Historical Records of Cloudiness and Sunshine in Australia*

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ABSTRACT

Historical records of mean monthly cloud amount over Australia have been studied to determine whether there is any long-term trend. Of 318 stations with more than 30 years of data, 252 show an increase and 66 a decrease. The cloud amount shows a rise of 5% between 1910 and 1989, when averaged over all stations. The trend is not uniform, however, with a slight fall in cloud between 1910 and 1930 and with most of the rise between 1930 and 1980. Sunshine records were used to check the cloud record for systematic errors. Monthly average cloud and sunshine fractions are correlated with coefficient $r = -0.87$ and with best-fit slope -1.00. The sum of cloud and sunshine fractions is around 1.2, whereas it may be expected that the sum should be 1.0 if the cloud and sunshine fractions are complementary. The sunshine and cloud variations are in close agreement for the period 1950 to 1989. The subset of stations that have sunshine records shows no overall change in cloudiness or sunshine over this period, with 31 stations showing an increase in cloud and 28 a decrease. An independent dataset of 41 stations, mostly airports, shows no significant trend over the period from 1940 to 1988, with 24 stations showing a decrease in cloud and only 17 showing an increase over this period. It is suggested that there is an overall long-term increase in total cloud amount over Australia, but that it does not occur uniformly for all stations, so that some groups of stations show no increase. However, the overall trend must remain tentative until the reason for the differences between the datasets is clarified.

1. Introduction

Cloud cover is a major feature of the climatic system, so that climatic changes detected in temperature (Jones et al. 1986) and precipitation (Diaz et al. 1989) might be expected to be reflected in the cloudiness record, although the complex feedbacks between cloud cover, cloud type, temperature, and precipitation, and the less objective nature of cloud observations may mitigate against the detection of any trend. The detection of variations in cloud cover would help in the understanding of such feedback processes, which are a major uncertainty in general circulation models (GCMs) of the climate. Satellite observations of clouds give good global coverage, but ground-based observers' estimates have a much longer period of record, so they are more useful in searching for long-term changes.

Changes in cloud cover this century have been detected over the United States, Canada, Europe, and India (McGuffie and Henderson-Sellers 1988, Henderson-Sellers 1989). If the amount of cloud cover has changed, then an inverse change would be expected in the duration of bright sunshine, so that it is useful to use both cloud and sunshine records (Angell 1990, Angell et al. 1984) or sunshine records alone (Weber 1990) to check for climatic change. This paper presents results from analysis of Australian cloudiness records. Sunshine records are used, where available, to check for consistency with the cloud data.

2. Australian cloud data

The historical records were obtained from the Australian Bureau of Meteorology National Climate Centre (NCC) archives as tabulated (TABS) elements that consist of monthly means of a large number of climatic parameters for more than 1000 stations. The 0900 and 1500 local time total cloud amounts were extracted for those stations that had more than 30 years of cloud data. The data were given as monthly mean total cloud amounts, to the nearest okta (one-eighth of sky covered by cloud). These observations have been made according to standard meteorological procedures since the nineteenth century. Observations were made in tenths of sky cover until 1949 and subsequently in eighths (oktas). The morning and afternoon total cloud observations were averaged for the 318 stations with data at both times of day.

The cloud data for many stations showed a sudden fall in 1949, by a factor 0.8, returning to the original level with a sudden rise in 1956. Before 1949 the original observations were in tenths, so that these data were

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subsequently converted by the NCC into oktas (by multiplying the monthly means by the factor 0.8). Apparently, for some of the stations, the data in the period 1949–56, already in oktas, were erroneously multiplied by 0.8 during the archiving processing (Bureau of Meteorology 1990, personal communication). The stations for which this occurred were identified by considering the ratios of mean cloud over three periods: before 1949, 1949–56, and after 1956. The monthly data for these 243 stations were multiplied by the factor 1.25 for the period 1949–56.

Trends in the annual average total cloud amount for individual stations were fitted with a simple linear regression of average cloud with time. Of the 318 stations, 252 showed an increase and 66 a decrease. The average fitted trend is 1.01% absolute cloud amount per decade. For the stations that have the longest record, the trends can be obtained with greater confidence, and the predominance of stations showing increasing cloud is clearer. For a subset consisting of 89 stations with more than 45 years of cloud data, 81 show an increase and 8 a decrease.

