Potential Effects of Climate Change on Water Resources in the Wide Bay-Burnett Region

prepared by

The Queensland Climate Change Centre of Excellence

for

The Department of Natural Resources and Water

WIDE BAY-BURNETT REGIONAL WATER SUPPLY STRATEGY

December 2008

Queensland Government
Environmental Protection Agency

Acknowledgements
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The authors would like to acknowledge the assistance provided by CSIRO Marine and Atmospheric Research (climate change projection datasets) and the Australian Bureau of Meteorology (observational datasets).

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Acronyms and Abbreviations

BOM	Bureau of Meteorology
CH_4	Methane
CO_2	Carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ENSO	El Niño Southern Oscillation
4AR	Fourth Assessment Report (IPCC)
GCM	General Circulation Model
GHGs	Greenhouse gases
HQ	High Quality
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
ITCZ	Intertropical Convergence Zone
MDB	Murray Darling Basin
MJO	Madden-Julian Oscillation
N_2O	Nitrous oxide
NRW	Department of Natural Resources and Water
NWCBs	North-west cloudbands
O_3	Ozone
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PDF	Probability density function
PDO	Pacific Decadal Oscillation
ppm	Parts per million
QCCCE	Queensland Climate Change Centre of Excellence
SOI	Southern Oscillation Index
SRES	Special Report on Emissions Scenarios
WBB	Wide Bay-Burnett

Executive Summary

Over the past few decades our knowledge of climate change has improved and a clear understanding of the impact of human activities on the climate system is beginning to emerge. The available scientific evidence indicates that warming of the climate system is unequivocal (IPCC 2007a), and most of the observed increase in global average temperature since the mid-20th Century is very likely due to the increase in the concentration of greenhouse gases arising from anthropogenic activities. While climate change is a significant challenge facing today's world, Queensland is particularly vulnerable because it has one of the most variable climates in the world. Climate change projections for Queensland suggest that this variability will increase, as a result of more extreme climate events within a generally warmer and drier climate.

The purpose of this report is to provide an up-to-date assessment of both observed and projected climate change for Queensland with a particular emphasis on the Wide Bay-Burnett region. The report provides a comprehensive analysis of information about projected climate changes in the region for 2030, 2050 and 2070. The results of this analysis are used as input to hydrological modelling to evaluate the likely impacts of climate change on water resources in the Wide Bay-Burnett region. The following summary sets out the structure and content of each chapter in the report.

Historical climate in Queensland

Chapter 1 provides an overview of the principal climate processes that affect Queensland and a comprehensive description of observed changes in a range of climate variables. To enable the reader to interpret the observed changes in a broader context, many of the analyses are provided on multiple spatial scales: across Australia, throughout Queensland and the Wide Bay-Burnett region.

Observational data records indicate that climate change is already having a significant impact on the Wide Bay-Burnett region. The analysis of historical datasets has shown that while the climate did not change substantially in the first half of the last century, significant and spatially coherent trends have emerged during the 1950–2007 period.

The trends for 1950–2007 include:

- Annual mean surface temperatures have increased by about 1.4°C (since 1950) in the Wide Bay-Burnett region, which is significantly larger than the Australian annual average increase of 0.8°C. Maximum temperatures in this region have increased by 1.5°C (annual average) and minimum temperatures have increased by 1.2°C (annual average).

- There have been significant and spatially coherent trends in rainfall over the latter half of the past century: generally wetter conditions over the north-west region of Australia and a general drying trend in the south-east. The Wide Bay-Burnett region is part of a larger area, consisting of coastal and sub-coastal areas of south-east and central Queensland, which exhibits a strong negative rainfall trend relative to the rest of Queensland.

- During this period, average annual rainfall in the Wide Bay-Burnett region shows a negative trend of approximately 47 mm per decade (or -5% of the 1950–2007 annual mean, per decade). The observed trend is robust at the 95% confidence level and is much larger than the trend observed for Queensland as a whole, which experienced a negative trend of 14 mm per decade (or -2% of the 1950–2007 annual mean, per decade).

- The Wide Bay-Burnett region experienced an increase in pan evaporation of approximately 3% of the annual mean per decade throughout the 1975–2007 period. The observed trend in the Wide Bay-Burnett region was weaker than that observed throughout the majority of southern and central Queensland, which experienced an increase in pan evaporation of approximately 5% of the annual mean per decade, over the same period.

Climate extremes

Global warming has the potential to alter both the frequency and severity of climatic extremes, such as droughts, floods and tropical cyclones. Even minor changes in extreme events can have a significant impact on ecosystems, agricultural production and water resources. Consequently, trends in extreme events are of particular importance.

Observed historical temperature records from Bundaberg and Gayndah indicate an upward trend in the number of days per year where the maximum temperature exceeds 35°C. The increase in the number of hot days was greater at the inland location of Gayndah compared to the coastal location of Bundaberg.

Analysis of rainfall data at selected sites throughout the Wide Bay-Burnett region indicates a general decline in both rainfall amount and intensity. Rainfall records from selected stations in the region indicate a decline in annual rainfall at all sites examined, and a weak decline in the number of rain days at most of the sites examined. Rainfall intensity (defined as the annual rainfall divided by the number of rain days) declined at all stations except Murgon, which experienced no change. The observed decline in rainfall intensity ranged between 0.1 and 0.5 mm/day per decade throughout the 1910–2007 period, equivalent to an absolute decline in rainfall intensity ranging between 0.9 and 5.0 mm/day.

The impacts of drought in Queensland have been more severe in recent times owing to the increased demand and competition for water. The impacts are further exacerbated by factors such as land cover change and increasing temperature and evaporation.

El Niño Southern Oscillation (ENSO)

It is well established that the ENSO phenomenon significantly influences seasonal rainfall patterns and cyclone activity in the Queensland region. Currently, the impact of climate change on the behaviour of ENSO is not well understood and is the subject of ongoing research. Understanding how climate change is likely to modify future ENSO behaviour is an important factor when considering climate change projections for Queensland.

Climate change projections

Chapter 2 provides an introduction to climate modelling and describes the emissions scenarios used to produce climate change projections. Climate change projection data, prepared by the CSIRO and the Bureau of Meteorology in 2007, has been used to construct customised projections for the Wide Bay-Burnett region.

The climate change projections presented in this report were compiled using the A1B and A1FI emissions scenarios. These scenarios were chosen as they track the current emissions more closely than all other SRES emission scenarios. However it should be noted that in recent years actual emissions have been higher than those predicted by both the A1B and A1FI scenarios.

It is important to appreciate that if emissions continue to track higher than those predicted under the A1FI scenario, then the accompanying projections may significantly underestimate the impact of climate change. One of the key uncertainties concerning climate change projections beyond 2050 is associated with the uncertainty of future greenhouse gas emission profiles. Climate change projections for the Wide Bay-Burnett region are summarised in Table I.

Climate change data for hydrological models

Chapter 3 provides information about the fidelity and robustness of various climate models in their ability to simulate Australian climate over the past 50 years. On this basis, a subset of models was selected to provide climate change datasets which were used as input into hydrological modelling of water availability in the Wide Bay-Burnett region.

Climate change impacts and implications

Chapter 4 discusses the potential impacts of climate change, both generally and in particular on the Wide Bay-Burnett region, and examines the implications for water resource planning. This section is based on outcomes stemming from a workshop where a panel of experts assessed the implications of climate change on water availability and demand. The workshop was conducted in Brisbane on June 26th, 2008. The summary presents the general estimates derived by the group for the effect of climate change on water demand per industry sector in several Queensland regions.

Table I. Summary of climate change projections for the Wide Bay-Burnett region in 2030, 2050 and 2070, based on the A1B and A1FI emissions scenarios. Projections are provided for the "best estimate" (50th percentile) and range (10th and 90th percentiles) derived from all 23 IPCC AR4 climate models.

	2030	2050	2070
Annual mean temperature Observed average annual mean temperature during the 1971–2000 period: 20.4°C			
best estimate	+0.9°C (A1B)	+1.6°C (A1B) +1.8°C (A1FI)	+2.2°C (A1B) +3.0°C (A1FI)
range	+0.6^{0}C to +1.3^{0}C (A1B)	+1.1°C to +2.2°C (A1B) +1.3°C to +2.6°C (A1FI)	+1.5°C to +3.0°C (A1B) +2.0°C to +4.2°C (A1FI)
Annual rainfall Observed average annual rainfall during the 1971–2000 period: 882 mm			
best estimate	-3% (-26 mm) (A1B)	-5% (-44 mm) (A1B) -6% (-53 mm) (A1FI)	-7% (-62 mm) (A1B) -9% (-79 mm) (A1FI)
range	-12% to +5% (-106 mm to +44mm) (A1B)	-19% to +9% (-168 mm to +79 mm) (A1B) -22% to +10% (-194 mm to +88 mm) (A1FI)	-25% to +12% (-221 mm to +106 mm) (A1B) -33% to +16% (-291 mm to +141 mm) (A1FI)
Annual potential evapotranspiration Observed average annual potential evaporation during the 1975–2000 period: 1708 mm			
best estimate	+3% (+51 mm) (A1B)	+6% (+102 mm) (A1B) +7% (+120 mm) (A1FI)	+8% (+137 mm) (A1B) +11% (+188 mm) (A1FI)
range	+2% to +5% (+34 mm to +85 mm) (A1B)	+4% to +8% (+68 mm to +137 mm) (A1B) +4% to +10% (+68 mm to +171 mm) (A1FI)	+5% to +12% (+85 mm to +205 mm) (A1B) +7% to +16% (+120 mm to +273 mm) (A1FI)

1. Historical climate in Queensland

1.1 Drivers of Queensland's climate

Queensland's climate is characterised by high spatial and temporal variability, especially in regard to rainfall. Natural forcings such as solar radiation and volcanic activity, as well as anthropogenic forcings such as greenhouse gases and emissions of sulphate aerosols, can all impact on climatic processes. Despite the complexity of the climate system, a number of large scale modes of climate variability have been identified as being significant for Queensland:

- *El Niño Southern Oscillation (ENSO)*

  The southern oscillation refers to the monthly or seasonal variation in surface level pressure across the tropical Pacific Ocean. The Southern Oscillation Index (SOI) is the normalised difference in mean sea level pressure between Tahiti and Darwin, and is a convenient parameter for monitoring ENSO events. When the tropical eastern Pacific is unusually warm, the SOI is negative and Queensland generally experiences below-average rainfall. These are known as El Niño events. In contrast, La Niña events arise when the tropical eastern Pacific is significantly colder than average (SOI is positive), and Queensland generally receives above-average rainfall.

- *Pacific Decadal Oscillation (PDO) and Interdecadal Pacific Oscillation (IPO)*

  The PDO and IPO are patterns of Pacific climate variability which operate on decadal to interdecadal time scales. The PDO is observed as warm or cool sea surface temperature anomalies in the Pacific Ocean, north of 20^{o}N. The IPO has similar patterns to the PDO, but its impact is observed in both the North and South Pacific. It has been established that both the IPO and PDO modulate the impact of ENSO in the Pacific region.

- *Synoptic circulation systems*

  North-west cloudbands (NWCBs) are associated with synoptic circulation systems which contribute significantly to winter and spring rainfall in some parts of Queensland. NWCB formation is driven by sea surface temperature anomalies east of deep low-pressure systems in the Indian Ocean. Interannual variability may be related to ENSO phenomena or additional processes operating in the Indian Ocean region.

- *Madden-Julian Oscillation (MJO)*

  The Madden-Julian Oscillation (also known as the 40-day wave) is a large-scale oscillation originating in the Indian Ocean. The oscillation moves eastward at approximately 5–10 ms^{-1}, bringing variations in wind, sea surface temperature, cloudiness and rainfall. The MJO influences the onset, duration and intensity of monsoonal rainfall and particularly affects the northern parts of Queensland.

Other broad-scale processes which are also known to affect the climate in Queensland include the Southern Annular Mode (Thompson & Wallace 2000; Meneghini et al. 2007) and the Indian Ocean Dipole (Meyers et al. 2007).

1.1.1 The Wide Bay-Burnett region

The Wide Bay-Burnett (WBB) Regional Water Supply Strategy area, comprising the Baffle, Burnett and Mary river catchments, is that part of coastal and sub-coastal Queensland between the latitudes of (approximately) 24°S and 26.5°S (see Figure 1-1). It has a subtropical climate with hot moist summers, and mild winters.

Land use in the region is predominantly agricultural, contributing significantly to the state's production of sugar, beef and peanuts. Other agricultural industries include cereal crops, dairying and various fruits and vegetables.

The region's population is currently just over 250,000 and is projected to increase beyond 350,000 by 2050. The region is served by eight major water storages and a number of smaller dams, weirs and barrages with a combined total capacity of 1.6 million megalitres. Recent extended periods of drought have shown that additional supply is required to service the region's future water needs, and major developments aimed at addressing this need are currently underway (LGPSR 2007).

Rainfall in the Wide Bay-Burnett region is highly seasonal, with most rain occurring during the summer months. The seasonal distribution of rainfall is caused by the seasonal north-south movement of large scale pressure systems; particularly the sub-tropical high-pressure cell and the Intertropical Convergence Zone. Other drivers and processes of climate in this region include trade winds, cyclones, thunderstorms, quasi-monsoonal air flows, upper level troughs and the incursion of cold fronts. Although these processes occur each year, there is significant variability on annual, decadal and longer time scales in their strength, position and hence influence. For further information on seasonal weather patterns in this region, see Tapper & Hurry (1993) and Sturman & Tapper (1996).

1.2 Historical climate trends in Queensland

Quality controlled observational data records extending over long periods of time can be used to detect climate change. The Australian Bureau of Meteorology ('the Bureau') maintains a network of meteorological stations which record a range of climate variables, such as rainfall, maximum and minimum temperatures, wet- and dry-bulb temperatures, pan evaporation, air pressure, wind speed and solar radiation. In addition to the climate recording stations maintained by the Bureau, there is a network of several thousand sites across Australia which record daily rainfall.

Observational data records may be corrupted or rendered unusable for a number of reasons, such as:

- human error in recording the data
- missing data (e.g. staff at monitoring stations may be sick or absent)
- instrument malfunction
- systematic bias due to instrument calibration or deterioration, and
- systematic bias due to inappropriate location of the monitoring station.

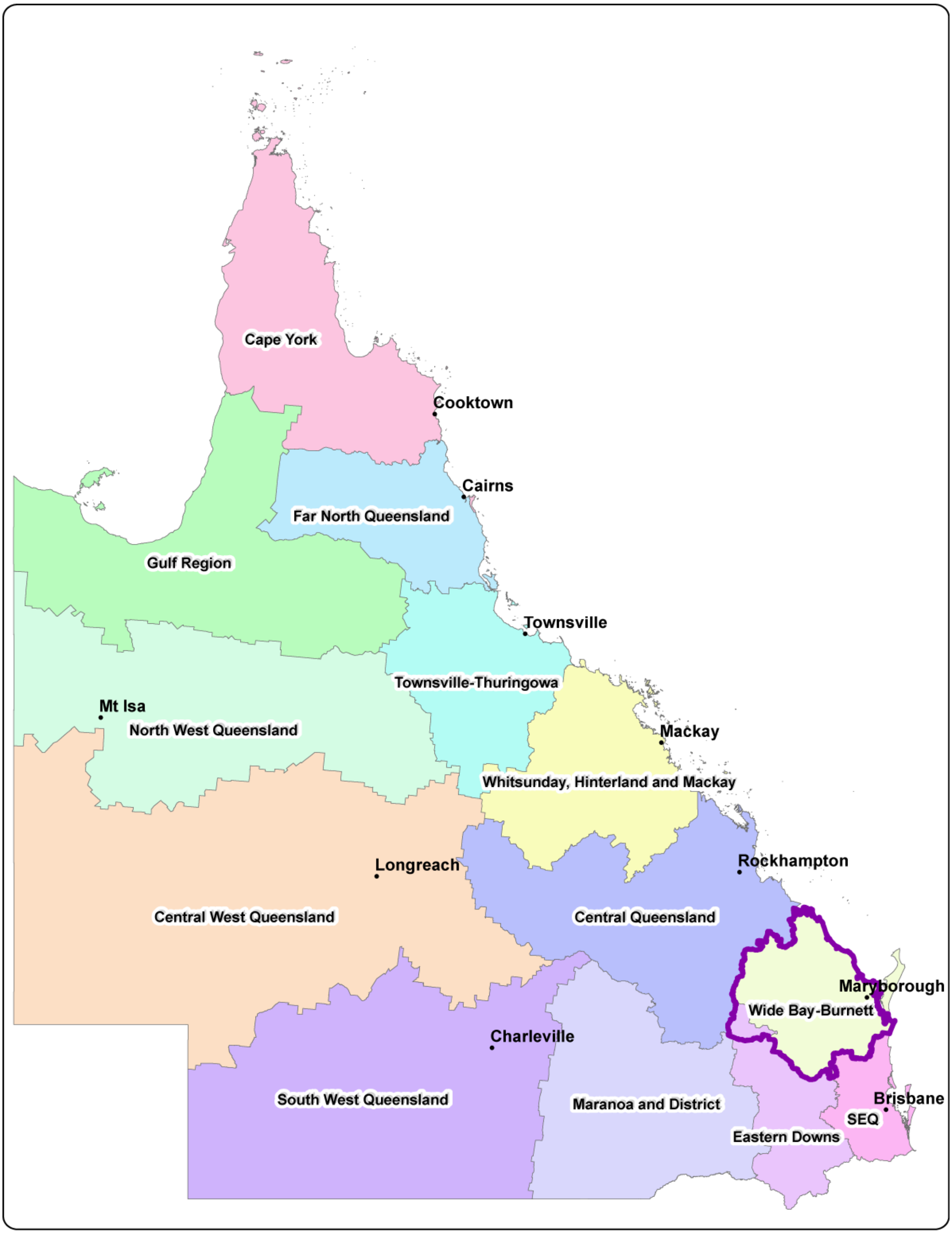

Figure 1-1. Location of the Wide Bay-Burnett Regional Water Supply Strategy area. The zones indicate the Queensland Government's Regional Planning Divisions.

Climate change is difficult to detect due to the natural variability present in our climate system, and the gradual nature of such changes. Detection, therefore, requires access to long-term climate records that are relatively free from the aforementioned problems associated with most observational records. To enable observational datasets to be used for climate change detection, the Bureau maintains a set of 'high quality' (HQ) datasets which have undergone rigorous scrutiny to derive a set of reliable long-term climate records. However, the 'high quality' datasets are only available for a limited subset of stations and the interpolated datasets for temperatures are only available as annual average anomalies.

In order to ensure that there was a sufficient density of stations in the WBB region and to be able to characterise the seasonal changes and trends, analyses were completed using a range of datasets. The choice of datasets is determined primarily by the availability of long term observational data of adequate quality and density. The following datasets were used in this chapter:

- Point datasets:
    - Temperature - daily records for the 1910–2007 period provided by BOM (HQ) and SILO (SILO 2008),
    - Rainfall – daily records for the 1910–2007 period provided by BOM and SILO.
- Interpolated datasets:
    - Temperatures – annual anomalies for minimum, mean and maximum temperature for the 1910–2007 period provided by BOM (HQ)
    - Temperatures – monthly data for minimum, mean and maximum temperature for the 1950–2007 period provided by BOM
    - Rainfall – monthly totals for the 1890–2007 period provided by BOM,
    - Potential evaporation – monthly totals for the 1975–2007 period provided by SILO.

The choice of analysis period is determined by the availability of the requisite datasets, and the need to characterise recent trends. For example rainfall records were analysed using two periods to enable recent climate trends (1950–2007) to be interpreted in a long term historical context (1890–2007).

The historical trends in temperature, rainfall and potential evaporation presented in this report were computed by fitting linear trends to spatially interpolated data. It should be noted that trends may also be computed using point datasets and spatial trends subsequently derived by interpolating the point based trends. For example, the trends for minimum, mean and maximum temperatures presented in the 'Climate Change in Australia' report (CSIRO & BOM 2007) were computed using this latter method, utilising only the high-quality subset of point data. Consequently the temperature trends provided in this report differ from those presented in the CSIRO/BOM report.

1.2.1 Historical temperature trends

The spatial distribution of long-term (1950–2007) average annual and seasonal minimum, mean and maximum temperatures throughout Queensland are shown in Figure 1-2. Average annual temperatures are coolest in the south-east and warmest in the north-west. During the summer season temperatures have an east-west gradient with the warmest temperatures inland.

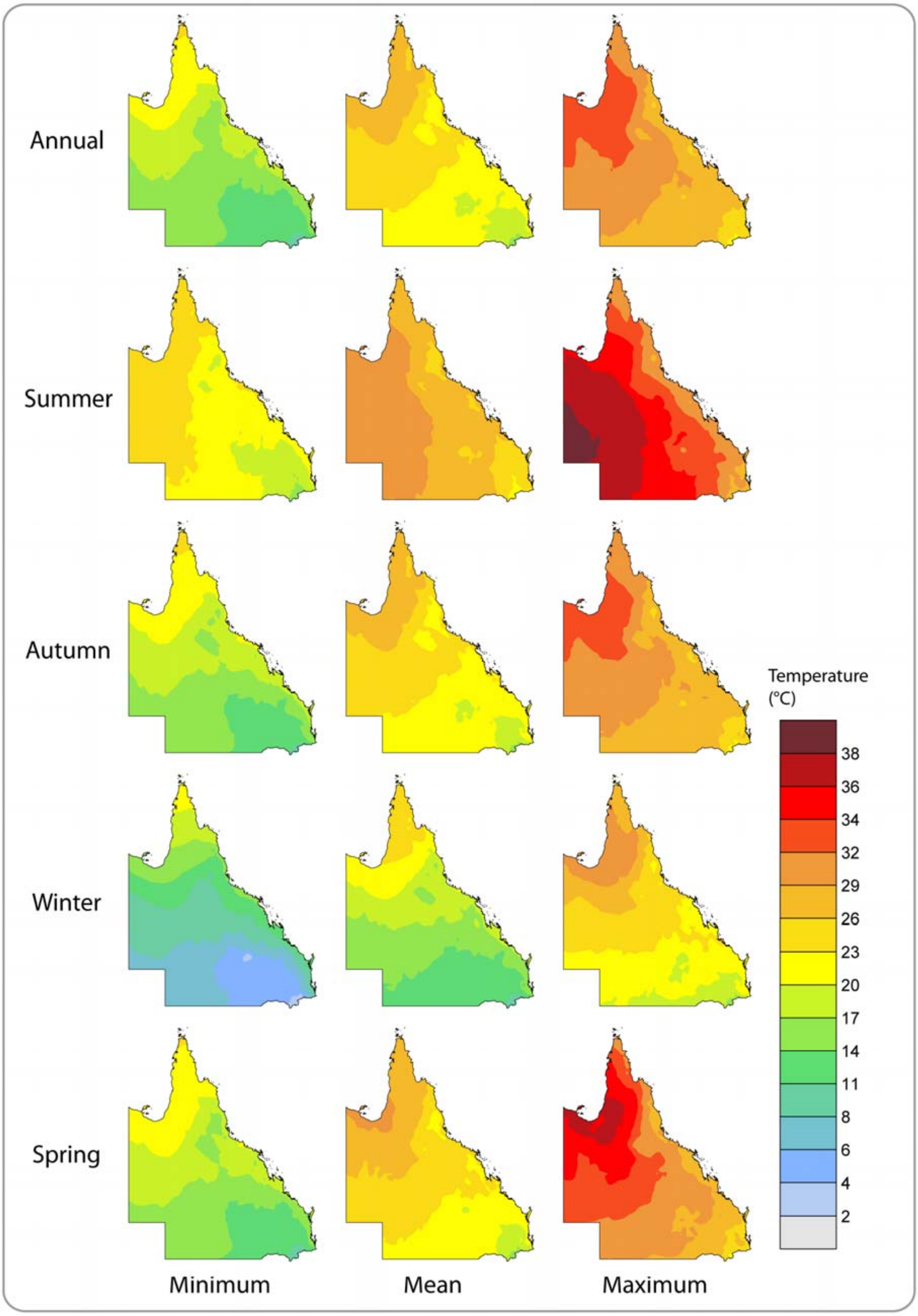

Figure 1-2. Long-term average annual and seasonal minimum (left column), mean (middle column) and maximum (right column) temperatures (°C) during the 1950–2007 period for Queensland. Data source: Australian Bureau of Meteorology 2008.

