A note on the relationship between annual rainfall and tree-ring indices for one site in South Africa

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Abstract

The only tree-ring-width index chronology presently available in South Africa is at a site in the Cedarberg Mountains north of Cape Town. The transformed indices of the 376 year record constitute a stationary time series which is autoregressive of order two. The residuals of this series were correlated with annual precipitation from the nearest available raingauge for which a record of 78 years was available. The correlation coefficient of 0,474 is statistically significant but not sufficiently high for satisfactory reconstruction of the rainfall record for engineering purposes. However, with a better data base, useful reconstruction is not out of the question.

Introduction

Most reservoir design criteria are based on critical periods of water shortages. Available stream flow and rainfall records, while perhaps satisfactory to describe the mean and the variance of the flow, are notoriously inadequate for the calculation of the risk associated with such extreme drought events – the records are simply too short. Tree-ring indices are a possible source of information which could be utilized to extend the record. La Marche *et al.*, (1979) provided a ring-width index chronology for a site, Die Bos, in the Cedarberg Mountains north of Cape Town, reproduced in Table 1.

The nearest reasonable raingauge record was at Wupperthal with data available from October 1898 to September 1977. These two sets of data allow an investigation into the relationship between ring-width indices and annual rainfall.

TABLE 1
TREE-RING INDICES FOR DIE BOS, LATITUDE 32°24'S LONGITUDE 19°13'E, ALTITUDE 1330 m

Date	Tree-ring Indices 0	1	2	3	4	5	6	7	8	9
1600			134	91	96	76	76	71	71	65
1610	75	102	99	88	103	108	76	72	93	108
1620	123	96	91	81	79	90	90	94	104	111
1630	116	94	100	93	106	108	99	116	117	121
1640	112	108	94	97	109	136	115	137	138	135
1650	116	97	98	93	89	88	82	99	94	86
1660	85	97	109	110	113	94	98	83	120	152
1670	124	104	126	111	108	71	82	88	98	89
1680	88	96	98	110	107	112	127	137	132	147
1690	103	135	97	84	136	115	131	113	117	126
1700	99	111	129	128	102	117	88	105	102	117
1710	108	104	83	99	94	88	78	77	81	81
1720	67	101	119	104	95	72	84	73	76	81
1730	80	67	79	87	102	85	85	104	88	71
1740	65	76	95	97	109	119	94	94	100	104
1750	121	121	134	105	98	79	95	99	98	75
1760	104	84	97	115	104	81	105	105	124	107
1770	112	110	104	106	111	132	151	135	113	99
1780	91	91	103	101	108	97	105	215	182	138
1790	127	94	101	87	91	146	93	94	69	89
1800	79	87	88	94	84	99	101	106	103	103
1810	124	110	104	108	107	85	157	97	90	97
1820	78	67	70	81	85	62	73	71	96	76
1830	95	103	100	86	95	103	91	79	92	101
1840	84	85	85	125	85	91	98	98	88	105
1850	113	102	83	76	97	82	100	88	99	103
1860	89	88	96	116	95	92	86	76	89	123
1870	92	85	61	76	107	106	110	132	101	124
1880	86	73	115	133	106	115	95	103	110	115
1890	93	92	119	107	110	132	93	117	107	127
1900	162	113	89	95	92	79	101	88	80	99
1910	80	80	90	86	85	138	125	107	129	127
1920	134	101	106	96	101	116	103	94	74	111
1930	71	109	75	116	115	101	106	99	85	71
1940	83	92	104	117	110	113	112	120	128	139
1950	184	167	131	127	120	123	108	90	59	99
1960	68	68	92	79	76	73	64	73	85	84
1970	86	79	91	89	96	85	145	73		

Method

About 2% of the monthly rainfall record was missing and had to be estimated using neighbouring rainfall records. This was done by simple linear regression.

The ring-width indices were transformed using:

$$z_t = x_t - \bar{x} \qquad (1)$$

where

$$x_t = \ln(w_t) \qquad (2)$$

and w_t represents the ring-width index for year t and $\bar{x}$ is the average of x_t. Although indices are available for the period 1564 to 1977 only those indices based on 4 or more samples were used. Hence the index-record from 1602 tot 1977 (376 observations) was used. The log of the ring-width index was used instead of the ring-width index in order to obtain normally distributed residuals. Except for a single outlier (1787) the residuals conform very well to a normal distribution.

The estimated serial correlation- and partial serial correlation functions of z_t are shown in Figure 1.

