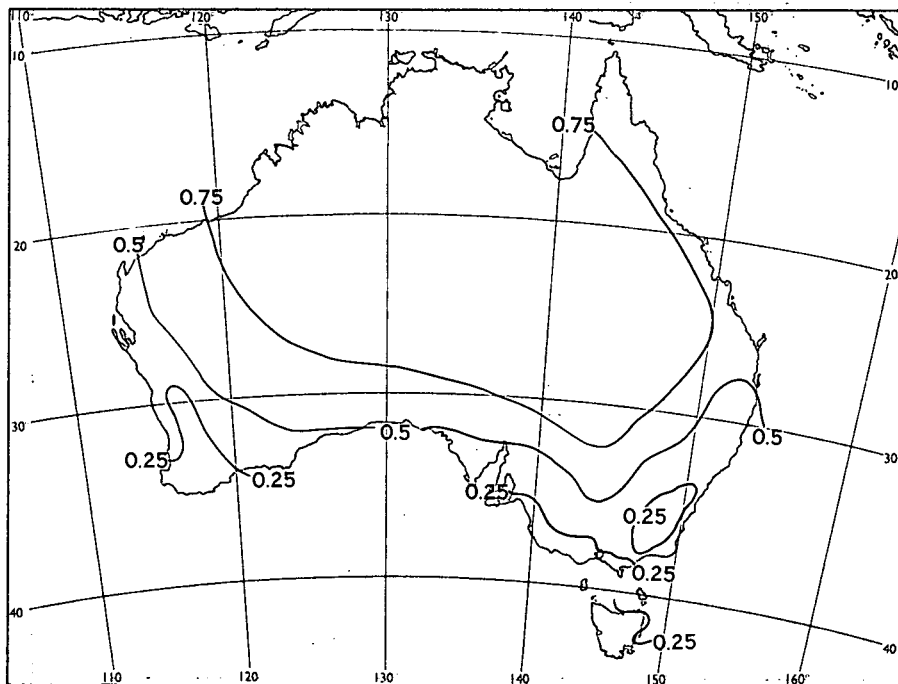


Fig. 2(h) Standard deviation of monthly evaporation for August (inches).

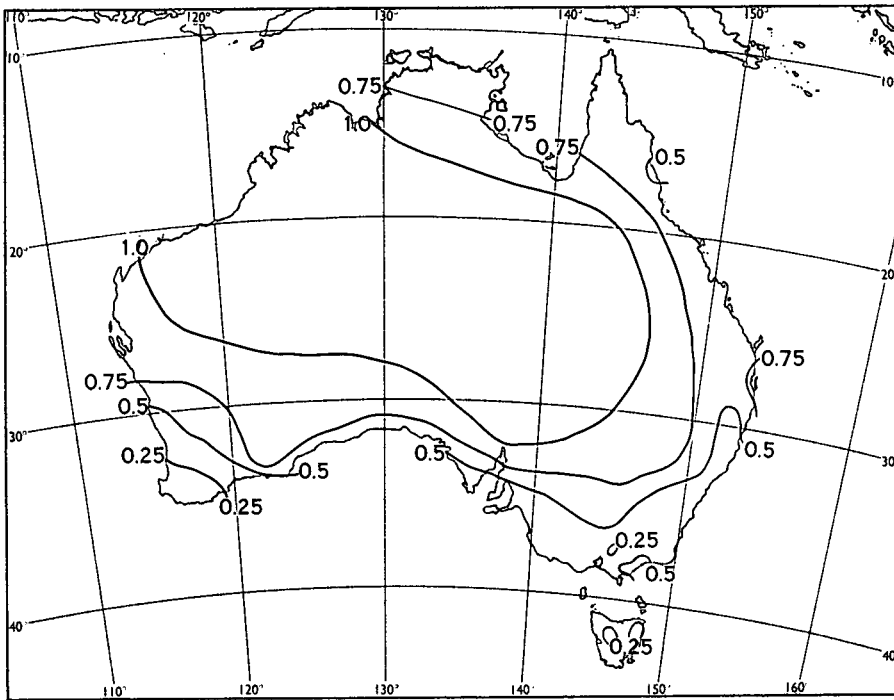


Fig. 2(i) Standard deviation of monthly evaporation for September (inches).

