564 THE DISTRIBUTION OF CLIMATE ZONES ACROSS AUSTRALIA: IDENTIFYING AND EXPLAINING CHANGES DURING THE PAST CENTURY

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1. INTRODUCTION

The paper describes the application of the *Australian Water Availability Project (AWAP)* (Jones *et al*., 2009 and Raupach *et al*., 2009) analyses of monthly rainfall, maximum temperature and minimum temperature to a climate classification scheme.

By this means, changes (both long-term trends and short-term fluctuations) in the distribution of climate zones across Australia during the past century are identified and explained.

2. BACKGROUND

Köppen's scheme to classify world climates was devised in 1918 by Dr Wladimir Köppen (Köppen, 1931) and is based on the concept that native vegetation is the best expression of climate, climate zone boundaries having been selected with vegetation limits in mind (Trewartha, 1943).

A modification, which addressed some concerns that had been expressed about the Köppen scheme, was developed by Stern *et al*. (2000) and illustrated with its application to Australia.

This modified climate classification is shown for Australia, using data from the standard 30-year period 1961-1990, on the Bureau of Meteorology's (BoM) website at:

http://www.bom.gov.au/climate/environ/other/kpn.jpg

There are many reasons to classify climates aside from that expressed by Köppen (1931). 'People classify the climate in many different ways depending on who needs the information, how much they know about the climate system and what information they need to know' (WMO, 2012).

One may undertake studies that examine climate change in terms of shifts in climate classification boundaries by using data from different historical periods.

One may also view such schemes as a potential diagnostic tool for general circulation models, with the aim of developing future climatologies (Löhmann *et al*., 1993).

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This has become possible now (Institute for Veterinary Public Health, 2012) with the ready availability of model output data bases such as CliMond (Kriticos et al., 2011).

Recently, as part of an investigation led by the Victorian Commissioner for Environmental Sustainability (CfES), climate change data from the output of global climate models were applied to IPCC scenarios in the context of the modified Köppen climate classification scheme.

For details, refer to Chapter 1 of the *'State of the Environment Foundation Paper 1 – Climate Change'* at:

http://www.ces.vic.gov.au/victorias-environment/state-of-environment-victoria-2009-2013/climate-change.

The AWAP analyses represent an updated representation of the distribution of the individual weather elements that make up the nation's climate and incorporate the use of data that was hitherto unavailable or had not yet been subject to the Bureau's new quality climate data management system. The AWAP analyses are shown on the BoM's website at:

http://www.bom.gov.au/climate/maps/.

3. ANALYSIS

Key drivers of the Australian climate include the ENSO phenomenon, the Indian Ocean Dipole, the Madden Julian Oscillation, the Southern Annular Mode, the monsoons and the SE trades.

Other drivers include synoptic features such as the position and intensity of long wave troughs, the jet streams, the subtropical ridge and the 'blocking' phenomenon.

Using global reanalysis data from the NOAA/ESRL Physical Sciences Division (Boulder, Colorado), data sets from the BoM's Australian Data Archive for Meteorology, data sets reflecting the key drivers of the Australian climate, in addition to some very old data sets pre-dating the BoM (Hunt, 1911), possible explanations for some of the detected changes in the distribution of climate zones may be given.

It is found that, during the past century, many changes in the distribution of Australian climate zones have taken place. Figure 1 depicts spatial distributions of the major climate groups and classes across Australia, calculated every ten years, and averaged over the preceding 30 years, including the most recent (1983-2012) 30 year period.

The most notable of these changes has been the contraction of the area covered by 'Desert' climates and the corresponding increase in the area covered by 'Grassland' and 'Tropical' climates.

This may be attributed to an increase in rainfall over much of northern and central Australia caused by the apparent northward shift of the sub-tropical jet from about 32°S to about 28°S over the past century (Figure 2), and the associated increase in the frequency of the 'blocking' phenomenon over the Tasman Sea, reflected by the substantial increase in the area with relatively light mean wind speeds at 250 hPa, especially during summer.

Figure 3 summarises the trends in the percentage area of Australia covered by the major climate groups. It may be seen that, whilst there has been an overall increase in the size of the area covered by 'desert' climates and a corresponding decrease in the area covered by 'grassland' climates, most of this change has occurred since the middle of the last century.