The dashed line given with the serial correlation coefficients indicate the approximate 95% critical points, $-2/\sqrt{376}$ and $2/\sqrt{376}$ for the null hypothesis that the series is serially uncorrelated. Clearly this hypothesis must be rejected. The dashed lines given with the partial serial correlation coefficients indicate

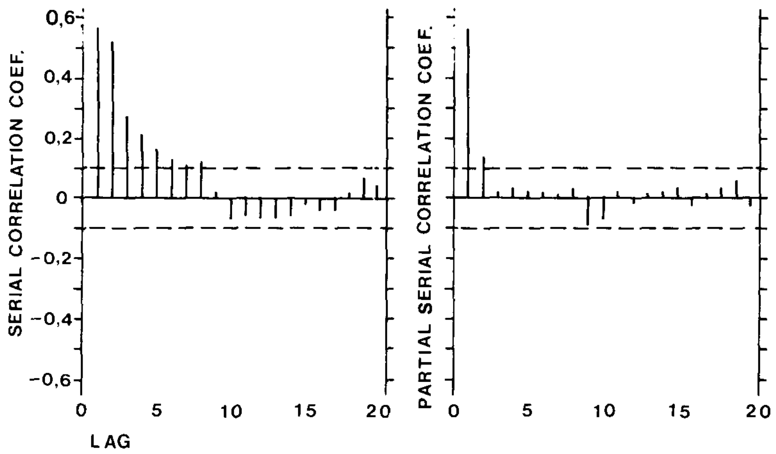

Figure 1
Serial correlation and partial serial correlation functions for transformed tree ring-width indices

the approximate 95% critical points, also $-2/\sqrt{376}$ and $2/\sqrt{376}$, for the null hypothesis that the partial serial correlation coefficients exceeding a given log are zero. Here one can see that the first two coefficients are significant. This indicates that the transformed tree-ring indices constitute an autogressive model of order 2, which means that the growth of the tree in any given year depends quite strongly on the growth in the previous two years. For a meaningful regression analysis this "memory" effect needs to be taken in account i.e. subtracted or "pre-whitened". (Jenkins, 1978). Fitting the model

$$z_t = \delta_1 z_{t-1} + \delta_2 z_{t-2} + a_t \quad (3)$$

by maximum likelihood results in the estimates:

$$\hat{x} = 4,5915$$
$$\hat{\delta}_1 = 0,4772$$
$$\hat{\delta}_2 = 0,1409$$

The residuals are therefore estimated using:

$$a_t = z_t - 0,4772\, z_{t-1} - 0,1409\, z_{t-2} \quad (4)$$

These residuals were found to be serially uncorrelated.

In the regression of annual rainfall on these residuals it must be kept in mind that the growth season of a tree does not necessarily coincide with the calendar year. For example the rainfall in November of one year may affect the growth of the next rather than the current year's ring-width. For this particular site (Winter rainfall region) growth should start in about March. This was confirmed by the correlation analysis shown in Figure 2.

This figure shows the estimated correlation coefficient between "annual rainfall" starting in a particular month and the residuals of the ring-width indices. The highest correlation of 0,474 was achieved with a "water year" starting in March. This correlation coefficient is statistically significant at the 1% level. For our purpose, however, this correlation coefficient is not high enough for reconstruction of the rainfall record back to 1602. One would like a somewhat higher coefficient, say 0,7. It should be noted that an attempt to correlate the untransformed ring-width indices before pre-whitening with annual rainfall is not only misleading but also results in a smaller correlation coefficient.

The distance between the raingauge and the tree-ring site is about 35 km. A closer raingauge may well have resulted in a higher cross-correlation. (The cross-correlation coefficient between annual rainfall totals at Wupperthal and Mertenhof, which are less than 15 km apart, was estimated to be 0,85. This estimate was based on data from 1898 to 1977).

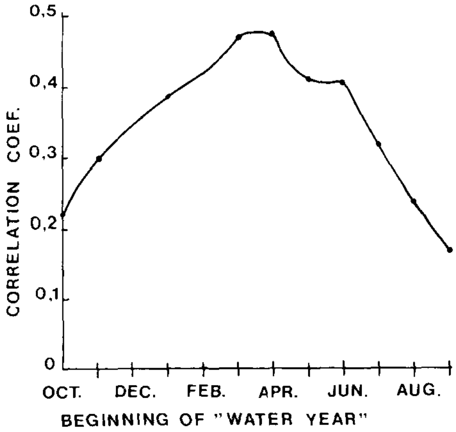

Figure 2
Correlation coefficients for tree ring-width residuals and annual rainfall for "water years" starting in the month shown.

Conclusion

This analysis suggests that with suitable data and proper methodology the possibility exists to extend rainfall records by means of tree-ring indices. Other measurements on trees, for example cell cross-sectional areas are potentially even more promising.

References

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