# CLIMATIC CHANGE IN AUSTRALIA SINCE 1880

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[*Manuscript received December 4, 1952*]

*Summary*

Australian climatic data show that, for the period 1911–1950, the summer rainfall over much of the southern part of the continent was considerably greater than in the previous 30 years and, for the same season, mean daily maximum temperatures in the interior were appreciably lower. A difference in character of the annual variation of atmospheric pressure between these periods also suggests a shift of mean position of the subtropical high pressure belt.

It is tentatively concluded that, contemporaneous with the increased meridional interchange which has taken place over large parts of the northern hemisphere, a similar increase has occurred in the Australian region.

## I. Introduction

The climate of large regions of the Earth has been subject to wide variation over long periods of time as has been amply shown by many lines of geological and palaeobotanical evidence. From these studies it seems that fluctuations of greatly varying intensity and time scale have occurred, ranging probably all the way from the ice age glaciations and interglacial epochs at one extreme to the year to year variations at the other. Although many theories have been advanced to explain these phenomena (see Brooks (1949) for a discussion and bibliography), none has yet achieved general acceptance and consequently much attention is being given to the lengthening series of instrumental observations in the hope that detailed study of such changes as have occurred in this period may eventually lead to an understanding of the causation of climatic variation. As yet the main emphasis is on establishing the extent of climatic change in the instrumental period and the relation of changes in any one region to those elsewhere.

Convincing evidence of an appreciable climatic trend in recent decades over much of the northern hemisphere has been put forward, and Ahlmann (1948) has reviewed much of this material together with the results of glaciological studies which have demonstrated a notable retreat and thinning of glaciers in many areas, trends which have in most cases accelerated since about the beginning of the century. The climatological evidence points to an increasing transport of heat into high latitudes by the general circulation of the atmosphere during this period, with an appreciable increase particularly in the mean winter temperatures over large areas mainly in high latitudes. A possible reversal of this trend since about 1940 is not yet fully established.

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A similar study for the southern hemisphere is handicapped by lack of data for high latitudes and by the shorter period of instrumental observations, but, in view of the small amount so far published for this region, it was considered to be useful to make the study of Australian data presented in this paper.

The search for climatic trends in Australia, which might have resulted from a change in pattern or intensity of the general circulation of the globe, was started with the guiding idea that such a change would probably most strongly affect the summer climate, as there is at this season a very strong temperature contrast between central Australia and the Southern Ocean. Most attention has therefore been given to the summer statistics and for this purpose the months December, January, and February comprise the summer. As will be explained later, it was found convenient in much of the work to examine the differences between 30-year mean values of various climatic elements and for brevity two 30-year periods are referred to as follows:

| | |
|---|---|
| Period 1 | 1881–1910, |
| Period 2 | 1911–1940. |

## II. Climatic Régime of Australia

Before proceeding to the changes in climatic elements since 1880 in Australia, it is necessary first to sketch very briefly the main features of the Australian climate in relation to the general circulation of the southern hemisphere, with particular attention to the more populated southern part of the continent, as the data for the north and west are too scanty for the present purpose.

The climate of Australia is largely influenced by the subtropical belt of high pressure, the axis of which moves north and south with the Sun. In winter the high pressure is sufficiently far north for the south of the continent to come intermittently under the influence of the westerlies and so have a winter maximum of rainfall. At this season the north is very dry; Darwin, for example, with a mean annual rainfall of 60 in., receives rather less than 1 in. of this in the four months May to August.

When the high pressure belt has moved south in summer much of the north and north-east, except far inland, receives a copious rainfall under the influence of tropical low pressure areas assisted by monsoonal action. Cyclonic activity along the east coast extends the area of mainly summer rainfall southward into eastern New South Wales. The continent south of the tropic then receives little rainfall except for the region embracing the highlands of south-east Australia; low pressure troughs between the migratory anticyclones of the high pressure belt cause this region to have a summer rainfall of similar magnitude to that in winter.

