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Historical records of cloud cover and climate for Australia

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Records of Australian climatic statistics, obtained from the Australian Bureau of Meteorology, have been analysed to investigate the relationship between cloud cover, precipitation, temperature and the Southern Oscillation Index (SOI). In particular, the role of cloud cover in climatic change is considered. Analyses show a close correlation between precipitation and cloud cover and an inverse correlation between the diurnal temperature range and cloud cover. Significant long-term trends are evident in the data, with an increase in cloud cover and a decrease in the diurnal temperature range. There is also a slight increase in daily mean temperature, but no significant long-term change in precipitation (although the lack of significant trend may, in part, be due to the shorter length of record). The fluctuations in cloud cover, diurnal temperature range and precipitation are correlated with the SOI. Correlations of cloud cover with SOI are strongest for the northeast and weakest for the southwest of the continent.

Introduction

Historical records of climate, most commonly temperature (e.g. Jones et al. 1986b) and precipitation (e.g. Diaz et al. 1989), have been used to investigate climatic change. In order to obtain some physical insight into the mechanisms of climatic change, it is useful to consider the records of several climatic parameters together (e.g. Plantico et al. 1990). Due to the limitations in the availability of data, such intercomparisons of climatic records are usually restricted to a regional, rather than a global basis. This paper presents data for cloud cover, precipitation and temperature for Australia. Because of the significant effect on Australian climate of the El Niño-Southern Oscillation (ENSO), the climatic records are also compared with the Southern Oscillation Index (SOI).

This paper concentrates on the role of cloud cover in climate, as a major determinant of temperature due to the effect on incoming visible solar radiation and outgoing infrared radiation, and as the source of precipitation. The effects of clouds are a major uncertainty in general circulation models (GCMs) of the climate (Webster and Stephens 1984). Historical observations may be used to clarify the processes involved and to suggest empirical models which can be related to GCMs.

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Data and methods

The historical climate records were obtained from the National Climate Centre (NCC) of the Australian Bureau of Meteorology. The data were in the form of tabulated (TABS) elements, which are monthly values of a large number of climatic parameters, for over 1000 stations, dating back over 100 years for some stations. The values are monthly means (for cloud cover and temperature) or monthly totals (for precipitation).

The main method of data analysis used in this paper is the least-squares linear fit of the climatic parameter (cloud cover, precipitation, temperature or Southern Oscillation Index) against time to give the long-term trend, or of one climatic parameter against another to give the empirical relation between the two parameters.

The significance of the correlation between the two parameters is described by the correlation coefficient r, with $r \approx 0$ where there is no correlation, $0 < r < 1$ for a positive relation and $-1 < r < 0$ for a negative relation. For n degrees of freedom, the critical value for significance at the 5 per cent level in the correlation coefficient r is approximately $r_c = 2 \times n^{-0.5}$. However, the climate records for consecutive months are not independent since there are climatic fluctuations lasting several months. Due to this serial correlation of the time series, the number of degrees of freedom is less than the number of monthly records. Assuming that the number of degrees of freedom is only half the number of monthly records, we get $r_c = 0.15$ for 30 years of data. The exact critical level depends on the number of records and the degree of serial correlation, but this does not affect the conclusion that the majority of the correlations considered here are highly significant. The climatic data were analysed in several different ways:

(a) Records for individual stations were fitted against time, to give the long-term trend for that station (for cloud cover, temperature and precipitation), and the Australia-wide trend is given as the mean of the trends for all stations.
(b) The relation between precipitation or temperature and cloud cover was considered by using the mean values (averaged over all years) for a given station and month of year.
(c) Cloud cover records for each station were compared to the time series of SOI.
(d) Time series of residuals of cloud cover, precipitation and temperature were generated by averaging the data for that month (normalised by the mean for that station) over all stations. These Australia-wide time series were correlated against each other and against SOI.
(e) The time series were correlated against time to give the overall trends.

The correlations between climatic parameters considered here, and the corresponding fitted relations, should be treated with caution as a statistical correlation does not imply a direct physical cause. Since physical feedbacks between the parameters are expected to be important, the cause of a correlation between any two parameters may not be simple. However, it is plausible that cloud cover has a direct effect on precipitation and diurnal temperature range.

Cloud cover

In order to obtain records of sufficient length, stations which had more than 30 years of cloud data were chosen. The cloud data were at two times of day, 9 am and 3 pm, and an average of these values was used to construct monthly mean cloud amounts for the 318 stations which had data at both times of day. The original observations were in oktas after January 1949 and in tenths before this date, but were converted to oktas by the NCC for the TABS data set. In this paper cloud cover is expressed as a percentage or a fraction of the total sky solid angle.