Observational data records indicate very little overall trend in surface temperatures throughout the first half of the last century. Throughout the second half of the last century, however, there was a general warming trend. The changes in surface temperatures as represented by linear trends are shown in Figure 1-3. Despite the considerable spatial variation, the general pattern is one of warming across the state, with greater warming in the south than the north. However during the winter season, there was a decrease in minimum temperatures across Cape York and during the summer season there was a decrease in maximum temperatures in the region south of the Gulf of Carpentaria. The area-averaged warming trends for each season and selected regions are summarised in Table 1-1.

To assess whether the observed temperature trends are robust, we have used the Pearson correlation coefficient (*r*) to quantify the correlation between observed data points and the linear regression line (see Smith 2004) fitted to this data (Figure 1-4). The correlation coefficient measures the strength of the relationship between the observational data and the linear fit. The strength of the relationship, expressed as a correlation value, provides an estimate of the robustness of a systematic trend, against the background of natural variability. The statistical significance of this relationship can be estimated from statistical tables, given the sample size and value of the correlation coefficient. For example, correlation values exceeding 0.25 are statistically significant at the 95% level, while values which exceed 0.33 are statistically significant at the 99% level. Using this criterion, the observed trends in temperatures are robust throughout a substantial proportion of the state (Figure 1-4).

The correlation values and significance levels previously quoted (and shown in Figure 1-4), were calculated using a sample size of 58 (i.e. n=58 years). The user should note that significance levels are sensitive to sample size, especially when $n<60$.

Table 1-1. Trends in surface temperature (°C per decade) for the 1950–2007 period. Data source: Australian Bureau of Meteorology 2008**.**

Feature		Australia	Queensland	WBB
Minimum temperature	Annual	+0.14	+0.23	+0.21
	Summer	+0.16	+0.23	+0.18
	Autumn	+0.12	+0.21	+0.20
	Winter	+0.07	+0.19	+0.21
	Spring	+0.20	+0.27	+0.26
Mean temperature	Annual	+0.14	+0.21	+0.24
	Summer	+0.10	+0.21	+0.24
	Autumn	+0.12	+0.23	+0.24
	Winter	+0.13	+0.18	+0.23
	Spring	+0.21	+0.23	+0.25
Maximum temperature	Annual	+0.14	+0.20	+0.26
	Summer	+0.05	+0.18	+0.30
	Autumn	+0.12	+0.25	+0.27
	Winter	+0.19	+0.17	+0.26
	Spring	+0.21	+0.19	+0.24

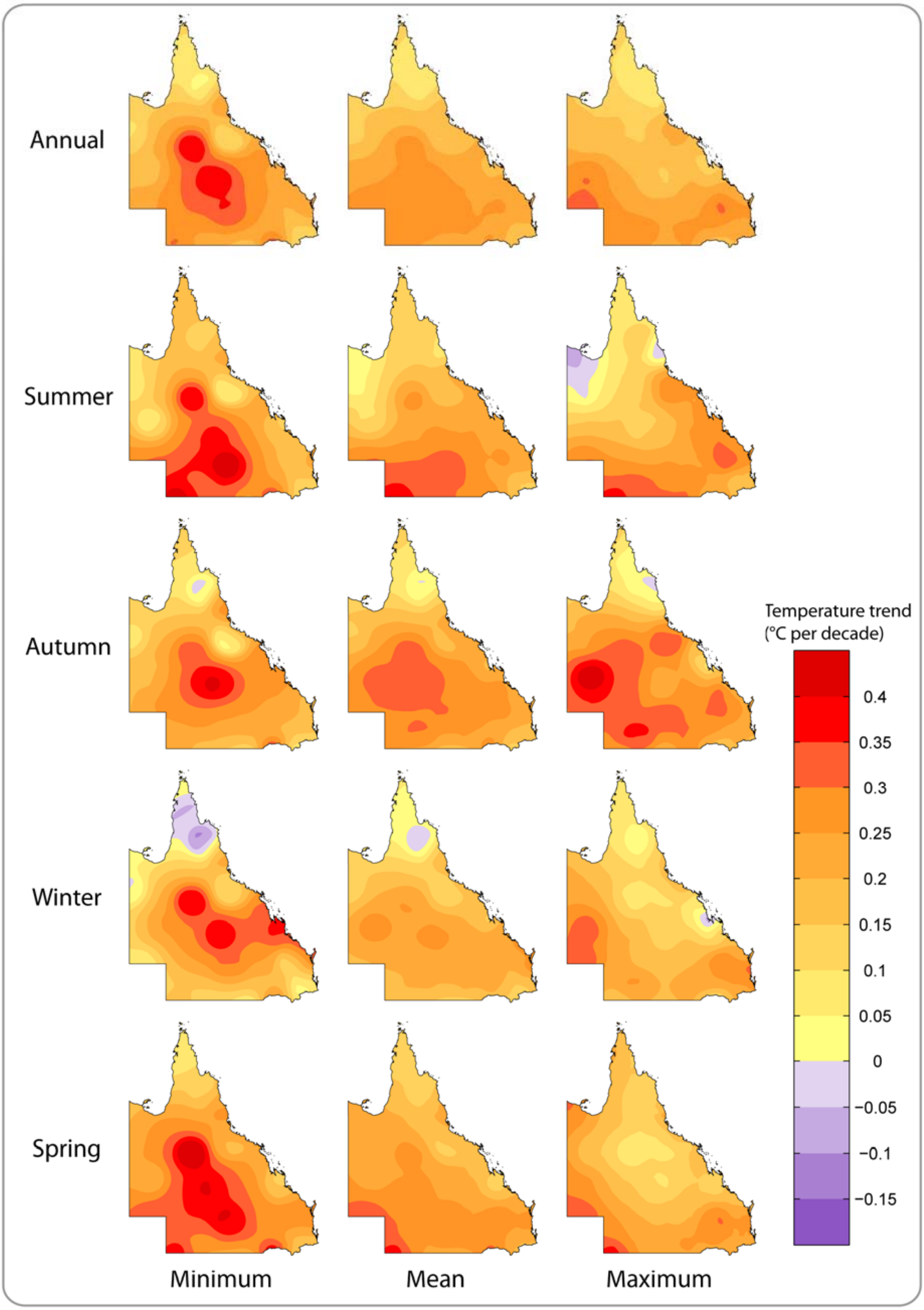

Figure 1-3. Trends in annual and seasonal minimum (left column), mean (middle column) and maximum (right column) temperatures (°C per decade) during the 1950–2007 period for Queensland. Data source: Australian Bureau of Meteorology 2008.

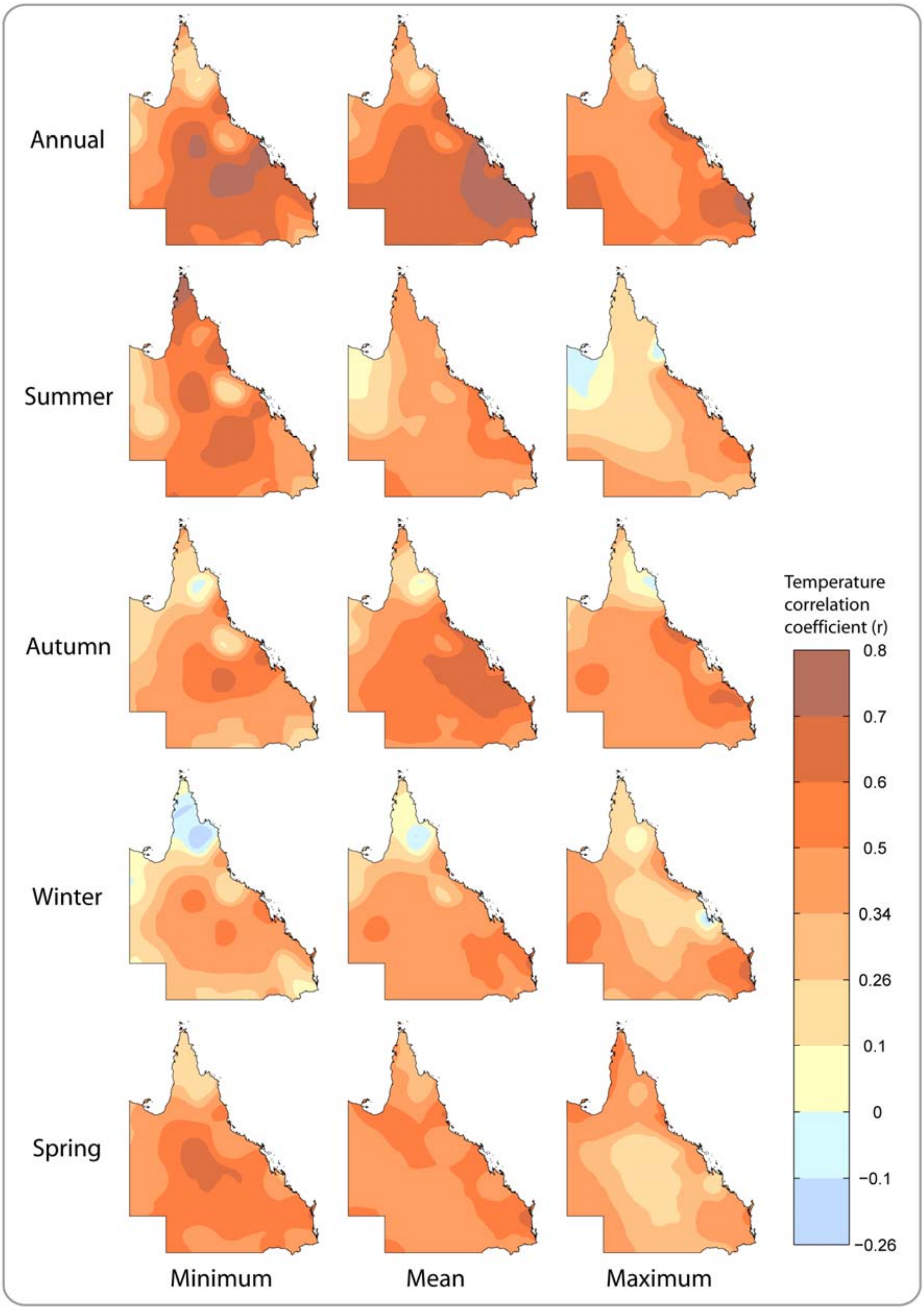

Figure 1-4. Pearson correlation coefficients (*r*) between observed temperatures and the temperatures based upon the linear trend for annual and seasonal minimum (left column), mean (middle column) and maximum (right column) temperatures during the 1950–2007 period for Queensland. Data source: Australian Bureau of Meteorology 2008.

In order to characterise the temporal patterns in temperature for the Wide Bay-Burnett region, the area-averaged time-series for temperatures are shown in Figures 1-5 to 1-11. Annual and seasonal average temperatures are obtained by spatially averaging over the region, and temporally averaging over all days within the given period.

There has been a systematic increase in the mean and minimum temperatures since the early 1960s (Figure 1-5). While such a clear trend is not evident for maximum temperature, throughout the last decade (1998–2007), maximum temperatures have generally been higher than average. Analogous plots for Australia and Queensland are in Appendix A (Figures A-1 and A-2, respectively). Figures 1-5, A-1 and A-2 were constructed by adding high quality annual anomaly gridded datasets to the 1961–1990 base period means as long term gridded data expressed as absolute values are not available.

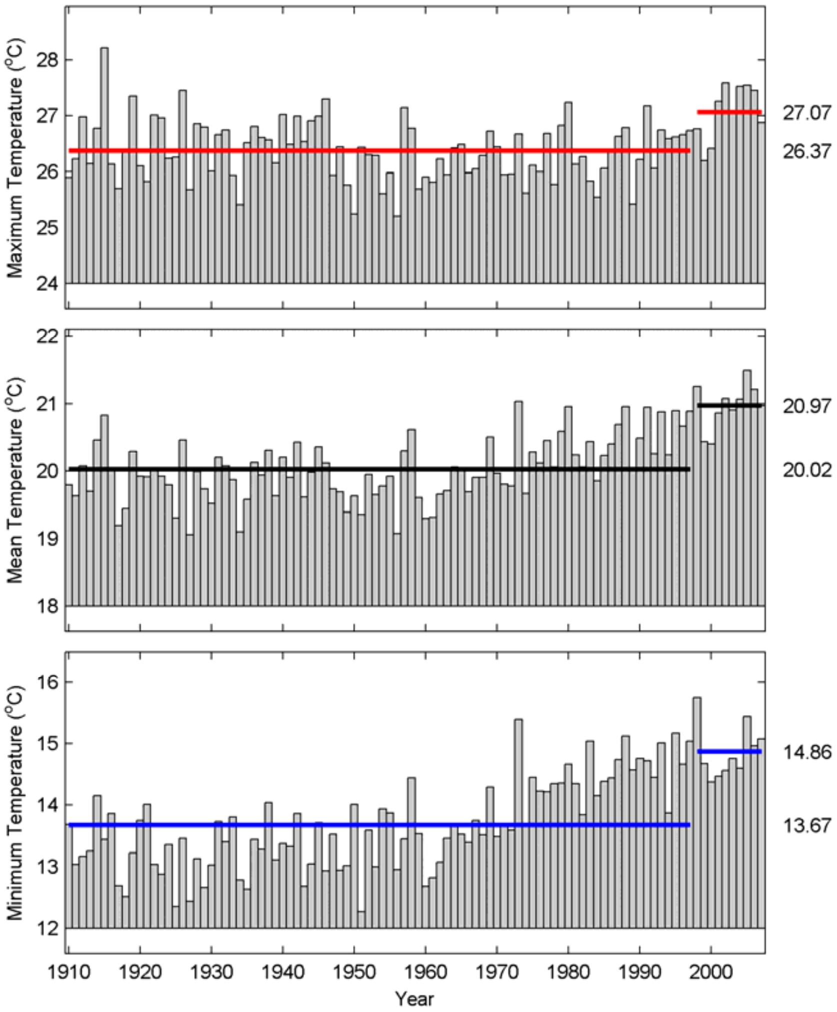

Figure 1-5. Annual minimum (bottom), mean (middle) and maximum (top) temperatures during the 1910–2007 period for the Wide Bay-Burnett region. The horizontal lines show the average for last decade (1998–2007) compared to the average over the 1910–1997 period. The numbers on the right are the means for the 1910–1997 (bottom) and 1998–2007 (top) periods. Data source: Australian Bureau of Meteorology 2008.

The increases in annual and seasonal average surface temperatures which occurred throughout 1950–2007 for minimum, mean and maximum temperatures are also evident in Figures 1-6 to 1-11. These figures show annual and seasonal means (left side) and decadal averages (right side). The data for annual and seasonal minimum, mean and maximum temperatures are absolute values, but are presented as anomalies from the 1961–1990 average. The observed warming through winter and spring has been generally consistent since 1950, with a stronger trend emerging in the last 20 years. Summer and autumn also exhibit a general warming trend, although the rate of warming slowed between the late 1980s and early 1990s.

The seasonal warming patterns evident in the Wide Bay-Burnett region are broadly consistent with area-averaged rainfall data for Queensland and Australia. That is, lower temperatures coincide with wetter periods (e.g. mid-1970s) and higher temperatures coincide with major periods of drought (e.g. 2002–2007). Similar time-series datasets for Australia and Queensland are provided for comparison in Appendix A (Figures A-3 to A-14). For further discussion of temperature trends see Stone et al. (1996), Lough (1997), Plummer et al. (1999) and Collins et al. (2000).

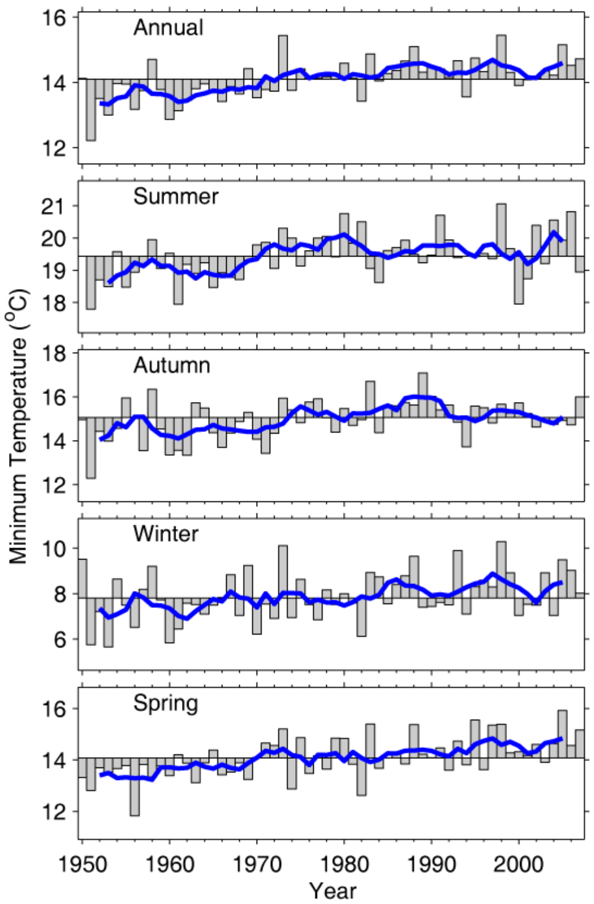

Figure 1-6. Annual and seasonal minimum temperatures during the 1950–2007 period for the Wide Bay-Burnett region. The blue line shows the five-year running average. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

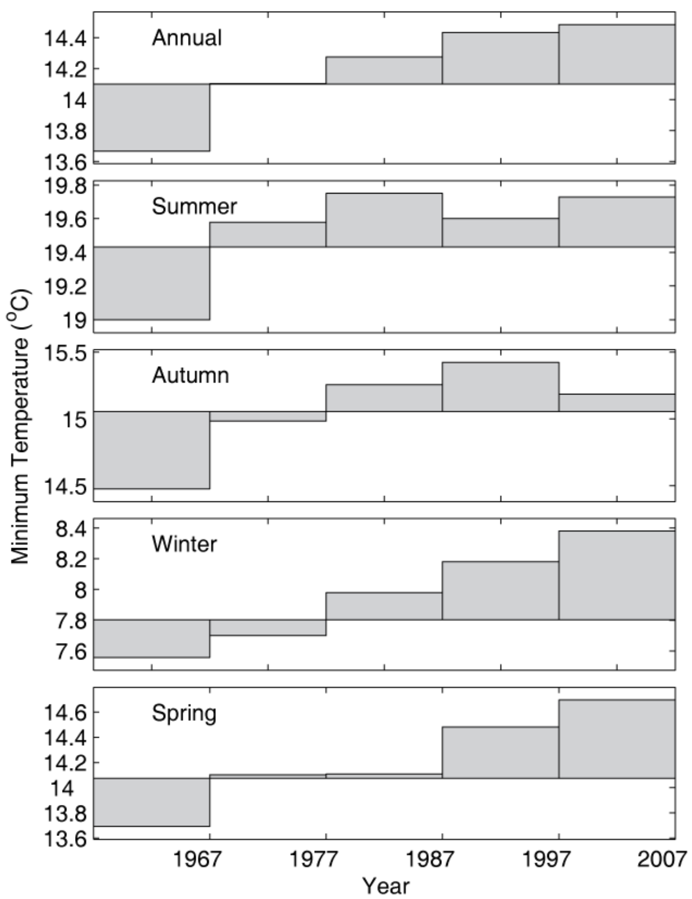

Figure 1-7. Decadal average annual and seasonal minimum temperatures during the 1957–2007 period for the Wide Bay-Burnett region. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

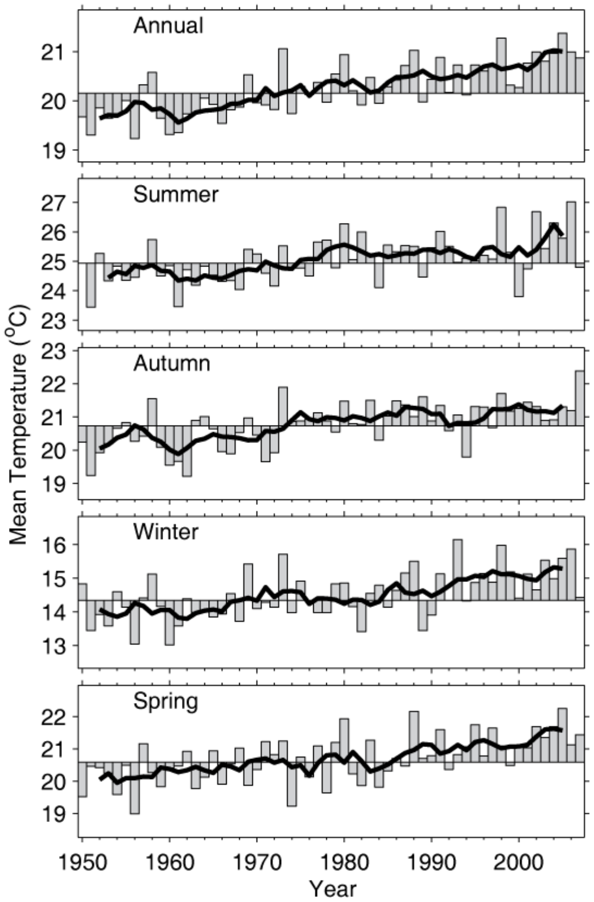

Figure 1-8. Annual and seasonal mean temperatures during the 1950–2007 period for the Wide Bay-Burnett region. The black line shows the five-year running average. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

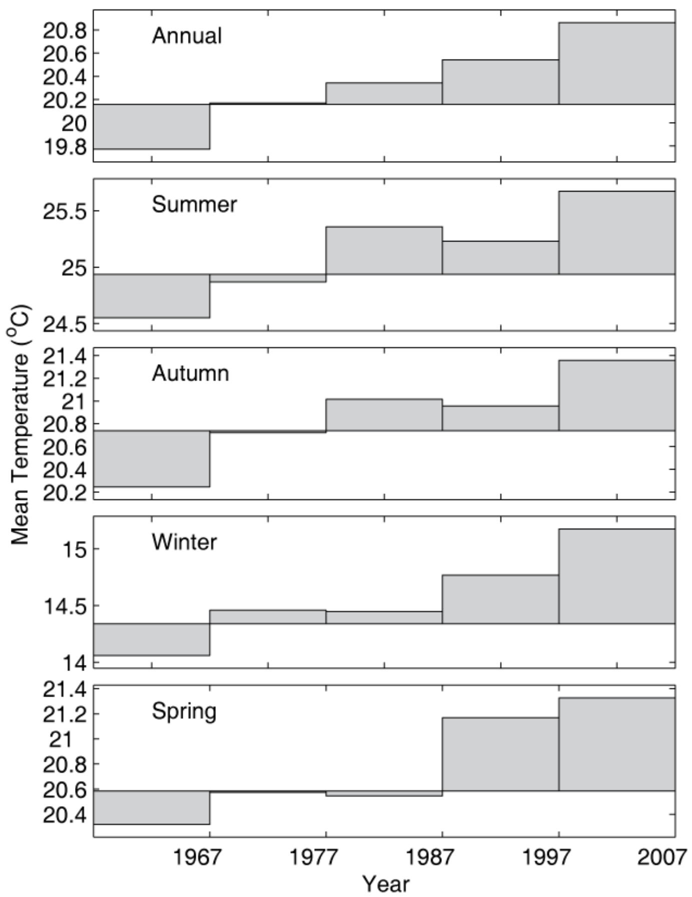

Figure 1-9. Decadal average annual and seasonal mean temperatures during the 1957–2007 period for the Wide Bay-Burnett region. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