## III. Air Temperature Changes

As already mentioned, a change in advective influences due to changing general atmospheric circulation would be expected most clearly to influence Australian inland summer temperatures. Climatic comparisons are commonly made in terms of some broad average such as the mean monthly or mean annual temperature. However, factors such as wind strength, cloud amount, and wetness of the soil affect minimum temperatures inversely to the maxima, so that changes in these elements may be taking place which are not reflected to a marked degree in the *mean* temperature. For the present purpose, where evidence for change in the circulation pattern is being sought, either the mean daily maximum or the mean daily minimum temperature would provide a more sensitive and revealing index. The choice between the two is to some extent arbitrary, but the former is on the whole preferred since the high rate of turbulent mixing of the lower atmosphere in the day-time should make the maxima more representative.

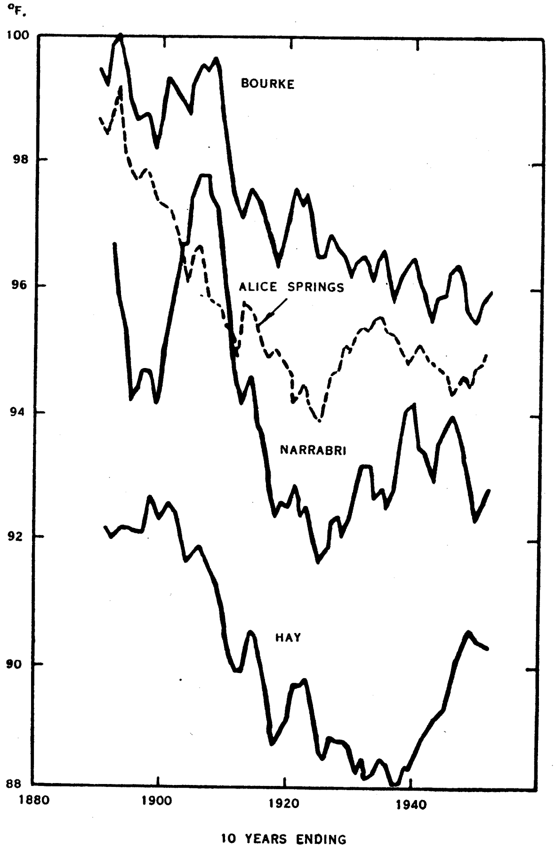


Fig. 1.—Ten-year running averages of mean summer maximum temperature.

Moving 10-year averages of mean daily maximum temperature for summer are shown in Figure 1 for some typical Australian inland stations. There are some differences in character between the graphs but all show a marked falling trend over much of the period with a levelling off or reversal in the last 10 or 15 years. This suggested studying the differences of the mean values for the two 30-year periods 1881–1910 (Period 1) and 1911–1940 (Period 2), a choice which also seemed appropriate in the light of the northern hemisphere trends. Table 1 gives these differences for the inland localities in central south and south-east