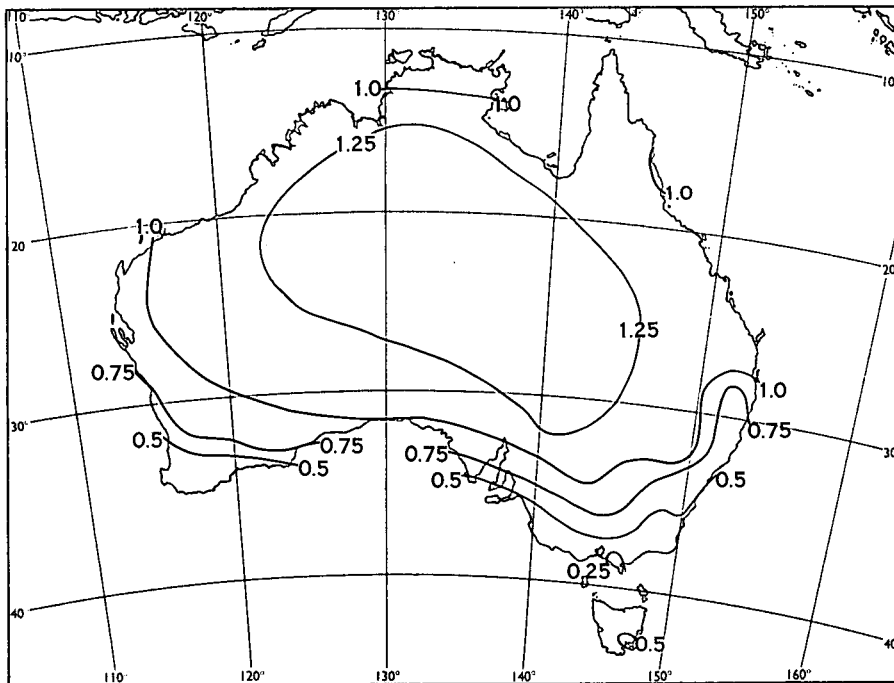


Fig. 2(j) Standard deviation of monthly evaporation for October (inches).

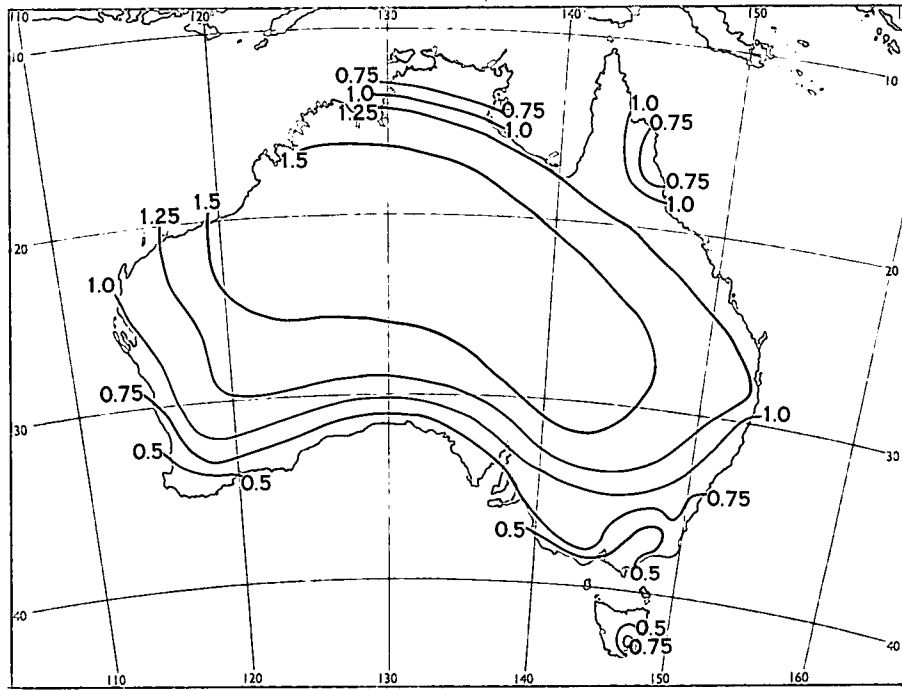


Fig. 2(k) Standard deviation of monthly evaporation for November (inches).

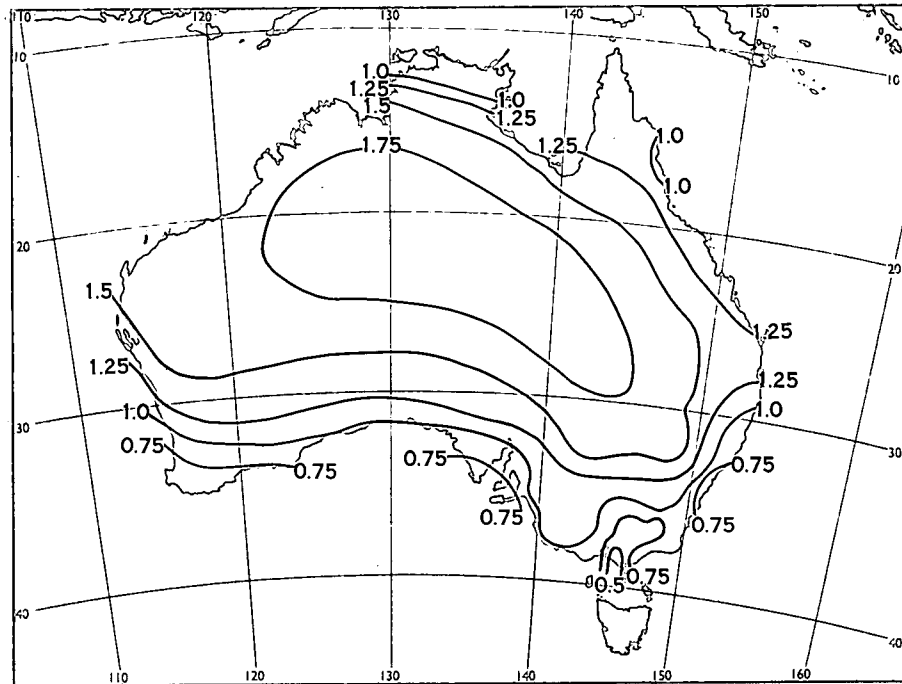


Fig. 2(l) Standard deviation of monthly evaporation for December (inches).