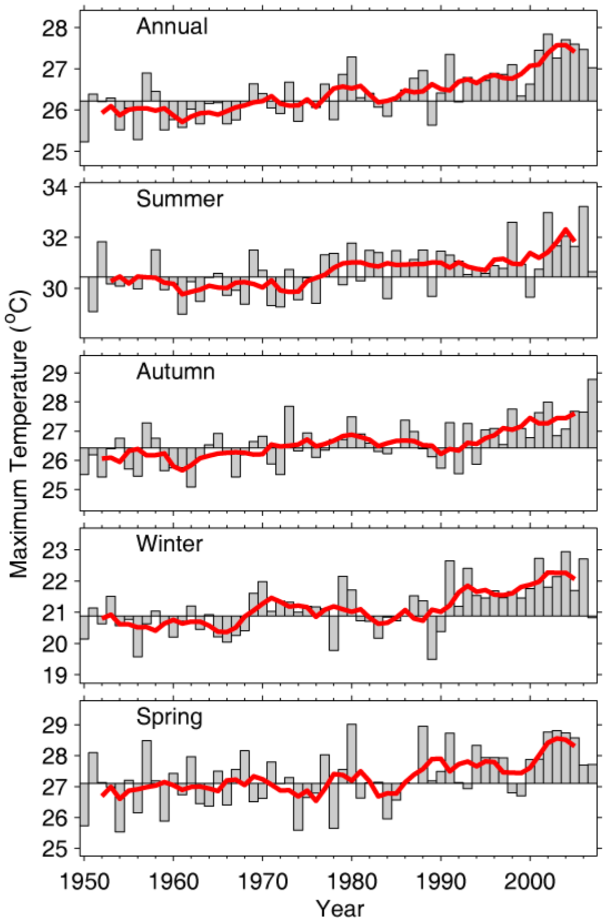

Figure 1-10. Annual and seasonal maximum temperatures during the 1950–2007 period for the Wide Bay-Burnett region. The red line shows the five-year running average. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

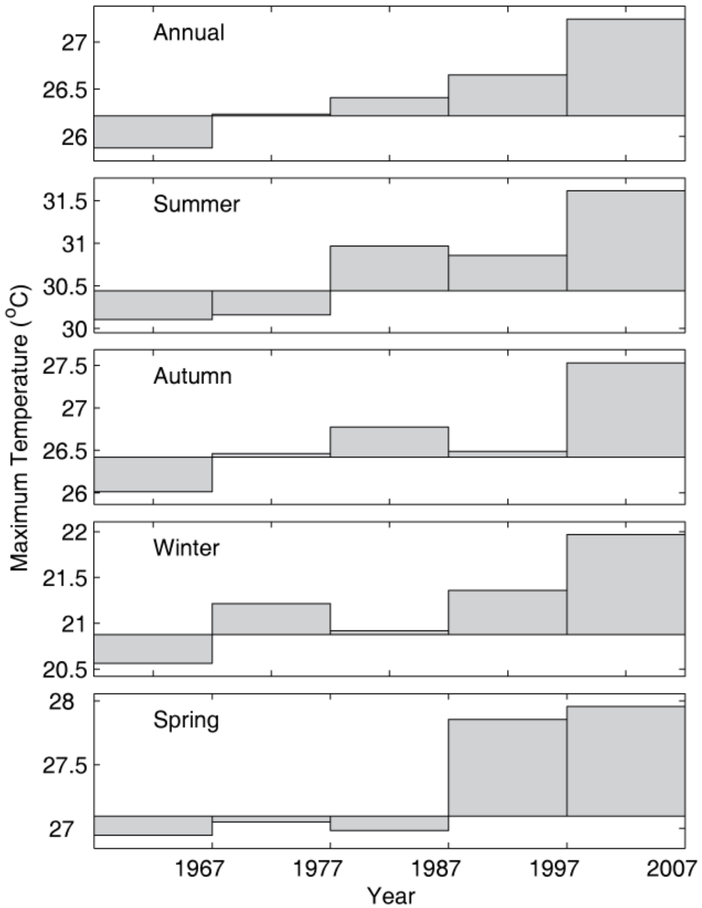

Figure 1-11. Decadal average annual and seasonal maximum temperatures during the 1957–2007 period for the Wide Bay-Burnett region. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

1.2.2 Historical rainfall trends

Queensland's rainfall is dominated by monsoonal activity in the north and trade wind flows in the east, and is also strongly influenced by topography. The majority of rainfall occurs throughout the summer months (Figure 1-12) through the passage of north-west monsoon flows and the south-east trade winds, as they bring warm, moist air masses into the region. These moist onshore trade winds are orographically lifted as they pass over the Great Dividing Range, resulting in the formation of cloud and heavy rainfall, particularly in the northern parts of the state. The north-west monsoon flows bring moist, unstable air masses into northern Australia, generating intense rainfall along the Intertropical Convergence Zone (ITCZ) where the monsoon and trade winds meet. The location of the ITCZ varies annually and in some years may lie to the north of Australia, causing a decline in summer rainfall across Queensland (Tapper & Hurry 1993).

Analysis of observational rainfall records reveals a number of disparate trends across differing spatial and temporal scales. While there has been a general increase in Australian rainfall over the last century (Table 1-2), significant and spatially coherent trends emerged throughout the second half of the past century, with generally wetter conditions over north-western Australia and a general drying trend over eastern Australia (CSIRO & BOM 2007). These patterns of rainfall decline extend throughout most of coastal Queensland, particularly during summer and autumn (Figure 1-13). The decline in summer and autumn rainfall was partially offset by an increase in spring rainfall, and there has been little overall change in winter rainfall. Focussing on the WBB region, the overall decline has been most severe in the north-eastern area where annual rainfall has declined by 5–10% of the mean per decade during the 1950–2007 period (Figure 1-13).

Table 1-2. Trends (mm per decade) in annual rainfall for the 1897–2007 and 1950–2007 periods. Data source: Australian Bureau of Meteorology 2008.

Years	Australia	Queensland	Wide Bay-Burnett
1897–2007	8.1	5.6	-7.3
1950–2007	13.0	-14.0	-46.9

In relation to Queensland as a whole, the Wide Bay-Burnett region is one of the areas within Queensland which has experienced strong declines in rainfall since 1950. While Queensland has experienced changes in annual rainfall ranging between +65 and -95 mm per decade for the 1950–2007 period, annual rainfall in the Wide Bay-Burnett region has declined by 35–65 mm per decade (Figure B-1 in Appendix B). The declining trends in rainfall for Queensland and the Wide Bay-Burnett region are strongest during summer and autumn.

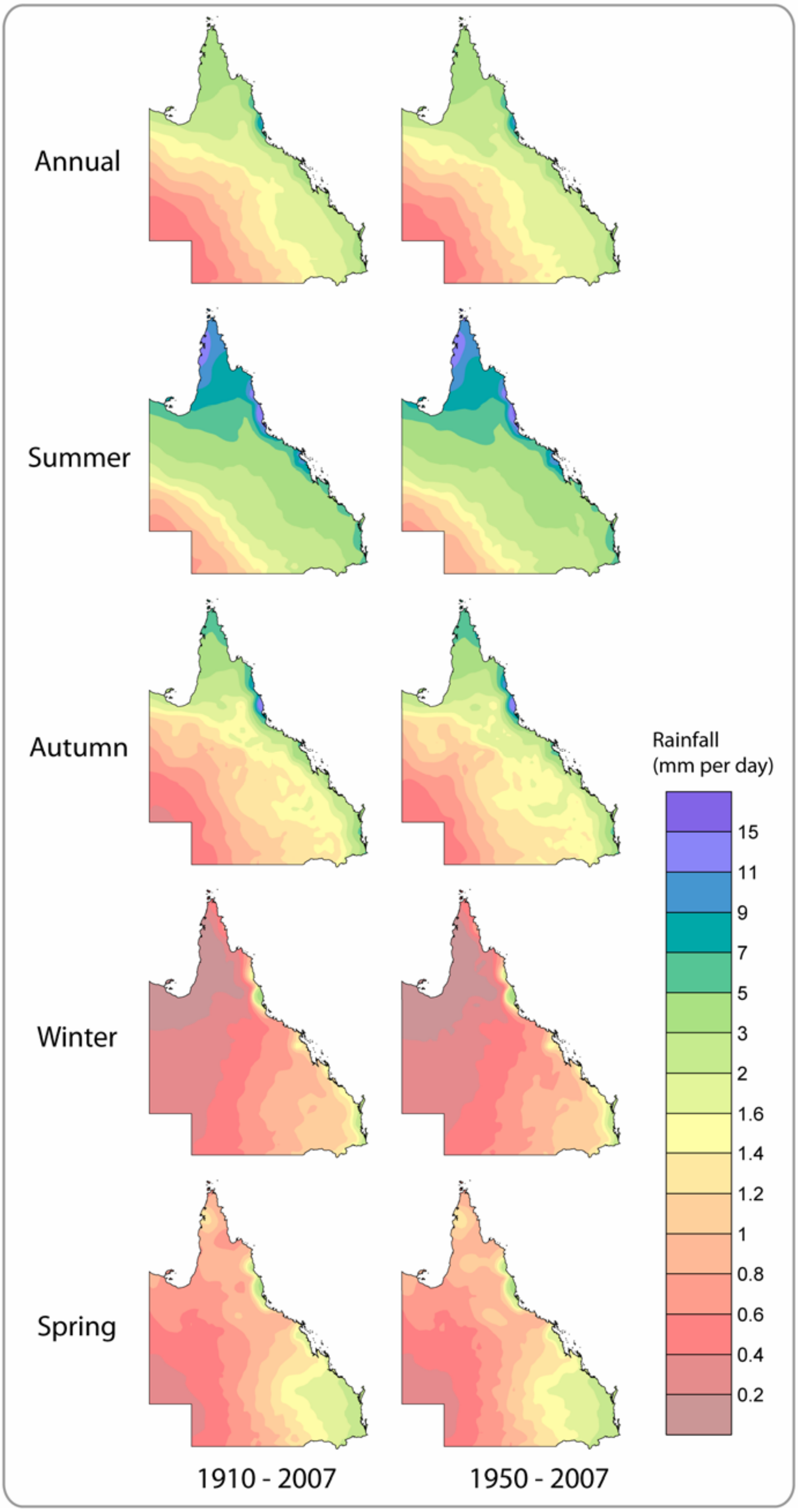

Figure 1-12. Long-term average annual and seasonal rainfall (mm per day) for the 1910–2007 (left column) and the 1950–2007 (right column) periods for Queensland. Data source: Australian Bureau of Meteorology 2008.

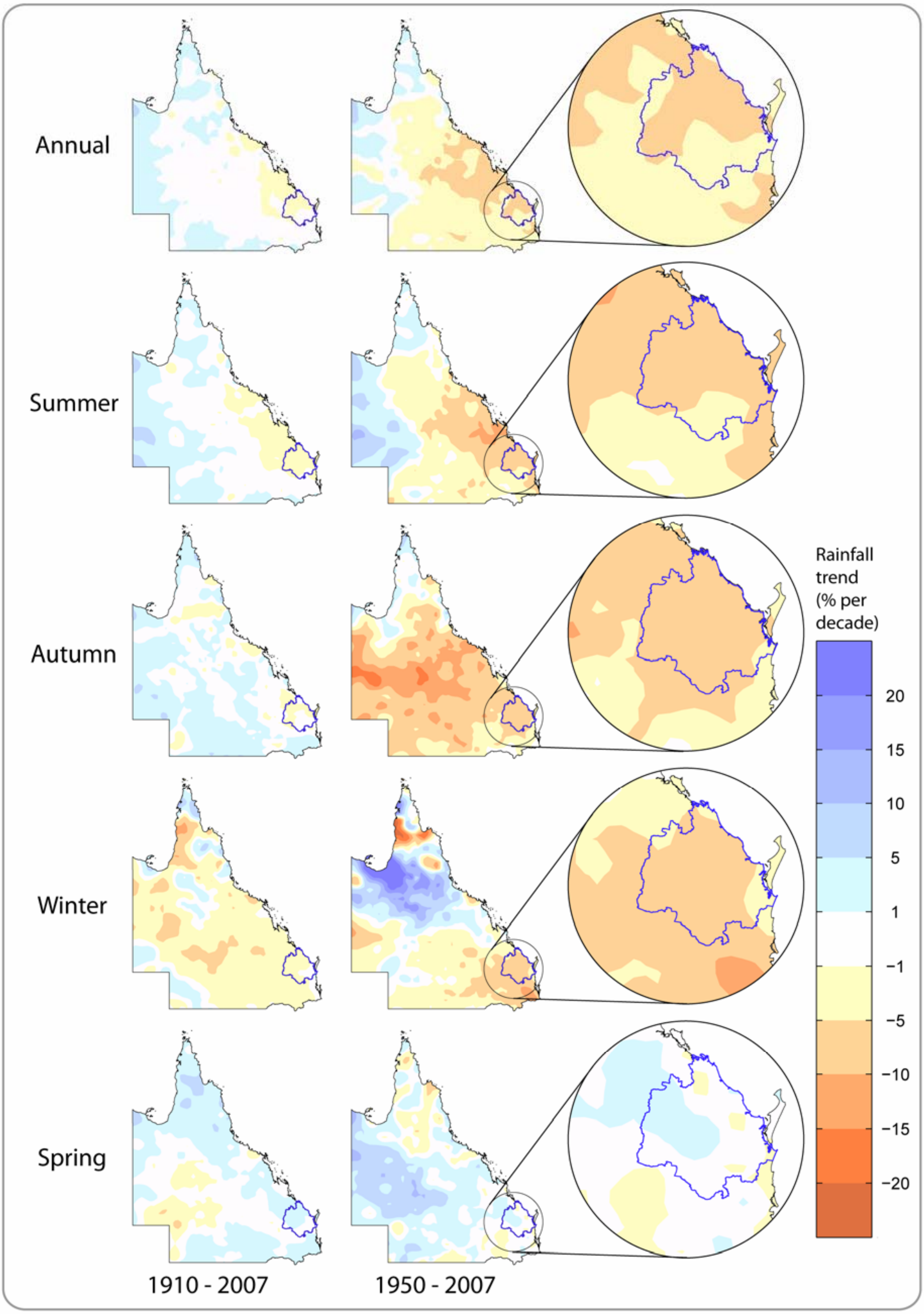

Figure 1-13. Trends in annual and seasonal rainfall (% of mean rainfall per decade) for the 1910–2007 (left column), and the 1950–2007 (right column) periods for Queensland. The Wide Bay-Burnett region is enlarged for the 1950–2007 period. Data source: Australian Bureau of Meteorology 2008.

To assess whether the observed rainfall trends are robust, we have used the Pearson correlation coefficient (*r*) to quantify the correlation between observed data points and the linear regression line (see Smith 2004) fitted to this data (Figure 1-14). The correlation coefficient measures the strength of the relationship between the observational data and the linear fit. The strength of the relationship, expressed as a correlation value, provides an estimate of the robustness of a systematic trend, against the background of natural variability. The statistical significance of this relationship can be estimated from statistical tables, given the sample size and value of the correlation coefficient. Using this criterion, the observed trends in temperatures are robust throughout a substantial proportion of the state (Figure 1-14). Annual and summer rainfall has declined throughout a large part of southern and central coastal Queensland during the 1950–2007 period. Furthermore, the observed decline is especially pronounced in the Wide Bay-Burnett region and the trends are robust at the 95–99% confidence level.

The general decline in rainfall throughout the Wide Bay-Burnett region in recent decades can be seen in the long-term time series of annual and seasonal rainfall (Figure 1-15). A decline is evident for summer, autumn and annual rainfall during the last decade (1998–2007), when compared to the average over all previous decades (1897–1997). Analogous plots for Australia and Queensland are provided for comparison in Appendix B (Figures B-2 and B-3).

The temporal difference between the rainfall trend experienced in the Wide Bay-Burnett region and Queensland as a whole is reflected in the time-series datasets for the two regions. Figures 1-16 shows the time series of area-averaged annual and seasonal rainfall in the Wide Bay-Burnett region, and Figure1-17 shows the corresponding decadal averages. The data shown in Figures 1-16 and 1-17 are absolute values, but are presented as anomalies from the 1961–1990 average. During the 1897–2007 period, the temporal distribution of rainfall for Queensland has been generally consistent with that for Australia (compare Figures B-4 and B-5 with Figures B-6 and B-7 in Appendix B). In contrast, over the past century the temporal distribution of rainfall for the Wide Bay-Burnett region has differed from the Queensland-wide distribution.

For further discussion on Australia-wide rainfall trends, see Suppiah & Hennessy (1998), Hennessy et al. (1999), Smith (2004) and Nicholls (2006).

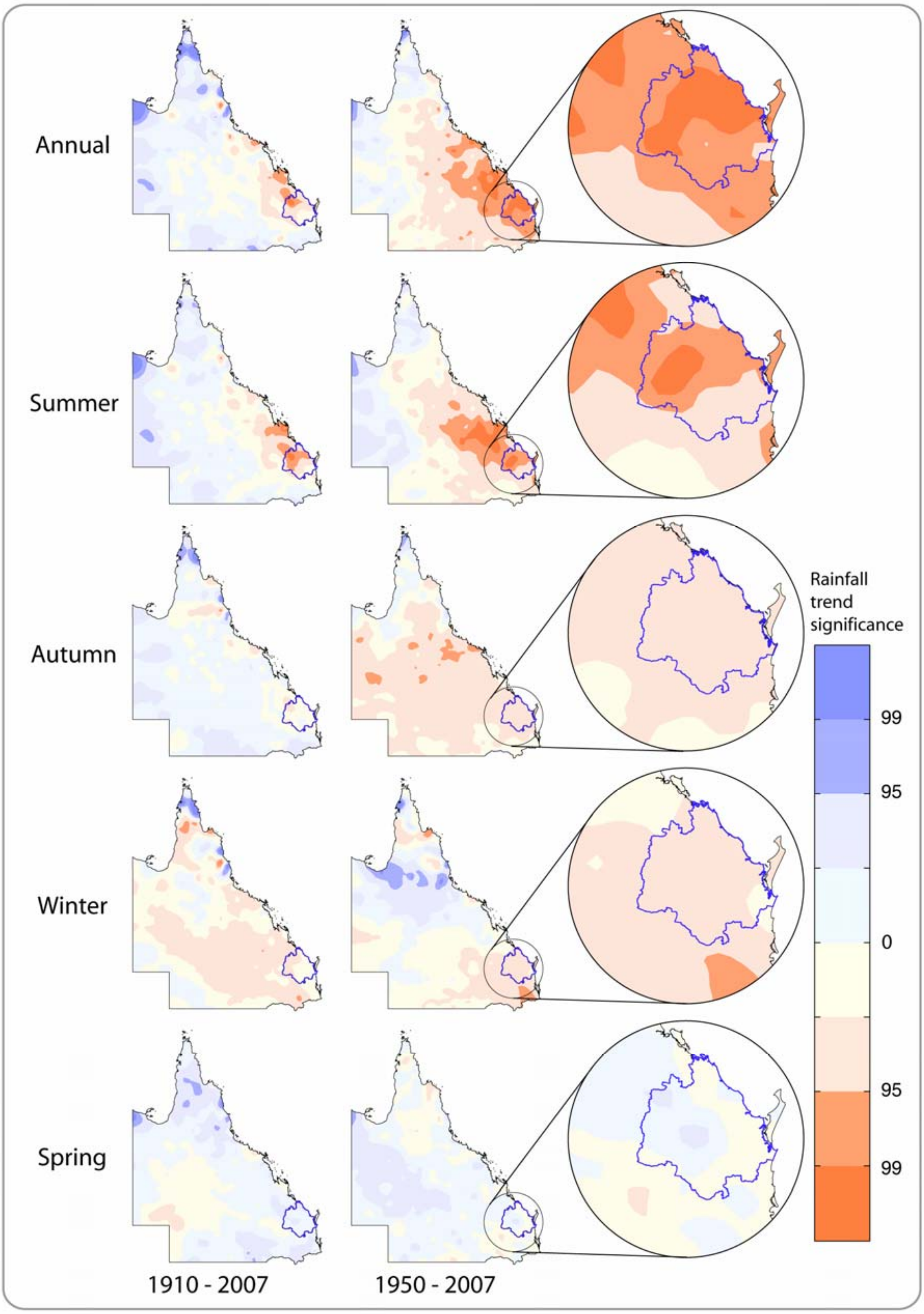

Figure 1-14. Statistical significance of the Pearson correlation coefficients (*r*) between observed rainfall and the rainfall based upon the linear trend in annual and seasonal rainfall during the 1910–2007 (left column), and the 1950–2007 (right column) periods for Queensland. The Wide Bay-Burnett region is enlarged for the 1950–2007 period. The significance level indicates the robustness of the trend. Data source: Australian Bureau of Meteorology 2008.