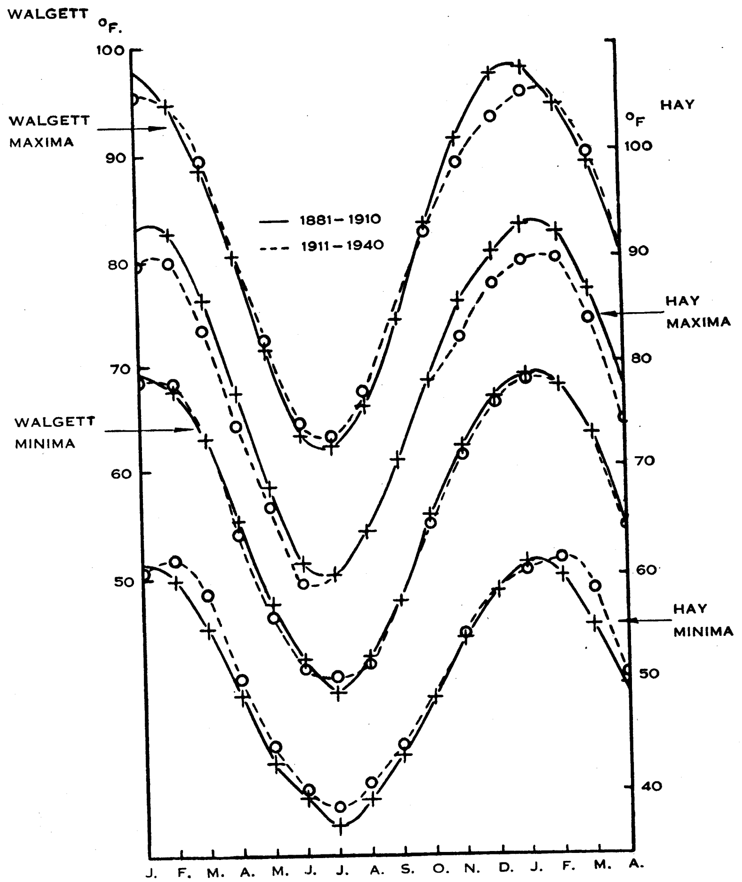


Fig. 2.—Thirty-year means of mean monthly maximum and minimum temperatures at Hay and Walgett.

TABLE 1

DIFFERENCES BETWEEN MEAN DAILY MAXIMUM TEMPERATURES FOR THE SUMMER SEASONS OF 1881–1910 ($T_1$) AND 1911–1940 ($T_2$) FOR INLAND AUSTRALIAN LOCALITIES

| Place | Lat. (°S.) | Long. (°E.) | $T_1$–$T_2$ (°F.) | Place | Lat. (°S.) | Long. (°E.) | $T_1$–$T_2$ (°F.) |
|---|---|---|---|---|---|---|---|
| Alice Springs .. | 23·6 | 133·6 | 2·3 | Hay .. .. | 34·5 | 144·9 | 3·1 |
| Walgett .. | 30·0 | 148·2 | 2·4 | Goulburn .. | 34·7 | 149·7 | 0·5 |
| Bourke .. | 30·1 | 146·0 | 2·4 | Albury .. | 36·1 | 146·9 | 0·8 |
| Narrabri .. | 30·3 | 149·8 | 3·0 | Echuca .. | 36·1 | 144·8 | 1·6 |
| Coonabarabran | 31·3 | 149·3 | 2·9 | Cooma .. | 36·2 | 149·1 | 4·7 |
| Dubbo .. .. | 32·3 | 148·6 | 2·3 | Bendigo .. | 36·8 | 144·3 | 3·6 |
| Bathurst .. | 33·4 | 149·6 | 2·1 | Omeo.. .. | 37·1 | 147·6 | 3·0 |

Australia which have sufficiently complete temperature records extending back to 1881.

All these localities show lower mean summer maximum temperatures in Period 2 and the average fall of 2·5 °F. is comparable in magnitude to the simultaneous changes in winter temperature in north-west Europe. The good consistency of the changes suggests the cause to be mainly climatic rather than changing observational technique or exposure.

Changes in the mean maximum temperature at other times of year and in minimum temperatures at all seasons are smaller,* as may be seen from Figure 2 in which the 30-year averages of monthly mean values are shown for Hay and Walgett. As a result the annual mean temperature at these places has not changed very appreciably, the decrease from the first to the second period being only 0·7 °F. at Hay, 0·4 °F. at Walgett, and 0·6 °F. at Alice Springs. This result shows how little informative annual mean temperatures may be. Hanzlik (1931) has remarked on the importance of studying circulation patterns by seasonal rather than annual means. The present results suggest that, in studying temperature, it may often be necessary to go a stage further and take the maxima and minima separately, as combining the two in mean temperatures may obscure significant features, particularly in climates where clear skies predominate.

## IV. Precipitation Changes

Rainfall data for south and south-east Australia were examined for evidence consistent with the trend in summer maximum temperatures. Too few records back to 1880 are available for the rest of the continent. Some rather remarkable increases in summer rainfall in the second 30-year period over that in the first period are displayed in Figure 3. It is also notable that the figures for the different localities, with but few exceptions, vary systematically over the region so that rough isopleths can be drawn with some confidence. The zero isopleth is almost coincident with the dividing line between two different rainfall régimes. The region to the north-east receives much of its rain under the influence of east coast cyclones but the summer rainfall in the southern area is largely associated with troughs of low pressure (meridional fronts) travelling from west to east between the migratory anticyclones and often being greatly intensified by the temperature contrast between the continent and the ocean.

