



**RANGELANDS**  
NRM CLUSTER



IMPACTS & ADAPTATION  
I N F O R M A T I O N  
FOR AUSTRALIA'S NRM REGIONS



## Australian rangelands and climate change – heatwaves



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An Australian Government Initiative



**NINTI ONE** RANGE LANDS CLUSTER



**Government of South Australia**

Alinytjara Wilurara Natural Resources Management Board



**Government of South Australia**

South Australian Arid Lands Natural Resources Management Board



**South West NRM Ltd**  
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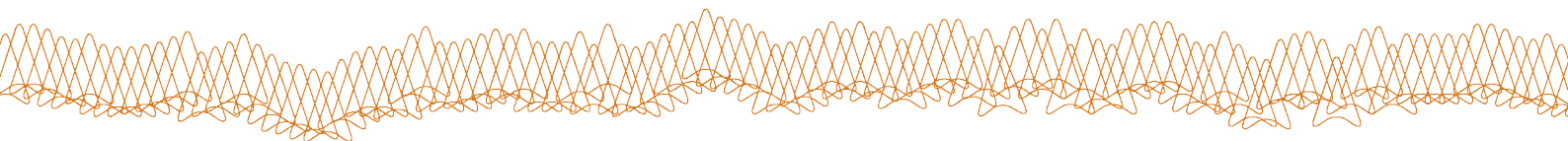
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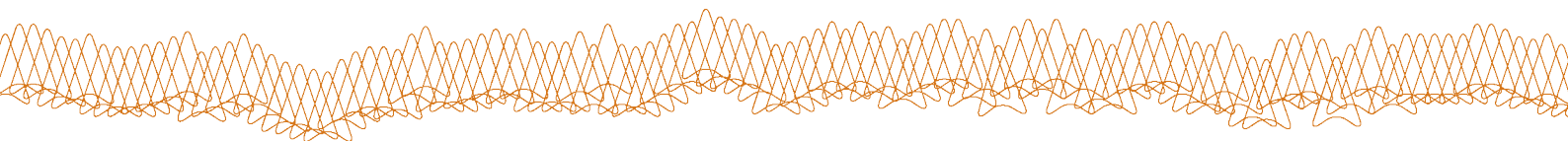


**Local Land  
Services  
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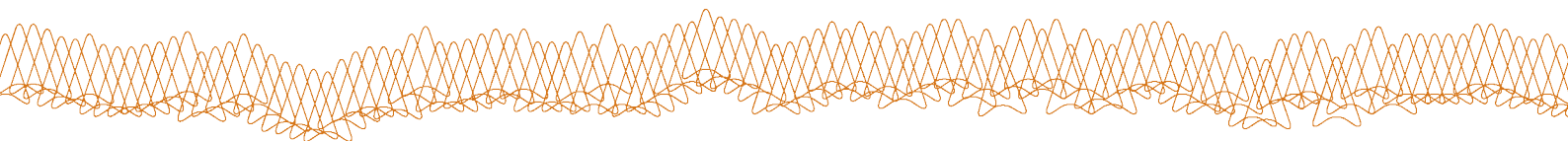


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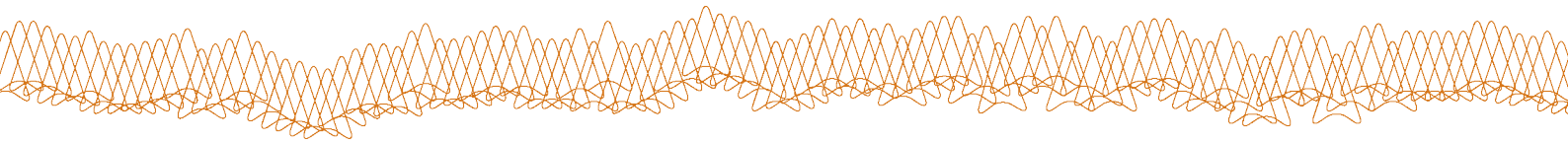
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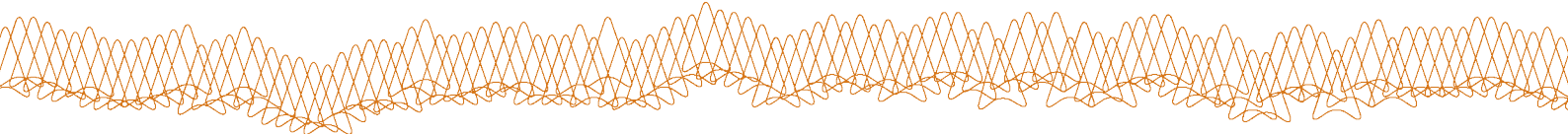
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## Key points

- It is hot and getting hotter – the regional projections report advises that the Rangelands Cluster region has warmed at a rate of 0.05–0.15°C per decade since 1911 (Watterson et al. in press). The recent experience of many rangelands communities in coping with increasing summer temperatures provides some foundation for adjusting to what is projected to come. This acknowledged, there will still be a considerable requirement for further adjustment and adaptation (not covered in this short document).
- Most towns in the region have had more hot days and heatwaves, and longer heatwaves, in the recent past, particularly during the first decade of this century. This pattern is consistent with projected hotter temperatures as part of climate change. More recent contributing factors also included low humidity, cloudless days and increased reflected and transmitted heat from areas with low ground cover associated with protracted and widespread drought conditions during much of the 2000s.
- The trend in heatwave conditions appears to be moderated for northern urban centres (Longreach, Mount Isa and Tennant Creek; not so for Newman). Here, the summer monsoon probably has a moderating effect on extreme maximum daily temperatures (i.e. periods of cloud cover, higher humidity, variable rainfall and increased ground cover).
- In this section, we report recent decadal patterns in the number of summer days exceeding a threshold daily maximum temperature (either 36° or 40° C) and the number and length of heatwaves (defined as continuous periods beyond a week when the threshold temperature was exceeded). Temperature data were sourced from the Bureau of Meteorology for 16 towns in (or on the edge of) the Rangelands Cluster.

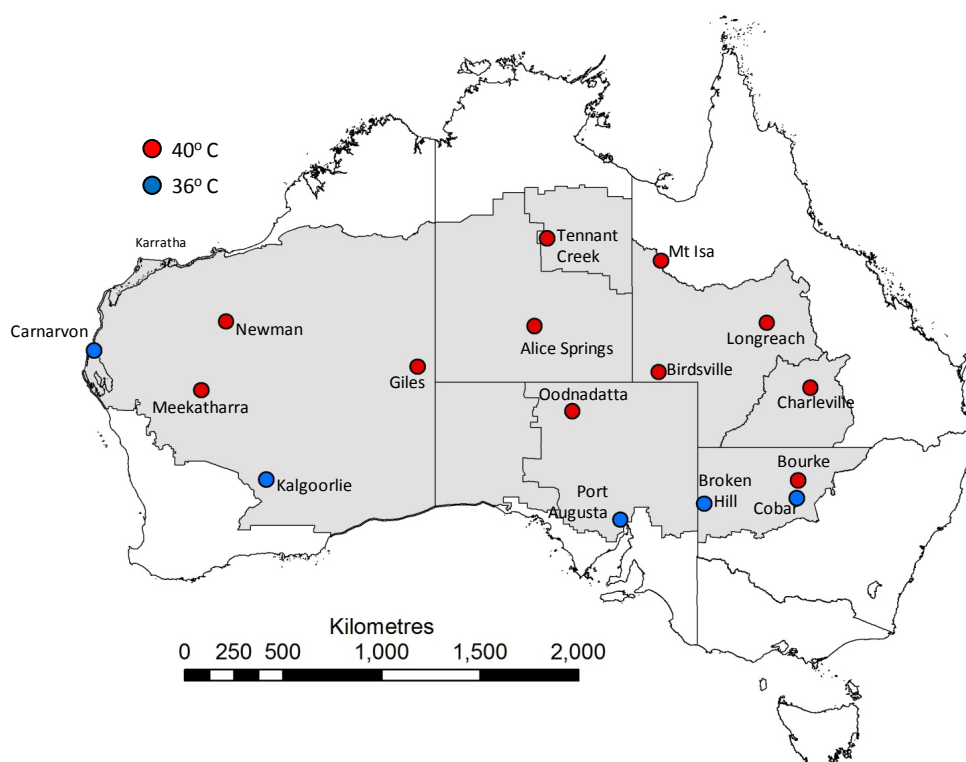
Gary Bastin  
CSIRO

# 1. Introduction

It is getting hotter and it is predicted that we should prepare for even hotter conditions (Watterson et al. in press). As context, much of the Rangelands Cluster region is no stranger to extended hot periods through the summer. An analysis of summer maximum temperatures since 1950 for larger towns in, and neighbouring, the Rangelands Cluster reveals some interesting patterns in the frequency and duration of hot spells. Temperature data analysed were downloaded as patched-point datasets from SILO at the Long Paddock web site.<sup>1</sup> This provides a convenient source of data for spreadsheet analysis (i.e. similar to the location-specific rainfall data reported in Bastin 2014).

# 2. Method

1. For this analysis, 'summer' is defined as the warmer (or hotter) months of October to March. The analysis period is the 1950–51 summer through to the 2012–13 summer (i.e. 63 summers).
2. Two regionally different threshold temperatures were used to define a 'hot' day: 36° C for southern centres (Figure 2.1) and 40° C for central and northern centres.
3. A 'heatwave' was defined, for each location, as a week or more of continuous maximum daily temperatures above the specified threshold.
4. Four indices are used to describe hot and heatwave conditions in the recent past:

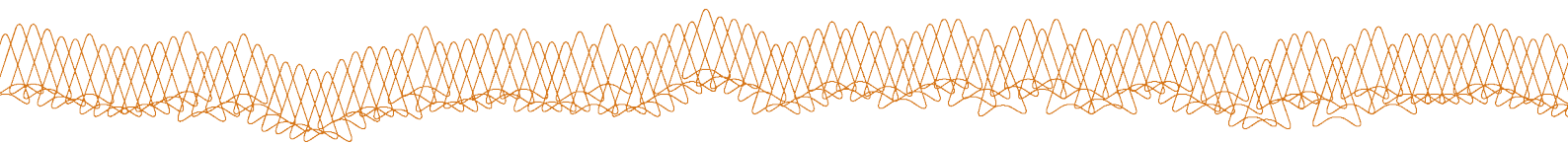


**Figure 2.1 Locations and temperature thresholds within the Rangelands Cluster for characterising heatwaves.**

Black lines show the boundaries of individual NRM regions within the combined cluster region (shaded in grey).