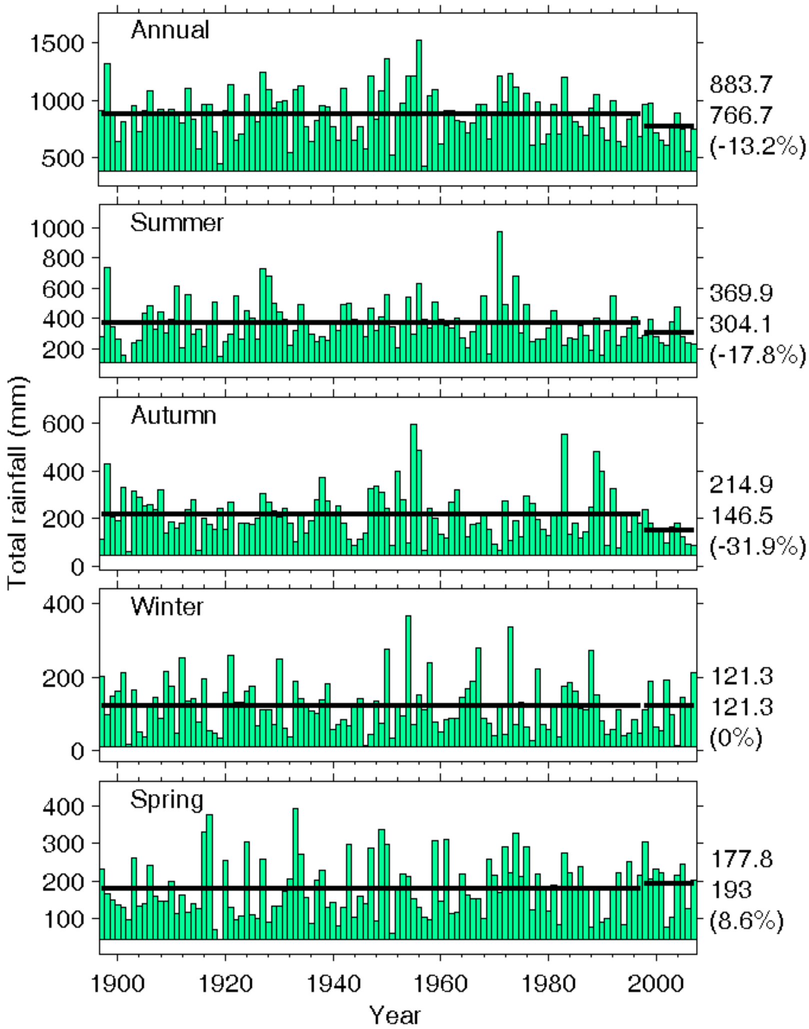

Figure 1-15. Annual and seasonal rainfall during the 1897–2007 period for the Wide Bay-Burnett region. The horizontal lines show the average for the last decade (1998–2007) compared to the average over the 1897–1997 period. The numbers shown on the right are the means for the 1897–1997 (top value) and 1998–2007 (middle value) periods. The relative change (%) between the two periods is also shown (bottom value). Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

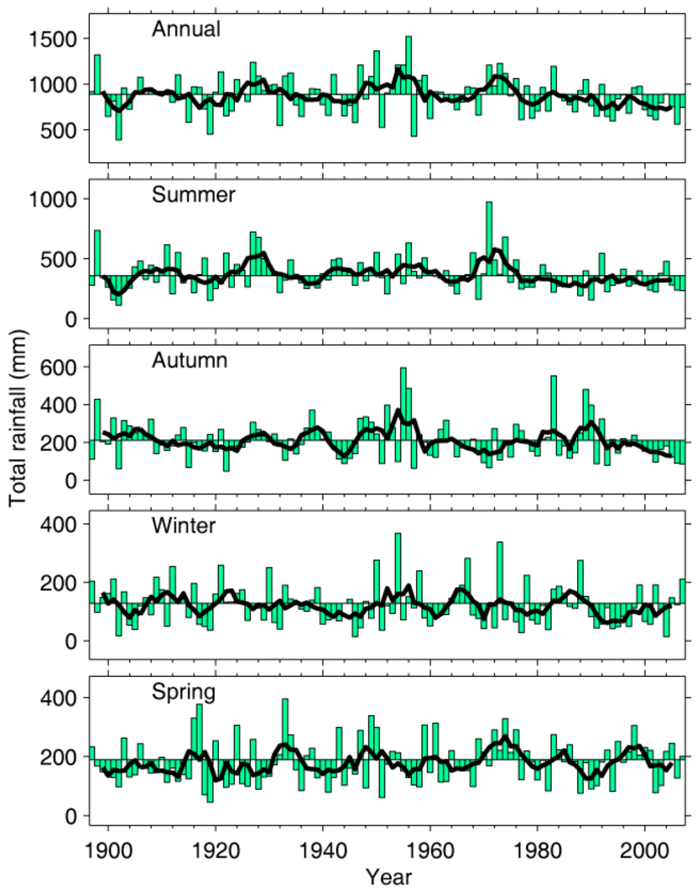

Figure 1-16. Annual and seasonal rainfall during the 1897–2007 period for the Wide Bay-Burnett region. The black line shows the five-year running average. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

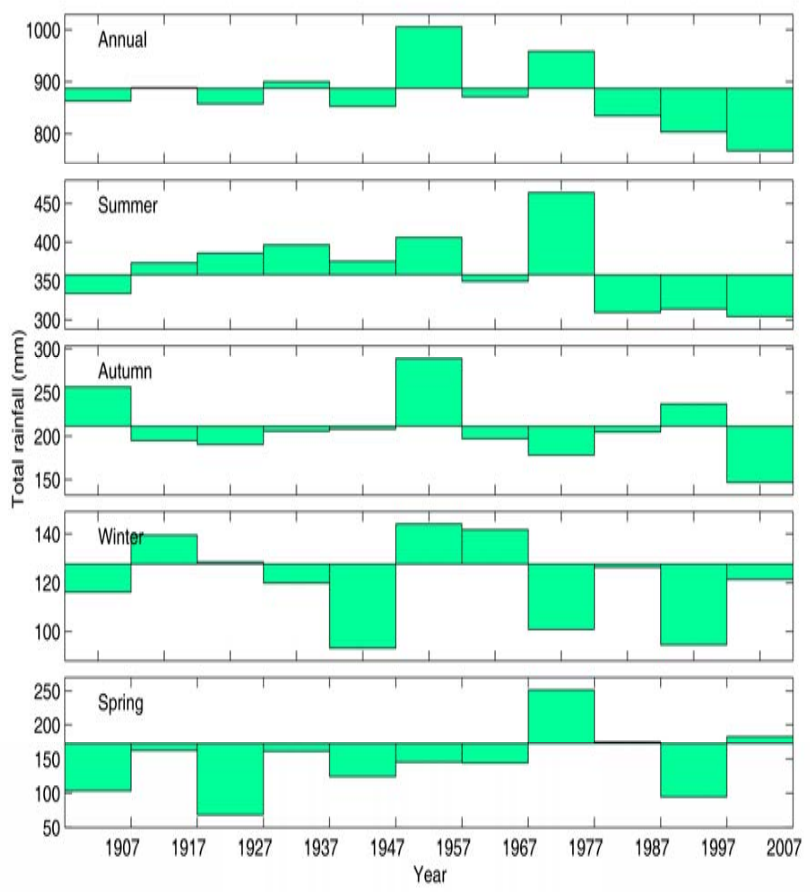

Figure 1-17. Decadal average annual and seasonal rainfall during the 1897–2007 period for the Wide Bay-Burnett region. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

1.2.3 Relationship between the SOI and rainfall

Rainfall in the north-eastern regions of Australia is strongly influenced by the El Niño Southern Oscillation (ENSO) phenomenon. Consequently there is a relationship between the Southern Oscillation Index (SOI) and Queensland rainfall. (The SOI is a simple but useful index for monitoring ENSO.) A number of mathematical tools have been used to characterise this relationship, and various forecasting systems have been developed using the rainfall-SOI relationship as their foundation. The SOI explains approximately 20–25% of the broad-scale year-to-year fluctuation in summer rainfall averaged across Queensland (Lough, 1991).

The correlation (Pearson correlation coefficient, *r*) between rainfall and the SOI across Queensland is shown in Figure 1-18. The correlation is almost always positive and is strongest in spring. During winter the correlation is stronger in the southern regions, while in spring the correlation is stronger in the northern regions. The correlation between the SOI and rainfall over the following season is shown in Figure 1-19. The figure shows that forecasting skill is low for autumn and winter, but improves in spring and summer.

The relationship between the SOI and Australian rainfall is changing (CSIRO & BOM 2007). In recent decades there has been an increase in the average rainfall associated with a given positive value of the SOI, and a decrease associated with a given negative value of the SOI. While the correlation between the SOI and Queensland rainfall may have increased slightly during the second half of the last century, changes in the relationship between the SOI and Australian rainfall are dominated by the increase in summer rainfall across Australia's north-west.

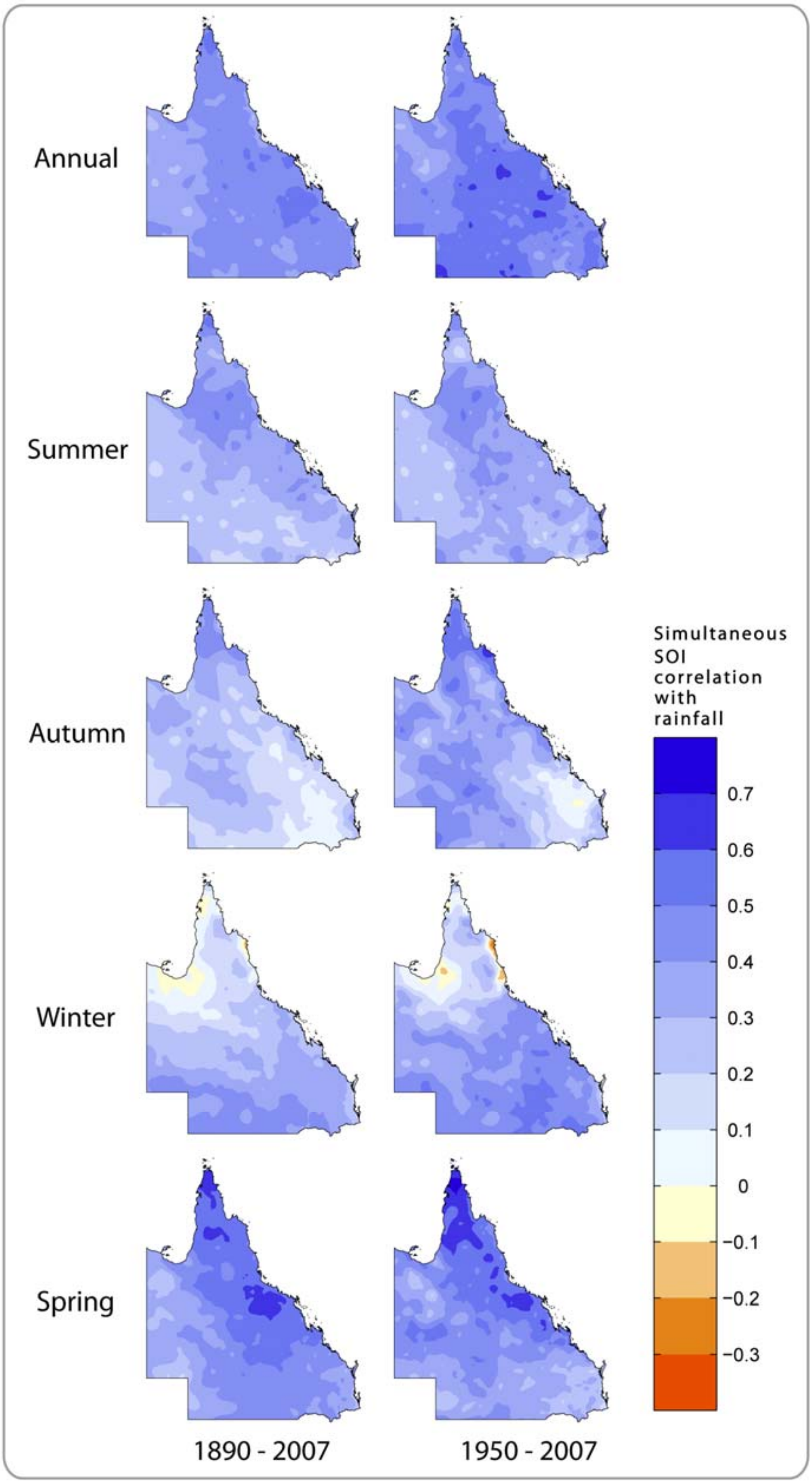

Figure 1-18. Simultaneous correlation (Pearson correlation coefficient, *r*) between annual and seasonal rainfall in Queensland and the mean SOI for the corresponding period. Correlations are shown for the 1890–2007 (left column) and 1950–2007 (right column) periods. Data source: Australian Bureau of Meteorology 2008.

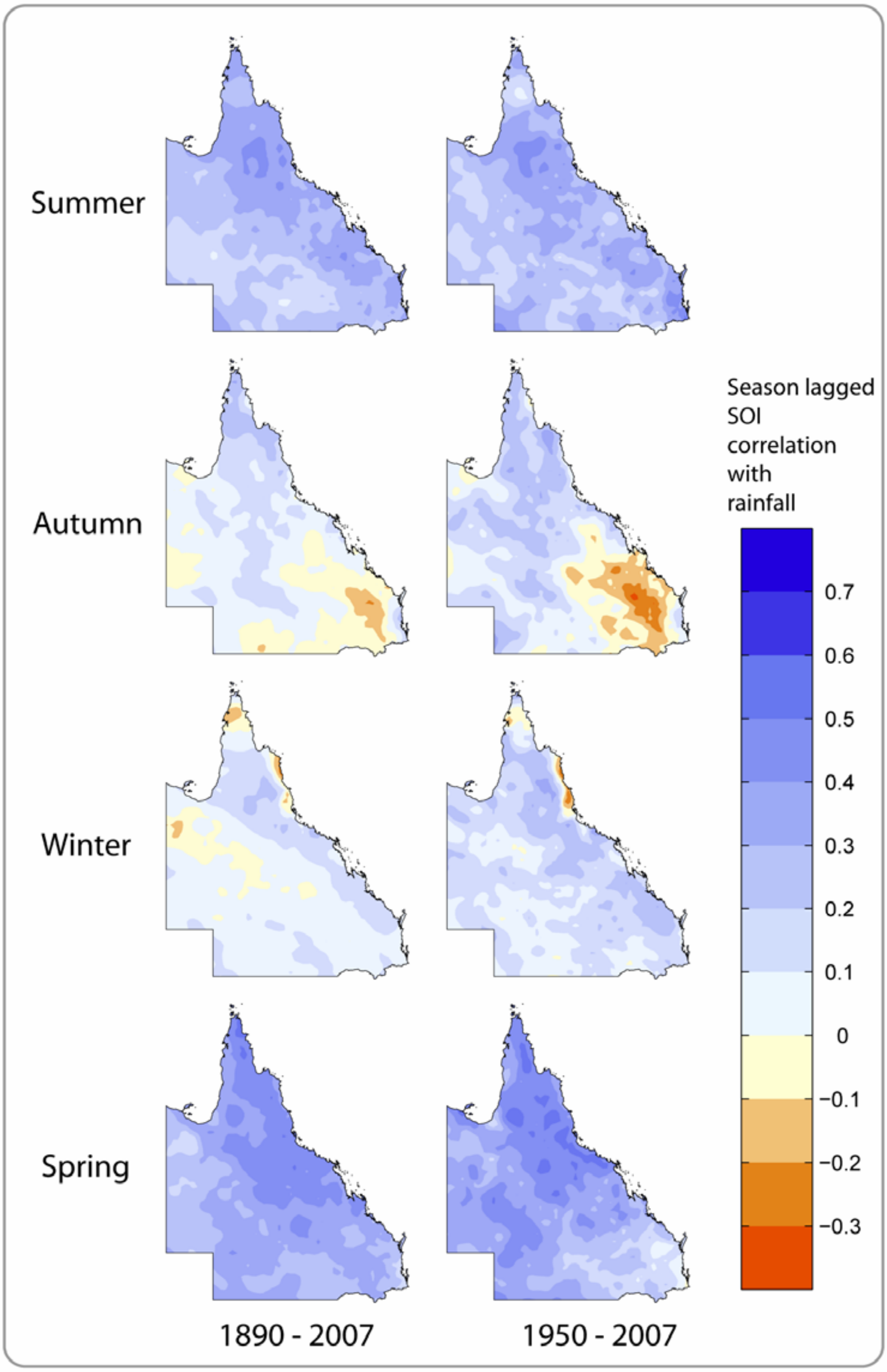

Figure 1-19. Lagged correlation (Pearson correlation coefficient, *r*) between seasonal rainfall in Queensland and the mean SOI. The values are correlations between the SOI and the rainfall for the following season e.g., summer mean SOI (Dec–Feb) and the autumn (Mar–May) rainfall) Correlations are shown for the 1890–2007 (left column) and the 1950–2007 (right column) periods. Data source: Australian Bureau of Meteorology 2008.

1.2.4 Potential evaporation trends

Evaporation is a transfer of water from land and water surfaces to the atmosphere. Potential evaporation is the amount of evaporation that would occur if an unlimited amount of water was available. Pan evaporation, which is the traditional estimate of potential evaporation, is measured by the loss of water from a pan over a specified period of time. Potential evaporation is driven by solar radiation, wind, vapour pressure deficit and air and surface temperatures. There is a complex relationship between pan evaporation and actual evaporation, as actual evaporation is strongly limited by soil water availability and plant water-use-efficiency. Estimates of potential evaporation (using pan evaporation measurements) are shown in Figure 1-20.

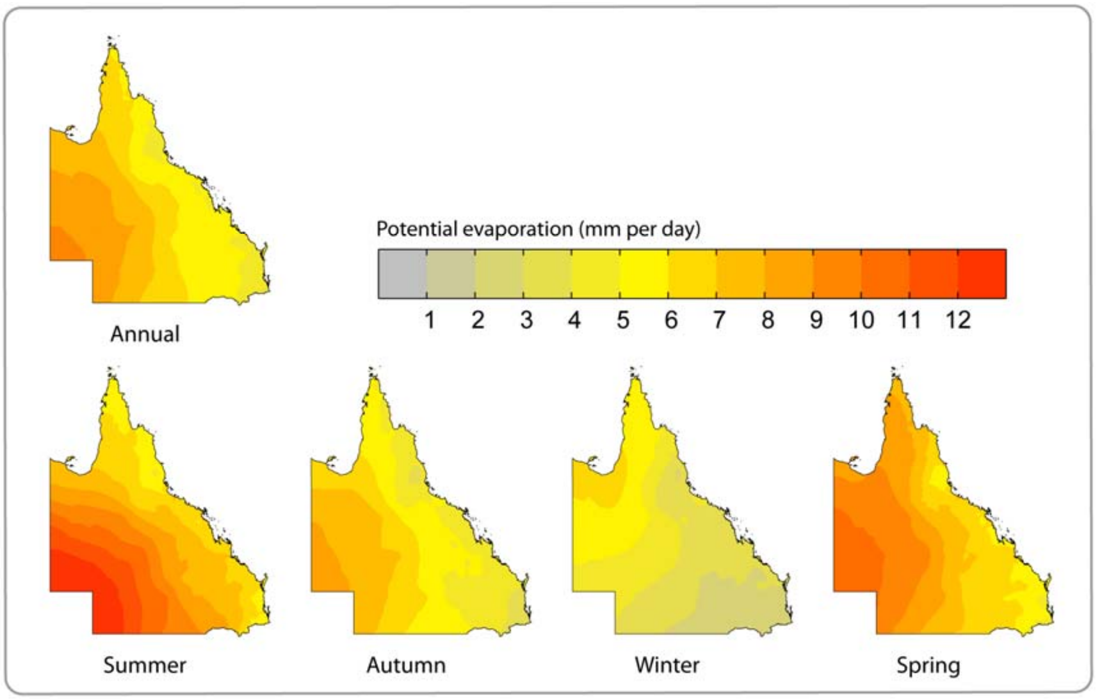

Figure 1-20. Long-term average annual and seasonal potential evaporation (mm per day) during the 1975–2007 period for Queensland. Data source: SILO 2008.

The datasets used to represent potential evaporation, including pan evaporation (Jovanovic et al. 2008), vapour pressure deficit (Jeffrey et al. 2001) and reference crop evapotranspiration (Fitzmaurice & Beswick 2005), have serious limitations regarding length, quality control and spatial completeness. Such shortcomings limit the accuracy and validity of using observational records to detect trends in evaporation. Nevertheless, trends in annual and seasonal potential evaporation are shown in Figure 1-21. This figure indicates an increasing trend in potential evaporation in southern and central Queensland, and a decreasing trend in northern Queensland. A previous study by Roderick and Farquhar (2004) reported negative pan evaporation trends over Australia as a whole, but the trends were not statistically significant. Further analysis suggests that many of the observed changes are linked to local wind effects caused by changes in the local environment around the observation stations (Nicholls 2006; Rayner et al. 2007).

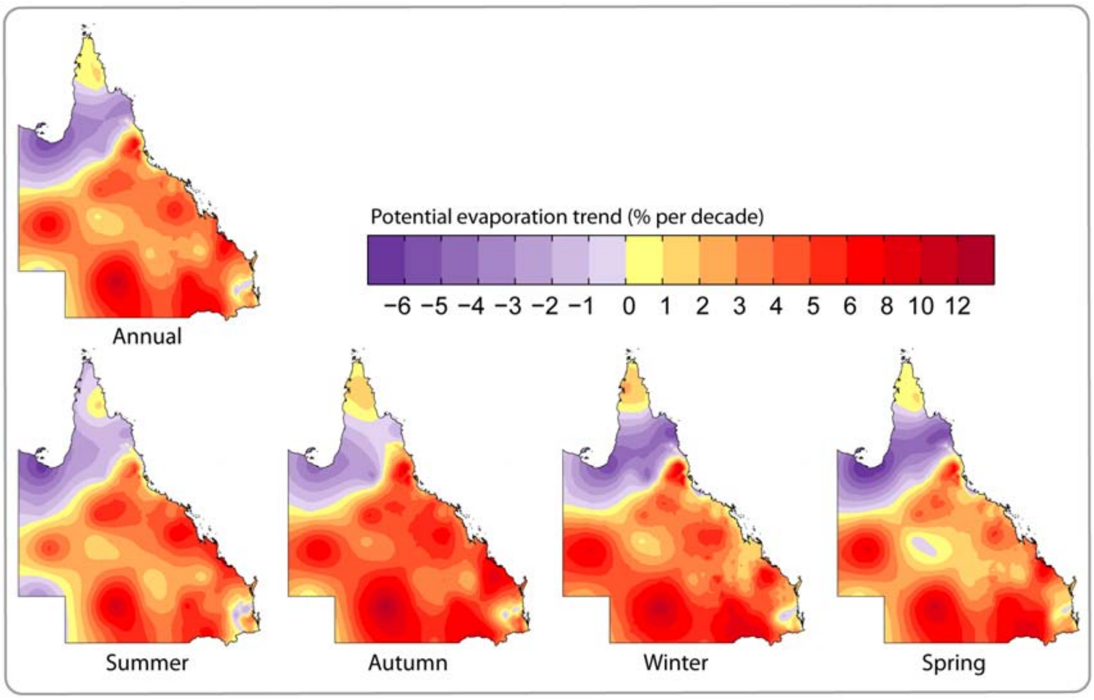

Figure 1-21. Trends (% of mean potential evaporation per decade) in annual and seasonal potential evaporation during the 1975–2007 period for Queensland. Data source: SILO 2008.

1.3 Regional rainfall and temperature extremes

Climate change is expected to have a more significant effect on climatic extremes than on average conditions (Pittock 2003). Furthermore, even relatively minor changes in extreme events can have a significant effect on ecosystems and agricultural production. For example, a warming trend can reduce the number of frost days during winter (impacting agriculture), and trigger the migration of plants and animals to cooler regions (impacting ecosystems).

An analysis of rainfall and temperature extremes is presented below for a number of locations throughout the Wide Bay-Burnett region. In this report, rainfall and temperature extremes are examined using the definitions outlined in Table 1-3.

Table 1-3. Definitions of rainfall and temperature extremes.

Term	Definition	Figures where used
Hot days	Annual count of days with temperature > 35°C	Figures 1-23 and 1-24
Rain days	Annual count of days with daily rainfall ≥ 1 mm	Figures 1-25 to 1-31
Rainfall intensity	Annual total rainfall divided by the number of rain days (daily rainfall ≥ 1 mm)	Figures 1-25 to 1-31

The meteorological data used in this analysis has been drawn from the Bureau's High Quality station dataset and from the SILO database. Figure 1-22 shows the station names, types and locations.