That the increased summer rainfall in the south of the continent is not due to one or two exceptionally wet summers in Period 2 is shown by the frequencies of summer rainfalls given in Table 2 for the region around Adelaide, the rainfalls at Adelaide, Georgetown, Kapunda, and Cape Borda having been meaned for this purpose.

On examining the summer months individually it was found, for the whole area for which the summer rainfall in the second period exceeded that in the first by 20 per cent. or more, that the increase was greatest for February, averaging about 70 per cent., moderately large for December, 30 per cent., and negligible for January.

* Nearly all the places given in Table 1 do show a rise from Period 1 to Period 2 in mean winter minima, the range being from —0·3 to +2·4 °F., with an average of +0·9° F.

Winter precipitation (June, July, August) has changed less markedly than that of the summer between the two 30-year periods but Figure 4 shows Period 2 to have been drier over much of the area, particularly in the interior of South Australia.

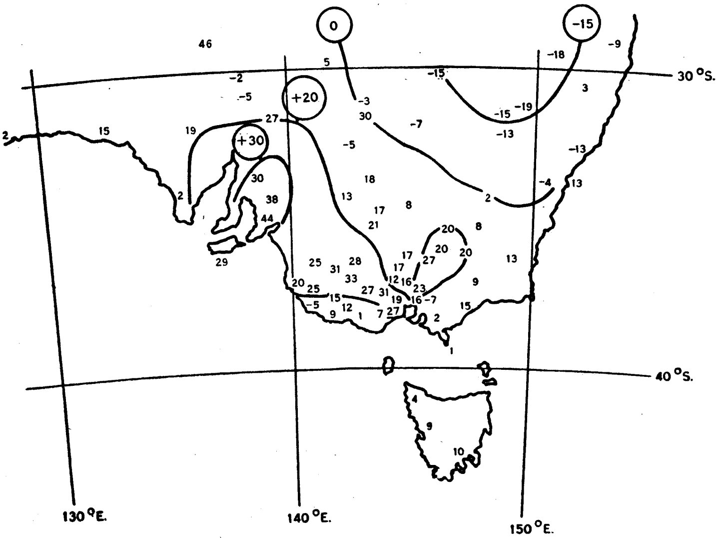


Fig. 3.—Percentage increase in summer rainfall between 1881–1910 and 1911–1940 periods.

In South Australia and western Victoria the average rainfall increases almost linearly with time during the months March to June which mark the transition from the summer minimum to the winter maximum. In Period 2 this increase has lagged behind that in Period 1 by about a fortnight. This tendency is apparent in the graphs given by Cornish (1936) in his study of the incidence and duration of the winter rains at Adelaide.

Table 2

SUMMER RAINFALL FREQUENCIES FOR REGION AROUND ADELAIDE

| Rainfall (in.) | Number of Summers in | |
|---|---|---|
| | 1881–1910 | 1911–1940 |
| <1 | 2 | 1 |
| 1–1·99 | 15 | 8 |
| 2–3 | 7 | 10 |
| >3 | 6 | 11 |

As a result of the opposite sense of the summer and winter rainfall trends for the south of the continent, the mean annual rainfalls have changed but little between the two periods. In South Australia the changes are negligible. In Victoria the second period has averaged a little wetter, some 7 per cent. in the central district (mean of 9 stations) but elsewhere the increases are only about 2 or 3 per cent.

## V. Barometric Pressure Changes

Atmospheric pressure data show interesting differences between the means of the two 30-year periods, as will be seen from the graphs for Adelaide and Sydney shown in Figure 5. During Period 1 at both places there is a definite secondary pressure minimum in June which is absent in Period 2. The annual