To show the change in cloud amount with time, the data are plotted in Fig. 1 as the annually averaged total cloud amount residuals, averaged over stations as a function of year. The cloud residuals are the yearly cloud amount for a station less the fitted mean cloud for that station. The mean cloud was obtained from the linear regression fit for 1950 (rather than a simple average). Since not every station has data for every year, the cloud amount averaged over stations active in that year could vary due to the different stations

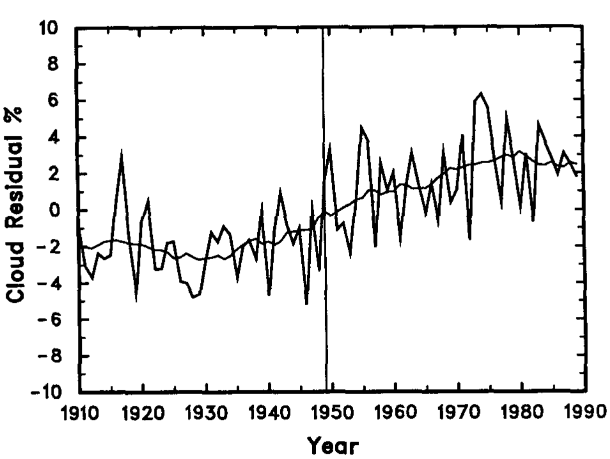

FIG. 1. Cloud residuals for the TABS dataset (from 1910 to 1989), averaged over stations, as a function of year. The cloud residual is the cloud amount less the mean cloud for that station (the fitted cloud for 1950 from the linear regression, section 2). The smoothed curve is the 15-yr running mean, that is, the average of data within ±7 yr (so that the smoothed data at the ends are the means over a shorter period). The line at 1949 indicates the date when the observing convention changed from tenths to oktas.

used over time. This effect is reduced by using the residuals.

Figure 1 indicates that the major change in cloud amount occurred between 1930 and 1970. The rise in cloudiness after 1930 is similar to that obtained for North America (Henderson-Sellers 1989). Increases in cloudiness have also been detected for Europe and India (McGuffie and Henderson-Sellers 1988). The agreement is suggestive of a climate-related change in total cloud over some continents.

The overall change in cloud is around 5% from 1910 to 1989, but the trend is not uniform. A simple linear fit to the change in cloud residuals is not adequate; at least a two-phase model is required. (However, the data for individual stations have greater scatter than the mean over all stations in Fig. 1, and more complicated models than the simple linear regression were not considered appropriate.) The smoothed curve (Fig. 1) indicates that most of the increase occurred in the period 1930 to 1980, with a slight fall from 1910 to 1930.

Due to the change in observing practice from tenths to oktas in 1949, it is possible that there is a small systematic difference between data before and after this date. The vertical line in Fig. 1 indicates the date of this change. However, the time series of monthly residuals (averaged over stations) after 1949 show a significant increase (0.78%/decade), similar to that of the whole record (0.86%/decade). The residuals before 1949 show no overall change, but this is ascribed to the fall in the period up to 1930 and the rise after 1930. The residuals from 1930 onwards are consistent with a linear rise, which would imply no (further) problem at 1949. Thus, while a small systematic difference between the data originally in tenths and in oktas cannot be excluded, this does not affect the conclusion that the cloud data show an increase. The residuals data show an increase in cloud after 1949, which is consistent with the residuals before 1949. It could be argued that the change in convention in 1949 led to confusion by observers over a period of 20 years leading to a long-term drift in the cloud data, rather than a sudden jump, but this explanation seems rather ad hoc. It is hard to see how the observers could introduce a large systematic error when the observing convention was stable, given the absence of any clear jump in the data at the critical year 1949, when problems would be expected at the change in convention.