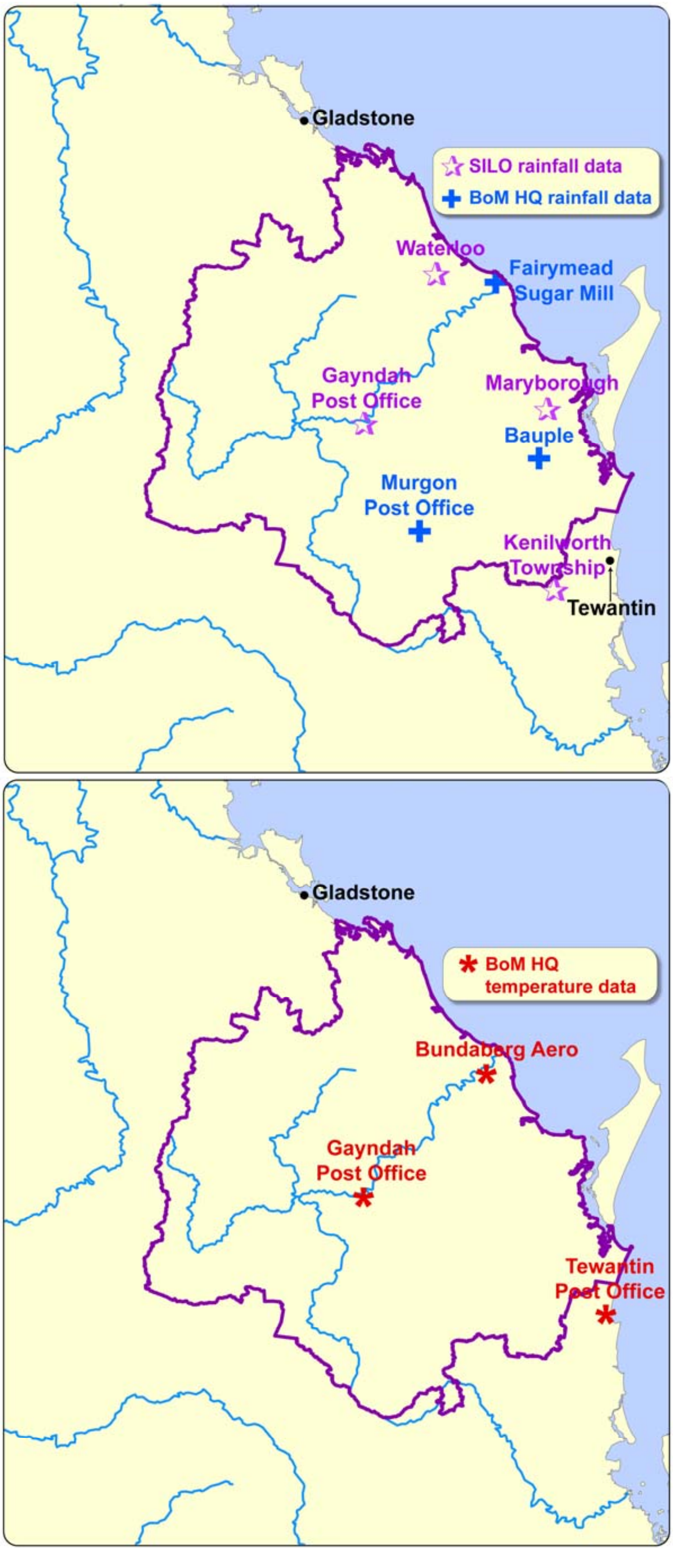

Figure 1-22. Location of the meteorological stations used in the analysis of rainfall (top) and temperature (bottom) extremes in the Wide Bay-Burnett region.

1.3.1 Temperature extremes

Observational records for Bundaberg (Figure 1-23) and Gayndah (Figure 1-24) indicate an upward trend in the number of days each year in which the temperature has exceeded 35°C. Gayndah, which is located inland, has experienced a greater increase in hot days than Bundaberg, which is located on the coast. The coastal location may be less prone to temperature extremes as the thermal mass of the nearby ocean can effectively modulate temperature fluctuations. Such observations are supported by the work of Alexander et al. (2007).

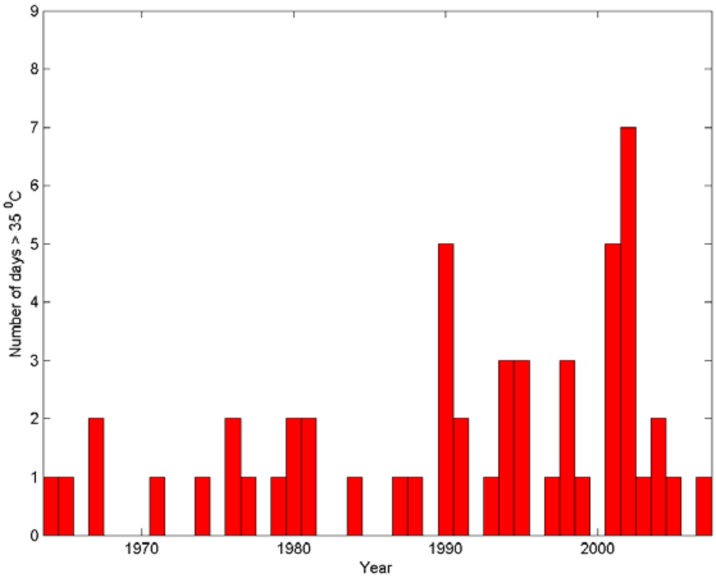

Figure 1-23. Number of days (per year) with maximum temperature exceeding 35°C for Bundaberg. Data source: Australian Bureau of Meteorology 2008. *Note: missing bars denote years in which the 35°C threshold was not exceeded.*

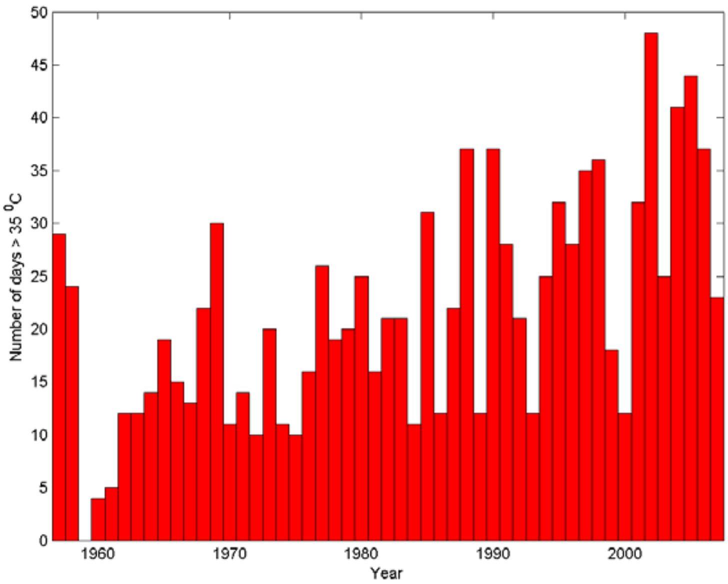

Figure 1-24. Number of days (per year) with maximum temperature exceeding 35°C for Gayndah. Data source: Australian Bureau of Meteorology 2008. *Note: missing bars denote years in which the 35°C threshold was not exceeded.*

1.3.2 Rainfall extremes

Rainfall data at selected sites in the Wide Bay-Burnett region were used to calculate annual rainfall totals, number of rain days and rainfall intensity using the definitions described in Table 1-3. The stations for which data was analysed included the BOM High Quality stations of Bauple, Fairymead and Murgon and the SILO stations of Gayndah, Kenilworth, Maryborough and Waterloo. The results of this analysis are shown in Figures 1-25 to Figure 1-31. Trends for the rainfall indices (see Table 1-3) were also calculated and plotted as a thick black line on each graph, with the numerical value of the calculated trend shown in the top right corner. While the observational data records indicate a general decline in both rainfall amount and rain intensity, it should be noted that there is considerable variation in the observed trends at the various locations. For further information see Alexander et al. (2007) and Suppiah & Hennessy (1998).

The observed trends over the period 1910–2007 are as follows:

Annual rainfall: Total annual rainfall declined at all seven sites. The smallest decline was 8.8 mm per decade (Murgon) and the largest was 29.9 mm per decade (Waterloo).

Rain days: The number of rain days each year decreased at all locations except Fairymead and Kenilworth (which recorded increases of 1.1 and 0.1 days per decade, respectively). The decline in rain days at all other stations ranged between 0.1 (Maryborough) and 1.0 (Waterloo) days per decade.

Rainfall intensity: The intensity of rainfall declined at all stations except Murgon, where there was a negligible (0.01 mm per day per decade) increase. The decline in rain intensity at these stations ranged between 0.1 mm (Gayndah) and 0.5 mm (Fairymead) per day per decade.

Note: The nominal analysis period for the investigation of rainfall extremes was 1910–2007. However due to dataset limitations, analysis periods of shorter duration were used at some locations (Bauple; Figure 1-25 and Waterloo; Figure 1-31).

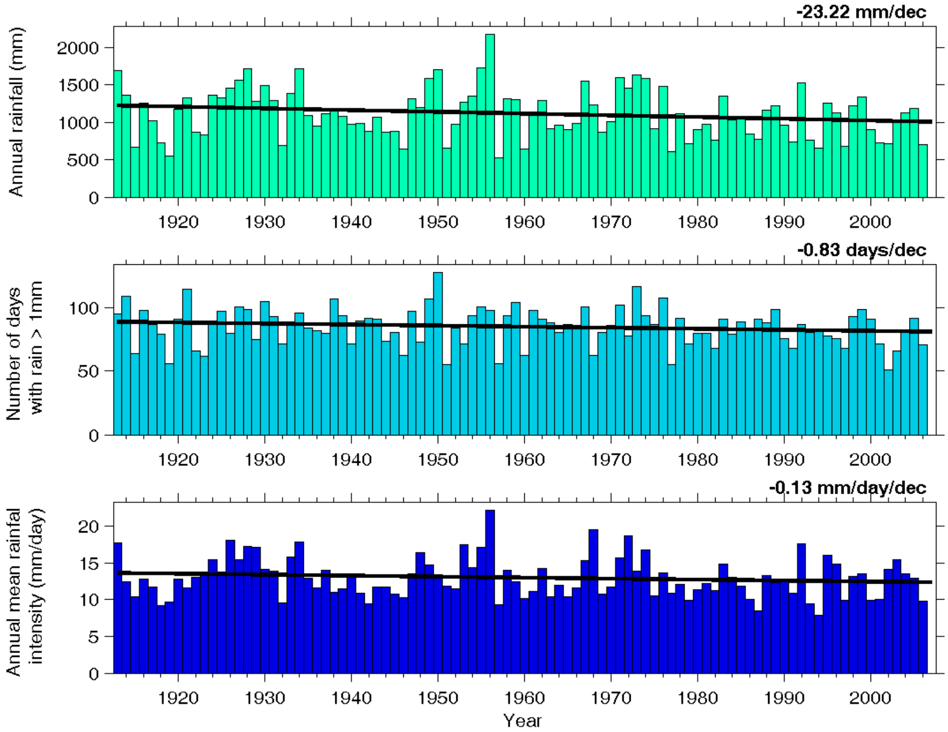

Figure 1-25. Annual rainfall (top), annual number of rain days (middle) and annual mean rainfall intensity (bottom) for Bauple. Data source: Australian Bureau of Meteorology 2008.

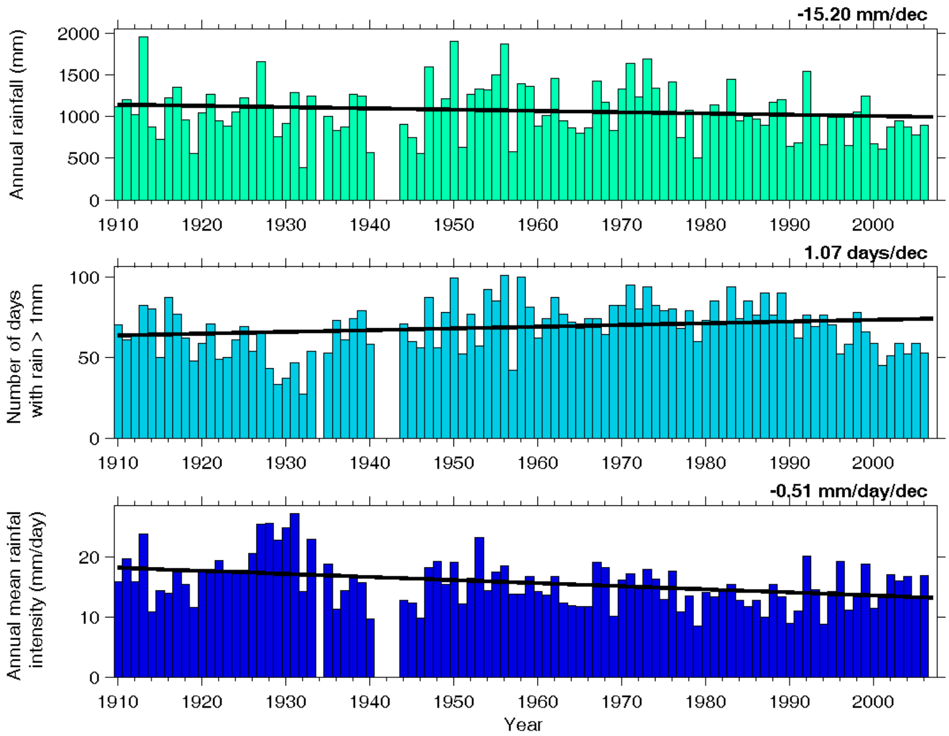

Figure 1-26. Annual rainfall (top), annual number of rain days (middle) and annual mean rainfall intensity (bottom) for Fairymead. Data source: Australian Bureau of Meteorology 2008. *Note: missing bars denote years for which insufficient data were available.*

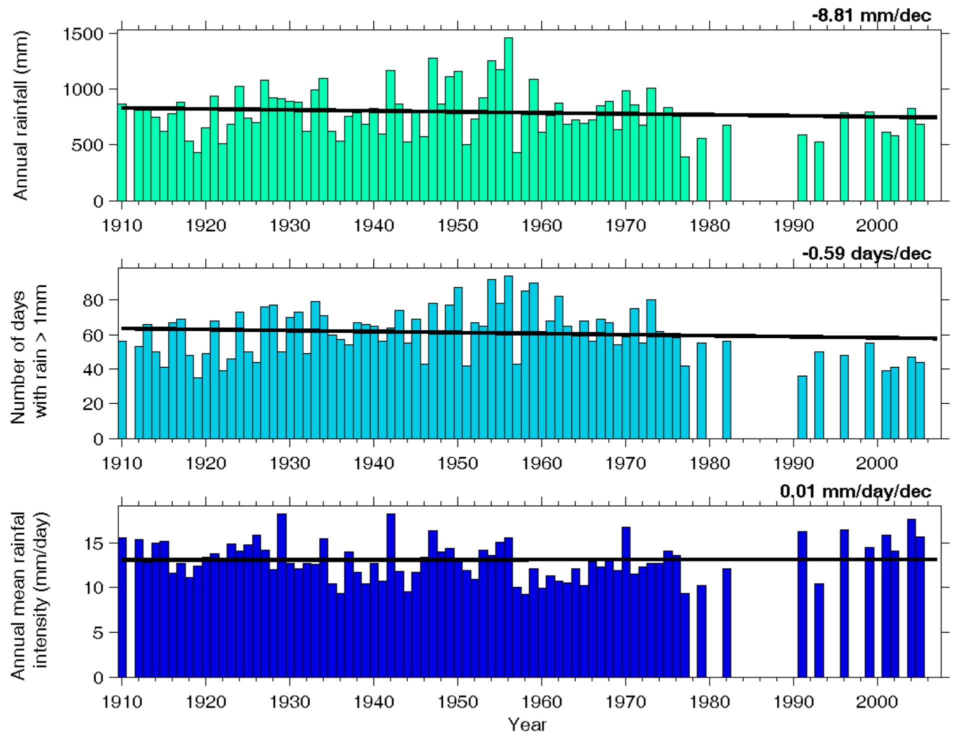

Figure 1-27. Annual rainfall (top), annual number of rain days (middle) and annual mean rainfall intensity (bottom) for Murgon. Data source: Australian Bureau of Meteorology 2008. *Note: missing bars denote years for which insufficient data were available.*

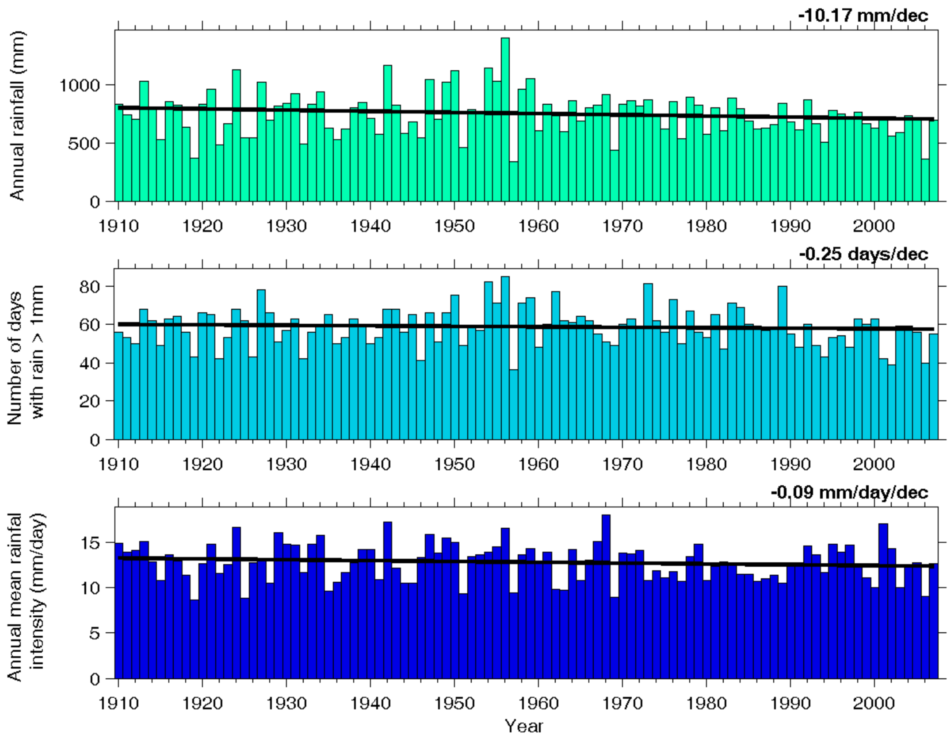

Figure 1-28. Annual rainfall (top), annual number of rain days (middle) and annual mean rainfall intensity (bottom) for Gayndah. Data source: SILO 2008.

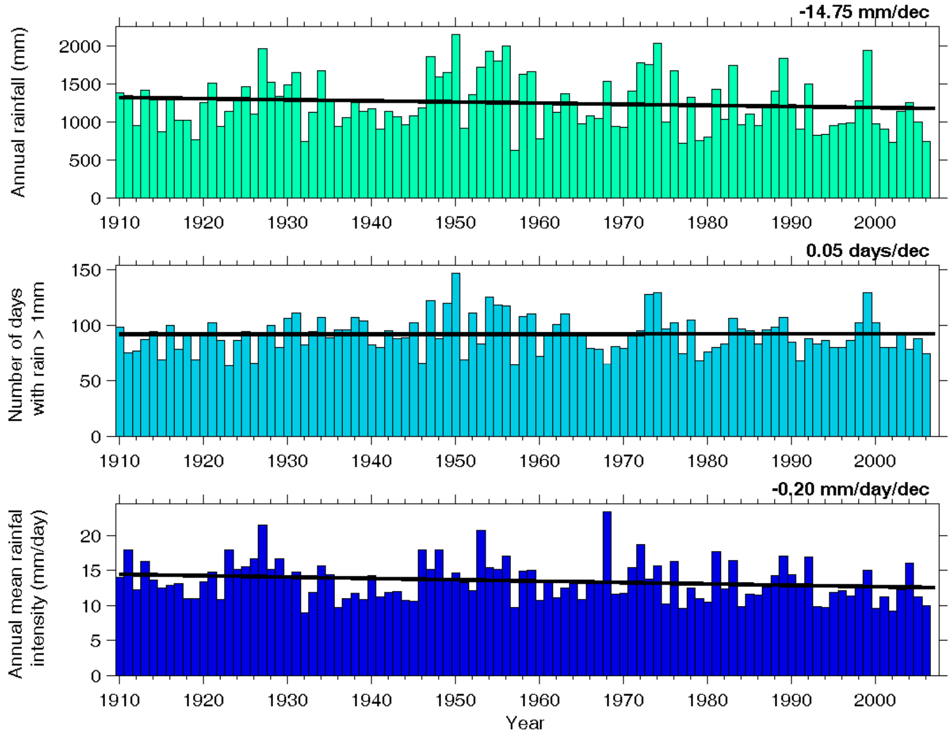

Figure 1-29. Annual rainfall (top), annual number of rain days (middle) and annual mean rainfall intensity (bottom) for Kenilworth. Data source: SILO 2008. Note: missing bars denote years for which insufficient data were available.

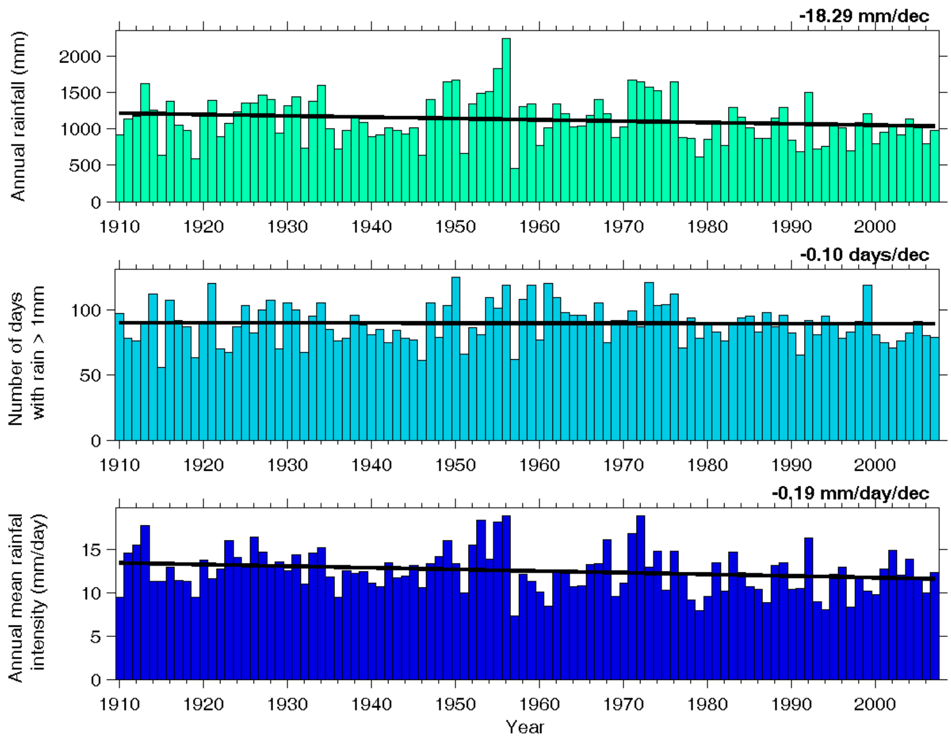

Figure 1-30. Annual rainfall (top), annual number of rain days (middle) and annual mean rainfall intensity (bottom) for Maryborough. Data source: SILO 2008.