<sup>1</sup> <http://www.longpaddock.qld.gov.au/silo/>, accessed 12 February 2014





- a. The total number of days in each decade when the threshold temperature was exceeded and the decadal frequency of continuously hot days (following graphs). The statistics for the current, incomplete, decade (with data for only three summers) are not directly comparable with previous decades.
- b. The mean annual number of days in each decade when the threshold temperature was exceeded (Table 5.1). This is a way of standardising (or normalising) data for the current decade.
- c. The number of heatwaves experienced per decade (Table 5.2), bearing in mind there are only three summers in the current decade.
- d. The duration and time of the longest heatwave.

### 3. Data source

Temperature data are readily available for many locations in the Rangelands Cluster. Data files can be downloaded from the SILO URL (<http://www.longpaddock.qld.gov.au/silo/>) or from the Bureau of Meteorology web site ([www.bom.gov.au](http://www.bom.gov.au)). The data used in the analyses below were patched-point SILO data for larger towns in the Rangelands Cluster region from October 1950 to March 2013 (63 summers).

### 4. Caveats

- The temperature thresholds defining a ‘hot’ day are arbitrary.
- The duration of consecutive hot days specifying a heatwave is similarly arbitrary.

## 5. Findings

The regional occurrence of past heatwaves is characterised in the following sub-sections. For ease of formatting, tables and figures for the various NRM regions (Tables 5.1 and 5.2 and Figures 5.1–5.16) are presented at the end of this section.

### 5.1 NSW: Western CMA

#### 5.1.1 Broken Hill

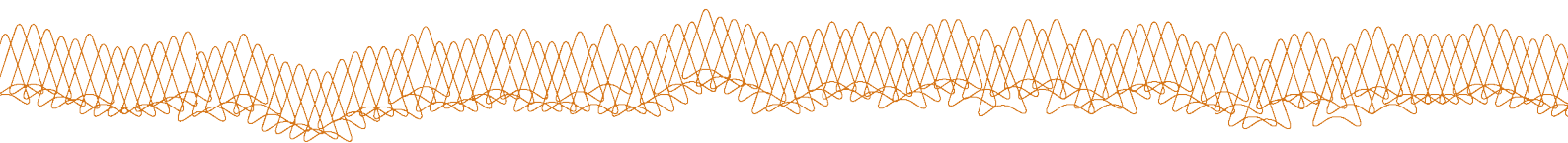
The 1980s and 2000s were the hottest decades in terms of number of days with a maximum temperature above the threshold (36° C, Figure 5.1 and Table 5.1). Both periods were associated with drought. There were more heatwaves in the last decade compared with the 1980s (Table 5.2). There were two record heatwaves (based on this analysis): 17 days in January–February 1979 and February–March 2004.

#### 5.1.2 Bourke

The 2000s was by far the hottest decade since the 1950s (Figure 5.2 and Tables 5.1 and 5.2). The current decade (2011–2013) has been more moderate (Table 5.1), no doubt due in part to the wetter period at its start (i.e. cloud cover and higher humidity reduce maximum temperatures). The hottest spell over the last 63 summers was 14 consecutive days in February 2004 (i.e. maximum daily temperature  $\geq 40^{\circ}$  C).

#### 5.1.3 Cobar

Both the 1950s and 2000s were notably hot decades (Figure 5.3 and Table 5.1), although the last decade had more heatwaves (Table 5.2). Also apparent from Figure 5.3 is that longer heatwaves were slightly more numerous (compared with the 1950s). The longest heatwaves were two periods of  $\geq 36^{\circ}$  C over 18 days in January–February 1999 and February–March 2004.



## 5.2 Queensland: South West NRM

### 5.2.1 Charleville

The last decade was remarkably hotter than preceding ones (Figure 5.4 and Table 5.1), although the 1970s had a small number of longer continuously hot periods (Figure 5.4 and Table 5.2). The longest continuously hot period ( $\geq 40^{\circ}\text{C}$ ) was 9 days in December 1972.

## 5.3 Queensland: Desert Channels

### 5.3.1 Longreach

There does not appear to have been any medium-term change in the decadal frequency of hot days ( $\geq 40^{\circ}\text{C}$ ), heatwaves or their duration (Figure 5.5 and Tables 5.1 and 5.2). The 1950s, 1980s and 2000s were similarly hot (Figure 5.5). It may be that monsoonal conditions (particularly cloud cover) in most summers moderate extreme temperatures and their duration. It may also be that early spring (August–September) and later autumn (April–May) are experiencing a higher frequency of maximum daily temperatures close to, but below, the threshold. This phenomenon is unrelated to heatwaves and the analysis has not been conducted.

The longest hot spell for Longreach was 13 days in December 1997.

### 5.3.2 Mount Isa

This city is on the edge of the Rangelands Cluster. The analysis of temperature data conducted here indicates that the 1980s was the hottest decade although the most recent decade was similar in terms of extended heatwaves (Figure 5.6 and Tables 5.1 and 5.2). As for Longreach, the summer monsoon probably moderates extreme temperatures in most summers. Maximum temperatures continuously exceeded  $40^{\circ}\text{C}$  over 15 days in January 1971.

### 5.3.3 Birdsville

Birdsville is truly a hot place (Figure 5.7)! It has experienced some very long heatwaves in the 1960s, 1970s and 2000s (Table 5.2). The 1980s were also hot (compared with other decades in the second half of the 20th century) but that decade did not have the extended heatwaves of the more recent past (Figure 5.7). The longest heatwave was quite recent: 37 days between December 2012 and January 2013.

## 5.4 SA: Arid Lands

### 5.4.1 Port Augusta

The last decade was by far the hottest experienced in the recent past, in terms of individual and cumulative days exceeding  $36^{\circ}\text{C}$  (Figure 5.8 and Tables 5.1 and 5.2). Based on normalised (i.e. per year within decade) data, the start to this decade has also been hot (Table 5.1). The continuously hottest period was 15 days in March 2008.

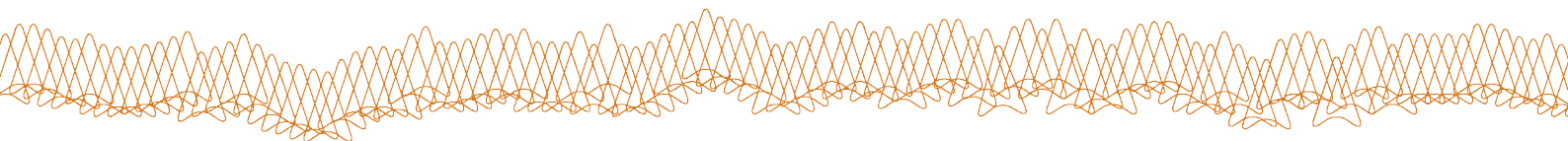
### 5.4.2 Oodnadatta

On a decadal time scale, Oodnadatta has, in the main, experienced an increasing number of summer days hotter than  $40^{\circ}\text{C}$  (Figure 5.9). This is also the case for standardised (mean per year) data (Table 5.1). Notably, the last decade and years to date in the current decade have had more and longer heatwaves (Table 5.2 and Figure 5.9). This was not the case for the absolute longest heatwave; it lasted 18 days between December 1978 and January 1979.

## 5.5 NT: Arid Lands and Tablelands sub-regions

### 5.5.1 Alice Springs

Based on the total number of summer days with temperatures  $\geq 40^{\circ}\text{C}$ , the last three decades of the 20th century were considerably hotter than the preceding decades (Figure 5.10). This was also the case when the data were normalised to an annual basis (Table 5.1). The first and current decades (to date) of this century



have also had more extended heatwaves than previously (Figure 5.10 and Table 5.2), including the longest heatwave (16 days in January 2013).

### 5.5.2 Tennant Creek

Contrasting with almost all other centres, heatwave conditions in Tennant Creek appear to have progressively moderated on a decadal and standardised year-within-decade basis (Figure 5.11 and Table 5.1). This may be due to a changing monsoonal influence (perhaps more cloud and higher humidity in some recent years), but this has not been investigated. As with the similar northern centres of Longreach and Mount Isa, it is likely that adjacent spring and autumn months are now experiencing hotter temperatures but because such days are unlikely to combine to constitute heatwaves (as defined here), this feature has not been analysed. The hottest continuous summer period since 1950–51 was 19 days in January 2008.

## 5.6 WA: Rangelands

### 5.6.1 Kalgoorlie

Summers over the last decade in Kalgoorlie were the hottest experienced since the 1950s, both in terms of days exceeding 36° C (Figure 5.12), normalised to a mean per year (Table 5.1) and number of heatwaves (Table 5.2). Both the 1990s and 2000s had increasingly longer heatwaves (Figure 5.12). Against this trend, the longest heatwave was 11 days in February–March 1953.

### 5.6.2 Meekatharra

Meekatharra experienced more hot days ( $\geq 40^{\circ}\text{C}$ ), more heatwaves and longer heatwaves in the last decade compared with previous decades back to the 1950s (Figure 4.13 and Table 5.2). There was a consistent decadal increase in normalised mean annual number of hot days between the 1960s and 2000s (Table 5.1). This trend has abated in the first three summers of the current decade.

The longest heatwave (24 days) extended from December 2007 into January 2008.

### 5.6.3 Carnarvon

The decadal pattern of an increasing number of hot summer days and heatwaves and progressively longer heatwaves for most towns in the Rangelands Cluster appear not to include Carnarvon (Figure 5.14). It may be that the proximity of the Indian Ocean moderates extremely hot temperatures in this town.

However, this may be about to change. One notable feature of the three summers to date in the current decade is the substantial increase in the normalised value for the annual number of hot days (Table 5.1), record heatwave (12 days in February 2013) and generally longer heatwaves (Figure 5.14), also apparent in the 1980s.

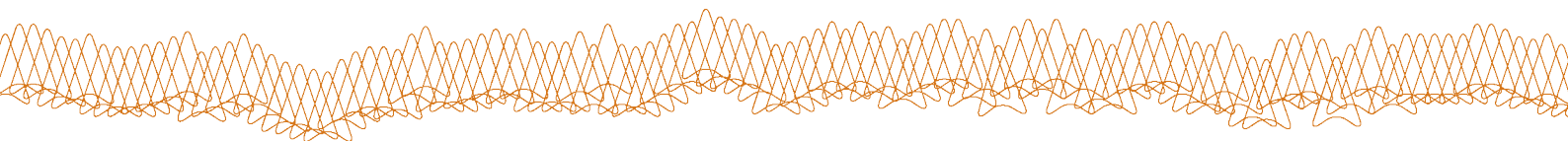
### 5.6.4 Newman

Like Birdsville, Newman is hot and getting hotter (Figure 5.15). There has been a remarkable increase since the 1970s in (i) the number of summer days per decade exceeding 40° C, (ii) the number of heatwaves (Table 5.2) and (iii) the length of heatwaves (Figure 5.15). This pattern has moderated with the first three summers of the current decade (Table 5.1).