Figure 1 shows year-to-year fluctuations in cloud as well as the long-term trend (see also Fig. 2). These fluctuations show similarities with the fluctuations in annual average precipitation over Australasia given in Diaz et al. (1989), for example, the peaks in 1916/17, 1955/56, and 1973/74/75. Thus, there is a correlation of cloud with the precipitation record (as expected), at least over short time scales. The variations in cloud (and precipitation) are related to ENSO (El Niño–Southern Oscillation) events. The time series of

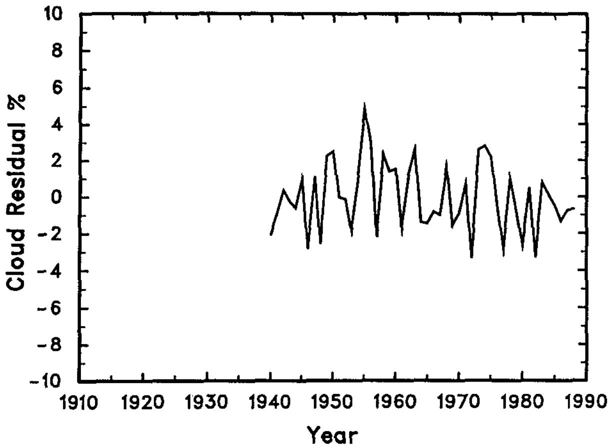

FIG. 2. Cloud residuals for the airport dataset (from 1940 to 1988), averaged over stations, as a function of year. Note the good agreement with the year-to-year variations in Fig. 1, but not with the overall trend.

monthly cloud residuals was compared with the Southern Oscillation Index (SOI) obtained from the Australian Bureau of Meteorology. The cloud residuals are correlated with the SOI with coefficient $r = 0.32$. A more detailed intercomparison of cloud, SOI, precipitation, and temperature for Australia, from the TABS data, is presented in Jones (1991). Cloud cover is found to be correlated with precipitation and inversely correlated with diurnal temperature range. A long-term decrease in diurnal temperature range has been found, which would be expected if the cloud cover has increased, so this supports the reliability of the cloud data.

3. The airport cloud dataset

A second cloud dataset was obtained from the NCC, consisting of 41 stations, mostly airports, with the longest period of data 1940–88. The data are monthly averages of 0600 and 1500 local time cloud in oktas, to two decimal places (not rounded off to the nearest okta, as in the larger dataset). It was expected that these data would be more reliable (M. Coughlan 1989, personal communication) because the observations were made by Bureau of Meteorology staff, although with the trade-off of fewer stations over a shorter period.

The morning and afternoon monthly cloud were averaged, in a similar analysis to that of the TABS dataset. Linear regression of the cloud amount with time showed that of the 41 stations, 17 increased and 24 decreased. The average trend was a small decrease in cloud (−0.24%/decade), but not at a statistically significant level.

The residuals were calculated by subtracting the overall mean for that station. (Note that the subtraction used the simple mean cloud for that station, and not the fit to 1950 cloud as used for the TABS dataset, since mean epoch of the airport data was much later than the TABS dataset and extrapolating back to 1950 with the large scatter in slope would introduce errors.) The residuals averaged over stations are plotted as a function of year in Fig. 2. This demonstrates the slight overall decrease in cloud, in contrast to Fig. 1. Note that there is good agreement in the year-to-year variations in Figs. 1 and 2 (correlation coefficient $r = 0.70$), suggesting that these variations represent real changes in cloud cover over short time scales and not noise. There is a difference in the long-term trends, however. For the period 1940–88 the airport residuals (Fig. 2) give trend −0.10%/decade and the TABS residuals (Fig. 1) give 1.12%/decade (for the same period). This discrepancy is discussed in section 5.

4. Sunshine and cloudiness

The monthly average hours of sunshine per day were also extracted from the TABS dataset, for those stations that had more than 15 years of sunshine data. These data were matched with the corresponding monthly cloud data, if available, to give a list of 59 stations for the sunshine and cloud comparison.

The monthly average hours of daily sunshine were converted to sunshine fraction using the "maximum possible hours of daily sunshine" (a function of month, latitude, and sunshine detector response). The sunrise-to-sunset times were not used, since when the sun is close to the horizon the increased air path means that the radiation is reduced below the detector cutoff. For Campbell–Stokes recorders, the U.K. Meteorological Office Observer's Handbook (1956) states: "The sun does not attain sufficient power to scorch the card until it is well above the horizon. Obstacles which subtend a small angle (not more than 3 degrees) above the horizon do not therefore cause a loss of record." The Handbook of Meteorological Instruments (1969) states that the loss of record for Campbell–Stokes recorders is 15 to 30 minutes in temperate latitudes according to season. The time that the sun was more than 5 degrees above the horizon was used. Changing this time simply increases or decreases the overall sunshine fraction, to first order. There is a large annual cycle in sunshine hours, due primarily to the annual cycle in maximum possible sunshine hours. If the adopted maximum possible sunshine time is not correct, there may be a small spurious annual cycle introduced in sunshine fraction, as the cycle in sunshine hours will not be correctly canceled.