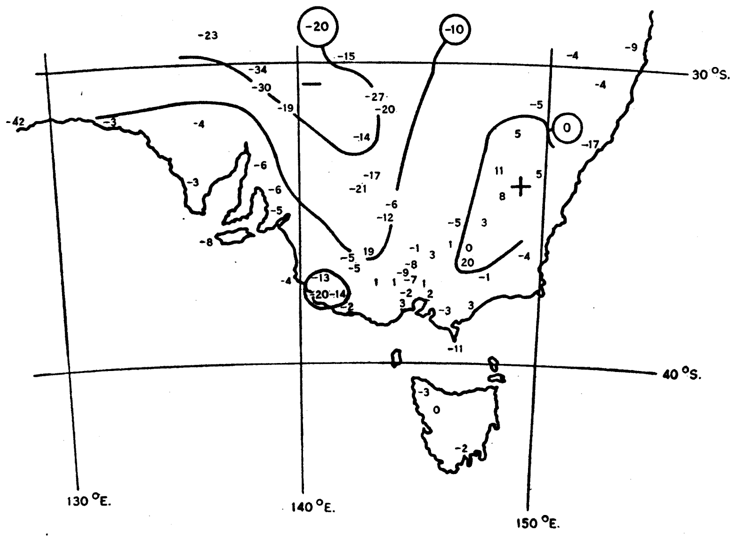


Fig. 4.—Percentage increase in winter rainfall between 1881–1910 and 1911–1940 periods.

oscillation in latitude of the high pressure belt was evidently such that its axis was appreciably to the north of Adelaide (35 °S.) and Sydney (34 °S.) in June during the first period, whereas these places mark approximately its most northerly average position in the second period.

The data for Wellington, N.Z., exhibit a similar effect but, owing to the higher latitude, the secondary minimum in winter was present in both periods. It was, however, considerably more pronounced in the first period than in the second.

This comparison of the form of the annual pressure variation has the advantage of avoiding a comparison between absolute pressure values for the two periods; such comparisons may frequently be doubtful owing to imperfections in the instrumental techniques of the earlier period. When, however, it is the change in pressure from one month to another that is compared between periods, then changing technique can be expected to have only a negligible influence.

Making the assumption that the difference in form between the graphs of Figure 5 was caused by displacement of the high pressure belt and not by a change in the form of its meridional profile, it was estimated that the southward displacement in the mean northerly limiting position of the high pressure axis was some 3° of latitude or 200 miles between the two periods.

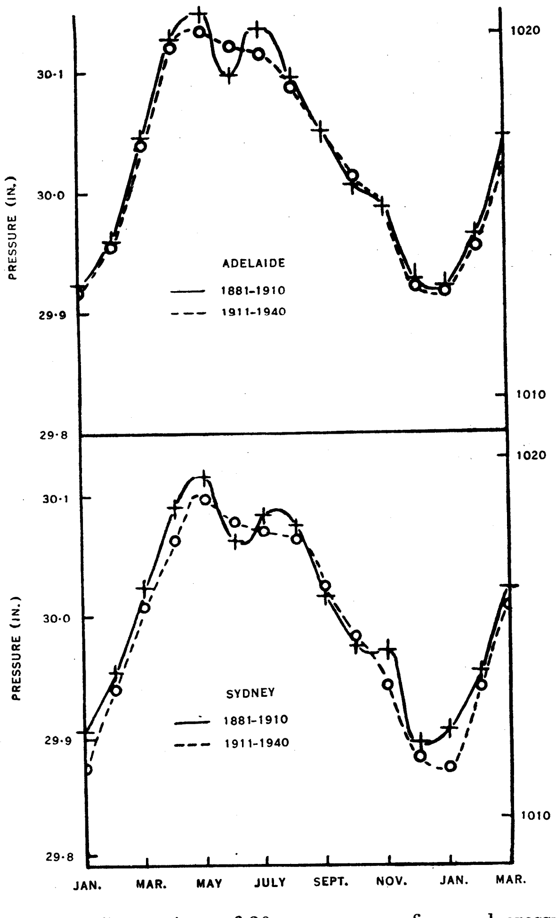


Fig. 5.—Comparison of 30-year means of annual pressure cycle at Adelaide and Sydney.