The longest heatwave was 29 days in January–February 2007.

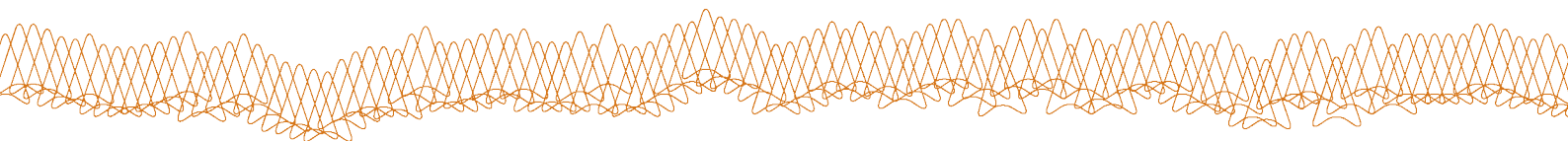
### 5.6.5 Giles

Although the normalised (mean per year within decade) and total number of days hotter than 40° C was relatively stable between the 1970s and 2000s (Table 5.1), there has been a more recent tendency of longer heatwaves (Figure 5.16). This translates to the highest normalised index value for mean annual hot days in the current decade (Table 5.1). The longest heatwaves have been quite recent: each 17 days, between February–March 2007, January–February 2011 and January–February 2013.



**Table 5.1 Mean annual number of days per decade when threshold temperature was exceeded**

| LOCATION IN NRM<br>REGION (DEGREE<br>THRESHOLD) | DECADE |       |       |       |       |       |               |
|-------------------------------------------------|--------|-------|-------|-------|-------|-------|---------------|
|                                                 | 1950s  | 1960s | 1970s | 1980s | 1990s | 2000s | 2011–<br>2013 |
| NSW: Western CMA                                |        |       |       |       |       |       |               |
| Broken Hill (36° C)                             | 25.5   | 26.4  | 24.7  | 36.4  | 26.0  | 37.9  | 25.3          |
| Bourke (40° C)                                  | 13.4   | 9.6   | 9.0   | 12.8  | 12.8  | 24.7  | 13.0          |
| Cobar (36° C)                                   | 43.5   | 32.8  | 26.7  | 32.7  | 32.5  | 45.4  | 31.3          |
| Queensland: South West NRM                      |        |       |       |       |       |       |               |
| Charleville (40° C)                             | 5.7    | 5.4   | 5.7   | 7.3   | 5.3   | 10.1  | 6.7           |
| Queensland: Desert Channels                     |        |       |       |       |       |       |               |
| Longreach (40° C)                               | 29.7   | 21.7  | 18.8  | 25.4  | 20.6  | 25.5  | 15.7          |
| Mt Isa (40° C)                                  | 21.4   | 21.0  | 12.2  | 24.5  | 15.7  | 20.2  | 16.3          |
| Birdsville (40° C)                              | 35.6   | 43.8  | 37.9  | 51.5  | 44.8  | 55.9  | 60.3          |
| SA: Arid Lands                                  |        |       |       |       |       |       |               |
| Port Augusta (36° C)                            | 32.0   | 30.7  | 25.7  | 31.7  | 32.8  | 43.2  | 40.0          |
| Oodnadatta (40° C)                              | 31.1   | 34.8  | 30.9  | 41.4  | 37.9  | 40.2  | 40.3          |
| NT: Arid Lands & Tablelands sub-regions         |        |       |       |       |       |       |               |
| Alice Springs (40° C)                           | 12.2   | 13.2  | 13.5  | 18.2  | 19.1  | 17.2  | 23.7          |
| Tennant Creek (40° C)                           | 33.2   | 23.5  | 14.1  | 26.1  | 18.8  | 18.1  | 14.0          |
| WA: Rangelands                                  |        |       |       |       |       |       |               |
| Kalgoorlie (36° C)                              | 29.8   | 31.1  | 33.3  | 29.8  | 32.4  | 38.8  | 28.7          |
| Meekatharra (40° C)                             | 24.9   | 20.0  | 26.7  | 29.5  | 30.2  | 36.8  | 23.7          |
| Carnarvon (36° C)                               | 16.8   | 19.1  | 21.9  | 21.2  | 18.8  | 17.9  | 32.0          |
| Newman (40° C)                                  | 33.9   | 40.2  | 31.7  | 39.7  | 44.9  | 61.8  | 39.3          |
| Giles                                           | 7.7    | 13.9  | 15.6  | 20.7  | 20.2  | 17.8  | 23.7          |



**Table 5.2 Number of heatwaves experienced in each decade since 1950 where a heatwave is defined as >1 week of maximum daily temperature above the specified threshold (Figure 2.1)**

| LOCATION IN NRM<br>REGION               | DECADE |       |       |       |       |       |               |
|-----------------------------------------|--------|-------|-------|-------|-------|-------|---------------|
|                                         | 1950s  | 1960s | 1970s | 1980s | 1990s | 2000s | 2011–<br>2013 |
| NSW: Western CMA                        |        |       |       |       |       |       |               |
| Bourke                                  | 1      | 0     | 0     | 1     | 3     | 17    | 0             |
| Broken Hill                             | 3      | 11    | 21    | 5     | 2     | 25    | 0             |
| Cobar                                   | 42     | 15    | 10    | 13    | 21    | 58    | 8             |
| Queensland: South West NRM              |        |       |       |       |       |       |               |
| Charleville                             | 0      | 0     | 2     | 0     | 0     | 0     | 0             |
| Queensland: Desert Channels             |        |       |       |       |       |       |               |
| Birdsville                              | 29     | 43    | 48    | 27    | 26    | 75    | 46            |
| Longreach                               | 8      | 13    | 7     | 6     | 11    | 12    | 0             |
| Mt Isa                                  | 5      | 4     | 10    | 10    | 5     | 8     | 0             |
| SA: Arid Lands                          |        |       |       |       |       |       |               |
| Oodnadatta                              | 7      | 10    | 32    | 11    | 21    | 58    | 13            |
| Port Augusta                            | 0      | 0     | 2     | 6     | 4     | 20    | 2             |
| NT: Arid Lands & Tablelands sub-regions |        |       |       |       |       |       |               |
| Alice Springs                           | 0      | 1     | 9     | 4     | 1     | 8     | 10            |
| Tennant Creek                           | 15     | 8     | 6     | 15    | 14    | 18    | 0             |
| WA: Rangelands                          |        |       |       |       |       |       |               |
| Carnarvon                               | 1      | 0     | 0     | 3     | 0     | 0     | 7             |
| Giles                                   | 1      | 0     | 13    | 3     | 8     | 11    | 20            |
| Kalgoorlie                              | 5      | 3     | 0     | 1     | 5     | 6     | 0             |
| Meekatharra                             | 17     | 10    | 19    | 16    | 21    | 53    | 3             |
| Newman                                  | 52     | 49    | 28    | 53    | 96    | 138   | 9             |

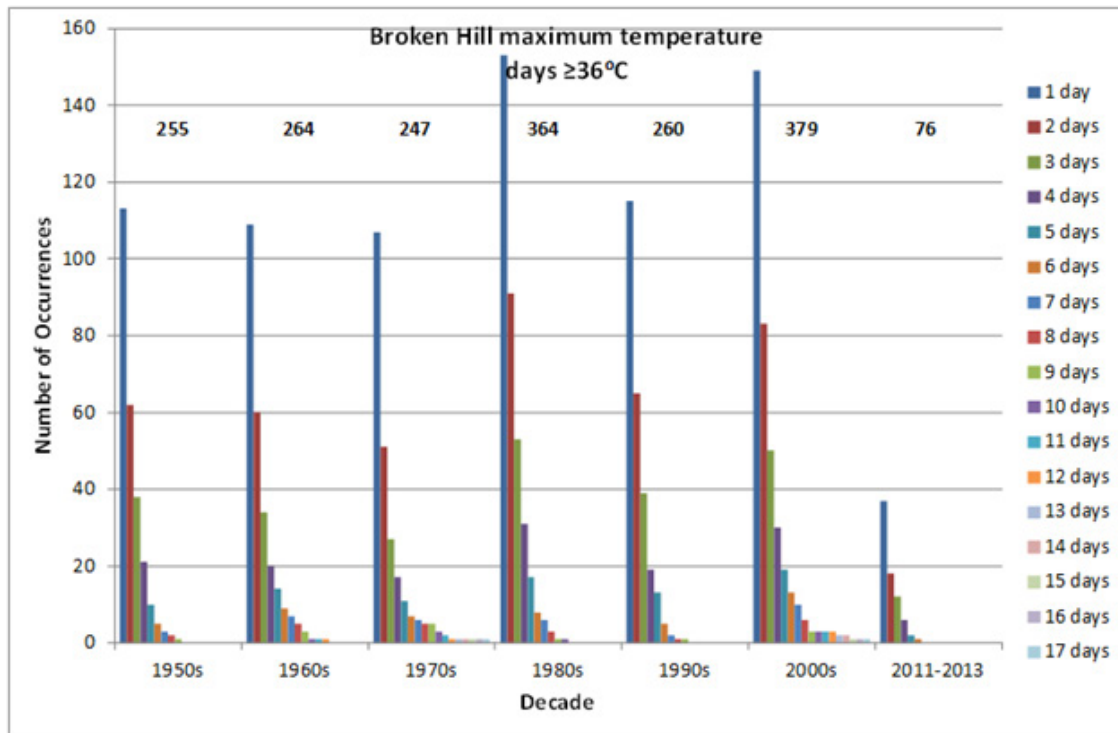


Figure 5.1 Broken Hill: total number of summer days per decade hotter than  $36^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