For the cloud fraction, the average of monthly mean 0900 and 1500 local time cloud amounts was used. Ideally, sunshine fraction integrated over the daylight hours should be compared to cloud fraction averaged over the same time, not simply from two observations per day. The 0900 and 1500 monthly cloud amounts are in good agreement (correlation coefficient $r = 0.83$) so the cloud values used are probably an acceptable approximation to the values expected if more observations per day were used (cf. Henderson-Sellers 1989). For 10 Australian stations with 3-hourly data, the average diurnal cycle shows only a difference of 0.02 oktas in using the average of two such times of day compared to more complete time coverage for the daytime cloud (see Fig. 3).

The relationship between annual sunshine and cloud fractions is plotted in Fig. 4. The monthly sunshine and cloud fractions have correlation coefficient $r = -0.87$ with best-fit slope -1.00 and scatter about the best-fit line of 0.08 in both variables. This relationship is similar to that found by Hoyt (1977) and Angell (1990). Note, however, that the sum of sunshine and cloud fractions is around 1.2, not 1.0. If a day has, on average, a fraction f of the sky hemisphere covered with clouds, then it might be expected that the sun would be obscured by clouds a fraction f of the time and so the sunshine fraction would be $(1 - f)$. The excess of the sum of sunshine and cloud fractions from unity may represent times when thin high cloud allows enough sunshine through to trigger the detector, but is visible to the observer and hence recorded as cloud. Alternatively, the excess may represent systematic errors in sunshine and/or cloud, but such a large systematic error is considered unlikely.

Due to geometric projection effects, cloud cover is greater near the horizon than zenith. The solar position does not sample the sky hemisphere uniformly; it undersamples the zenith relative to the horizon so that the sunshine amount is slightly underestimated relative to the cloud-free sky (depending on the details of the cloud projection effects, the latitude, and the solar declination). This effect would tend to underestimate the sum of cloud and sunshine, but this is in the opposite sense to the excess found.

In order to check the relation between sunshine and cloud with time, the sum of sunshine and cloud fractions has been plotted as residuals in Fig. 5. The data are plotted as monthly values, so for each station the residual was obtained by subtracting the mean for that station and month (to remove the gross differences between stations and the annual cycles) and then the residuals, averaged over stations, were plotted. There are variations of a few percent on the time scale of

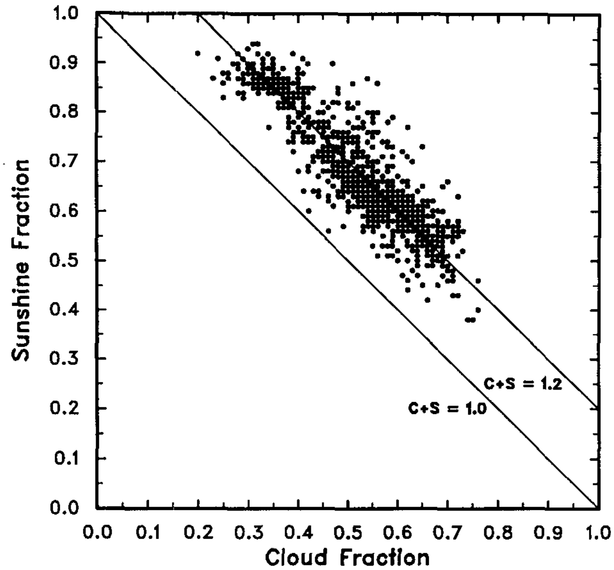

FIG. 4. The relation between annual cloud and sunshine fractions, where each point is the mean for one year's data at one station. Note that there is a good anticorrelation between cloud and sunshine fractions, but that the sum of the two quantities is 1.2, not 1.0.