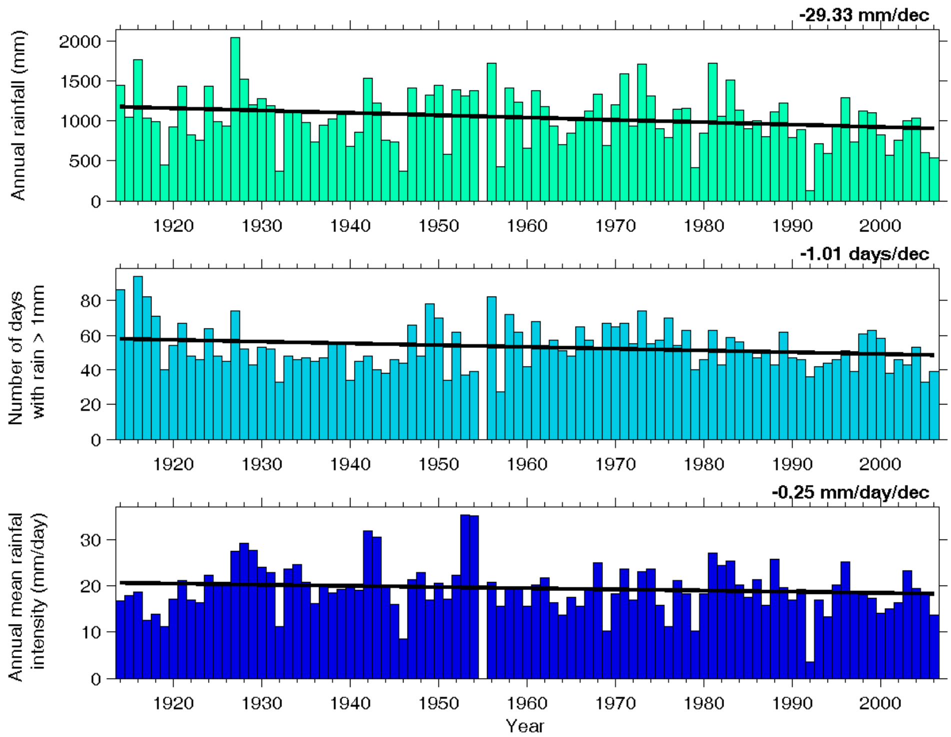

Figure 1-31. Annual rainfall (top), annual number of rain days (middle) and annual mean rainfall intensity (bottom) for Waterloo. Data source: SILO 2008. Note: missing bars denote years for which insufficient data were available.

1.3.3 Drought

Drought is a recurring feature of Queensland's climate. The extent and impact of droughts in Queensland is shown in Figure 1-32 and the trends are summarised in Table 1-4. The definition of drought used here is based on a five-year (April-March) rainfall deficiency with varying levels of severity as outlined in Table 1-4.

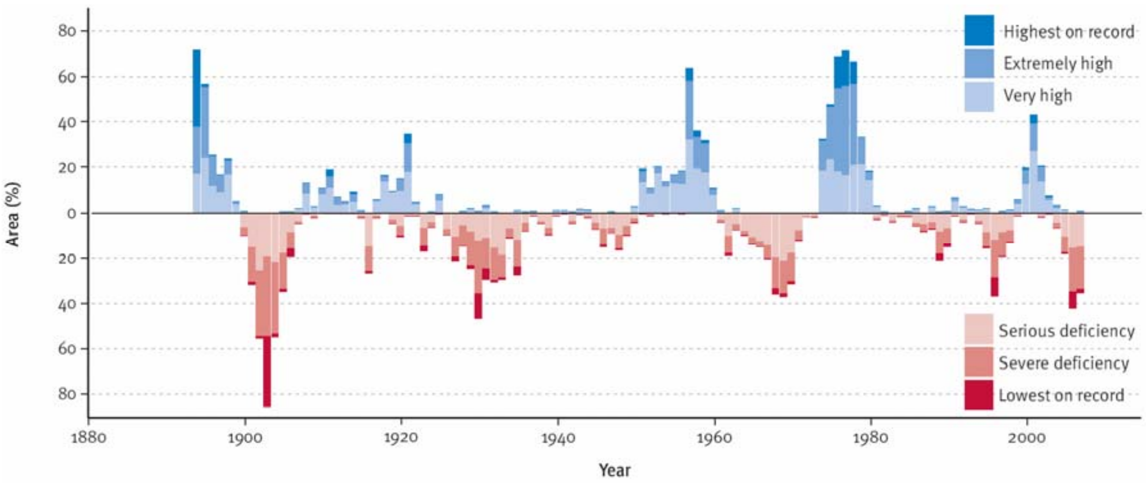

Figure 1-32. Percentage of Queensland with five-year rainfall classified as highest on record, extremely high (> percentile 95), very high (> percentile 90), serious deficiency (< percentile 10), severe deficiency (< percentile 5) and lowest on record. Each bar represents the five-year (April–March) rainfall relative to the highest and lowest on record during the 1897–2007 period e.g. the last bar corresponds to rainfall deficiencies from April 2002 to March 2007. Data source: Rayner et al. 2007.

During the 1897–2007 period there was a statistically significant decline in the area impacted by the two most severe categories of drought; however during the 1950–2007 period there was a statistically significant increase for these same categories (Table 1-4). These findings are reflected in the map of rainfall trends (Figure 1-13) which shows that rainfall increased over most of Queensland during the 1897–2007 period, but decreased during the 1950–2007 period. Similarly, time-series annual rainfall data for both Australia and Queensland (see Appendix B; Figures B2 to B7) show that rainfall was lower in the first half of the last century than in the latter half.

Table 1-4. Trend in the severity and spatial extent of droughts during the 1897–2007 period for Queensland. The significance level indicates the probability that the trend is non-zero. Data source: Rayner et al. 2007.

Five-year rainfall deficiency	1897–2007		1950–2007	
	Trend (% area/decade)	Significance level	Trend (% area/decade)	Significance level
Serious deficiency (< percentile 10)	-0.07	Not sig.	0.32	Not sig.
Severe deficiency (< percentile 5)	-0.31	90%	0.93	95%
Lowest on record	-0.20	85%	0.36	90%

When interpreting these datasets one should be aware of two key issues. Firstly, the perception of drought can be strongly influenced by the length of the available data records; and secondly, the analysis of trends requires careful consideration of the analysis periods. For example, rainfall was low throughout the first half of last century associated with the severity and spatial extent of the “Federation drought” of 1895–1902, while rainfall throughout the latter half was high due to extended wet periods throughout the 1950s and 1970s. While rainfall records may indicate that the first half of last century was drier than the latter half, the impact of recent droughts on water supplies has been more severe than earlier droughts due to the increased demand for water, driven mainly by the increasing population (QCCCE 2007).

The longest period of rainfall deficiency across Queensland was from the late 1920s through to the 1940s. Towards the end of this period (1938) the Queensland population was just under 1 million, whereas the population at the end of the recent 2002–2007 drought was approximately 4.3 million (ABS 2007). Other factors, such as increased land clearing and increasing temperature in recent decades, may also have influenced the impact of recent droughts.

While land clearing may increase surface run-off and thereby increase catchment inflows, soil moisture content is reduced and subsequently drives additional demand for irrigation water provided by catchments (McAlpine et al. 2007). Furthermore, droughts have become hotter. A study of droughts in the Murray-Darling Basin showed that increased temperatures associated with global warming have increased the severity of droughts by increasing evaporative demand (Nicholls 2004).

1.3.4 Cyclones

Tropical cyclones in the Queensland region develop during the period from November to April and predominantly impact on the coastal regions of northern Queensland. Although the Wide Bay-Burnett region is further south than the main area of tropical cyclone development and occurrence, tropical cyclones can affect the region either directly or indirectly through associated weather patterns.

The Bureau of Meteorology recently produced a High Quality data set of Australian tropical cyclones (B. Trewin [Bureau of Meteorology] 2008, pers. comm.). Construction and availability of the dataset has overcome previous difficulties in identifying trends in tropical cyclones due to the poor quality of the data, the definition used for classifying a tropical cyclone and the effect of introducing satellite technology. Analysis of the dataset indicates a decrease in the total number of tropical cyclones occurring along the Queensland coast, especially in recent decades (Figure 1-33). The decrease is linked to increasing numbers of El Niño events (Nicholls et al 1998).

While the total number of cyclones may have declined in recent decades, the number of severe cyclones (defined as having a minimum central pressure less than 970 hPa) has not (CSIRO & BOM 2007).

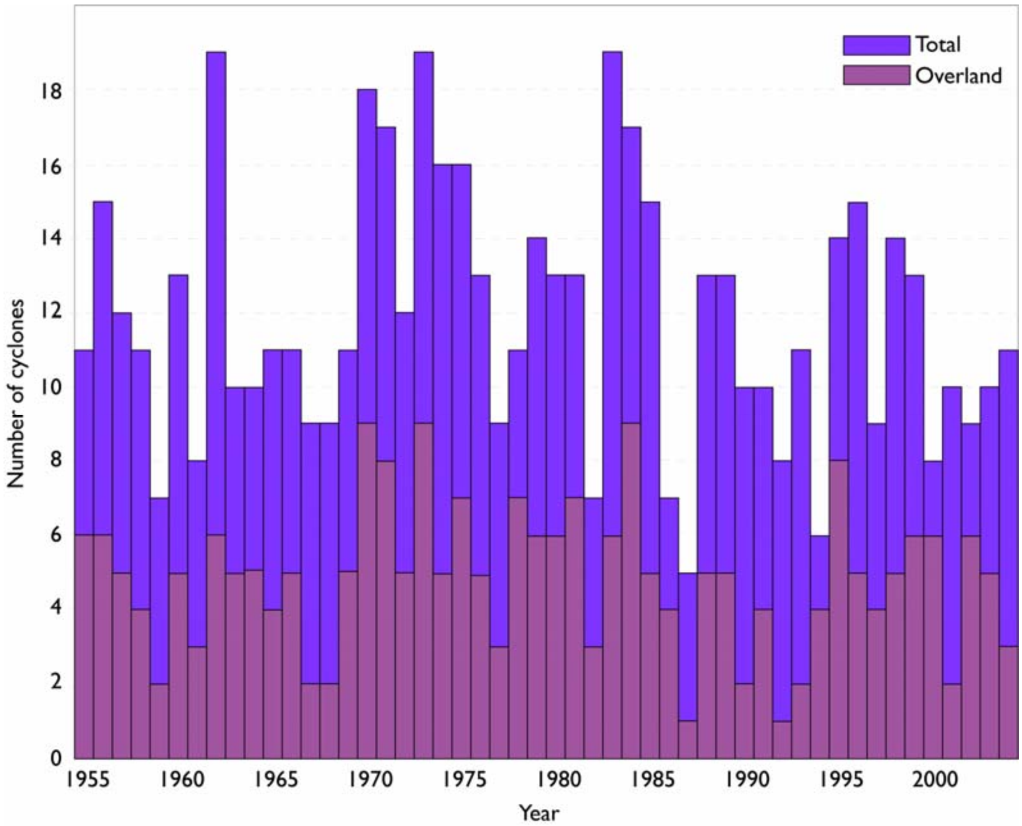

Figure 1-33. The total number of tropical cyclones during the 1955–2004 period in the Queensland region. The subset which crossed overland is also shown. Data source: Australian Bureau of Meteorology 2008.

1.4 Summary

Observational climate records for the Wide Bay-Burnett region show that while the climate did not change substantially in the first half of the last century, strong and spatially coherent trends have emerged during the 1950–2007 period. These include:

- Annual mean surface temperatures have increased by about 0.24°C per decade in the Wide Bay-Burnett region, which is stronger than the Australian annual average increase of 0.14°C per decade. Maximum temperatures are increasing more rapidly than minimum temperatures.

- Annual average rainfall in the Wide Bay-Burnett region decreased by approximately 47 mm per decade, which equates to a decline of approximately 5% of the 1950–2007 annual mean, per decade. The observed trend in the Wide Bay-Burnett region is considerably stronger than the trend for the whole of Queensland, which experienced an average decline of 14 mm per decade, or approximately 2% of the 1950–2007 annual mean, per decade.

- The Wide Bay-Burnett region experienced an increase in potential evaporation of approximately 3% of the annual mean per decade during the 1975–2007 period. The increasing potential evaporation trend for the Wide Bay-Burnett region is slightly lower than that for the rest of southern and central Queensland. There is some uncertainty associated with potential evaporation trends due to the observational datasets having limitations regarding length, quality control and spatial completeness.

- The frequency of hot days (temperature exceeding 35°C) has increased in recent decades at both Bundaberg and Gayndah.

- For a majority of the rainfall stations analysed in the Wide Bay-Burnett region, there has been a weak decline in the number of rain days. Rainfall intensity declined at all stations except Murgon. The observed decline ranged between 0.1 and 0.5 mm/day per decade during the 1910–2007 period.

- There has been a statistically significant increase in the severity of droughts across Queensland during the 1950–2007 period. In addition, recent droughts have been particularly severe in terms of their impact on water supply due to both higher temperatures (leading to higher evaporative demand) and increased water demand.

It is important to appreciate that trends in the historical record may, in part, be manifestations of ongoing ‘climate change’, but could also be due to natural variability occurring on annual to decadal time-scales.

2. Climate change projections

2.1 Climate change science

2.1.1 Introduction

Climate varies on interannual, decadal and longer timescales. The climate system evolves in response to both natural and anthropogenic forcings. Natural forcings include solar and volcanic activity as well as climate processes internal to the Earth's climate system. Anthropogenic forcings are those caused by humans and include, among others, changes in atmospheric concentration of greenhouse gases, aerosols, stratospheric ozone depletion, and land cover change.

Greenhouse gases (GHGs) and aerosols affect the energy balance of the climate system. Aerosols can cool the atmosphere by reflecting incoming solar (short-wave) radiation, and GHGs can warm the atmosphere by trapping outgoing infrared (long-wave) radiation. The primary (most abundant and longest lived) greenhouse gases are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The concentrations of these gases began to increase with the onset of the industrial revolution in the mid-1700s, and increased rapidly throughout the 20th Century. Figure 2-1 shows the concentrations of the primary GHGs during the last 2,000 years. The increase in the abundance of man-made GHGs and aerosols in the Earth's atmosphere is now believed to have contributed to an overall warming of the climate system (IPCC 2007a).

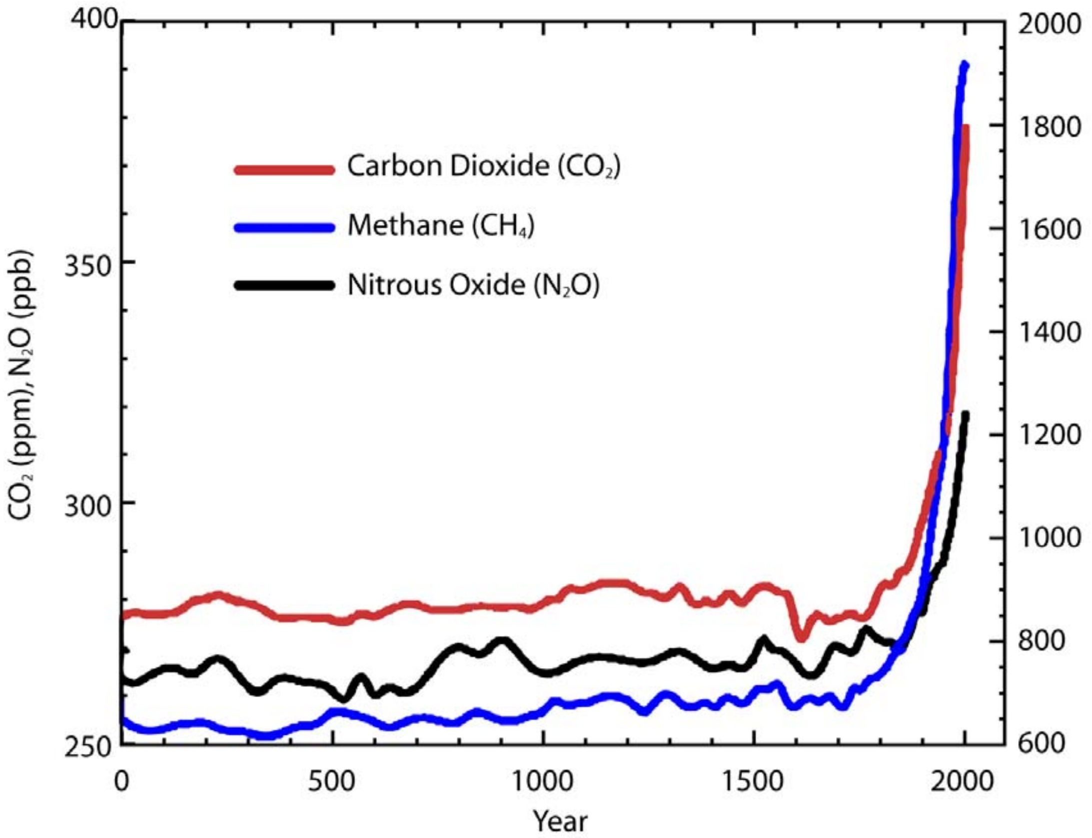

Figure 2-1. Atmospheric concentrations of the primary greenhouse gases during the past 2000 years. Source: IPCC 2007a.

Halocarbons are another important class of GHGs associated with ozone depletion. While only present in relatively small concentrations, they are powerful greenhouse gases and are known to cause the catalytic destruction of stratospheric ozone. Chlorofluorocarbons are an important class of halocarbons, and their release into the atmosphere has been reduced in recent decades as a result of international regulations aimed at protecting the ozone layer.

Studies based on climate models have shown that the observed rise in temperature throughout the 20th Century can only be explained if anthropogenic forcings are taken into account (c.f. IPCC 2007b; Suppiah et al. 2007). The global mean temperature obtained from multi-model simulations (thick red line; Figure 2-2a) effectively tracks the observed global mean temperature (thick black line; Figure 2-2a) when both natural and anthropogenic forcings are included. This is not the case when anthropogenic forcings are excluded (Figure 2-2b).

2.1.2 Key uncertainties in climate change science

Modelling the Earth's climate system is scientifically and computationally challenging. The research community is actively working to resolve technical limitations, such as: the difficulties associated with modelling convection mechanisms; feedback processes (such as the impact of melting snow and ice on surface albedo) are not well understood; nor is the sensitivity of the climate system to changes in greenhouse gas concentrations.

In addition to the technical challenges, there is still considerable difficulty in predicting societal development over the coming decades, and in particular, anthropogenic activities which affect the climate system, such as land clearing. One of the primary sources of uncertainty associated with future climate change projections is the estimated composition of the atmosphere, due to the uncertainty surrounding future anthropogenic emissions of GHGs and aerosols.

Emission profiles can change relatively rapidly in response to regulation, economic pressure and emerging technologies. The Intergovernmental Panel on Climate Change (IPCC) has developed a range of scenarios under different storylines which attempt to forecast societal and technological development and the resulting changes in GHGs. These scenarios are explained in the following section.

2.1.3 Emissions scenarios

In 1996, the IPCC commissioned a *Special Report on Emissions Scenario*s (known as SRES). The SRES report describes six primary scenarios and a family of secondary scenarios, which were developed to facilitate economic assessment of the impact of climate change and climate modelling underpinning IPCC climate change assessment reports. The scenarios provide projections of GHG emissions resulting from human activities such as energy generation, transport, agriculture, land clearing, industrial processes and waste. The emission profiles of the six primary SRES scenarios are shown in Figure 2-3. Two other scenarios are also presented which show how global emissions need to be reduced over the coming decades in order to stabilise GHG concentrations at either 450ppm or 650ppm at the end of the 21st century. Actual global emissions are also shown, to enable comparison of the historical emission profile with the SRES scenarios.

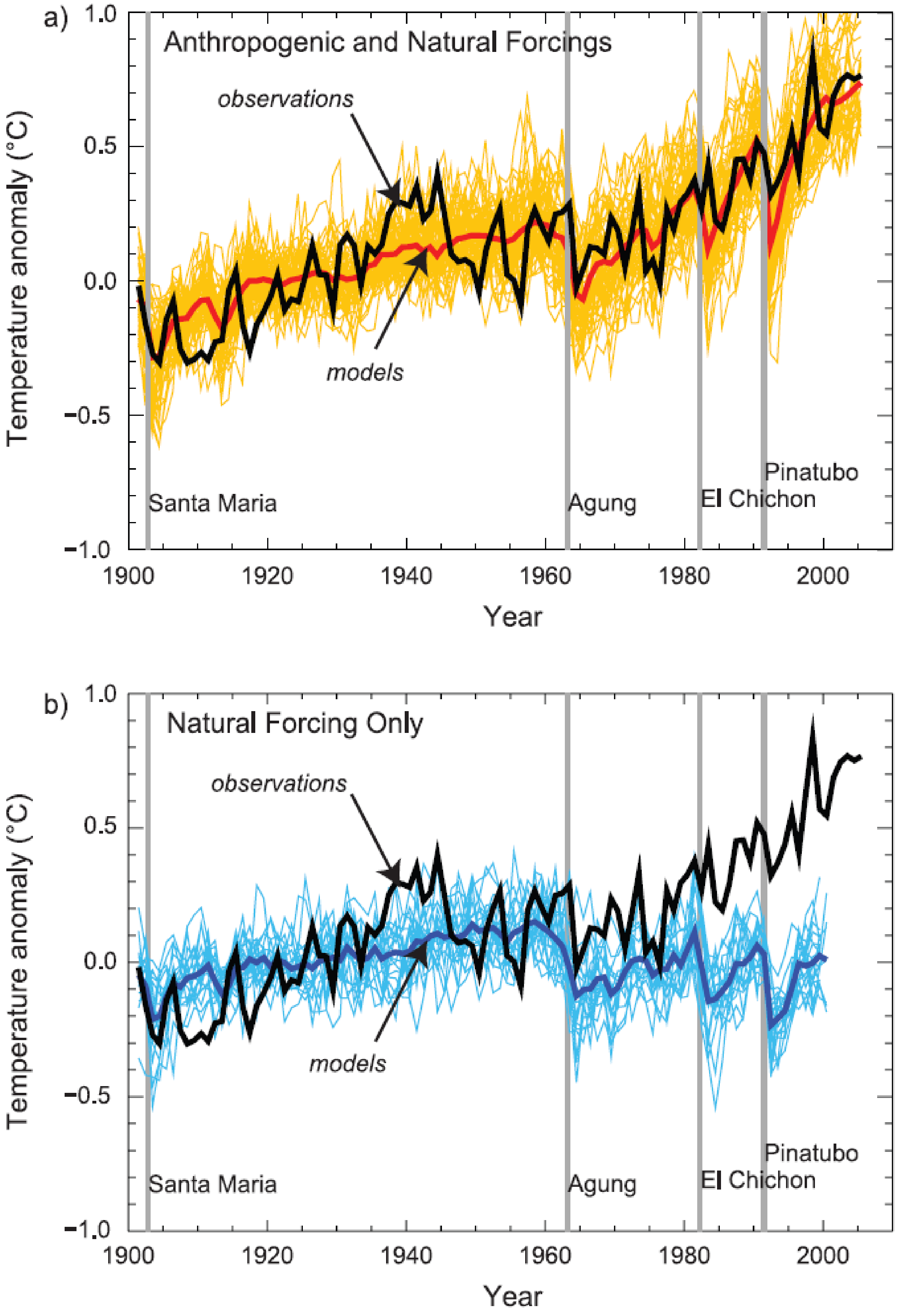

Figure 2-2. Comparison of the observed and simulated global mean surface temperature anomalies using (a) both natural and anthropogenic forcings; and (b) natural forcings only. Observed temperature is indicated by thick black lines, individual simulations by thin orange (a) and blue (b) lines, and the multi-model mean by thick red (a) and blue (b) lines. Vertical grey lines indicate the timing of major volcanic events. Source: IPCC 2007b.