## VI. Discussion

As evidence has been found above for an appreciable climatic change in the Australian region contemporaneous with the notable amelioration of climate in higher latitudes of the northern hemisphere, it is desirable to discuss the present work in relation to the main findings as to the type of change in the northern hemisphere. Until recently it was far from clear whether the rising winter temperatures in north-west Europe and elsewhere were a consequence of increased activity of the zonal westerly winds or whether increased meridional transport, usually associated with a more broken and less intense zonal circulation, was responsible. Pettersen (1949) has, however, made use of the northern hemisphere charts of the Historical Weather Map Series of the U.S. Weather Bureau to investigate more thoroughly the changing pattern of zonal motion and meridional interchange for the North Atlantic region in the period 1899–1939. He concluded that it was not possible to ascribe the increased temperatures in high latitudes to a speeding-up of the general westerly winds in middle and high latitudes and found the most systematic and pronounced change in the general circulation to consist in " a vast intensification of the rate of total transport between the cold arctic source and middle latitudes, and a much smaller intensification of the total exchange across subtropical latitudes ".

The increased summer rainfall in South Australia and Victoria in 1911–1940 as compared with 1881–1910 is most probably a result of increased activity in the troughs between the migratory anticyclones and it points to an increase in meridional interchange, which, together with the resultant increase in cloud amount, would account for the decreased inland maximum temperatures at this season. If this interpretation is correct then it suggests that, in these southern latitudes, the climatic trend was of a similar basic nature to that in the North Atlantic region. Unfortunately, it is impossible to obtain much information of occurrences in higher southern latitudes owing to lack of observations but it may be noted, however, that Willett *et al.* (1949, p. 49) find some evidence (presumably based, almost entirely, on observations in the South American sector) that during 1910–1934 the mean spring pressure at 50–60 °S. was distinctly lower than in the period 1873–1909, and this suggests some change in pattern or intensity of the westerlies.

The Australian pressure data suggest that the high pressure belt did not move so far north in Period 2 as in Period 1. Some evidence that pressure changes at about 35 °S. in the neighbourhood of South Africa, South America, and Australia were similar in some respects is afforded by a pressure change chart given by Lysgaard (1950) who used the same two periods as in the present work. His chart for January shows that in the second period, as compared with the first, pressures at 30–35 °S. have fallen on the eastward side of each of the three land masses and risen or remained steady on the westward side, so that in all three cases there has been an increase in the mean southerly geostrophic wind component at this time of year.

The differences in 30-year mean pressure gradients between Adelaide and Sydney were examined to obtain more information on this point. There was no appreciable change in the winter months but for the summer half-year (November to April) there was an increase in the mean southerly geostrophic wind component from 0·5 m./sec. in the first period to 1·0 m./sec. in the second, which lends a little support to increased meridional interchange in the second period as compared with the first.

As the subtropical high pressure belts are stronger heat sources than the equatorial belt, it seems that increase in meridional heat transfer is compatible with the rising trend of temperatures in Indonesia which have been studied by de Boer and Euwe (1949) and Schmidt-ten Hoopen and Schmidt (1951).

## VII. Changes Since 1940

The data for the decade 1941–1950 (referred to hereafter as the last decade) were examined to see whether or not the trend displayed by the earlier observations continued.

The changes in summer rainfall from Period 2 to the last decade have followed a mainly similar pattern to that of Figure 3 and, over the large area in that figure enclosed by the 20 per cent. isopleth, the rainfall of the last decade has averaged about 20 per cent. greater than in Period 2. Around Adelaide (4 stations) the mean increase was 19 per cent., while in western Victoria it was 22 per cent. (12 stations). Over this region, therefore, the last decade had an average summer rainfall nearly 50 per cent. greater than in the period 1881–1910.

The mean summer maximum temperatures at the places in Table 1 were mainly lower in the last decade than in Period 2, with the exception of the more easterly stations Bathurst, Goulburn, and Cooma, which showed rises of 0·3, 1·5, and 1·3 °F. respectively. The average change at the other 11 stations was a fall of 0·74 °F., so the general indication is that the trend shown by the earlier data continued into the last decade over much of the area.

The mean southerly geostrophic wind component (November to April) between Adelaide and Sydney was greater in the last decade as compared with Period 2 by 0·1 m./sec., a change in the same sense as that from Period 1 to Period 2.

As all these differences are of a similar character to that between Periods 1 and 2 it seems that the main trend up to 1940 was continued in the decade 1941–1950.

## VIII. Acknowledgment

Acknowledgment is made to the Director, Commonwealth Meteorological Branch, for making available climatological data used in this work.

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