There has been an overall increase in cloud over Australia of around 5 per cent since 1910, but the change is not linear over time, and the trend is not uniform over all stations. A simple linear fit to the monthly records for each station gave an increase in cloud cover for 252 stations and a decrease for 66 stations. The mean fitted change in cloud cover was 1.01%/decade (standard error of the mean $SEM = 0.08$, standard deviation $SD = 1.42$%/decade).

The amount of sunshine is closely linked to cloud cover but, due to the small number of stations with sunshine data and the short length of record, is not discussed in detail here. The monthly sunshine fraction (sunshine hours divided by the maximum possible sunshine hours for that station and month) was correlated with cloud cover with coefficient $r = -0.87$. The sum of cloud and sunshine fractions was found to be 1.2, not the value of 1.0 expected if the fractions are complementary, probably due to thin high cloud which allows sunshine through but it still visible to the observer.

Precipitation

Since one of the major aims of studying the precipitation data was to compare it with the cloud data, only stations which had more than 30 years of cloud data and 20 years of precipitation data were extracted from the TABS data set. This gave 263 stations, a subset of the 318 stations considered above. The period of record was mostly later than 1957, with a few stations having data back to around 1940.

A simple linear fit to the monthly total precipitation for each station gave an increase for 149 stations and a decrease for 114 stations. The mean fitted change in precipitation was 0.6 (mm/month)/decade ($SEM = 0.2$, $SD = 3.7$ (mm/month)/decade). However, these results should be treated with caution as the precipitation data are not normally distributed; the distribution is highly skewed with many low values and a long tail at the high end. Thus the assumptions made in applying a least-squares linear fit are not strictly valid.

There are large differences in mean precipitation between different stations and large annual cycles of precipitation. In order to detect small changes in precipitation (and for later analysis), the original data were normalised by dividing the data by the mean for that station and month of year. This suppresses the annual cycle, making the distribution of the normalised data closer to a normal distribution. A linear fit to the normalised data for each station gave an increase for 175 stations and a decrease for 88 stations. The mean fitted change in precipitation was 3.9%/decade ($SEM = 0.5$, $SD = 7.9$%/decade).

It is expected that there should be a positive correlation between cloud cover and precipitation. Consider the mean precipitation for a given station and month of year (that is, the values used to normalise precipitation above) and similarly the mean cloud cover for that station and month of year. The relation between these values of cloud cover and precipitation are plotted in Fig. 1. Note that precipitation increases with cloud

Fig. 1 The relation between cloud cover (expressed as a fraction) and precipitation, where each point is the mean value (cloud cover and precipitation) for a given station and month of year, so that this represents the variation due to differences between stations and the annual cycle. Note that there is a positive correlation, as expected, but that the relation is non-linear.

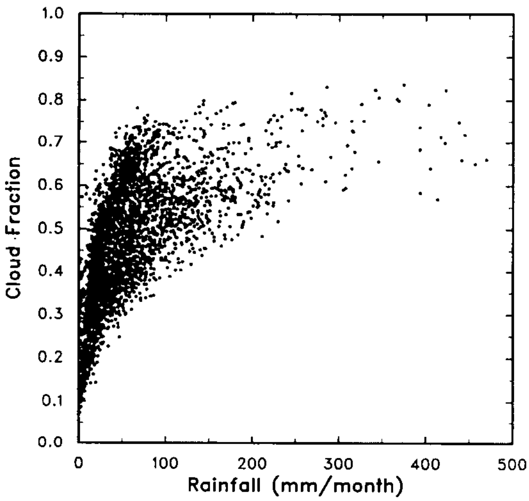
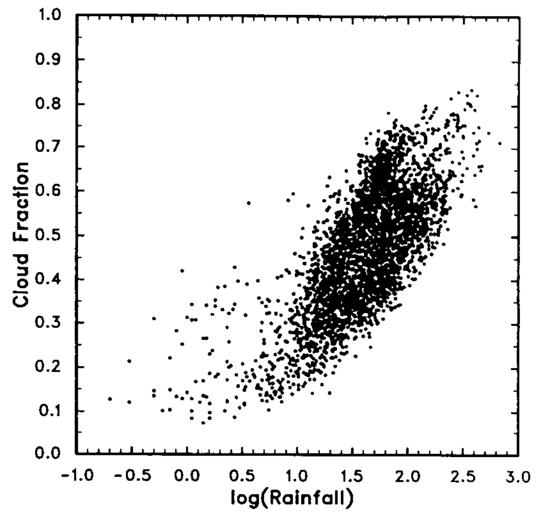