There has also been a decrease in the, albeit very small, area covered by 'equatorial' and 'polar' climates.

There has almost been a doubling of the area covered by 'tropical' climates which is largely a reflection of the increase in rainfall over northern Australia, possibly a consequence of the aforementioned northward shift in the subtropical jet enhancing the dynamics of the atmosphere there.

In recent years, there has been a decline in the area covered by both 'temperate' and 'subtropical' climates, a reflection of the 'drying' trend that has affected much of southern Australia and has sometimes been attributed to the strengthening and southward movement of the subtropical ridge.

Figure 4 presents an analysis of trends in Melbourne's average annual mean sea level pressure (reflecting the strength of the subtropical ridge) and rainfall.

Figure 4 clearly shows the strong inverse relationship between trends in the two parameters at different times of the year (the more rapidly rising pressures associated with the greater declines in rainfall, and *vice versa*), with the trends strongest during the transition months of late autumn and early spring.

Figure 5 contrasts changes in the coverage by two of the temperate classes and two of the grassland classes.

Although both of the temperate classes whose trends are depicted, *no dry season (hot summer)* and *no dry season (mild summer)*, exhibit an increase in area covered followed by a decrease during the period of analysis, the former exhibits an overall increase (from 2.0% to 2.4%), whilst the latter exhibits an overall decrease (from 1.9% to 1.6%), the difference in the overall direction of the trend largely a consequence of the gradually rising average temperature.

Regarding the grassland classes whose trends are depicted, *hot persistently dry* and *warm persistently dry*, the former exhibits a doubling in the area covered (from 6.8% to 13.6%), whilst the area covered by the latter only slightly increases (from 5.2% to 6.1%).

The much greater increase in the area covered by *hot persistently dry grassland* may be attributed to the overall increase in rainfall over large parts of central and northern Australia, previously covered by *hot persistently dry desert.*

Some of the subtle changes that may be identified include –

- the expansion, and southward advance, of the 'Tropical' zone;
- the contraction of the 'Temperate' area of southwest Western Australia;
- an increase in the area covered by 'Hot Desert' just inland from the Head of the Bight;
- a decrease in the area of coastal Victoria classified as having a 'cool summer';
- an increase, followed by a decrease, in the area covered by 'Temperate' climates; and,
- the highland regions of Tasmania classified as 'Polar' having all but disappeared.

4. SUMMARY

The AWAP analyses have enabled changes in the distribution of climate zones across Australia to be both identified and explained. To summarise, over the period of analysis, the percentage area of Australia designated –

- *Desert*, has decreased from 51.1% to 38.0%;
- *Grassland*, has increased from 26.3% to 35.6%;
- *Temperate*, has decreased from 10.9% to 10.2%;
- *Tropical*, has increased from 5.5% to 9.0%;
- *Subtropical*, has increased from 5.5% to 6.8%;
- *Equatorial*, has decreased from 0.7% to 0.3%; and,
- *Polar*, has decreased from 0.004% to <0.001%.

These and other changes have been explained in terms of corresponding shifts in some of the key drivers of the Australian climate.