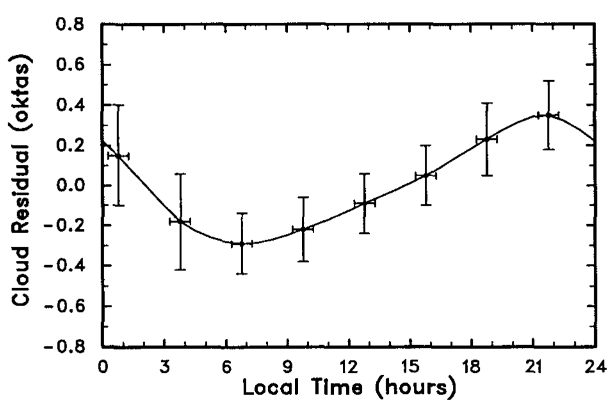

FIG. 3. The average diurnal cycle in total cloud amount obtained for 10 Australian stations with observations every 3 hours over 10 years (from 1979 to 1988). The error bars show the standard deviations in cloud residuals and local times. Note that there is little change between 0600 and 0900 local time and that the mean of cloud at 0900 and 1500 is a good approximation to the value expected if more observations during the daylight hours were used.

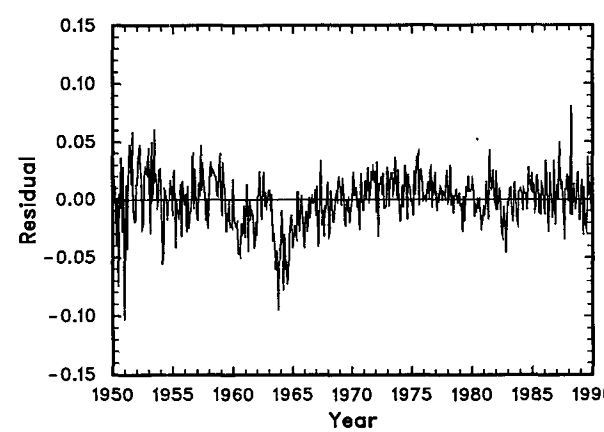

FIG. 5. The sum of residuals of cloud and sunshine fractions (from 1950 to 1989), averaged over stations, as a function of month. Note that there are variations on the scale of years, but no long-term change.

years (e.g., 1963–65), but no overall long-term change in the period 1950–89. This is as expected, if the close (inverse) relationship of cloud and sunshine records is constant over time. However, Karl and Steuer (1990) find that for the United States the long-term increase in cloud cover is not matched by a corresponding decrease in sunshine, so that the sum of cloud and sunshine fractions increases by more than 10% between 1900 and 1990 and by more than 3% since 1950. They attribute this to systematic errors in cloud or sunshine, or both. A systematic change of this magnitude can be ruled out for the Australian data analyzed here.

The 59 stations that have been used for the sunshine and cloud comparison show, on average, no overall change in either sunshine or cloud in the period 1950–1989. (The average fitted trends are $-0.1 \pm 0.4\%$/decade in cloud and $0.5 \pm 0.4\%$/decade in sunshine, which are not significant at the 5% level.) Thus, the lack of any trend in the sum of sunshine and cloud fractions may not be surprising, but it does confirm the consistency of the two records.

5. Comparison of the cloud datasets

The discrepancy in the apparent trend in total cloud amount between the datasets needs explanation. Of the 59 stations with sunshine data, 33 are included in the 318-station TABS list. Both groups of stations are subsets of the TABS archive, so it is difficult to see how a systematic error in the data should affect one group and not the other. There is a significant difference between the mean trend of the two groups. This cannot be explained by the difference in the period over which the trends were fitted, since the mean trend for 265 TABS stations 1949–89 (with more than 20 years of data in this period) is 0.9%/decade (Table 2), compared to −0.1% for the 59 stations with sunshine data. This difference in trend must represent real differences between stations (see the following).

The 41 stations in the airport dataset are a subset of the 318 stations in the TABS dataset. A comparison of the data in the two sets for these common stations indicates, on average, less than 0.2 oktas difference in mean cloud and no significant difference in the trend. The rounding of monthly means in the TABS data to the nearest okta would explain much of the scatter between the data in the two sets. Slight differences in mean cloud may be due to the diurnal cycle, with the "morning" cloud observations being at different times in the two sets: 0900 for the TABS and 0600 for the airport datasets. Analysis of 10 Australian stations with data at 3-hourly intervals indicates, on average, peak-to-peak diurnal cycle amplitudes of 0.7 oktas (Fig. 3). There is little change between 0600 and 0900 since this is near the minimum of the cycle (Fig. 3) but all but one of these stations is coastal, so the diurnal cycle here may well not be representative of the whole continent.