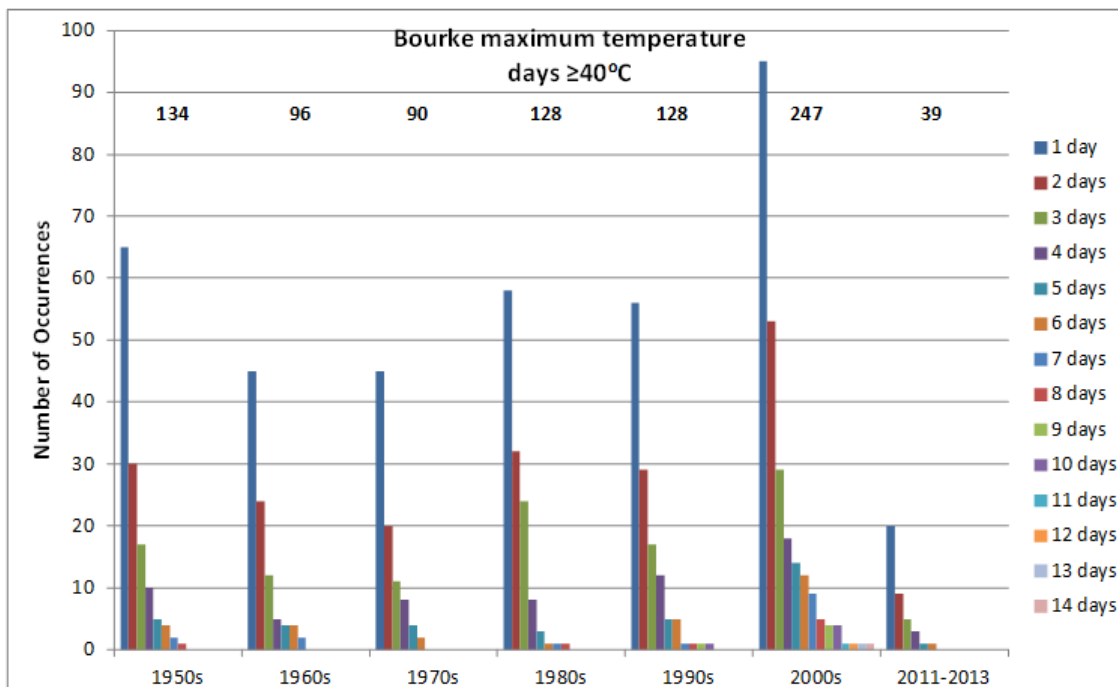


Figure 5.2 Bourke: total number of summer days per decade hotter than  $40^{\circ}\text{C}$  and the decadal frequency of continuously hot days.



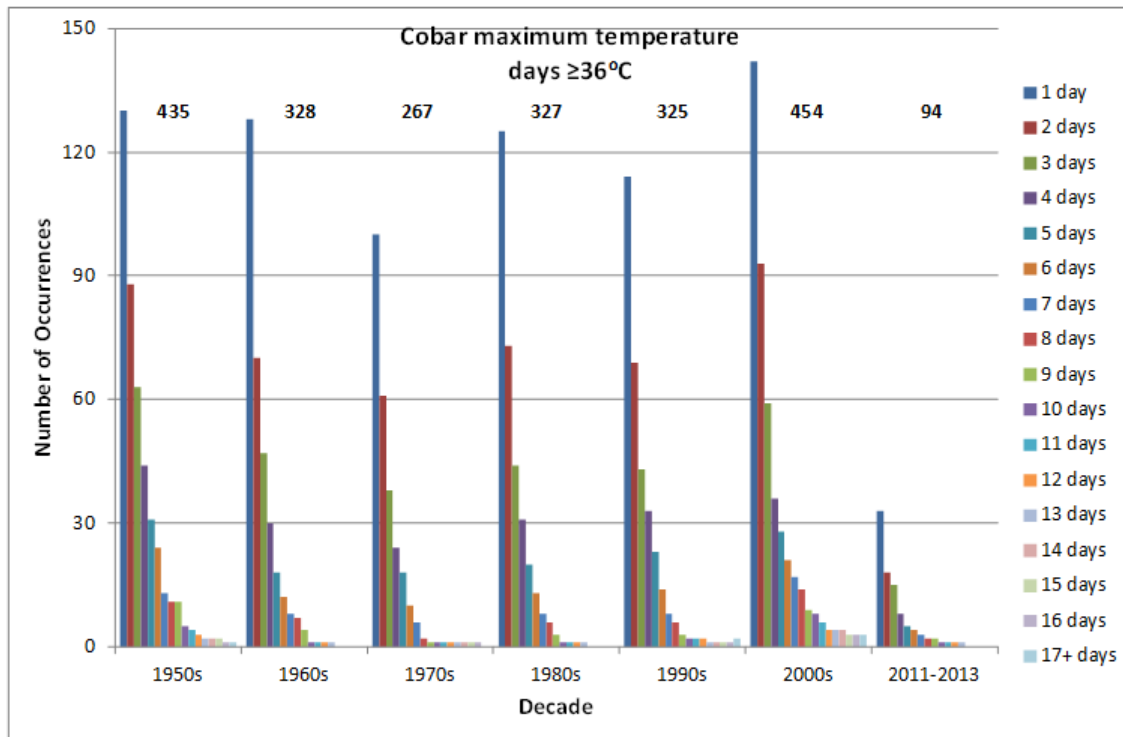


Figure 5.3 Cobar: total number of summer days per decade hotter than  $36^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

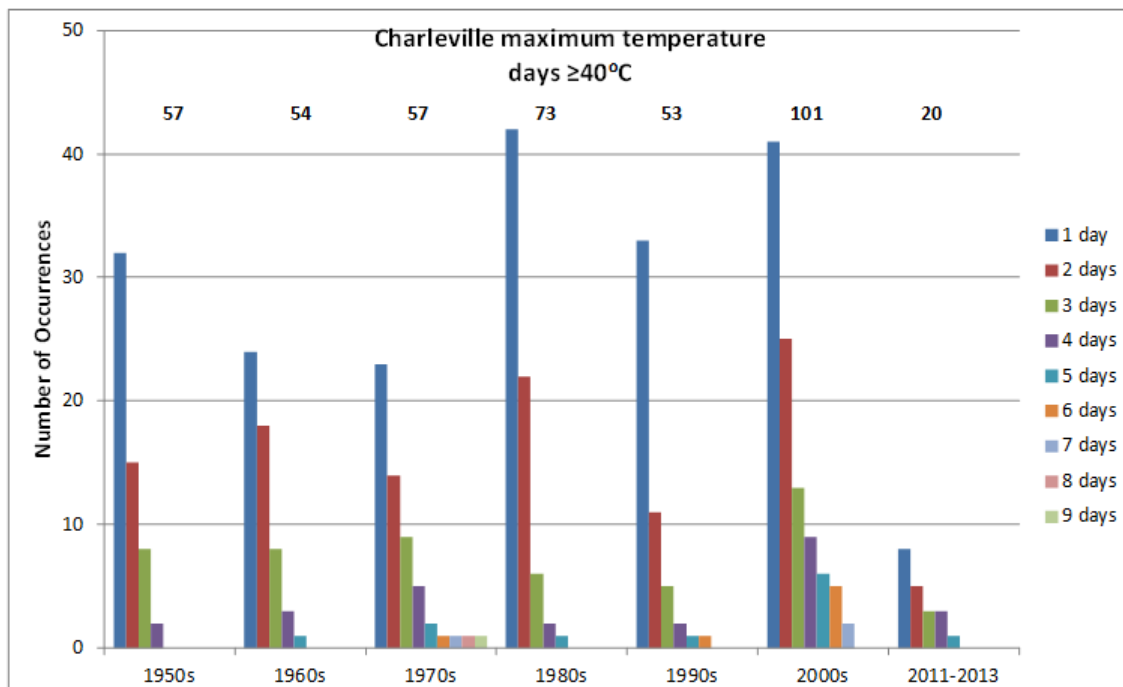


Figure 5.4 Charleville: total number of summer days per decade hotter than  $40^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

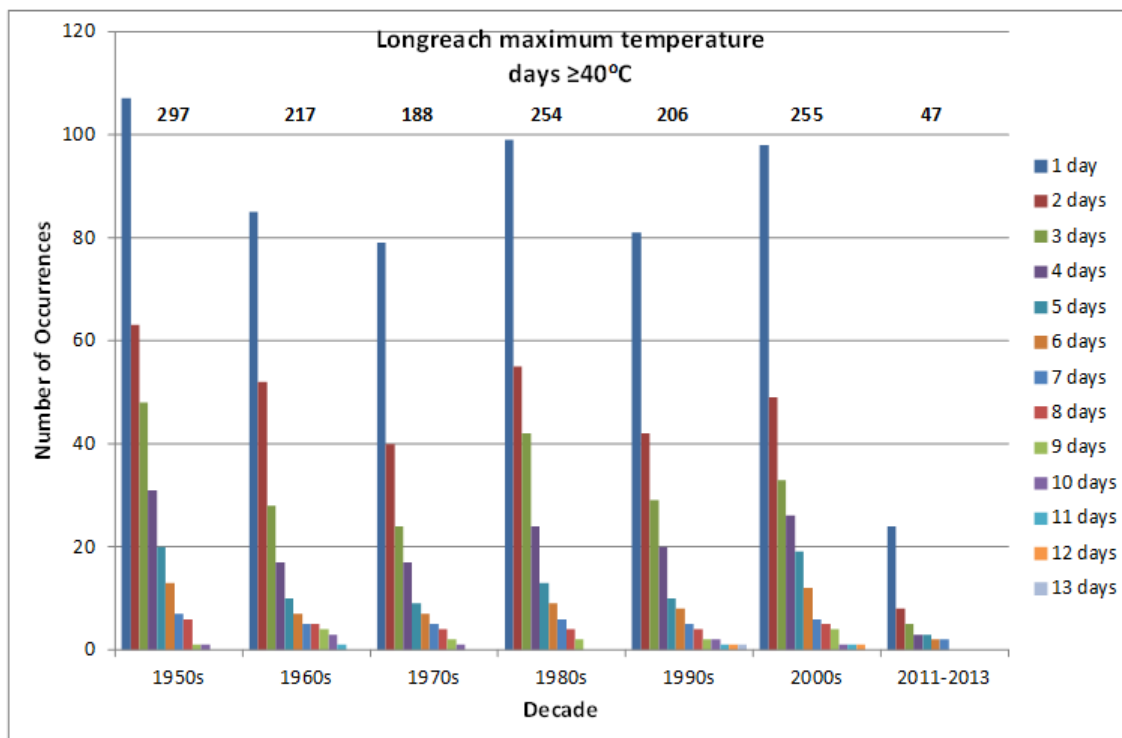


Figure 5.5 Longreach: total number of summer days per decade hotter than  $40^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