Fig. 2 The same data as in Fig. 1 except that precipitation is plotted on a logarithmic scale as the logarithm (base 10) of precipitation in mm/month. This indicates that precipitation varies roughly as an exponential of cloud cover.



cover, as expected, but that the relation is non-linear. The relation is approximately given by an exponential dependence of precipitation with increasing cloud cover, as shown by Fig. 2 where precipitation is plotted on a logarithmic scale. The correlation coefficient between cloud cover and log(precipitation) given by these points is 0.73. The amount of precipitation depends on parameters other than cloud cover, but the high correlation here indicates that cloud cover is the major determinant; variations in cloud cover explain $r^2 = 53\%$ of the variance in precipitation. The slope of the dependence of precipitation on cloud cover is 5.1; that is, when cloud cover changes by 0.1%, precipitation changes by a factor of 1.0051.

Temperature

The temperature values in the TABS data set are given as monthly averages of the daily maximum and minimum temperatures. (Monthly averages of wet and dry-bulb temperatures at 9 am and 3 pm are also included in the TABS data but are not considered here.) The temperature data for the stations selected in the cloud data (above) were extracted giving a list of 316 stations (out of 318). Linear fits to the monthly temperature values for each station were considered for the daily maximum and minimum. For the minimum temperature T_{min} the results were an increase for 256 stations and a decrease for 60 stations, with the mean trend 0.12°C/decade ($SEM = 0.01$, $SD = 0.18$°C/decade). For the maximum temperature T_{max} the results were an increase for 195 stations and a decrease for 121 stations, with the mean trend 0.06°/decade ($SEM = 0.02$, $SD = 0.31$°/decade).

Another way of describing the temperature data is to use the mean of the daily maximum and minimum temperatures, $\overline{T} = (T_{max} + T_{min})/2$, and the difference, or temperature range, $\Delta T = T_{max} - T_{min}$. Since $\overline{T}$ and ΔT are linear combinations of T_{min} and T_{max}, they provide the same information but may be more useful when considering the relation of temperature and other parameters such as cloud cover and SOI. Converting the original temperature data to $\overline{T}$ and ΔT and fitting to individual stations, the results were; for $\overline{T}$, 244 stations showed an increase and 72 stations showed a decrease, with the mean trend 0.08°C/decade ($SEM = 0.01$, $SD = 0.21$°C/decade); for ΔT, 132 stations showed an increase and 184 stations showed a decrease, with the mean trend −0.04°C/decade ($SEM = 0.02$, $SD = 0.27$°C/decade).

Cloud cover affects the temperature due to effects of cloud in reflecting and absorbing incoming visible solar radiation and outgoing infrared radiation. The effect of clouds on the mean temperature ($\overline{T}$) depends on the balance of the two competing effects, in reducing the temperature by reducing the amount of incoming radiation and increasing the temperature by reducing the amount of outgoing radiation. The result is expected to depend on cloud type and cloud height (Webster and Stephens 1984). Clouds reduce the diurnal temperature range (ΔT) since they reduce the drop in temperature due to outgoing radiation at night, when there is no incoming solar radiation.

The empirical relationship between temperature and cloud cover cannot easily be determined by simply comparing the parameters obtained for a given station and month of year (as done for precipitation, Figs 1 and 2) since the temperature is strongly dependent on other parameters, notably the geographic position of the station and the month of year (seasonal cycle). The major determinant of mean temperature ($\overline{T}$) for a given station is latitude and the seasonal dependence is given approximately by a sine wave in phase with the cycle of declination of the sun. Thus a combined parameter of midday solar angle (SA = latitude(station) − declination(month)) was considered to describe the temperature for a given station and month of year. The correlation of $\overline{T}$ with SA has coefficient $r = 0.82$ so that this parameter describes $r^2 = 67\%$ of the variance in $\overline{T}$.