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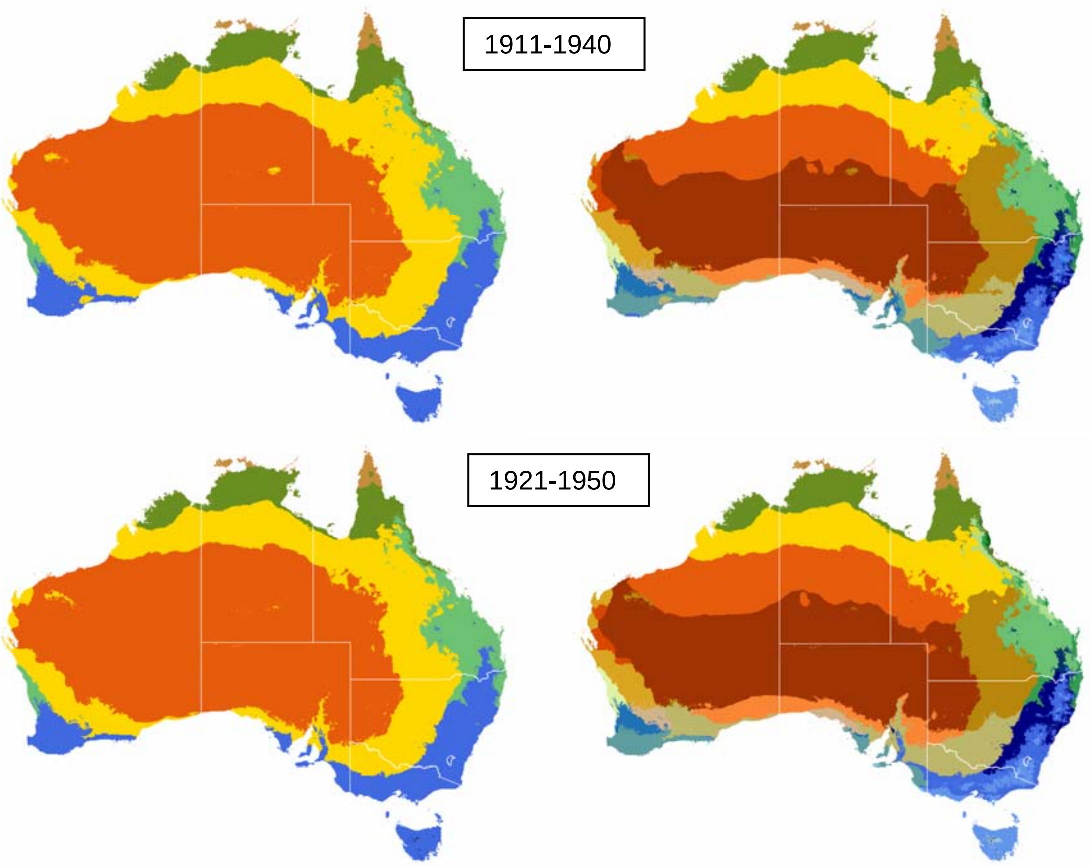
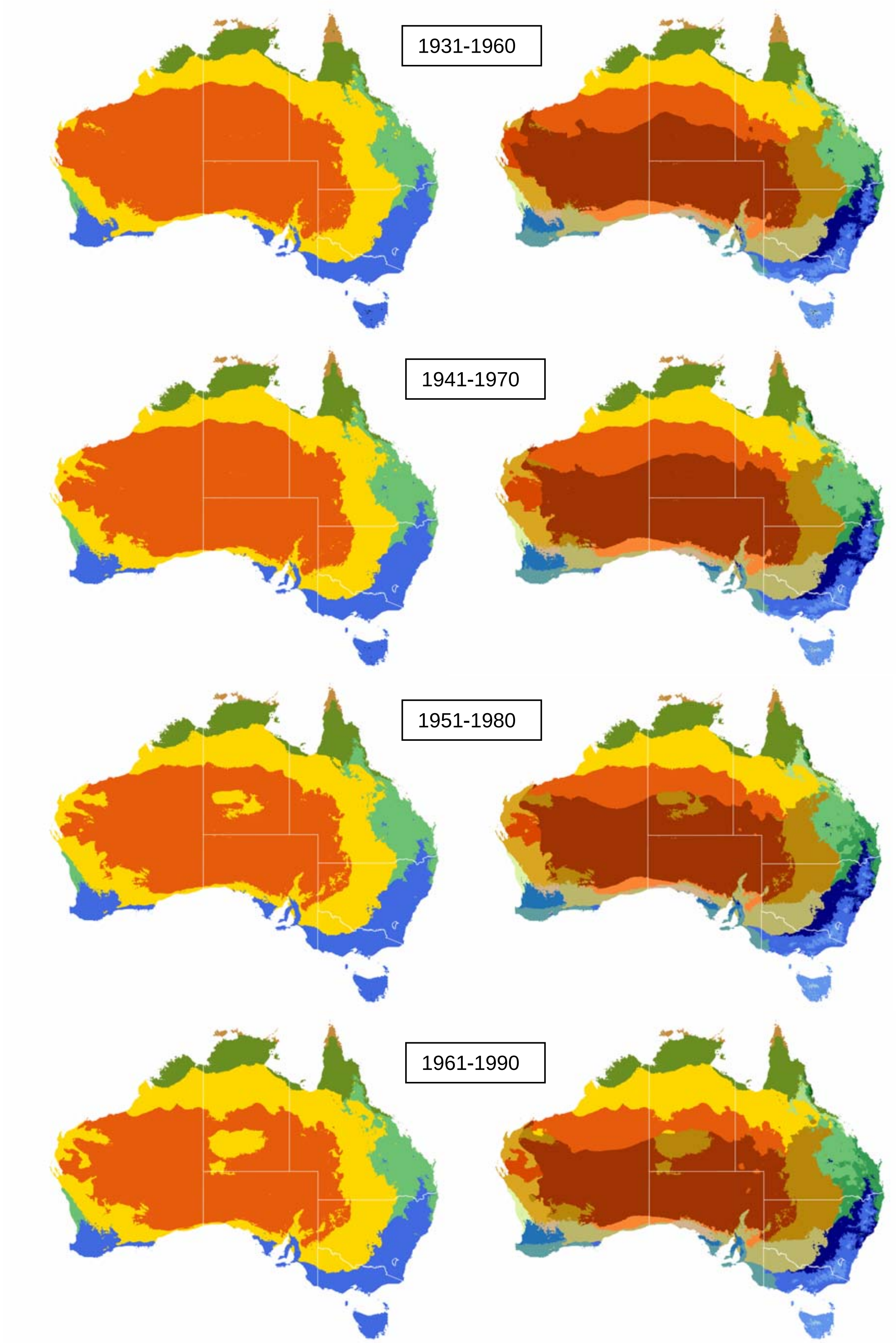
http://www.wmo.int/pages/themes/climate/understanding_climate.php