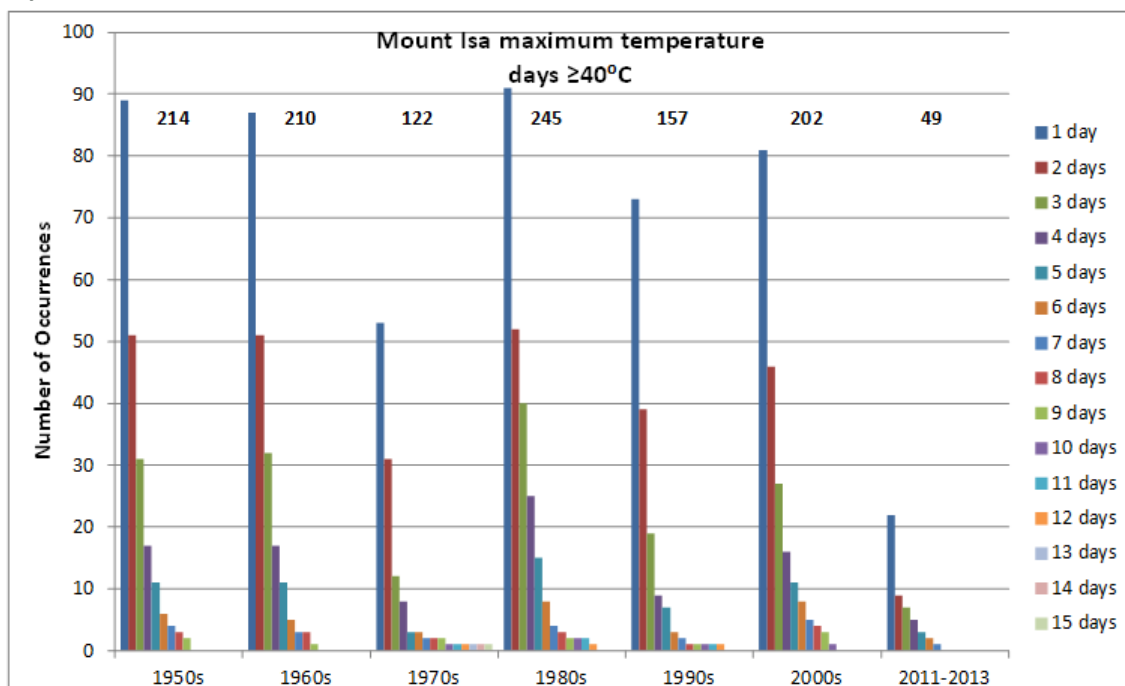


Figure 5.6 Mount Isa: total number of summer days per decade hotter than  $40^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

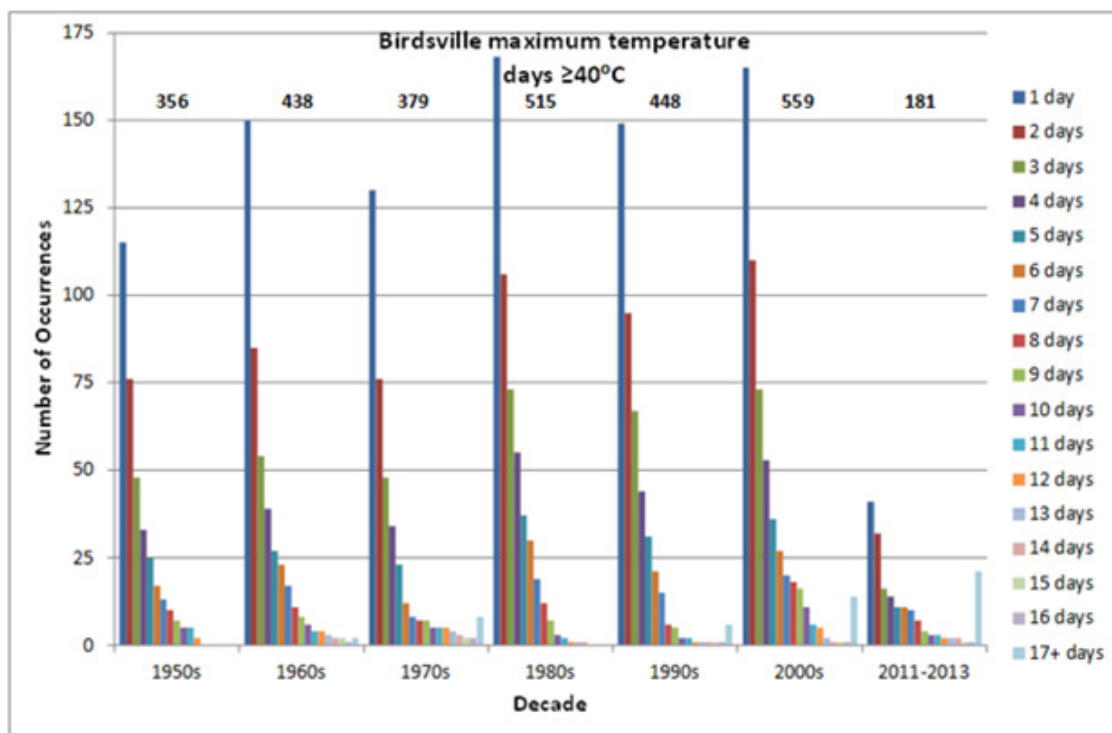


Figure 5.7 Birdsville: total number of summer days per decade hotter than  $40^{\circ}\text{C}$  and the decadal frequency of continuously hot days

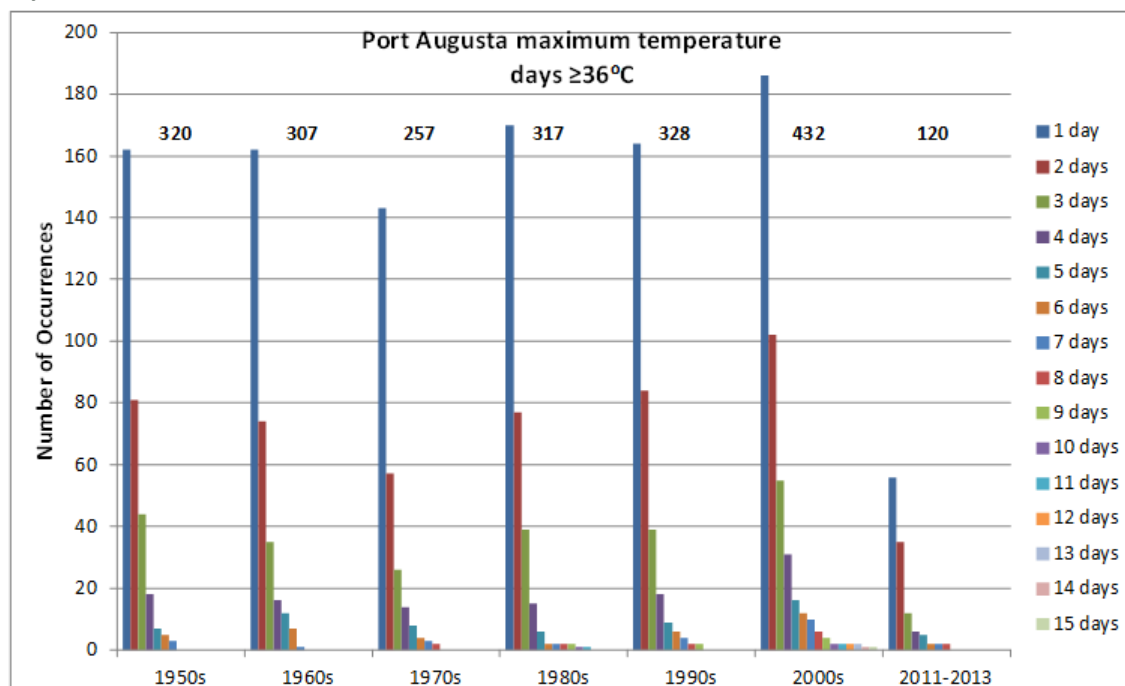


Figure 5.8 Port Augusta: total number of summer days per decade hotter than  $36^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

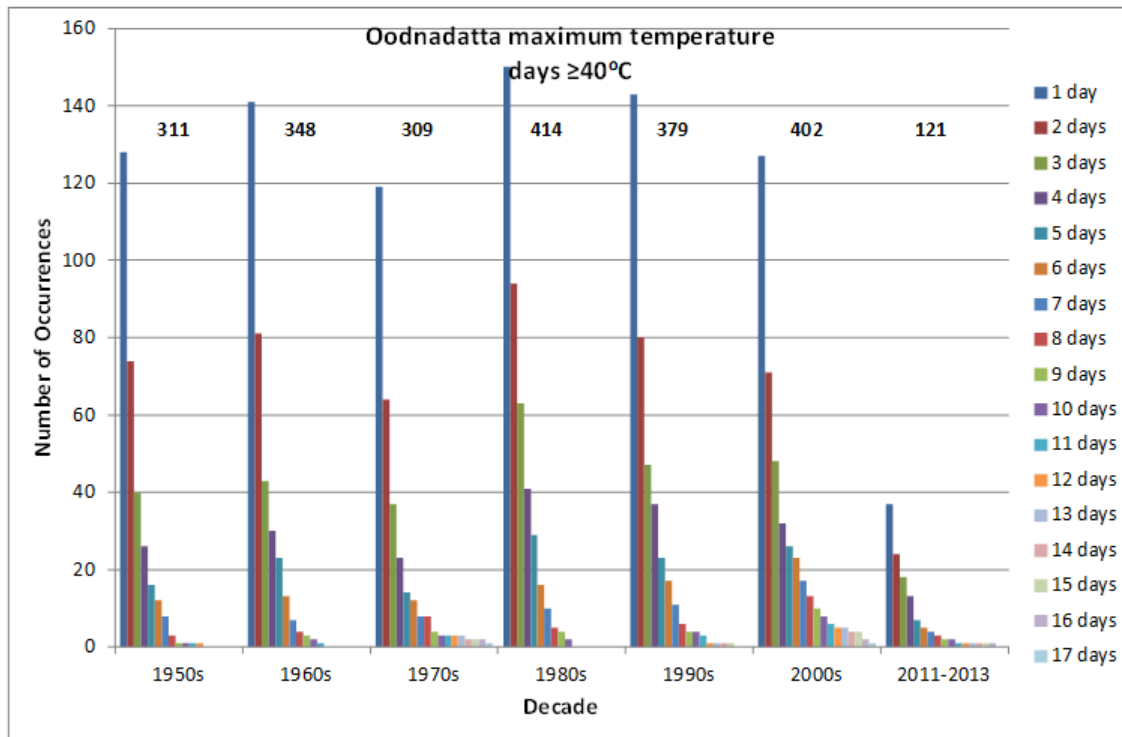


Figure 5.9 Oodnadatta: total number of summer days per decade hotter than  $40^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