Thus, the difference in the change in cloud between the datasets arises from the selection of stations. Individual stations show increases and decreases in total cloud amount (significant at the 5% level), with the overall Australia-wide trend depending on the stations used. The 41 stations in the airport dataset show no significant trend (in either dataset), but when the other stations are included in the TABS dataset, the mean trend over all stations is a clear increase. The TABS dataset was therefore examined for explanations for these differences among stations.

The stations used in the different datasets are plotted in Fig. 6, with symbols denoting the fitted trend in order to show the variation between stations. The fitted change in cloud shows no striking geographic variations such as differences between north and south or east and west of the continent. Neither does it show obvious differences between the climatic regions that have the cloud maximum in summer (northern Western Australia, Northern Territory, Queensland, and coastal New South Wales) and cloud maximum in winter (southern Western Australia, South Australia, Victoria, inland New South Wales, and Tasmania) similar to the summer and winter rainfall regions. While the distribution of stations that show increases and decreases is patchy (with nearby stations showing large local differences), it appears that the stations showing decreases are mostly on the coast, while the inland stations show more increases. There is a tendency for stations in the TABS dataset, which have the most positive change in cloud, to have lower mean cloud. (The mean cloud and the change in cloud have correlation coefficient $r = -0.37$, which is highly significant given the number of stations.) This is consistent with the above inland/coastal difference since coastal stations have more cloud than nearby inland stations.

The distribution of stations is not uniform over Australia (Fig. 6), but because there are no obvious large-scale geographic variations, the simple mean of the trend over all stations is similar to that obtained from an area-weighted mean. If the fitted trend of the 318 TABS stations is first averaged over $5° \times 5°$ (latitude and longitude) areas and then the means for these areas averaged, the result is 1.3%/decade (compared to 1.0%/decade for the simple average). Table 1 shows the mean trend over these $5° \times 5°$ areas, indicating the geographic variation of the trend. If the trend for the 41 airport stations is averaged over $10° \times 10°$ areas and then these area averages themselves averaged, the result is 0.2%/decade (compared to −0.2%/decade for the simple average). For Figs. 1 and 2 the simple average over all stations, rather than the area-weighted average, is used, as this gives a better signal-to-noise ratio. Weighting the TABS stations by area in calculating the monthly residuals leads to a time series that