Figure 1 The distribution of major climate groups and individual climate classes across Australia during the past century and most recent (1983-2012) 30-year period of data available.




1931-1960
1941-1970
1951-1980
1961-1990

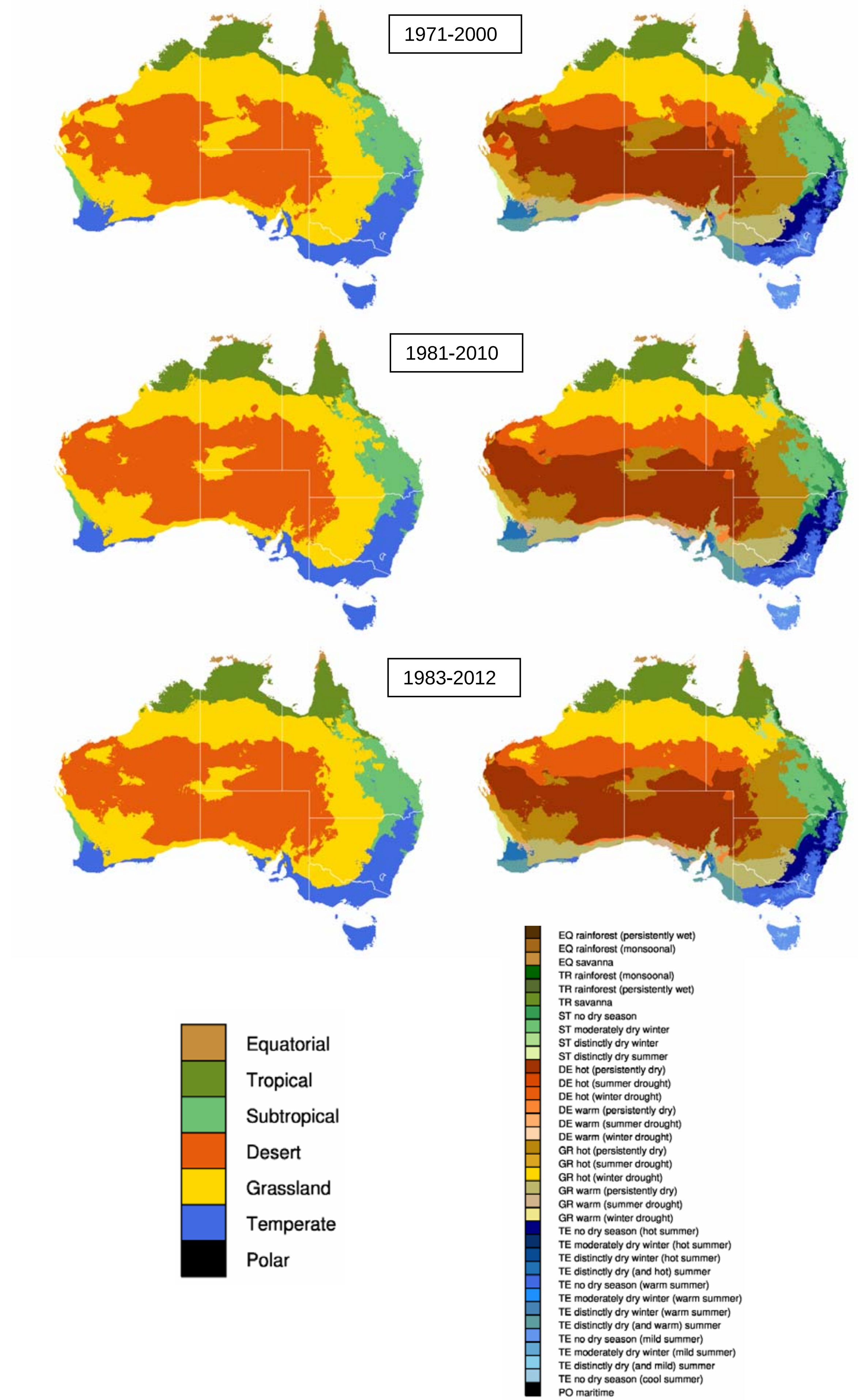

1971-2000
1981-2010
1983-2012
Equatorial
Tropical
Subtropical
Desert
Grassland
Temperate
Polar
EQ rainforest (persistently wet)
EQ rainforest (monsoonal)
EQ savanna
TR rainforest (monsoonal)
TR rainforest (persistently wet)
TR savanna
ST no dry season
ST moderately dry winter
ST distinctly dry winter
ST distinctly dry summer
DE hot (persistently dry)
DE hot (summer drought)
DE hot (winter drought)
DE warm (persistently dry)
DE warm (summer drought)
DE warm (winter drought)
GR hot (persistently dry)
GR hot (summer drought)
GR hot (winter drought)
GR warm (persistently dry)
GR warm (summer drought)
GR warm (winter drought)
TE no dry season (hot summer)
TE moderately dry winter (hot summer)
TE distinctly dry winter (hot summer)
TE distinctly dry (and hot) summer
TE no dry season (warm summer)
TE moderately dry winter (warm summer)
TE distinctly dry winter (warm summer)
TE distinctly dry (and warm) summer
TE no dry season (mild summer)
TE moderately dry winter (mild summer)
TE distinctly dry (and mild) summer
TE no dry season (cool summer)
PO maritime

Figure 2 The apparent northward shift of the sub-tropical jet over the past century across Australia during the first (1911-1940) and most recent (1981-2010) 30-year period of data available.