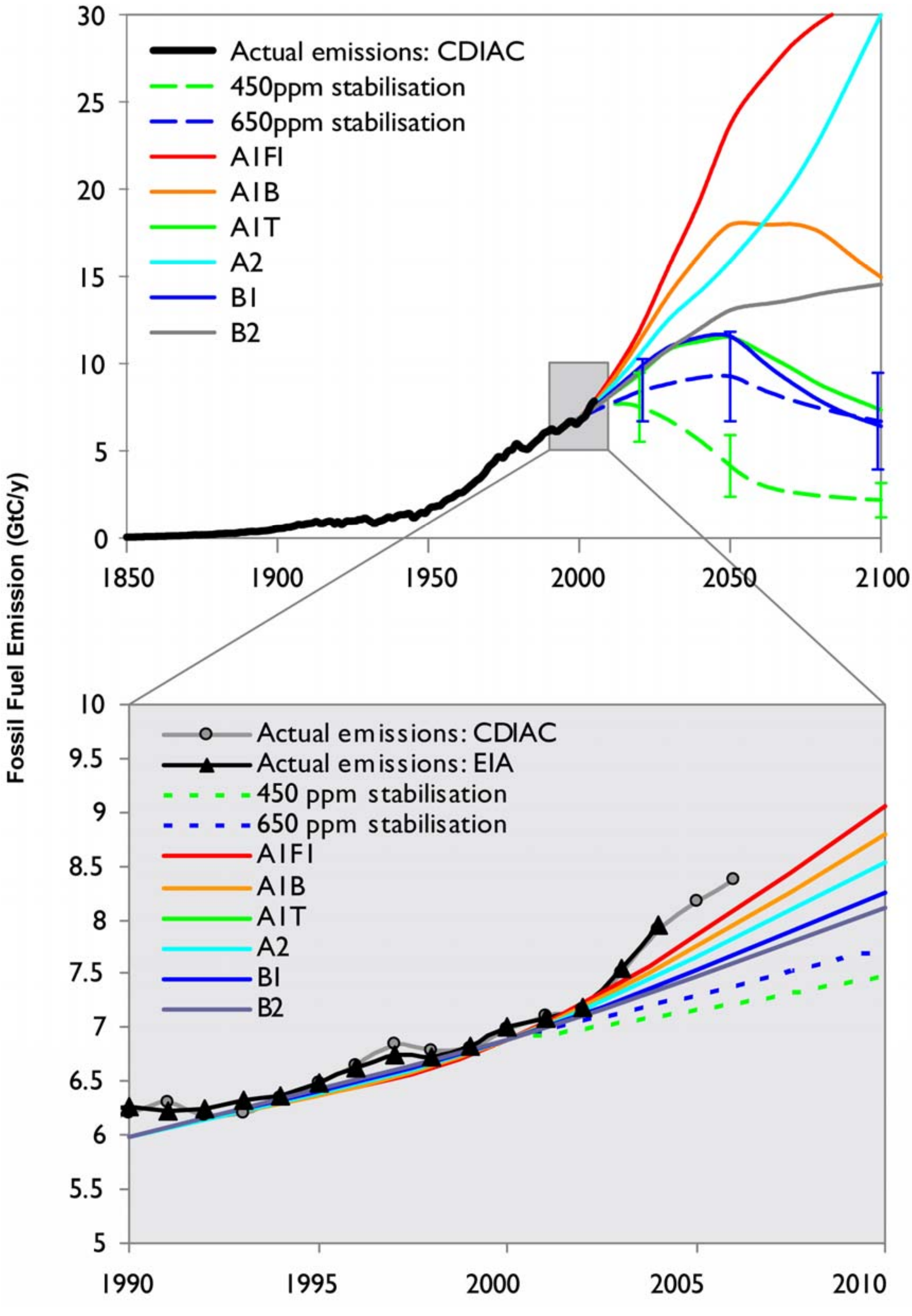

Figure 2-3. Comparison of historical greenhouse gas emissions with selected SRES emissions scenarios (Gigatonnes of carbon per year). Source: Raupach et al. 2007.

In this chapter we present climate change projections (CSIRO & BOM 2007) for the WBB region based on the A1FI and A1B scenarios. The A1FI scenario assumes a high reliance on fossil fuels, while the A1B scenario assumes a balance of fossil and non-fossil technologies (IPCC 2007a). These scenarios were chosen as they track actual emissions more closely than the other major scenarios. However it should be noted that in recent decades actual emissions have been higher than those projected by both the A1FI and A1B scenarios (see Fig 2-3). If actual emissions continue to track higher than those predicted under the A1FI scenario, then the projections provided in this report may underestimate the impact of climate change. The climate change projections are provided as the average of 10-year periods centred around 2030, 2050 and 2070.

There is relatively little difference between the A1B and A1FI emissions scenarios for 2030 (see Figure 2-3). Consequently, there is little difference between the projections for 2030 developed under the two scenarios and therefore climate change projections for 2030 are only shown for the A1B scenario. Beyond 2030, the emission trajectories of the A1FI and A1B scenarios diverge to such an extent that by 2050 there is a significant difference in the temperature projections modelled using the two different scenarios (CSIRO & BOM 2007). Consequently, climate change projections for 2050 and 2070 are presented based upon both the A1FI and A1B scenarios.

Emissions scenarios are difficult to develop due to the intractable problems encountered when attempting to forecast economic, political, technological and societal developments. As a result, there is a high degree of uncertainty associated with future emission pathways, especially beyond 2050 (Garnaut 2008).

2.2 Queensland Government policy on climate change

The Queensland Government is committed to responding to climate change and playing a part in meeting a national target of 60 per cent reduction in greenhouse gas emissions by 2050 (NRW 2007a).

ClimateSmart 2050 (NRW 2007a) is Queensland's climate change response strategy. It establishes Queensland's long-term climate change goals and provides a platform for government, community and industry to move to a low-carbon future.

ClimateSmart 2050 outlines a comprehensive suite of initiatives covering the community, energy, transport, primary and other industries, and the planning and building sectors. It represents a total initial investment of $1.4 billion, including $844 million by the Queensland Government. *ClimateSmart 2050* is currently being reviewed to take account of the latest scientific assessments, including national and international developments in the area of climate change. The review aims to ensure that Queensland has an up-to-date and comprehensive climate change strategy that builds upon the measures adopted in *ClimateSmart 2050*, and will outline new measures that will contribute to achieving our emissions reduction and adaptation objectives.

In addition to the range of climate change mitigation measures currently being undertaken, work is also underway to prepare Queensland for the likely impacts of climate change. *ClimateSmart Adaptation 2007–12* (NRW 2007b) is the Queensland Government's action plan to enhance Queensland's resilience to the impacts of climate change. Through the plan, both government and private enterprise are encouraged to consider the potential effects of climate change when they make decisions about:

- water planning and services
- agriculture
- human settlement
- natural environment and landscape
- emergency services and human health, and
- tourism, business and industry.

Action 15 of the plan focuses on water planning, requiring the integration of climate change projections, and considerations of their likely consequences, into water resource plans.

2.3 Climate change projections for the Wide Bay-Burnett region

2.3.1 Overview

The Climate Change in Australia report was prepared by the CSIRO and the Bureau of Meteorology (CSIRO & BOM 2007). The report describes a set of projections for climate change in Australia that is based on the results from 23 climate models which contributed to the Fourth Assessment Report (4AR) of the IPCC (IPCC 2007a). The report presents climate change projections derived using a new methodology that enables the characterisation of projections as Probability Distribution Functions (PDFs), based on data from a range of models (Watterson et al. 2007; Hennessy et al. 2007a). Probability distributions for individual model results were weighted in accordance with their ability to reproduce features of Australia's present-day climate. The weighted results were then combined to form a single PDF of projected changes at each location for each variable of interest e.g. rainfall. These changes were then expressed per degree of mean global warming and estimates of the 10^{th}, 50^{th} (median), and 90^{th} percentile values were calculated. The 50^{th} percentile provides the best estimate of projected change for a given variable, and the 10^{th} and 90^{th} percentiles indicate the range of uncertainty. The total range of projected change for a given year is derived by multiplying the PDF for the local response by the range of global warming across all emissions scenarios for that year, as recommended by the IPCC (see CSIRO & BOM 2007, Table 4.3, page 46).

In this chapter we present climate change projections based on the aforementioned datasets prepared by the CSIRO and the Bureau of Meteorology (CSIRO & BOM, 2007). The projection data was derived from datasets which contained output from climate models with horizontal resolutions ranging from about 100km to 300km. These datasets were interpolated to a common grid of 1^{o} x 1^{o} (approximately 100km x 100km). The projections for temperature and rainfall were computed using the output from all 23 climate models included in the IPCC's 4AR. Computation of projections for potential evapotranspiration requires data for air temperature, relative humidity and downward solar radiation at 2 meters above the surface. Only 14 of the 23 4AR models had the requisite datasets, and consequently the potential evapotranspiration projections in this chapter were derived from 14 models, not the full set of 23 models.

Climate model projections are usually specified as changes from a model-generated base climatology, as model-simulated climate should not be directly compared to observational datasets for two reasons. Firstly, model outputs may be subject to systematic biases; and secondly, the observed and simulated long-term climate signals (such as inter-decadal oscillations) may not be synchronised. To overcome these difficulties, climate models are first used to simulate the climate over the historical period and then used to project the future climate. Climate change projections are then derived by computing the change (either relative or absolute) between the simulated average climate for a selected period in the future (typically 20 to 30 years), and the simulated average climate for the historical period. The data from the historical period is used to define the base period which is also typically 20 to 30 years long. The resulting projections (sometimes referred to as *delta* changes) may then be used in conjunction with observational datasets. The climate change projections described in this report were derived using the 1980–1999 base period unless specified otherwise.

To enable the projections to be referenced against historical climate, observational means have been computed using a 30-year base period (1971–2000) as recommended by the World Meteorological Organisation.

It should be noted that the interpretation of climate change projections is relative to the choice of observational base period. As previously noted, the projections contained in this report have been presented relative to the observed climate over the 1971–2000 base period. The analysis of historical datasets in Chapter 1 revealed that there have been significant changes in many key climate components throughout the latter half of the past century. Consequently, the projections presented in this chapter (and Chapter 3) must be interpreted as projected changes relative to a climate which has already undergone significant change in recent decades. However, it should be noted that observational trends and datasets cannot be directly combined with the projections generated by climate models. Aligning observational and climate model datasets is a complex scientific problem, primarily due to the difficulty in: (i) removing the biases in model datasets; and (ii) synchronising the observed and simulated longer term climate signals (such as ENSO).

2.3.2 Climate change projections for Queensland in 2050

In this section we describe projected climate change as a departure from the multi-model mean for the 1980–1999 base period. Median (best estimate) changes in projected annual mean temperature for Queensland range from 1.3°C to 2.0°C under the A1B scenario by 2050 (Figure 2-4). For the A1FI scenario, greater temperature changes are projected with a range of 1.5°C to 2.3°C by 2050. Projected warming is greater for inland regions than coastal regions, under both scenarios. The greatest range of warming is projected for spring with temperature changes of 1.2°C to 2.2°C for the A1B scenario, and 1.4°C to 2.5°C for the A1FI scenario by 2050. The lowest warming is projected for winter, with temperature changes ranging from 1.2°C to 1.8°C for the A1B scenario, and 1.5°C to 2.1°C for the A1FI scenario. The pattern of warming is similar for summer and autumn except that projected temperature changes are greater for inland regions in summer.

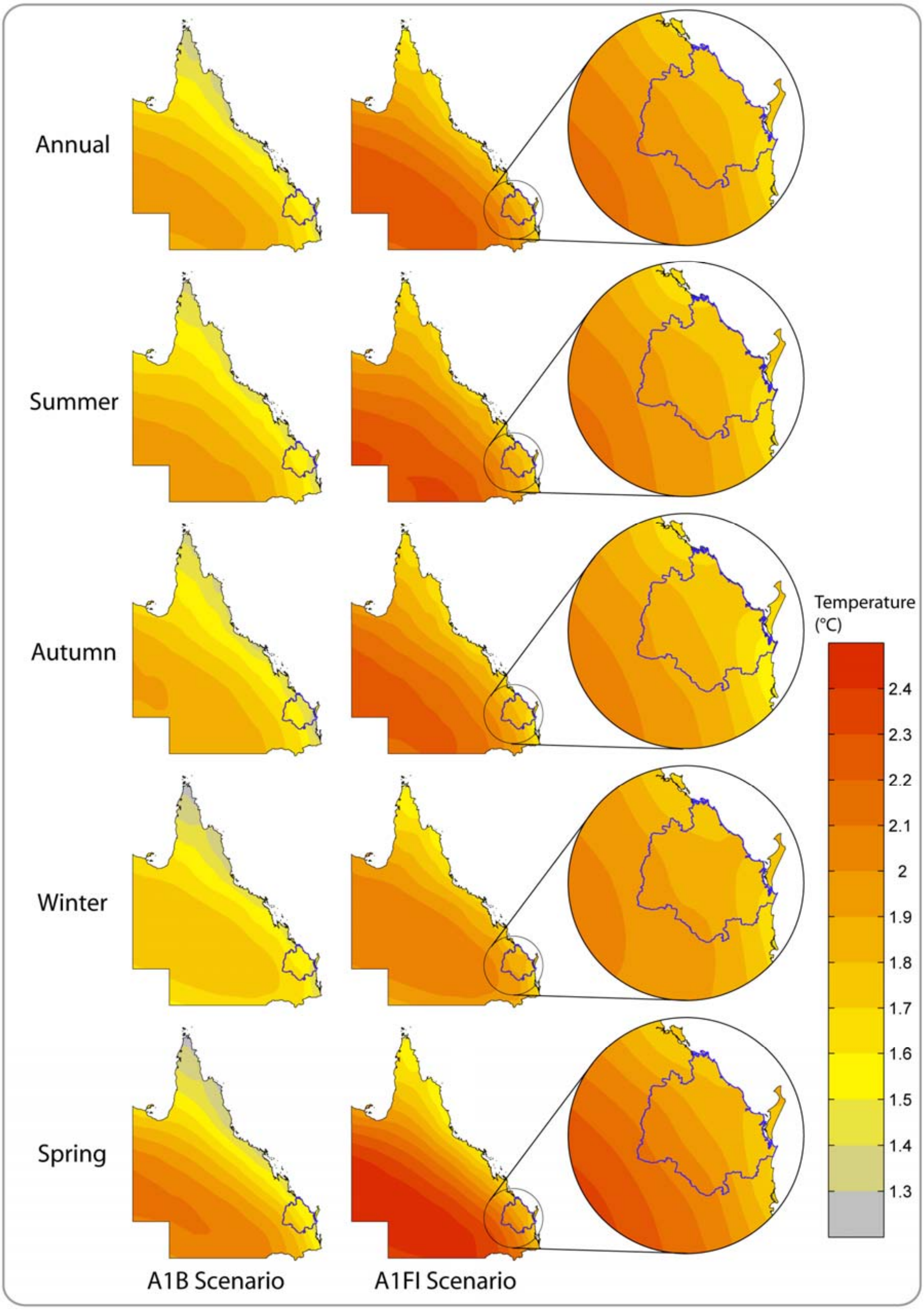

Figure 2-4. Best estimate (median) of projected changes (as absolute changes from the means for the 1980–1999 period) in annual and seasonal mean temperatures (°C) for Queensland by 2050 for the A1B (left column) and A1FI (right column) emissions scenarios. The Wide Bay-Burnett region is enlarged for the A1FI scenario. Data source: CSIRO & BOM 2007.

Median (best estimate) changes in projected annual rainfall for Queensland under the A1B scenario range from -8% to +2% by 2050 (Figure 2-5), with a range of -4% to +2% for northern regions and decreases of -2% to -8% for southern Queensland. For the A1FI scenario, changes for the northern regions of Queensland are similar to those under the A1B scenario, although decreases of 6% to 8% are projected for large regions of southern Queensland by 2050. The largest relative decreases in rainfall are projected for spring (up to 16% under the A1B scenario and up to 18% under the A1FI scenario by 2050), with the reductions for south-west Queensland being the most pronounced. The smallest relative changes are projected for summer, with any increase being relatively small and confined to north-west Queensland and Cape York.

Median (best estimate) changes in projected annual potential evapotranspiration for Queensland range from 3.5% to 6.0% for the A1B scenario by 2050 (Figure 2-6), with the greatest increases projected for the coast (except for Cape York) and smaller increases projected for inland regions. For the A1FI scenario, projected increases are slightly higher with a range of 4.0% to 7.0%. The spatial patterns of change are similar for both emissions scenarios across all seasons, with the greatest increases projected for winter and the smallest increases projected for spring.

2.3.3 Climate change projections for the Wide Bay-Burnett region

Projected changes in temperature, rainfall and potential evapotranspiration for the Wide Bay-Burnett region are shown in Table 2-1. The data presented includes the 50th (median), 10th and 90th percentile values from the entire range of models included in the IPCC's 4AR (with the exception of potential evapotranspiration which used a subset of 14 models). The values represent spatial averages over the grid cells spanning the Wide Bay-Burnett region.

The input datasets were provided by the CSIRO, and are consistent with the projections in the recent Climate Change in Australia report (CSIRO & BOM 2007). The table contains projections for the years 2030, 2050 and 2070, which (with the exception of 2030), are based upon the A1FI and A1B emissions scenarios. As there is little difference between the projections based on the A1FI and A1B emissions scenarios for 2030, only the projections for the A1B scenario are shown for that year.

The projected best estimates and ranges of climate change for the Wide Bay-Burnett region are summarised below. The projected temperature changes are shown as absolute values, whereas the projected changes for rainfall and potential evapotranspiration are shown as percent change relative to the mean for the model base period. The absolute changes for rainfall and potential evapotranspiration (shown in brackets, below), have been estimated by multiplying the projected relative changes (percent) by the observed long-term mean (1971–2000 and 1975–2000 respectively; see Table 2-1). The absolute changes presented below should be used with caution however, as: (i) the relative changes were computed using a 1980–1999 model base period, and then applied to an observed mean computed using the 1971–2000 historical base period; (ii) observational and model datasets should not be directly combined; and (iii) the absolute change for potential evapotranspiration was derived by multiplying the projected relative change in potential evapotranspiration by the observed mean potential evaporation. While the two variables are closely related, evapotranspiration includes a plant transpiration component and therefore should not be used interchangeably with evaporation.

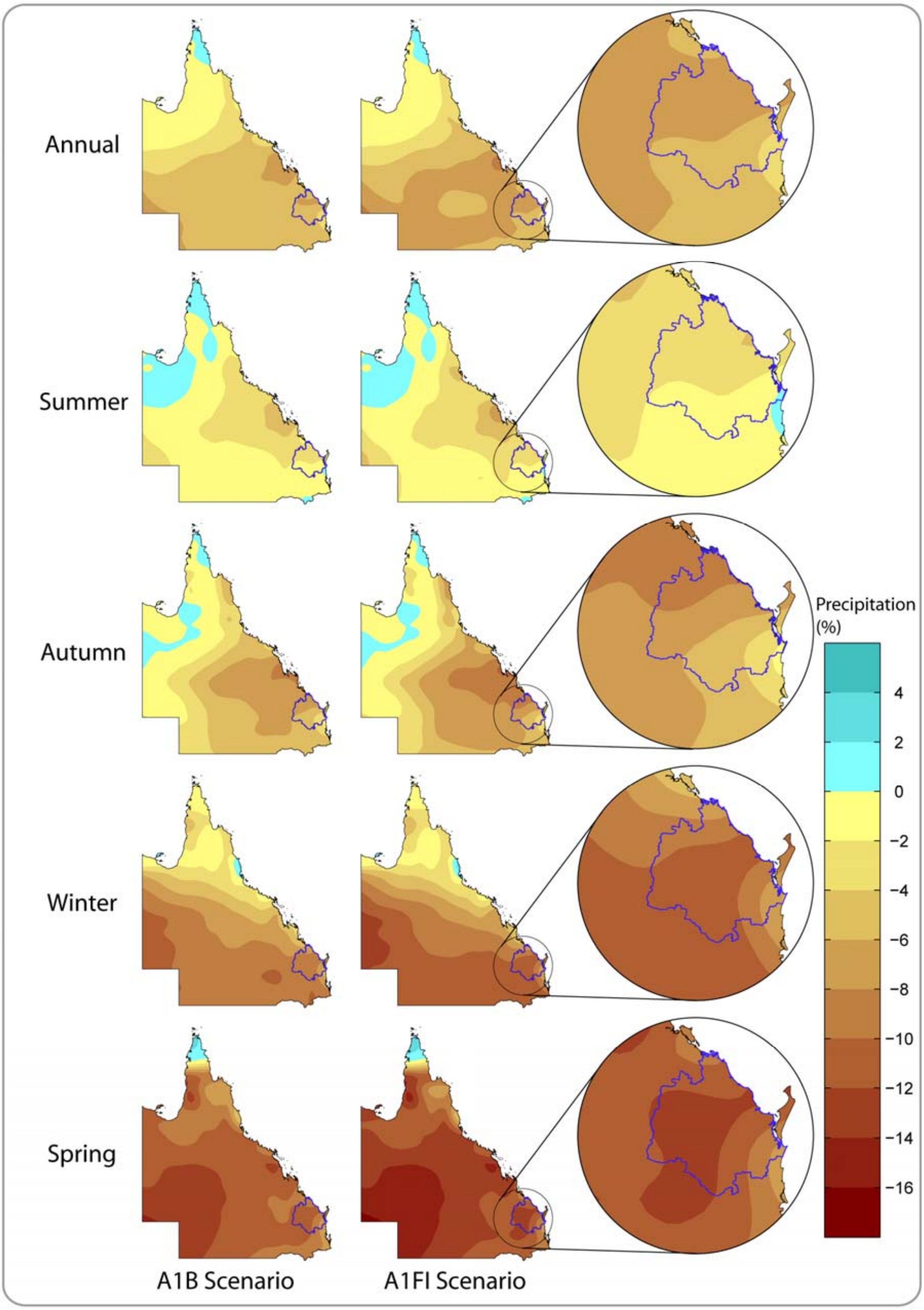

Figure 2-5. Best estimate (median) of projected changes (as percentages of the means for the 1980–1999 period) in annual and seasonal rainfall for Queensland by 2050 for the A1B (left column) and A1FI (right column) emissions scenarios. The Wide Bay-Burnett region is enlarged for the A1FI scenario. Data source: CSIRO & BOM 2007.