The temperatures ($\overline{T}$ and ΔT, for a given station and month of year) were fitted for solar angle and the result used to correct the temperature for the solar angle dependence, when fitting temperature against cloud cover. Similarly, the fits of temperature against solar angle used temperature corrected for the cloud dependence, and the process was repeated until the fits converged. This is equivalent to a multiparameter fit of temperature for solar angle and cloud simultaneously, but makes the separate correlations more explicit. The dependence of mean temperature ($\overline{T}$) on cloud has slope −0.102°C/% and correlation coefficient $r = -0.42$ (Fig. 3). The dependence of temperature range (ΔT) on cloud has slope −0.47°C/% and correlation coefficient $r = -0.68$ (Fig. 4). Thus there is a fall in both the mean temperature and the temperature range with increasing cloud. The correlation coefficients of the fits of temperature against solar angle are $r = 0.83$ for $\overline{T}$ and $r = 0.16$ for ΔT, so that variations in $\overline{T}$ are dominated by solar angle differences and variations in ΔT are dominated by cloud differences. Expressing the temperature results in terms of (monthly average) daily maxima and minima, T_{max} has a strong negative dependence on cloud (slope −0.176°C/%) and T_{min} a weak negative dependence (slope −0.029°C/%).

Fig. 3 **The relation between the mean temperature, $\overline{T}$, and cloud cover, where each point is the mean for a given station and month of year. The temperature has been corrected for the dependence on station latitude and annual cycle (parametrised by midday solar angle) to better show the dependence on cloud cover.**

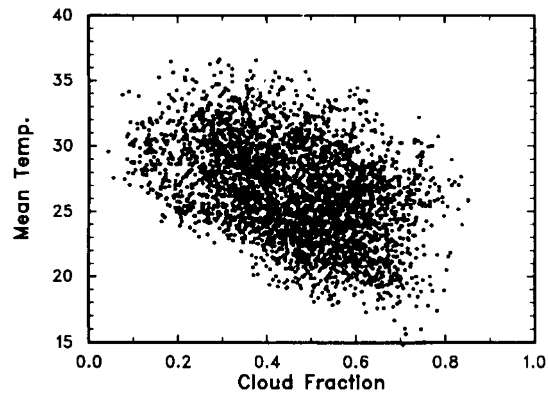
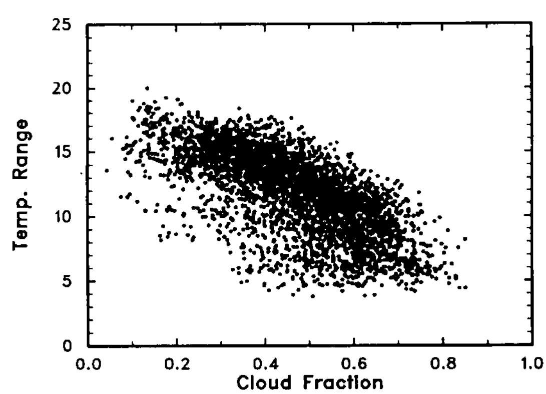


Fig. 4 **The relation between the diurnal temperature range, ΔT, and cloud cover, the data treated as for Fig. 3.**



Southern Oscillation Index

The list of monthly Southern Oscillation Index (SOI) values was obtained from the National Climate Centre of the Australian Bureau of Meteorology. The SOI is based on the difference in monthly mean (sea level) pressure between Tahiti and Darwin. There are several slightly different definitions of SOI (Ropelewski and Jones 1987), but the one used here (Troup form) considers the difference in pressure between Tahiti and Darwin less the mean difference for that month of the year (to remove the annual cycle, and to make the mean of SOI zero) and normalised by the standard deviation of the differences for that month of the year (to fix the standard deviation of the SOI).

It is well established that fluctuations in Australian precipitation are related to the SOI, in the sense that El Niño periods (low SOI) are associated with periods of drought (Pittock 1975; Ropelewski and Halpert 1987; Allan 1988). Thus, a positive correlation between cloud cover and SOI would be expected. The monthly cloud cover records for individual stations were compared with the SOI. The highest correlations were obtained for stations in the north and east of the continent, as shown by Fig. 5 where the correlation coefficient is plotted against latitude and longitude. The Southern Oscillation is a phenomenon of the tropical Pacific so its effect may be expected to be strongest for the northeast of Australia (however the Southern Oscillation does influence the climate over a much larger area). The geographic variation in the correlation of cloud with SOI is similar to that obtained by Pittock (1975) for the correlation of precipitation with SOI. Figure 6 plots the geographic variation of the correlation coefficient r (as in Fig. 5), with the station positions plotted with an open circle if $-0.15 < r < 0.15$ and with a filled dot if $r > 0.15$. The cut-off value was chosen to be the level at which the correlation is considered significant at the 5 per cent level, thus only the areas of Western Australia, Tasmania and the coast of South Australia and Victoria do not show a significant correlation.