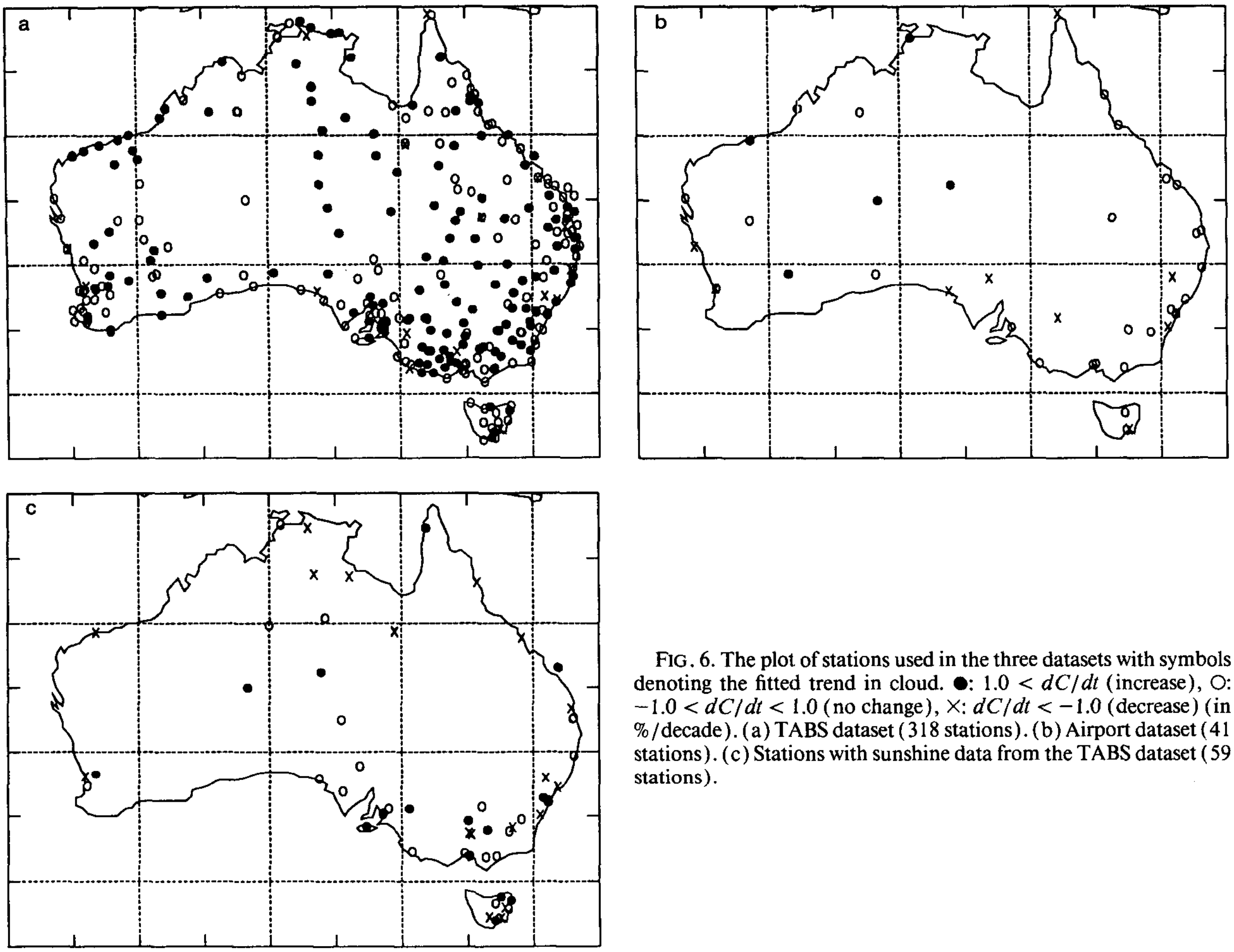

FIG. 6. The plot of stations used in the three datasets with symbols denoting the fitted trend in cloud. ●: $1.0 < dC/dt$ (increase), ○: $-1.0 < dC/dt < 1.0$ (no change), ×: $dC/dt < -1.0$ (decrease) (in %/decade). (a) TABS dataset (318 stations). (b) Airport dataset (41 stations). (c) Stations with sunshine data from the TABS dataset (59 stations).

TABLE 1. The mean fitted trend in cloud (a) from the TABS dataset, in %/decade, for stations in 5° × 5° bins in latitude and longitude, and (b) the number of stations in these bins used to calculate the mean. These tables are arranged in the form of maps of Australia, from 10° to 45° S and from 110° to 155° E, as in Fig. 6.

(a)

			7.91	1.45	2.47	0.45		
		1.42	0.71	2.36	2.81	0.65	1.08	
0.26	1.76	0.76	—	2.75	1.72	0.42	1.60	0.55
0.12	0.60	0.92	0.92	2.84	1.38	2.41	0.80	0.76
	0.72	1.16	0.79	0.87	0.93	1.50	1.44	0.65
	1.20				0.94	0.78	1.07	−0.01
							0.25	

(b)

			1	8	2	3		
		4	4	4	3	6	10	
2	9	2	0	2	2	7	9	10
3	4	5	1	1	3	6	7	22
	23	6	4	5	21	9	13	17
	2				7	30	20	3
							18	

is almost indistinguishable from that of the residuals obtained with equal station weighting. (The weighting factor is inversely proportional to the density of stations, which was obtained by weighting the nearby stations with a Gaussian width 1.5°.) The area-weighted mean TABS residuals leads to a trend of 0.95%/decade which is consistent with that of the equally weighted mean residuals (0.86%/decade) within the uncertainties of the fits. While the stations in the different datasets have different geographic distributions (Fig. 6), this cannot be used to explain the differences between the datasets, since the trend in the TABS data is quite uniform over the continent.

The 41 stations in the airport dataset have a different period of record (after 1940) than the overall TABS dataset (including data from 1910 and earlier). It might be expected that this could explain part of the difference in the overall trend, as the changes need not be linear, so the trend may also depend on the period chosen. However, restricting the analysis of the TABS data to later than 1940 indicates a significant increase in cloud

TABLE 2. The fitted trends in cloud for the different datasets and periods, expressed as the mean, standard deviation (σ), and standard error of the mean (SEM), all in %/decade. This implies that there are significant differences in the mean trends of the datasets, which is most likely due to the different stations used in the different sets.