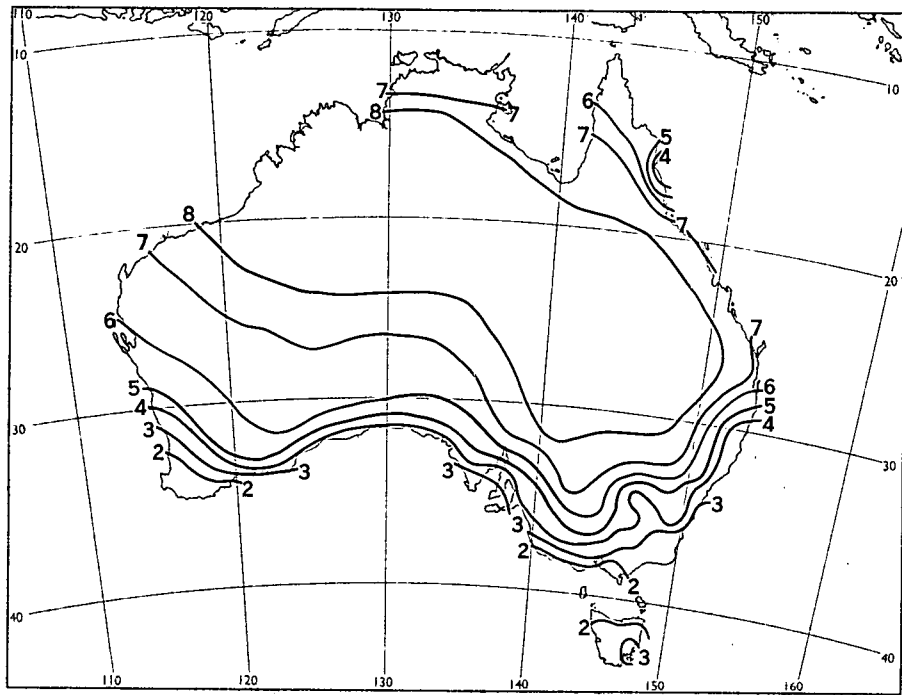


Fig. 2(m) Standard deviation of yearly evaporation (inches).

5. GEOGRAPHICAL DISTRIBUTION OF $\hat{\sigma}_E$

Monthly and annual values of $\hat{\sigma}_E$ for stations, together with upper and lower confidence limits, were plotted and Fig. 2(a-m) shows smoothed isopleths.

Generally speaking there is relatively good agreement between values over southeastern Australia. Gradients over Tasmania are apparently quite weak and isopleths have little significance. However, great uncertainties exist regarding σ_E over most of central and northern Australia in view of the short period of record.

Variability is least over the far south and southeast and is a maximum over the central and northern interior; this pattern is maintained for each month of the year. Annual values of $\hat{\sigma}_E$ range between under 3 inches over Tasmania and southern Victoria and over 8 inches over a wide belt extending from the Upper Darling to the northwest coast of Western Australia. Values are less, below 5 inches in parts, over the wetter tropical areas. Gradients are strongest over the south and eastern districts.

Variability at all stations is a maximum in the summer months and a minimum in the winter months; this characteristic is also shown in Fig. 1. Whilst $\hat{\sigma}_E$ is approximately proportional to the magnitude of \bar{E} , it is not demonstrated that the greatest variability coincides with the area of maximum evaporation. Unfortunately records are too short to give reliable values of σ_E over most of central and northern Australia but Section 4 above indicates how variability depends on climate and therefore on geographical location.

Generally speaking the distribution of the annual value of σ_E from the short samples agrees with that for the Class A pan over the United States as described by Kohler, Nordenson and Baker (1959). It is noteworthy that the centre of maximum variability (over Kansas) is significantly different from that of maximum pan evaporation (southwest Texas).

6. CONCLUSIONS

Variability of tank evaporation exhibits a definite geographical pattern, being least in the southeast of Australia. Although records are sparse and short over the central and northern inland region, it is fairly certain that variability is a maximum there.

Variability follows a seasonal trend corresponding approximately to E with summer maximum and winter minimum. It is related to climate, being relatively higher in areas where radiation (or sunshine) is more variable. The variability of evaporation is appreciably less than the variability of rainfall.

Average values of evaporation should be adequate in some hydro- and agro-meteorological studies.

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