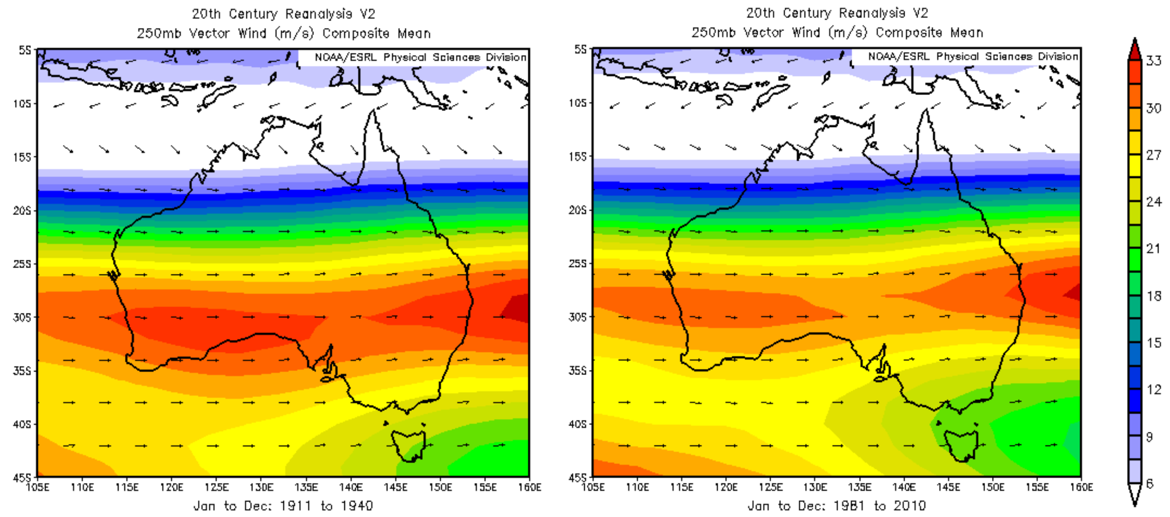


Figure 3 The trends in the percentage area of Australia covered by the major climate groups.