Dataset	Number of stations	Mean trend (%/decade)	σ	SEM
TABS	318	1.01	1.42	0.08
Airport	41	−0.24	1.10	0.17
Sunshine subset	59	−0.16	3.08	0.40
TABS after 1940	285	1.24	1.63	0.10
TABS after 1949	265	0.90	1.71	0.11

even over this later period. For the 285 stations with more than 20 years of data after 1940, the average fitted change in cloud is 1.24%/decade (Table 2) compared to −0.24%/decade for the airport stations over this period.

Analysis of the uncertainties of the mean trend for the different datasets confirms that the differences are significant. The ability to detect a trend in the data for a single station depends on the statistical uncertainty of the fitted slope, which is determined by the scatter of the data (due to noise or month-to-month fluctuations) and the length of record. Thus, it might be expected that the airport dataset, which has more precise observations (better observers and monthly data given to a hundredth of an okta), would be preferable to the TABS data (monthly values rounded off to the nearest okta). However, the TABS data has a longer period of record. The uncertainty in slope is given roughly by $(n - 3)^{-0.5}(1 - r^2)^{0.5}\sigma_y/\sigma_x \approx n^{-0.5}\sigma_y/\sigma_x$ (for large n and small correlation coefficient r), where n is the number of points in the correlation and σ_x and σ_y are the standard deviations in the x and y coordinates. Thus, the uncertainty in slope varies as $t^{-1.5}$, where t is the length of record (since σ_y is roughly constant and n and σ_x vary as t). This is confirmed by restricting the TABS data to shorter periods, and by simulations of data with known slope and scatter. The scatter of fitted slopes for the 318 stations from the TABS dataset is 1.42%/decade and for the 41 stations from the airport dataset 1.10%/decade (Table 2). Thus, despite the shorter period of record, the airport stations show less scatter in fitted slope. This is probably because the airport stations were chosen to have more reliable data (see above), although some of the scatter represents real differences between stations.

For a number (M) of stations, the standard error of the mean slope depends on the scatter in slopes (due to uncertainty in slope, or real differences in trends between stations) and varies as $M^{-0.5}$. Thus, the TABS dataset is preferred as it has many more stations. The standard error of the mean slope for the TABS dataset is 0.08%/decade and for the airport dataset 0.17%/decade (Table 2). A similar analysis has been carried out for the sunshine subset, and fits to the TABS stations over restricted periods (Table 2). Note that the airport and sunshine sets are consistent with zero change in cloud, but that the TABS data show a significant increase. The discrepancy is not due to the different periods of record, as the increase in the TABS data is still apparent when the fits are restricted to the period after 1940 (to match the airport data). The increase in the TABS data is not due to a systematic offset at 1949 (when the observing convention changed from tenths to oktas) since using only data after 1949 also leads to an increase. The fact that the airport and sunshine sets have shorter periods of record, and fewer stations, means that the standard errors of the mean trends are larger than for the TABS data, but these uncertainties do not mean that the discrepancies in trends can be explained. The differences between the datasets are statistically significant and cannot be explained by the expected fluctuations obtained by choosing smaller subsets (in time and number of stations) at random from the larger TABS dataset.

A more detailed table of the results for individual stations (including station positions, years of record, and fitted trends) is not included in this paper, but may be requested from the authors.

6. Summary

The long-term records of Australian cloudiness (the TABS dataset) show a significant increase in total cloud of around 5% in absolute amount from 1910 to 1989, with the change mostly occurring between 1930 and 1980. However, not all stations show the change. The trend is clear in the list of 318 stations selected simply by length of record (and the 89 stations selected similarly by a more stringent condition on the length of record). Two other groups of Australian stations (the 41 airport stations and the list of 59 stations with sunshine data), however, show no significant trend in cloudiness. This difference is not due to the fact that the two smaller sets have data over a shorter period, since the increase in the TABS dataset is still significant when the data are restricted to the period after 1940. In these smaller groups of stations, stations that show no change are preferentially selected from the larger set, since the average trend of the subset differs from the average of the whole set. It is possible that there are real climatic differences between the groups of stations, since a climate change need not affect the whole continent in the same way. However, the physical cause of the differences between the datasets is not clear, so that unrecognized systematic errors are also possible.

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