Fig. 5 The correlation coefficient of monthly cloud data (for available stations) with SOI plotted as a function of (a) latitude and (b) longitude to show the geographic variation of the strength of correlation. Note that the correlation is significant at the 5 per cent level for points with $r > 0.15$ and that the correlation is strongest to the north and east.

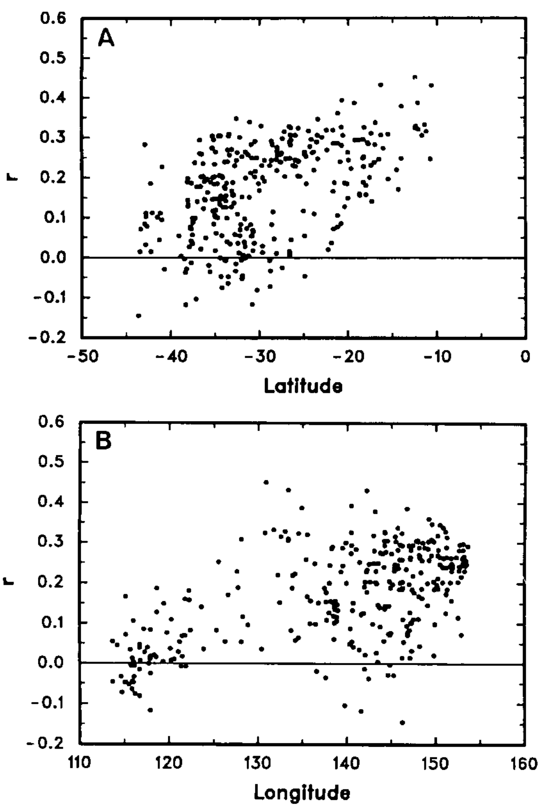
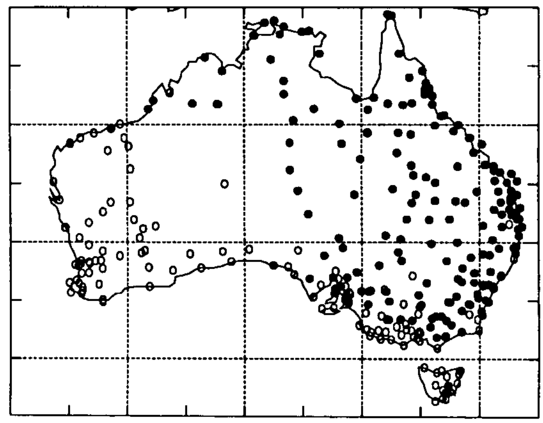


Fig. 6 The plot of station positions for the cloud data showing the correlation of cloud cover with the SOI (as for Fig. 5) with ○ denoting stations with no significant correlation $r < 0.15$ and ● denoting stations with a good correlation $r > 0.15$. Thus the correlation is significant for all regions except south Western Australia, Tasmania and the coast of South Australia and Victoria.



Trends and comparisons of time series

Time series of cloud cover, precipitation and temperature residuals were calculated and compared with each other and with the SOI. The residuals were calculated from the raw data by subtracting (for cloud and temperature) or dividing by (for precipitation) the mean value for that station and month of year. This removes the gross differences between stations and the annual cycle. Since there are possible long-term changes in the records, the 'mean' value for a given station in the normalisation was taken as the mean for epoch 1950 (from the linear fit for that station over time). The residuals for a given month were averaged over all stations (which have data for that month) to form the time series. The time series used here all ended at December 1989, the cloud series starting in January 1910, the precipitation series in January 1940, the temperature series (expressed as $\overline{T}$ and ΔT) in January 1900 and the SOI in January 1900. Note, however, that the precipitation data have few stations before 1957, so the analysis uses the time series after this date, and that the SOI has a few gaps before the mid 1930s. Since the relation between cloud cover and precipitation is non-linear (Fig. 1) the precipitation residuals are expressed on a logarithmic scale; the natural logarithm (base e) is used, so that a month with 101 per cent of the mean precipitation has $\ln P = 0.01$. In practice, once the residuals are averaged over all stations the fluctuations are small and the difference between the linear and logarithmic scales is small.

The time series of residuals of cloud cover (C), precipitation (ln P), mean temperature ($\overline{T}$), diurnal temperature range (ΔT), and Southern Oscillation Index (SOI) are plotted in Figs 7 to 11 respectively. In order to show the fluctuations more clearly by reducing the noise, the plots show the time series smoothed by a 12-month running mean (although the unsmoothed values are used in the analysis).