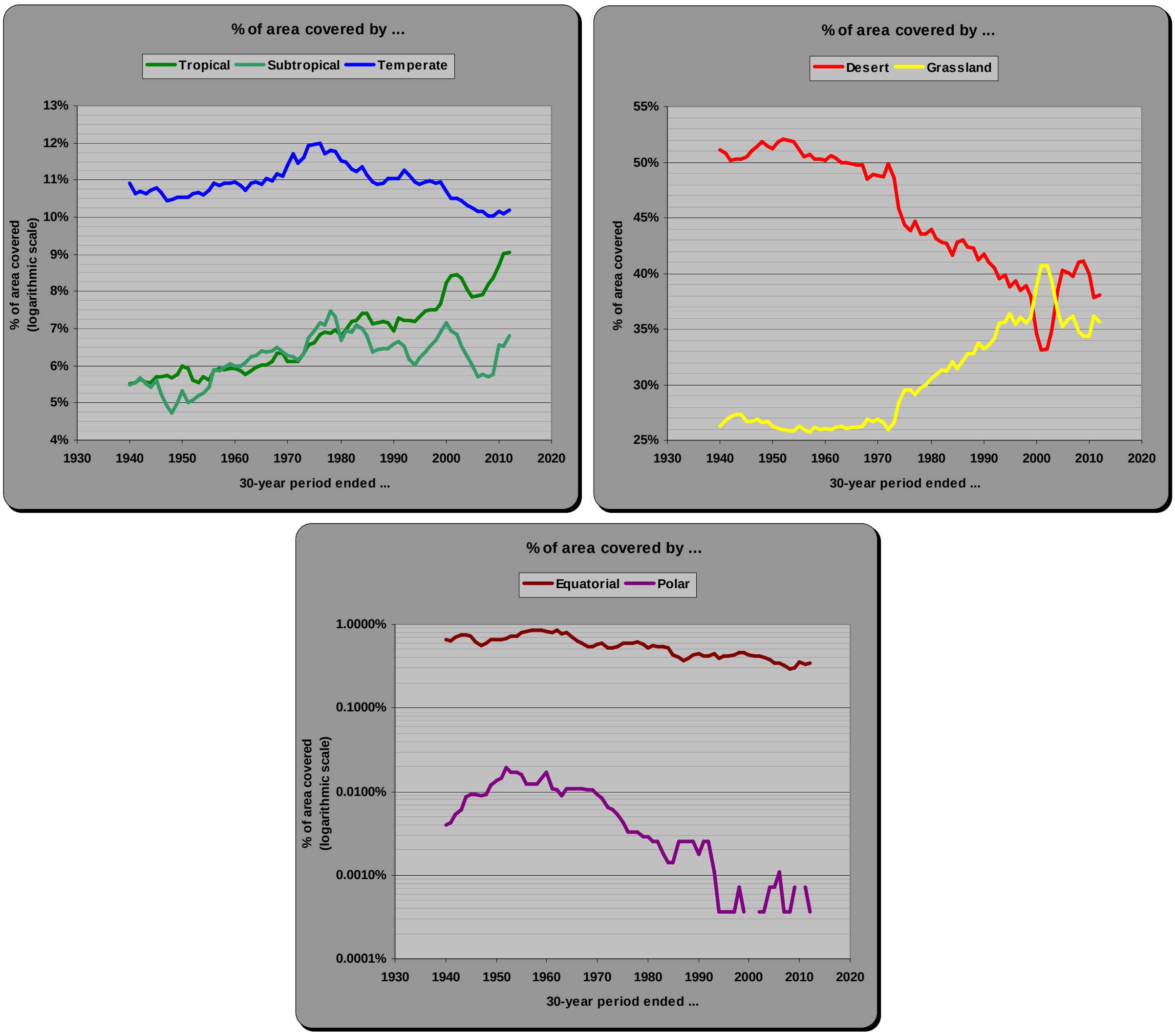


Figure 4 The long-term trends and fluctuations in Melbourne's average mean sea level pressure and rainfall, both annually and seasonally.

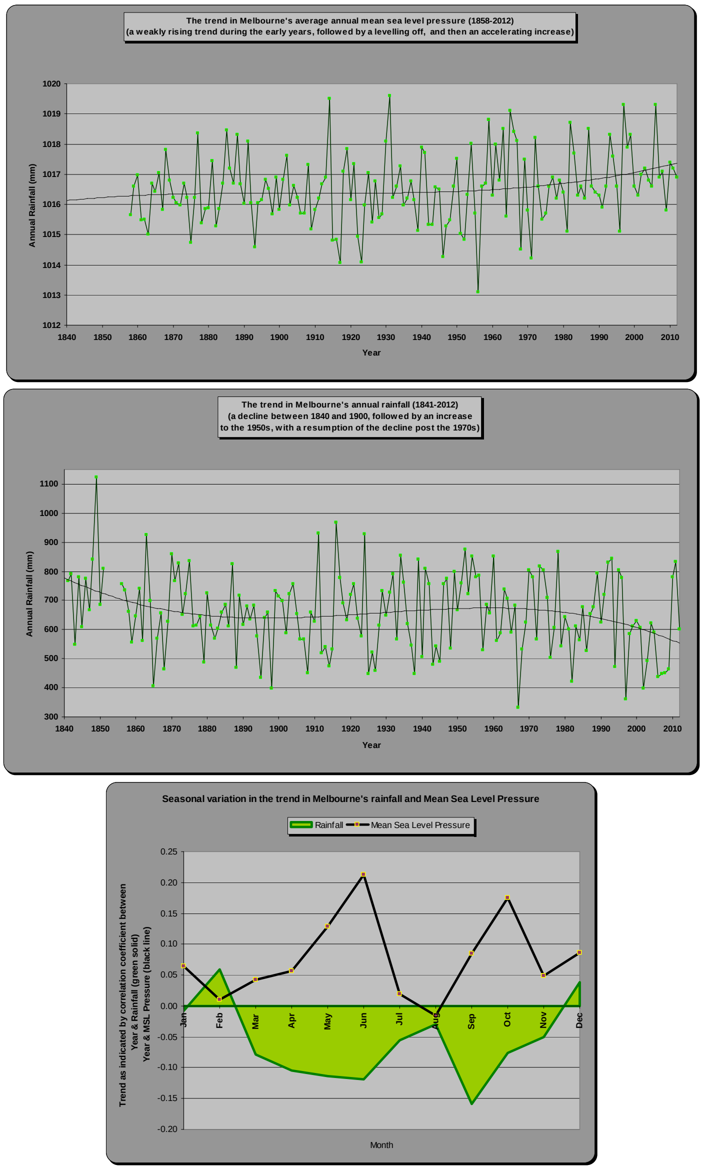


Figure 5 The trends in the percentage area of Australia covered by two of the temperate climate classes, *no dry season (hot summer)* and *no dry season (mild summer)* (left), and two of the grassland climate classes *hot persistently dry* and *warm persistently dry* (right).