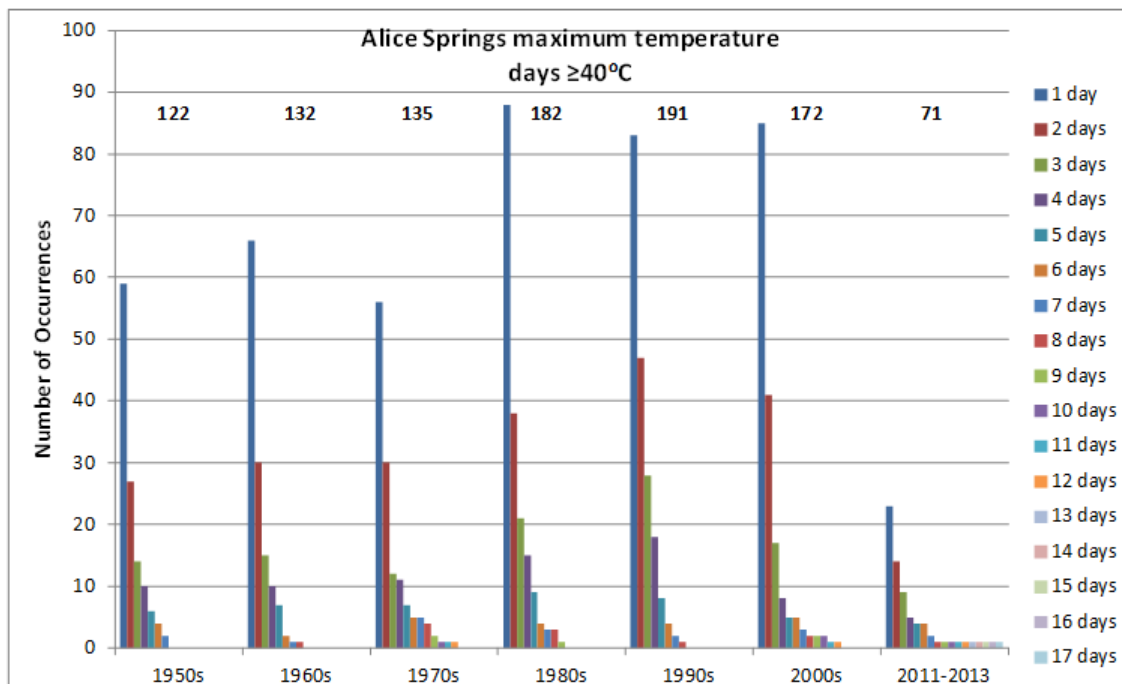


Figure 5.10 Alice Springs: total number of summer days per decade hotter than  $40^{\circ}\text{C}$  and the decadal frequency of continuously hot days

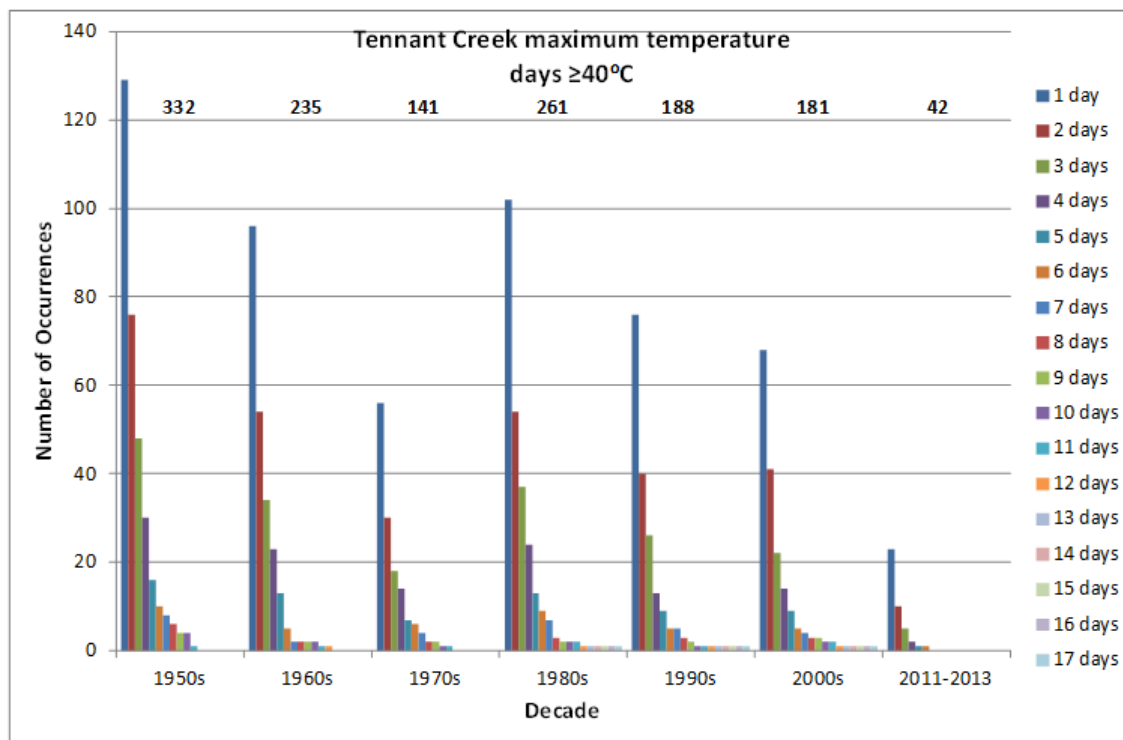


Figure 5.11 Tennant Creek: total number of summer days per decade hotter than  $40^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

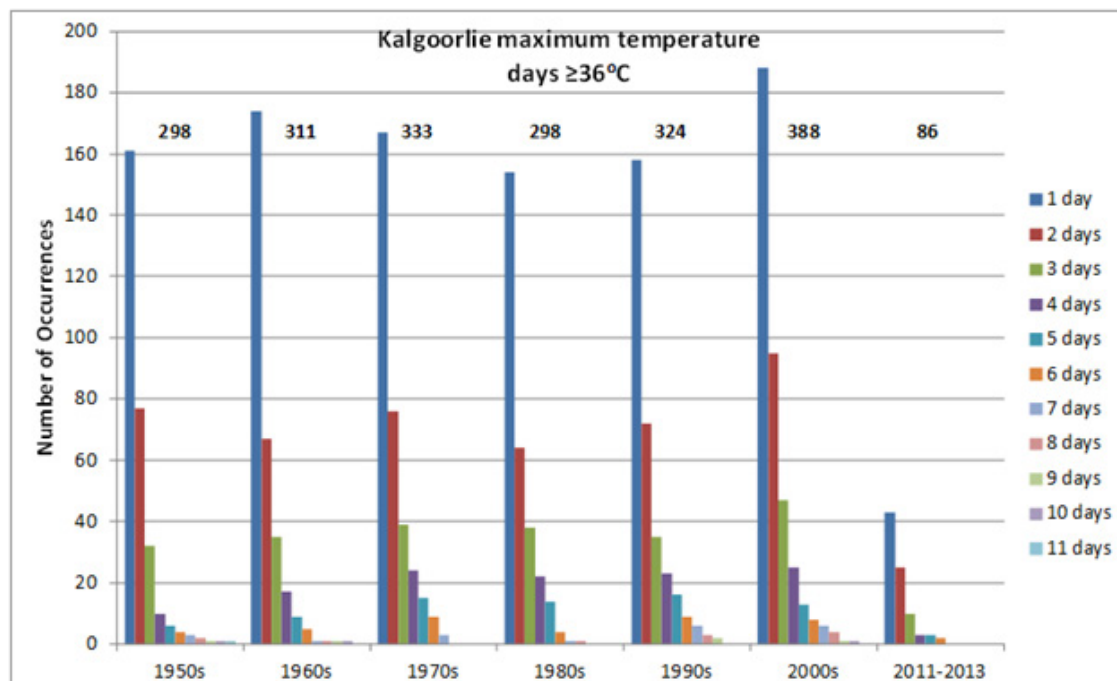


Figure 5.12 Kalgoorlie: total number of summer days per decade hotter than  $36^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

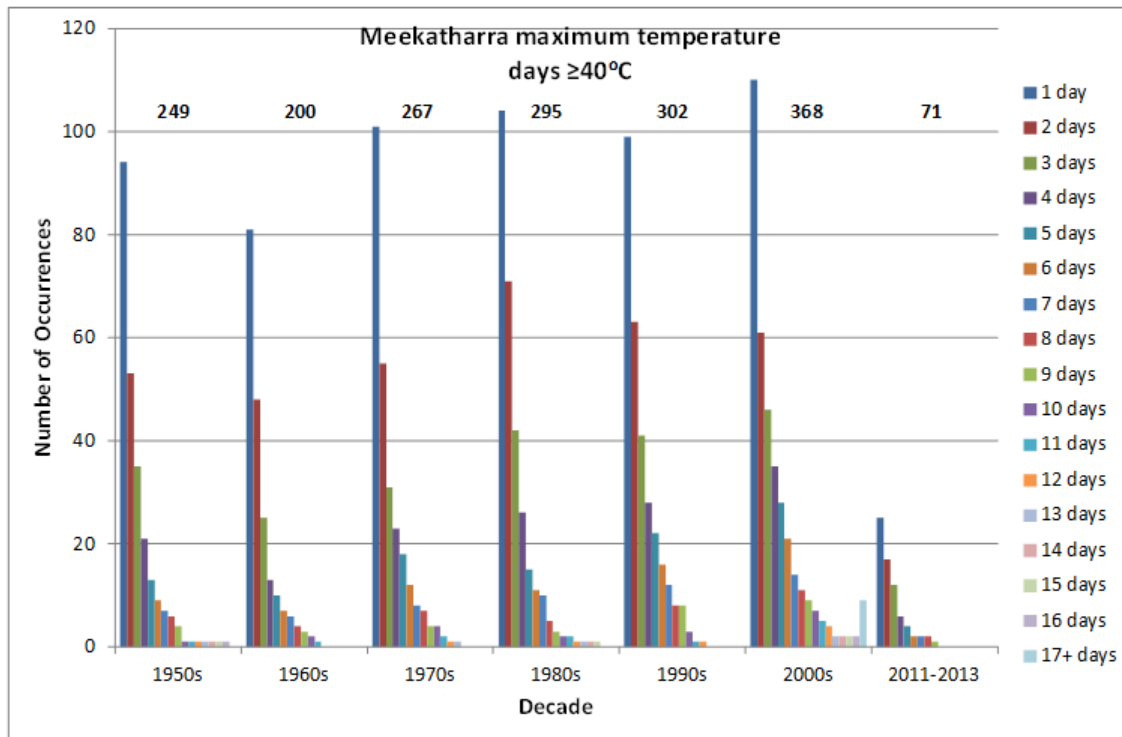
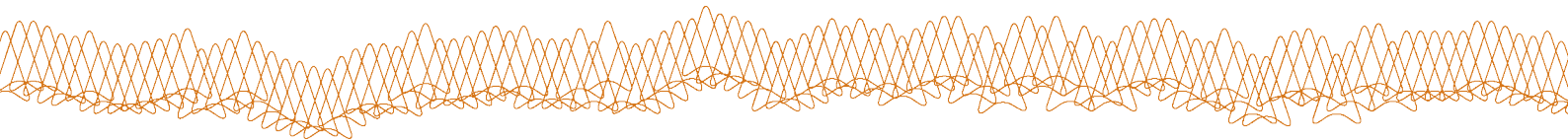


Figure 5.13 Meekatharra: total number of summer days per decade hotter than  $40^{\circ}\text{C}$  and the decadal frequency of continuously hot days.