Simple inspection of the plots (Figs 7 to 11) indicates that cloud cover and mean temperature have increased and the diurnal temperature range has decreased. Similarities in the fluctuations in cloud cover, precipitation, temperature range and Southern Oscillation Index indicate that these parameters are correlated. The fluctuations in temperature range are in the opposite sense to the other three parameters. A more rigorous analysis of these relationships is given below.

Fig. 9 The time series of average residuals of daily mean temperature ($\overline{T}$), smoothed by a 12-month running mean, in °C.

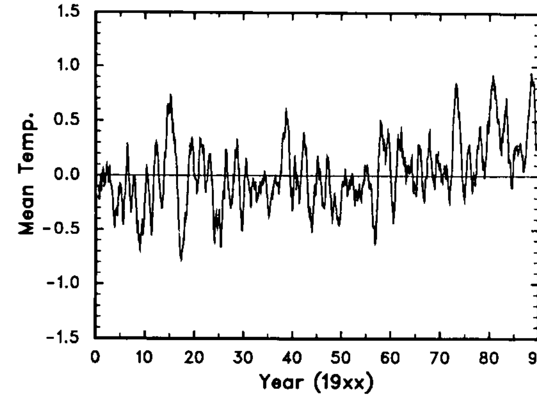


Fig. 7 The time series of average residuals of cloud cover, smoothed by a 12-month running mean, expressed as a percentage of the total sky solid angle.

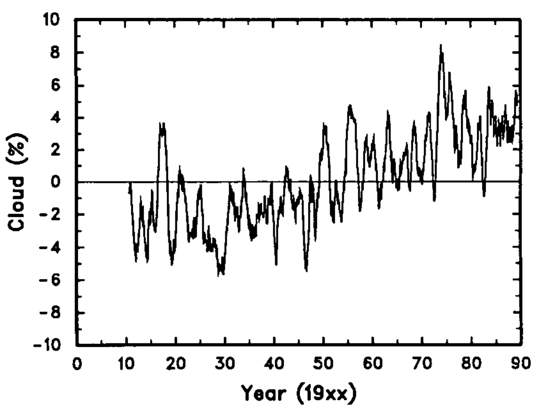


Fig. 10 The time series of average residuals of diurnal temperature range ($\triangle T$), smoothed by a 12-month running mean, in °C.

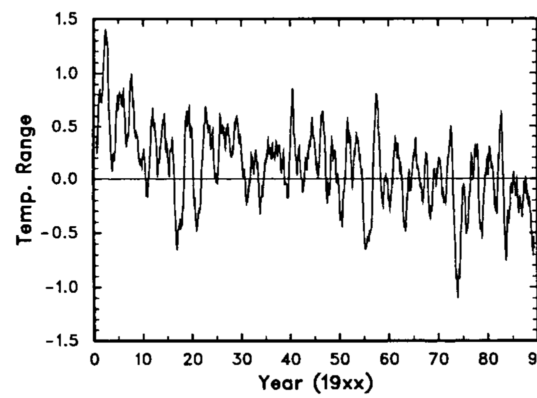


Fig. 8 The time series of average residuals of precipitation, smoothed by a 12-month running mean, expressed as the natural logarithm of the ratio of precipitation to the long-term mean (ln P).

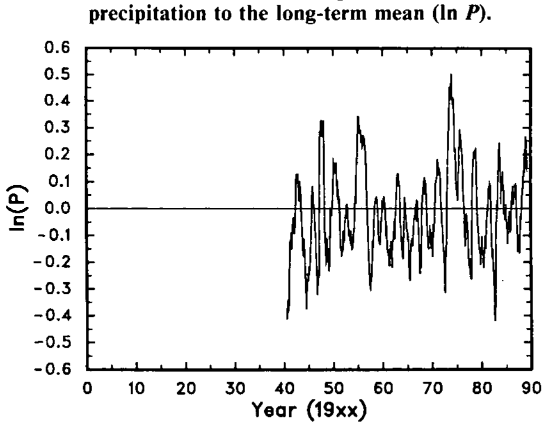
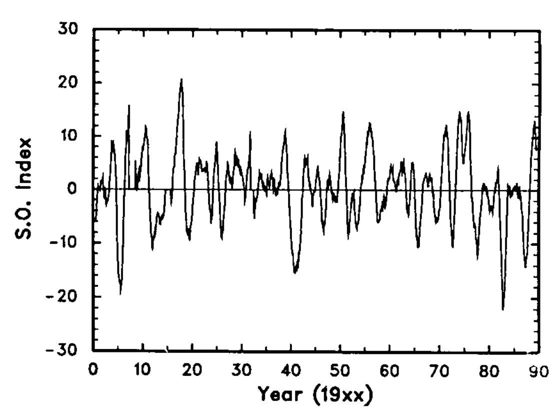


Fig. 11 The Southern Oscillation Index (SOI), smoothed by a 12-month running mean.



The five time series were correlated against each other to show the relationship between parameters, and correlated against time to show long-term changes. The correlation coefficients (r) are given in Table 1. Using a cut-off level of $|r| > 0.15$ for a significant correlation, there are nine significant correlations (out of a possible 15 pairs). These are the relations between cloud cover, temperature range, precipitation and SOI (six pairs) and the trends in cloud cover, mean temperature and diurnal temperature range mentioned above.

Table 1. The correlation coefficients obtained by the comparison of the time series of average residuals of cloud cover, precipitation ($\ln P$), daily mean temperature ($\overline{T}$), diurnal temperature range ($\triangle T$) and Southern Oscillation Index (SOI) with each other and fits to changes in the parameters over time. Correlations with $|r| > 0.15$ are considered significant. Negative coefficients denote an inverse correlation.

	Time	*Cloud*	ln P	$\overline{T}$	$\triangle T$	*SOI*
Time		0.43	0.07	0.23	−0.28	−0.03
Cloud	0.43		0.83	0.01	−0.87	0.36
ln P	0.07	0.83		−0.07	−0.84	0.42
$\overline{T}$	0.23	0.01	−0.07		0.12	−0.08
$\triangle T$	−0.28	−0.87	−0.84	0.12		−0.39
SOI	−0.03	0.36	0.42	−0.08	−0.39	

The strongest correlations are those between cloud cover, diurnal temperature range and precipitation ($|r| = 0.8-0.9$), with the variations in temperature range in the opposite sense to the other two parameters, giving negative correlations. The physical explanation is presumably in the sense that clouds cause a reduced diurnal temperature range, due to their radiative effect, and that clouds are the source of precipitation. There are feedbacks involved so it could also be argued that precipitation leads to increased humidity, which in turn causes increased cloud cover, and that increased humidity could cause a reduction in the diurnal temperature range due to the greenhouse effect of water vapour.

The above three parameters are also correlated with the Southern Oscillation Index, in the sense that cloudy wet periods occur with high SOI, but the correlations with SOI are lower ($|r| = 0.35-0.45$) than those between the other parameters. This is due to the fact that the time series use data from all over Australia, whereas the Southern Oscillation affects the northeast of Australia most strongly so that the relation is 'diluted' by stations which are not significantly affected by the Southern Oscillation.

The most significant long-term change in the time series is the increase in cloud cover ($r \approx 0.4$) with the changes in temperature weak but still considered significant ($|r| = 0.2-0.3$). A decrease in diurnal temperature range may be expected if cloud cover has increased, so the detection of such a decrease in temperature range supports the claim that the increase in cloud cover is real and not, for example, an artifact due to the change in observing convention in 1949. If cloud cover has increased, it may be expected that precipitation should have also increased. However, the long-term change in precipitation from the time series here is not significant. This may simply be due to the relatively short period of record (from 1957, compared to 1900 onwards for temperature and 1910 onwards for the cloud time series) making any long-term change difficult to detect against the large year-to-year fluctuations.

The relations between cloud cover, precipitation and temperature discussed earlier in this paper have been considered on the basis of mean values for a given station and month of year. The variations with time (apart from the annual cycle) were suppressed. The correlations in this section (Table 1) consider the inverse, that is the variations with time, with the differences between stations and the annual cycles suppressed. The fitted relation between precipitation and cloud cover from the time series has slope 7.0 (compared to 5.1 in 'Precipitation'), that is when cloud cover changes by 0.1 per cent precipitation changes by a factor of 1.0070. The fitted relation between diurnal temperature range and cloud cover from the time series has slope −0.120°C/% (compared to −0.147 in 'Temperature'). Thus the two methods of obtaining the relations (between cloud cover and precipitation and temperature) give qualitatively the same results, although with slightly different slopes. However, the fitted relation beetween mean temperature and cloud cover from the time series has slope 0.001°C/% (compared to −0.102 in 'Temperature'). Thus while cloud cover has a negative effect on the mean temperature for the mean climate of a given station and season, small changes in cloud cover from this mean climate have little effect. As suggested in 'Temperature' the effect of cloud on mean temperature is complex as it depends on the result of two competing radiative effects and depends on cloud type and height, as well as cloud amount.