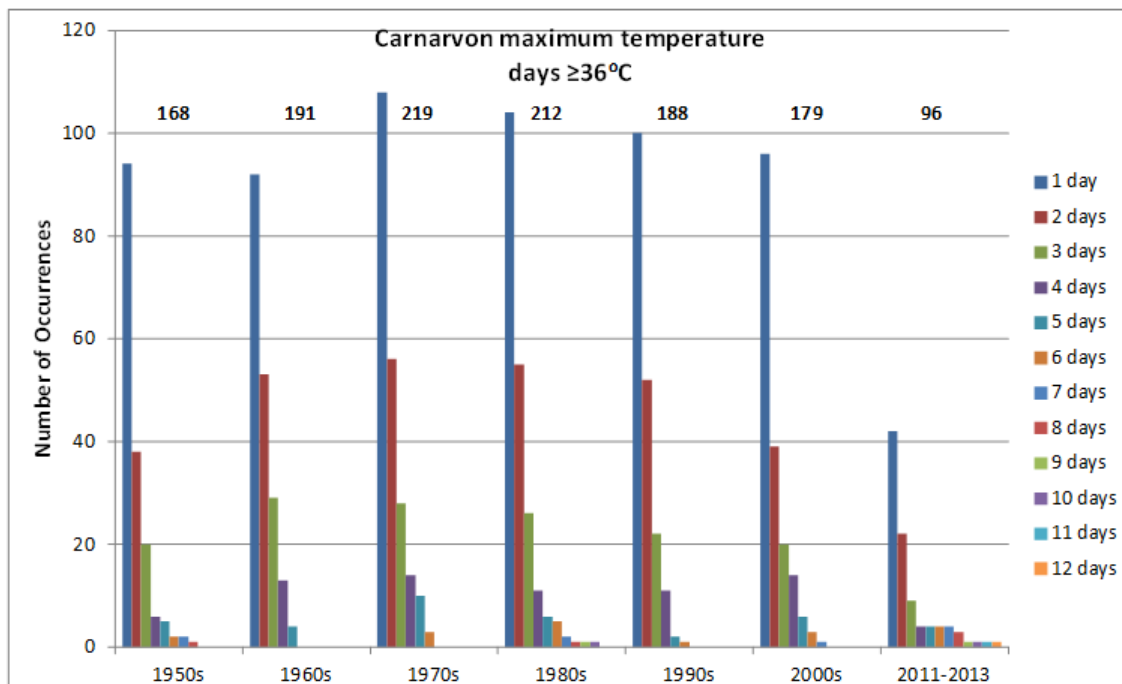


Figure 5.14 Carnarvon: total number of summer days per decade hotter than  $36^{\circ}\text{C}$  and the decadal frequency of continuously hot days



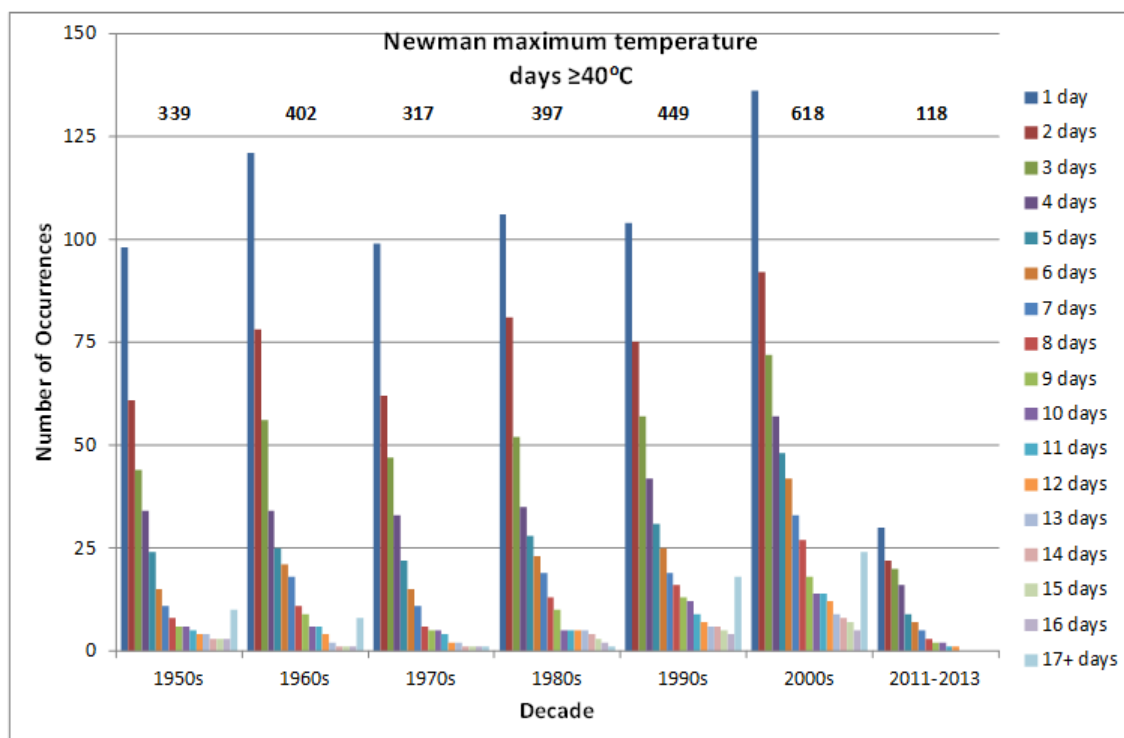
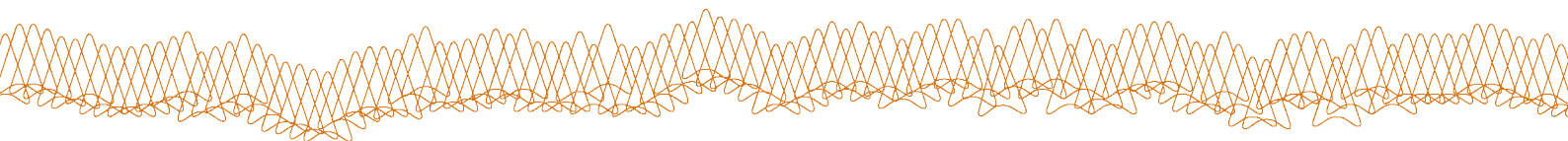


Figure 5.15 Newman: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days.

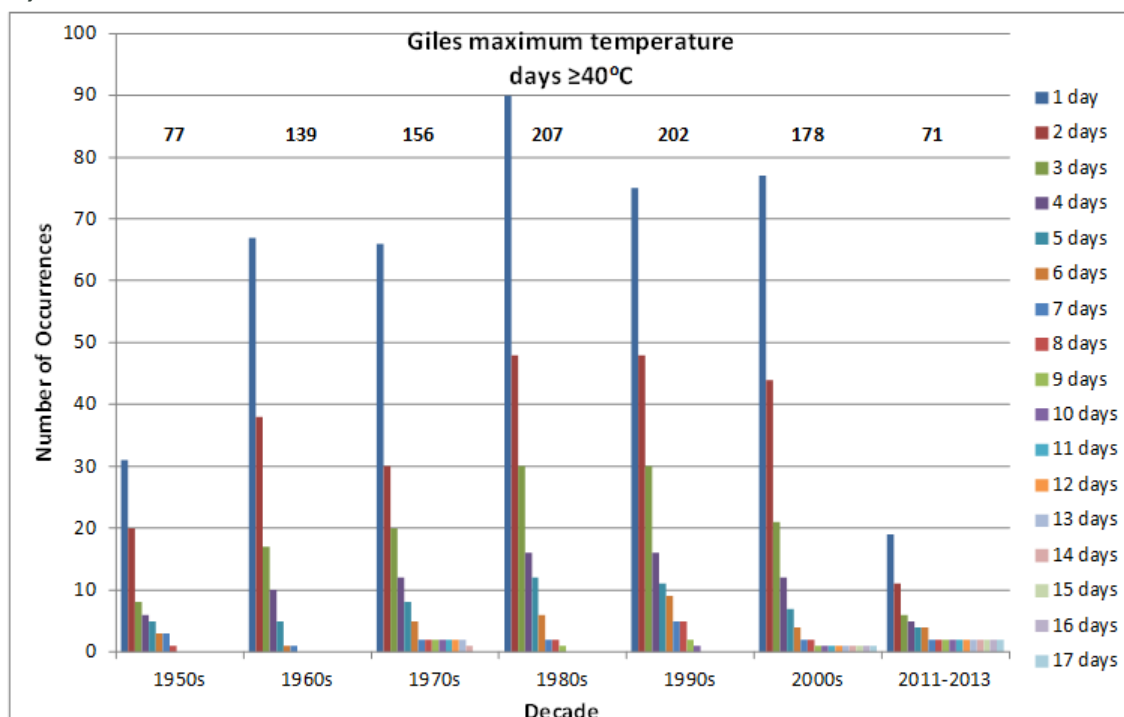
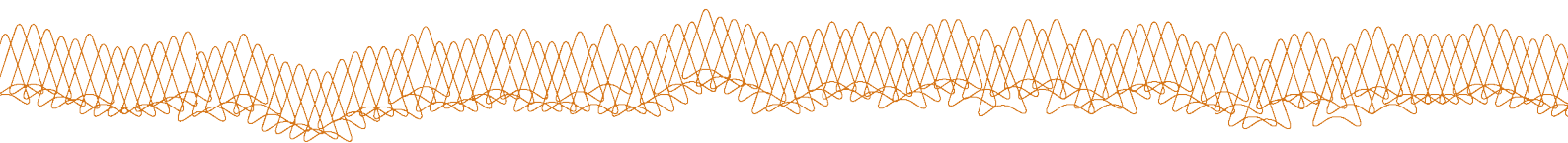


Figure 5.16 Giles: total number of summer days per decade hotter than 40° C and the decadal frequency of continuously hot days



## 6. Key adaptation strategies

Urban rangeland communities in the Rangelands Cluster will probably cope with rising temperatures with increased use of air conditioners, at least into the medium term (e.g. next 30 years). Remote communities and the pastoral industry face particular challenges.

Measham (2014) describes how a vulnerability framework may assist remote communities to adapt to the expected increased frequency and intensity of heatwaves (his information adapted from Maru et al. 2014).

Information relevant to the pastoral industry is provided in Bastin et al. (2014).

# Abbreviations

## IN THIS REPORT

| TERM | DEFINITION                     |
|------|--------------------------------|
| CMA  | Catchment Management Authority |
| NRM  | natural resource management    |

## IN ALL REPORTS IN THE SERIES

| TERM  | DEFINITION                                                |
|-------|-----------------------------------------------------------|
| ABS   | Australian Bureau of Statistics                           |
| ACRIS | Australian Collaborative Rangelands Information System    |
| AFCMP | Australian Feral Camel Management Project                 |
| BoM   | Bureau of Meteorology                                     |
| BS    | bare soil                                                 |
| DKCRC | Desert Knowledge Cooperative Research Centre              |
| DSI   | Dust Storm Index                                          |
| EI    | Ecoclimatic Index                                         |
| EMU   | Ecosystem Management Understanding™                       |
| ENSO  | El Niño Southern Oscillation                              |
| FIFO  | fly in, fly out                                           |
| GAB   | Great Artesian Basin                                      |
| GCM   | General Circulation Model                                 |
| GDM   | Generalised Dissimilarity Modelling                       |
| GHG   | greenhouse gas                                            |
| GW    | Groundwater                                               |
| GWW   | Great Western Woodlands                                   |
| IBRA  | Interim Biogeographic Regionalisation for Australia       |
| ICLEI | International Council for Local Environmental Initiatives |
| IPCC  | Intergovernmental Panel on Climate Change                 |
| LEB   | Lake Eyre Basin                                           |
| LGM   | last glacial maximum                                      |
| MOF   | manual observation frequency                              |
| mya   | million years ago                                         |
| NAFI  | North Australian Fire Information                         |

## IN ALL REPORTS IN THE SERIES

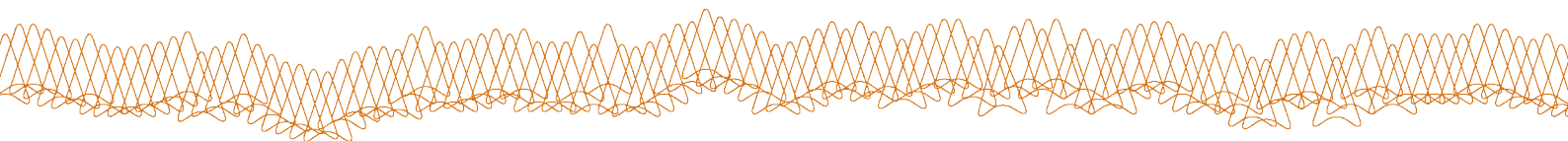
| TERM        | DEFINITION                                                  |
|-------------|-------------------------------------------------------------|
| NCCARF      | National Climate Change Adaptation Research Facility        |
| NPV         | non-photosynthetic vegetation: senescent pasture and litter |
| OH&S        | occupational health and safety                              |
| PV          | photosynthetic vegetation: green                            |
| RCP         | Representative Concentration Pathways                       |
| SAAL        | South Australia Arid Lands                                  |
| SDM         | species distribution modelling                              |
| SW          | Surface water                                               |
| TGP         | total grazing pressure                                      |
| TM          | Thematic Mapper                                             |
| Western CMA | Western Catchment Management Authority                      |
| Western LLS | Western Local Land Service                                  |

# Glossary

| IN THIS REPORT |                                                                                     |
|----------------|-------------------------------------------------------------------------------------|
| TERM           | DEFINITION                                                                          |
| Heatwave       | Continuous period beyond a week when a particular threshold temperature is exceeded |

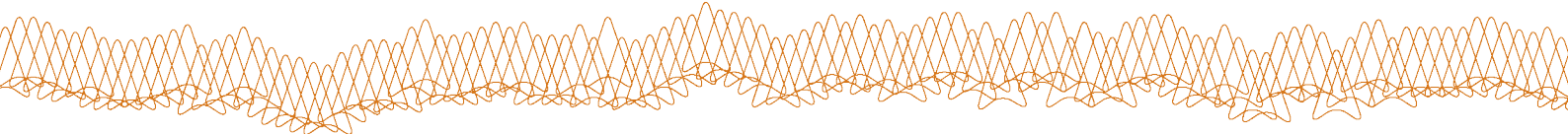
| IN ALL REPORTS IN THE SERIES             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| TERM                                     | DEFINITION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Adaptive capacity                        | The ability to change and therefore reduce gross vulnerability; includes issues such as mobility, financial resources and education                                                                                                                                                                                                                                                                                                                                                                    |
| Bioregion                                | A large, geographically distinct area of land that has groups of ecosystems forming recognisable patterns within the landscape                                                                                                                                                                                                                                                                                                                                                                         |
| C <sub>3</sub> and C <sub>4</sub> plants | The different methods plants use to convert carbon dioxide from air into organic compounds through the process of photosynthesis. All plants use C <sub>3</sub> processes; some plants, such as buffel grass and many other warm climate grasses, also use C <sub>4</sub> processes. C <sub>4</sub> plants have an advantage in a warmer climate due to their higher CO <sub>2</sub> assimilation rates at higher temperatures and higher photosynthetic optima than their C <sub>3</sub> counterparts |
| Contentious species                      | A species that presents special challenges for determining the adaptation response to climate change, because it is both a threat and a beneficial species (Friedel et al. 2011, Grice et al. 2012)                                                                                                                                                                                                                                                                                                    |
| Dust Storm Index (DSI)                   | The Dust Storm Index is based on visibility records made by Bureau of Meteorology (BoM) observers. The DSI provides a measure of the frequency and intensity of wind erosion activity at continental scale. It is a composite measure of the contributions of local dust events, moderate dust storms and severe dust storms using weightings for each event type, based upon dust concentrations inferred from reduced visibility during each of these event types.                                   |

| IN ALL REPORTS IN THE SERIES              |                                                                                                                                                                                                                                                                  |
|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| TERM                                      | DEFINITION                                                                                                                                                                                                                                                       |
| DustWatch                                 | DustWatch is a community program that monitors and reports on the extent and severity of wind erosion across Australia and raises awareness of the effects of wind erosion on the landscape and the impacts of dust on the community.                            |
| Ecological refugia                        | Refugia defined according to the water requirements of the species they protect. The conservation significance of ecological refugia, and the priority assigned to their conservation, depends on the level of knowledge available for the species they support. |
| Evolutionary refugia                      | Those waterbodies that contain <i>short-range endemics</i> or <i>vicariant relics</i> . Evolutionary refugia are most likely to persist into the future and should be accorded the highest priority in NRM adaptation planning.                                  |
| Generalised Dissimilarity Modelling (GDM) | A method of modelling based on compositional turnover of a group of species at a location; it considers whole biological groups rather than individual species                                                                                                   |
| Gross vulnerability of a system           | The combination of exposure and sensitivity of system                                                                                                                                                                                                            |
| Hyporheic water flows                     | Below-surface flows                                                                                                                                                                                                                                              |
| Indicators of exposure                    | Factors such as days above a certain temperature, days without rainfall, population density                                                                                                                                                                      |
| Indicators of sensitivity                 | How sensitive a system is to hazards; indicators include the types of dwellings people live in and the percentage of the population with certain health characteristics                                                                                          |
| 'No regrets' strategies                   | These strategies yield benefits even if there is not a change in climate                                                                                                                                                                                         |
| Novel ecosystem                           | Species occurring in combinations and relative abundances that have not occurred previously within a given biome (Hobbs et al. 2006)                                                                                                                             |



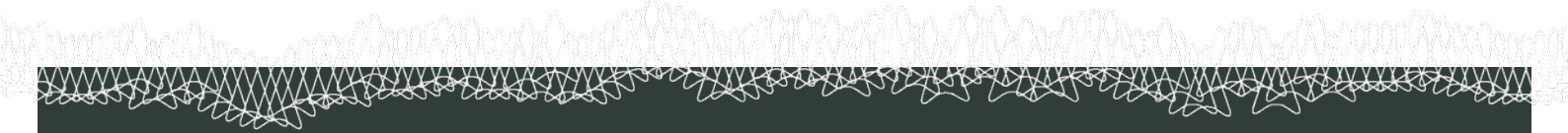
#### IN ALL REPORTS IN THE SERIES

| TERM                                 | DEFINITION                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rainfall event                       | One or more closely spaced rainfalls that are large enough to produce a significant vegetation response                                                                                                                                                                                                                                                                                                         |
| Refugia                              | Habitats that biota retreat to, persist in and potentially expand from under changing environmental conditions                                                                                                                                                                                                                                                                                                  |
| Return period                        | The number of days from the end of one rainfall event to the start of the next                                                                                                                                                                                                                                                                                                                                  |
| Reversible strategies                | Flexible strategies that can be changed if predictions about climate change are incorrect                                                                                                                                                                                                                                                                                                                       |
| Safety margin strategies             | Strategies that reduce vulnerability at little or no cost                                                                                                                                                                                                                                                                                                                                                       |
| Species Distribution Modelling (SDM) | A species-specific approach whereby observational records are used to model the current potential distribution of a species                                                                                                                                                                                                                                                                                     |
| Short-range endemics                 | Species that occur only within a very small geographical area                                                                                                                                                                                                                                                                                                                                                   |
| Soft strategies                      | Strategies that involve the use of institutional, educational or financial tools to reduce species vulnerability to climatic change                                                                                                                                                                                                                                                                             |
| Species invasiveness                 | A species that causes environmental or socioeconomic impacts, is non-native to an ecosystem or rapidly colonises and spreads (see Ricciardi and Cohen 2007). In the Invasive animals report it refers to non-native species (that is, those introduced to Australia post-1788) that have caused significant environmental or agricultural changes to the ecosystem or that are believed to present such a risk. |
| Strategies that reduce time horizons | Strategies that reduce the lifetime of particular investments                                                                                                                                                                                                                                                                                                                                                   |
| Vicariant relicts                    | Species with ancestral characteristics that have become geographically isolated over time                                                                                                                                                                                                                                                                                                                       |



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## Contact Details

Gary Bastin  
CSIRO Land & Water, Alice Springs  
+61 8 8950 7137  
[Gary.Bastin@csiro.au](mailto:Gary.Bastin@csiro.au)

<http://www.csiro.au/Organisation-Structure/Divisions/Ecosystem-Sciences/GaryBastin.aspx>