The fitted trends in cloud cover, precipitation and temperature from the overall time series (residuals averaged over all stations) can be compared to the mean trend obtained from fits to individual stations. The fitted trends from the time series (with estimates of uncertainty) are 0.90 ± 0.06%/ decade for cloud cover (compared to 1.01 in 'Cloud cover'), 2.7 ± 2.1%/decade for precipitation (compared to 3.9 in 'Precipitation'), 0.055 ± 0.007°C/decade for mean temperature (compared to 0.08 in 'Temperature') and -0.075 ± 0.008°C/decade for diurnal temperature range (compared to -0.04 in 'Temperature'). The differences in trend are probably due to the fact that individual stations do not have as long a record as the overall time series and the fitted trends depend on the period chosen (since the change need not be linear).

The time series of precipitation shows little trend (a slight increase but not significant at the 5 per cent level). This is consistent with the results for the Australasian region (0°–60°S, 60°–180°E) of Diaz et al. (1989) who, using a somewhat different method of analysis, find an overall increase in precipitation over global land areas. The short-term fluctuations in precipitation found here are similar to those in Diaz et al. (1989), and are related to the Southern Oscillation.

The overall trend in mean temperature from the time series is similar to that obtained for southern hemisphere land areas (2.5°–62.5°S) by Jones et al. (1986a), an increase of 0.052°C/decade (for their time series from 1904 onwards, which is close to the period considered here, and 0.049°C/decade from 1881 onwards). Jones et al. (1990) find a warming over the period 1930–1988 of around 0.6°C for eastern Australia, giving a rate of increase 0.10°C/decade (for this shorter period). Jones et al. (1990) also find that the warming for eastern Australia (1930–1988) is greater for the minimum temperature (0.81°C) than for the maximum temperature (0.30°C) so that there is a decrease in the diurnal temperature range. The southern hemisphere sea-surface temperatures also show an increase (Paltridge and Woodruff 1981), suggesting that the temperature changes are widespread and not a local effect. World-wide marine temperatures (Folland et al. 1984) show an increase since 1900, but the long-term trend is not a monotonic increase as the data show a fall in marine temperatures over the latter half of the 19th century.

The trends and interrelationships between cloud cover, temperature range and precipitation can be compared with the results for the United States and Canada. A significant decrease in the diurnal temperature range for the United States and Canada was noted by Karl et al. (1984), which they suggested may be related to the greenhouse effect of CO_2 and water vapour or cloud cover in reducing the outgoing infrared radiation at night. A negative relationship between variations in temperature range and precipitation noted by Karl et al. (1986) would be consistent with changes in atmospheric water (in the form of vapour or clouds) affecting the temperature range through the greenhouse effect. An increase in cloud cover over the United States and Canada has been detected (e.g. Henderson-Sellers 1989), although this is not supported by the sunshine record which does not show a corresponding decrease (Karl and Steuer 1990).

In a comparison of historical records of cloud cover, precipitation, temperature and sunshine for the United States, Plantico et al. (1990) found overall significant increases in cloud cover and precipitation and a significant decrease in temperature range, although there are seasonal and regional differences. (The trend in mean temperature was not significant and the small decrease in sunshine was not consistent with the change expected from the increase in cloud cover.) Thus the increase in cloud cover and decrease in temperature range found for Australia are similar to the changes in the United States. Plantico et al. also considered the correlation of precipitation, temperature and sunshine with cloud fluctuations giving results similar to the correlations from the time series for Australia (except using data on a yearly rather than monthly basis and using area-weighted data rather than residuals). The correlation coefficients obtained by Plantico et al. are $r = -0.816$ for temperature range, $r = -0.243$ for mean temperature, $r = 0.715$ for precipitation and $r = -0.740$ for sunshine fraction against cloud amount. For Australia and the United States, temperature range and sunshine fraction show a clear inverse correlation with cloud and precipitation a clear positive correlation. The relation between mean temperature and cloud amount is less clear.

Conclusion

Historical climate records for Australia have been analysed to determine the long-term trends and interrelationships of cloud cover, precipitation, temperature and the Southern Oscillation Index. As expected, precipitation, diurnal temperature range and cloud amount are correlated, and these three quantities are correlated with the SOI (with temperature range varying in the opposite sense to the other parameters). The relation between daily mean temperature and cloud cover is not as simple. There is a significant long-term increase in cloud amount and daily mean temperature and a significant decrease in diurnal temperature range. There is a small overall increase in precipitation, but this is not considered significant given the large fluctuations in precipitation and the short period of record considered.

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