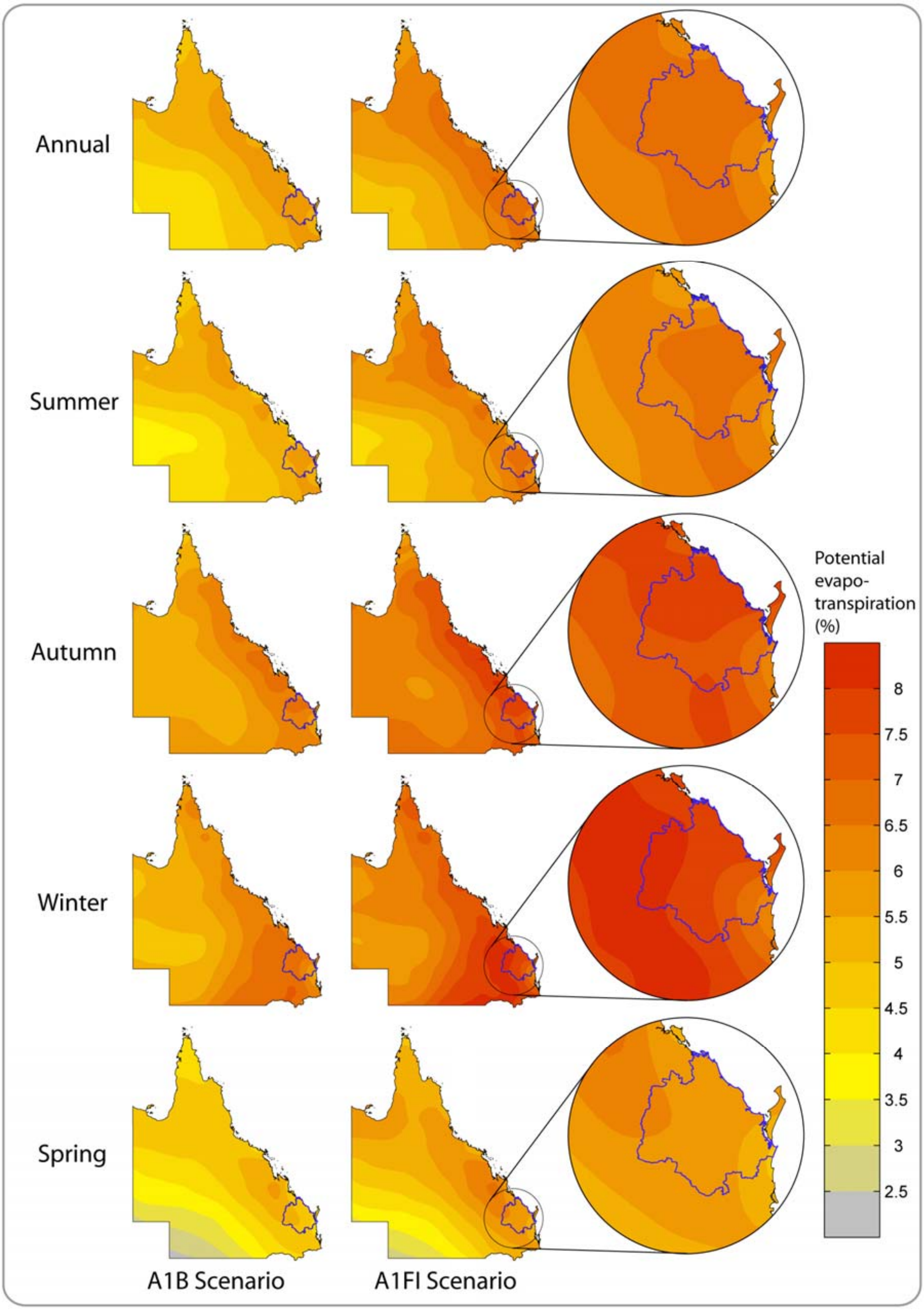

Figure 2-6. Best estimate (median) of the projected changes (as percentages of the means for the 1980–1999 period) in annual and seasonal potential evapotranspiration for Queensland by 2050 for the A1B (left column) and A1FI (right column) emissions scenarios. The Wide Bay-Burnett region is enlarged for the A1FI scenario. Data source: CSIRO & BOM 2007.

Climate change projections for the Wide-Bay Burnett region are summarised as follows:

2030

- **Annual mean temperature:** Projected annual change under the A1B scenario for 2030 is +0.9°C with a range of +0.6°C to +1.3°C. There is little variation in projections across the seasons.
- **Annual rainfall:** Projected change under the A1B scenario for 2030 is -3% (-26 mm), with a range of -12% to +5% (-106 mm to +44 mm). The largest change is projected for spring (-6%, or -12mm) with a range of -19% to +6% (-37 mm to +12 mm).
- **Annual potential evapotranspiration:** Projected change under the A1B scenario for 2030 is +3% (+51 mm) with a range of +2% to +5% (+34 mm to +85 mm). There is little variation in projections across the seasons.

2050

- **Annual mean temperature:** Projected annual changes under the A1B and A1FI scenarios for 2050 are +1.6°C and +1.8°C respectively, with ranges of +1.1°C to +2.2°C and +1.3°C to +2.6°C respectively. There is little variation in projections across the seasons.
- **Annual rainfall:** Projected changes under the A1B and A1FI scenarios for 2050 are -5% (-44 mm) and -6% (-53 mm) respectively, with ranges of -19% to +9% (-168 mm to +79 mm) and -22% to +10% (-194 mm to +88 mm) respectively. The largest changes are projected for spring.
- **Annual potential evapotranspiration:** Projected changes under the A1B and A1FI scenarios for 2050 are +6% (+102 mm) and +7% (+120 mm) respectively, with ranges of +4% to +8% (+68 mm to +137 mm) and +4% to +10% (+68 mm to +171 mm) respectively. The largest change is projected for winter (A1FI scenario).

2070

- **Annual mean temperature:** Projected annual changes under the A1B and A1FI scenarios for 2070 are +2.2°C and +3.0°C respectively, with ranges of +1.5°C to +3.0°C and +2.0°C to +4.2°C respectively. There is little variation in projections across the seasons.
- **Annual rainfall:** Projected changes under the A1B and A1FI scenarios for 2070 are -7% (-62 mm) and -9% (-79 mm) respectively, with ranges of -25% to +12% (-221 mm to +106 mm) and -33% to +16% (-291 mm to +141 mm) respectively. The largest changes are projected for spring.
- **Annual potential evapotranspiration:** Projected changes under the A1B and A1FI scenarios for 2070 are +8% (+137 mm) and +11% (+188 mm) respectively, with ranges of +5% to +12% (+85 mm to +205 mm) and +7% to +16% (+120 mm to +273 mm) respectively. The largest changes are projected for autumn and winter.

Table 2-1. Climate change projections for the Wide Bay-Burnett region. Projection data are presented as a best estimate (50th percentile, shown in bold) followed by the 10th and 90th percentile range (shown in brackets). Projections are computed as the change from the 1980–1999 model base period. The observed values are means for the periods 1971–2000 (temperature and rainfall) and 1975–2000 (potential evaporation), and are shown for reference purposes. Data source: CSIRO & BOM 2007.

Variable	Season	Observed (1971/5–2000)	2030	2050		2070	
			A1B	A1B	A1FI	A1B	A1FI
Temperature (changes in °C)	Annual	20.4°C	**+0.9** [+0.6 – +1.3]	**+1.6** [+1.1 – +2.2]	+**1.8** [+1.3 – +2.6]	+**2.2** [+1.5 – +3.0]	+**3.0** [+2.0 – +4.2]
	Summer	25.2°C	**+0.9** [+0.6 – +1.3]	**+1.5** [+1.0 – +2.2]	+**1.8** [+1.2 – +2.6]	+**2.1** [+1.4 – +3.1]	+**2.9** [+1.9 – +4.2]
	Autumn	21.0°C	**+0.9** [+0.6 – +1.3]	**+1.5** [+1.0 – +2.2]	+**1.8** [+1.2 – +2.5]	+**2.1** [+1.4 – +3.0]	+**2.9** [+1.9 – +4.1]
	Winter	14.7°C	**+0.9** [+0.6 – +1.3]	**+1.6** [+1.1 – +2.2]	+**1.8** [+1.2 – +2.6]	+**2.2** [+1.5 – +3.1]	+**3.0** [+2.0 – +4.2]
	Spring	20.8°C	**+1.0** [+0.6 – +1.4]	**+1.6** [+1.1 – +2.3]	+**1.9** [+1.3 – +2.8]	+**2.3** [+1.5 – +3.3]	+**3.1** [+2.0 – +4.4]
Rainfall (changes in %)	Annual	882 mm	**-3** [-12 – +5]	**-5** [-19 – +9]	**-6** [-22 – +10]	**-7** [-25 – +12]	**-9** [-33 – +16]
	Summer	346 mm	**-1** [-11 – +8]	**-2** [-18 – +14]	**-2** [-21 – +17]	**-3** [-24 – +20]	**-4** [-31 – +27]
	Autumn	218 mm	**-3** [-15 – +9]	**-5** [-24 – +15]	**-6** [-28 – +17]	**-7** [-32 – +21]	**-10** [-41 – +28]
	Winter	120 mm	**-5** [-15 – +5]	**-8** [-24 – +8]	**-10** [-27 – +9]	**-11** [-31 – +11]	**-15** [-40 – +15]
	Spring	197 mm	**-6** [-19 – +6]	**-10** [-29 – +10]	**-11** [-33 – +12]	**-13** [-38 – +14]	**-18** [-48 – + 19]
Potential evapo-transpiration (changes in %)	Annual	1708 mm*	**+3** [+2 – +5]	**+6** [+4 – +8]	**+7** [+4 – +10]	**+8** [+5 – +12]	**+11** [+7 – +16]
	Summer	574 mm*	**+3** [+2 – +5]	**+6** [+3 – +9]	**+6** [+3 – +10]	**+8** [+4 – +12]	**+10** [+6 – +17]
	Autumn	376 mm*	**+4** [+2 – +6]	**+6** [+4 – +10]	**+7** [+4 – +12]	**+9** [+5 – +14]	**+12** [+7 – +19]
	Winter	259 mm*	**+4** [+2 – +6]	**+6** [+4 – +10]	**+8** [+5 – +12]	**+9** [+6 – +14]	**+12** [+7 – +19]
	Spring	502 mm*	**+3** [+2 – +4]	**+5** [+3 – +8]	**+6** [+3 – +9]	**+7** [+4 – +11]	**+9** [+5 – +14]

* Observed variable is potential evaporation.

2.3.4 Climate change impact on rainfall frequency and intensity

The projected impact of climate change on rainfall frequency and intensity is important for assessing how climate change may affect runoff into water catchments. In addition to the projected changes in mean rainfall, increases in extreme daily rainfall and the number of dry days (i.e. decrease in the number of rain days) are likely in the future. For Australia as a whole, extreme daily rainfall is expected to increase in the north and decrease in the south. In addition to the projected decline in extreme daily rainfall during winter and spring, the projections also show a substantial decline in mean rainfall in the south.

Table 2-2 shows projected changes in rainfall frequency and intensity for Tewantin and Gladstone under the A1B and A1FI emissions scenarios by 2050. Projections are presented for these two sites as they are the only locations in the vicinity of the Wide Bay-Burnett region for which detailed projections are available. Tewantin and Gladstone are located just beyond the southern and northern boundaries of the Wide Bay-Burnett region, respectively. Rainfall events in this section are defined as follows: *Rain days* is the mean number of days per year in which total daily rainfall exceeds 1mm; and *Extreme rainfall* events are the mean number of rain days per year in which the total daily rainfall exceeds the 99th percentile value (i.e. the threshold rainfall value computed using data from the model base period, such that only 1% of rain days have a total rainfall exceeding this value). Key findings can be summarised (see Table 2-2) as follows:

- Apart from a marginal increase in summer rain days, the number of rain days is projected to decline across most seasons at both locations
- The number of extreme rainfall events occurring throughout summer and spring is projected to increase at both locations. A substantial decline in extreme rainfall events during winter is projected for both locations, and
- Projections for rainfall extremes are generally consistent between the two locations, whereas the projected number of rain days differs significantly, with Gladstone having a larger decrease in rain days than Tewantin.

2.3.5 Climate change impact on climatic extremes

In addition to changes in temperature and rainfall, climate change may also alter the frequency and severity of extreme weather events such as tropical cyclones and heatwaves. While a number of climate change studies have investigated projected changes in climatic extremes throughout the Australian basin, none have specifically focused on the Wide Bay-Burnett region. Therefore, in the following discussion, we draw upon data from the most recent studies which are relevant to Queensland. However it should be noted that at present there is considerable uncertainty as to how climate change may alter the frequency and severity of climatic extremes. As climate models evolve, their ability to simulate extreme events will improve, and hence reduce the level of uncertainty in their projections.

Table 2-2. Projections for rainfall frequency and intensity for Tewantin and Gladstone. Frequency is indicated by the projected number of rain days per year (where total daily rainfall exceeds 1mm) and intensity is indicated by the number of projected rain days per year where the total rainfall exceeds the 99th percentile value. Data are shown as a best estimate (50th percentile, shown in bold) followed by the 10th and 90th percentile range (shown in brackets). Projections are computed as the % change from the 1980–1999 model base period. Data source: CSIRO & BOM 2007.

Variable	Season	2050	
		A1B	A1FI
Tewantin:			
Rain days	Annual	**+0** [-10 – +6]	**+0** [-11 – +7]
	Summer	**+1** [-9 – +9]	**+1** [-11 – +11]
	Autumn	**-3** [-11 – +6]	**-4** [-13 – +7]
	Winter	**-3** [-11 – +7]	**-4** [-13 – +8]
	Spring	**-2** [-17 – +4]	**-3** [-20 – +5]
Extreme rainfall	Annual	**-2** [-8 – +10]	**-3** [-10 – +12]
	Summer	**+4** [-11 – +32]	**+5** [-13 – +38]
	Autumn	**+0** [-18 – +16]	**+0** [-22 – +19]
	Winter	**-12** [-21 – +5]	**-14** [-25 – +5]
	Spring	**+2** [-12 – +17]	**+2** [-14 – +20]
Gladstone:			
Rain days	Annual	**-5** [-10 – +4]	**-6** [-12 – +5]
	Summer	**+1** [-8 – +9]	**+1** [-9 – +11]
	Autumn	**-6** [-14 – +1]	**-8** [-17 – +1]
	Winter	**-1** [-10 – +13]	**-1** [-11 – +15]
	Spring	**-8** [-23 – +9]	**-9** [-27 – +11]
Extreme rainfall	Annual	**-3** [-8 – +8]	**-4** [-9 – +10]
	Summer	**+3** [-12 – +24]	**+3** [-15 – +28]
	Autumn	**-1** [-21 – +20]	**-2** [-25 – +23]
	Winter	**-13** [-22 – +11]	**-15** [-26 +13]
	Spring	**+3** [-13 – +20]	**+3** [-16 – +23]

The potential impact of climate change on extreme rainfall and cyclones in Australia has been investigated by Abbs et al. (2006). Model results show only small changes, or a slight decrease, in the intensity of extreme rainfall events in south-east Queensland by 2030. However, the intensity of such events is projected to increase by 2070. The modelling suggests that the intensity of extreme rainfall events will increase over mountainous terrain, but tend to decrease elsewhere.

The frequency of severe tropical cyclones (Categories 4 and 5) on the east Australian coast has been projected to increase by 15% from 2000 to 2050 (Leslie et al. 2007), with a 200 km southward shift in the cyclone genesis region. Even without changes in cyclone severity or frequency, such events will (under climate change conditions) pose an increased risk to south-east Queensland due to the associated impacts of climate change. For example, it has been estimated that if a tropical cyclone, similar to TC Wanda which devastated south-east Queensland in 1974, were to impact upon the Gold Coast under climate change conditions, then the concomitant effects of climate change would cause an additional 18% of people and dwellings to be affected by the associated flooding (Abbs et al. 2006). The estimate was based on the assumption of a 10–40cm rise in mean sea level by 2050, and no change in population density in the area.

Droughts and heatwaves are also expected to be impacted by climate change. Droughts are likely to become more frequent in some parts of Australia, and their impact exacerbated by increasing temperature and evaporation. Using the current criteria for drought classification, current projections estimate that most of Australia will spend 20% more time in drought by 2030, and eastern Australia will spend 40% more time in drought by 2070 (Mpelasoka et al. 2007a, 2007b).

While droughts can severely impact on agriculture and other water-reliant industries, increasing surface temperatures can have both short-term effects on human settlements (e.g. heatwaves), and longer term effects on entire ecosystems (e.g. species migration). The impact which climate change may have on temperature extremes can be examined by counting the number of days per year with temperature exceeding 35°C, as this is an accepted indicator of heat stress for human health and subsequent demand on emergency services. The historical and projected annual average number of days with temperature greater than 35°C for Tewantin is shown in Table 2-3. The projections indicate a 170% increase in the number of hot days by 2050 (A1FI), and a 320% increase by 2070 (A1FI).

Table 2-3. Projected change in the number of days per year with temperature exceeding 35°C for Tewantin. Projection data are shown as the best estimate (50^{th} percentile, shown in bold) followed by the 10^{th} and 90^{th} percentile range (shown in brackets). Projections are computed as the change from the 1980–1999 base period. The observed value is shown for reference purposes. Source: CSIRO & BOM 2007.

Time period & scenario	Number of days with T >35°C
Present (1971–2000)	**2.6**
2030 A1B	**4.0** [3.5 – 4.7]
2050 A1B	**4.7** [3.9 – 6.4]
2050 A1FI	**6.9** [5.0 – 9.7]
2070 A1B	**6.1** [4.5 – 7.8]
2070 A1FI	**11** [7.2 – 20]

2.4 Summary

Climate change projections for the Wide Bay-Burnett region have been presented based on projection data released by the CSIRO and described in the Climate Change in Australia report. The projections presented were derived using the A1B and A1FI emissions scenarios. These emissions scenarios were chosen as they closely track the current actual emissions. However, it should be noted that in recent years actual emissions have been higher than that predicted by both the A1B and A1FI scenarios. If emissions continue to track higher than those predicted under the A1FI scenario, then the projections provided in this report may significantly underestimate the impact of climate change.

The projected climate changes for the Wide Bay-Burnett region are as follows:

2030

- **Annual mean temperature:** Projected annual change under the A1B scenario for 2030 is +0.9°C with a range of +0.6°C to +1.3°C. There is little variation in projections across the seasons.
- **Annual rainfall:** Projected change under the A1B scenario for 2030 is -3%, with a range of -12% to +5%. The largest change is projected for spring (-6%) with a range of -19% to +6%.
- **Annual potential evapotranspiration:** Projected change under the A1B scenario for 2030 is +3% with a range of +2% to +5%. There is little variation in projections across the seasons.

2050

- **Annual mean temperature:** Projected annual changes under the A1B and A1FI scenarios for 2050 are +1.6°C and +1.8°C respectively, with ranges of +1.1°C to +2.2°C and +1.3°C to +2.6°C respectively. There is little variation in projections across the seasons.
- **Annual rainfall:** Projected changes under the A1B and A1FI scenarios for 2050 are -5% and -6% respectively, with ranges of -19% to +9% and -22% to +10% respectively. The largest changes are projected for spring.
- **Annual potential evapotranspiration:** Projected changes under the A1B and A1FI scenarios for 2050 are +6% and +7% respectively, with ranges of +4% to +8% and +4% to +10% respectively. The largest change is projected for winter (A1FI scenario).

2070

- **Annual mean temperature:** Projected annual changes under the A1B and A1FI scenarios for 2070 are +2.2°C and +3.0°C respectively, with ranges of +1.5°C to +3.0°C and +2.0°C to +4.2°C respectively. There is little variation in projections across the seasons.
- **Annual rainfall:** Projected changes under the A1B and A1FI scenarios for 2070 are -7% and -9% respectively, with ranges of -25% to +12% and -33% to +16% respectively. The largest changes are projected for winter and spring.
- **Annual potential evapotranspiration:** Projected changes under the A1B and A1FI scenarios for 2070 are +8% and +11% respectively, with ranges of +5% to +12% and +7% to +16% respectively. The largest changes are projected for autumn and winter.

3. Climate change datasets for hydrological modelling

3.1 Overview

This chapter provides an overview of techniques which may be used to produce climate change data for use in hydrological modelling. One of the challenges associated with developing climate projections is how to deal with the requirements of end users, particularly those who are faced with making immediate decisions about coping with the future impacts of climate change. In a risk management framework, the preference is for probabilistic information with relatively narrow bands of uncertainty (see Chapter 6 in CSIRO & BOM, 2007).

The recently released climate change projections for Australia (CSIRO & BOM 2007) were based on the output from models included in the IPCC's Fourth Assessment Report (4AR). In order to provide better information for end users, the projections were presented in terms of probability density functions (PDFs) which account for uncertainties in both model outputs and natural variability (Watterson et al. 2007). The PDF presentation can facilitate decision making as the projected changes are accompanied by an estimate of the associated uncertainty. However, end users may still find PDFs to be problematic due to the uncertainty associated with projections of climate variables at different scales and for different times in the future. In particular, the PDFs tend to be relatively wide, reflecting the uncertainty inherent in the full range of 4AR model outputs, as well as the uncertainty in future emissions scenarios. This uncertainty can be propagated and subsequently magnified when the information is used as input for impacts models (e.g. hydrological models), to such an extent that the resultant information can be too imprecise to assist decision-making (Preston & Jones 2008). Considerable research effort has thus been focused on trying to reduce this uncertainty.

The selection of climate change information for use in impact studies or risk assessment may be determined by (Preston 2007):

- Availability of datasets for the climate variable(s) of interest
- Spatial and temporal scale of the assessment, and
- Management of uncertainty.

The first two criteria may be used to establish the plausibility of the study or assessment, while the last criterion (information about uncertainty) may be used to establish confidence in the results of the study or assessment. The previous chapter contained projections derived from all 23 models which participated in the IPCC's 4th Assessment. While such datasets provide a broad characterisation of climate change projected for the future, the use of such information for supporting impact studies needs further consideration. Climate processes are complex and typically incorporate feedback mechanisms. Consequently, many climate variables are highly interactive, meaning that a change in one variable may have an effect on other variables. For example, rainfall and evaporation are tightly coupled processes, and it is therefore critical that the projection datasets selected for rainfall, evaporation and humidity are consistent. When assessing the impact of climate change on water resources it may be tempting to identify the worst possible scenario by using the most pessimistic rainfall projection and pair this data with the most pessimistic evaporation projection, possibly obtained from another climate model. If the rainfall and evaporation datasets were drawn from different models (or even a different ensemble member from a given model), then the two datasets would most likely be inconsistent. Consequently, the projected impacts would be: (i) invalid; and (ii) artificially larger than that derived from internally consistent projections. The best approach is to independently model the impacts using climate change projection data from each climate model individually, and subsequently combine the outputs. The derived results then provide a range of impact estimates which are representative of the plausible impact of climate change on the system of interest. The results can then be used to derive probabilistic information, such as ranking potential impacts based upon the uncertainty associated with the underlying datasets. Arbitrary selection of projection datasets without reference to their consistency may: (i) render the analysis invalid; (ii) generate assessments which are physically inconsistent; and (iii) produce misleading estimates of the potential impacts of climate change.

In this chapter we describe the selection of climate change datasets for use in hydrological modelling. Projection datasets are drawn from climate models which have been selected based on their performance in the Australian region. Rainfall and temperature projections are presented (based on a subset of 11 models), and potential evapotranspiration projections are also presented (based on a subset of 6 models).

The climate change factors presented in this chapter refer to annual and seasonal changes in the aforementioned climate variables. Monthly climate change factors from 11 models were derived in a similar manner, and provided as an input to hydrological modelling undertaken by the NRW Water Assessment Group. When these climate projection data were used in hydrological modelling, the evapotranspiration data for the five missing models were estimated using a regression fit between projected mean temperature change (from 11 models) and evapotranspiration (from 6 models).

3.2 Introduction to general circulation models

A general circulation model (GCM) is a mathematical representation of the climate system with atmospheric and oceanic processes represented by a system of mathematical equations that are based on well-established physical laws, e.g. the law of conservation of momentum. GCMs are the best available tools that we have for forecasting weather and projecting climate (Suppiah et al. 2007a; Suppiah et al. 2007b; CSIRO & BOM 2007). GCMs can be used to simulate and predict changes in climatic processes such as the El Niño Southern Oscillation (ENSO), and also model the climatic response to both natural and anthropogenic influences. Such influences include natural variations in solar output and volcanic activity, as well as human induced drivers such as land clearing, the emission of greenhouse gases and aerosols, and the release of halocarbons which destroy atmospheric ozone.

GCMs are bound by a number of limitations, including the resolution at which they can represent the Earth's surface (typical horizontal resolutions range from 100 to 200 km) and atmosphere (typically about 20 layers), and how best to represent small scale physical processes (such as convection) at these resolutions. To overcome these limitations, models are becoming more complex in an effort to better represent important geophysical and biochemical processes. These improvements tend to require considerable increases in computing power. The relatively coarse horizontal resolution of GCMs can limit their ability to simulate the interaction between local topography and the atmosphere (Suppiah et al. 2007a), and in some cases it becomes necessary to downscale GCM output to much finer scales in order to capture the interactions between the atmosphere and regional features such as mountains and coastlines.

Model resolution can have significant implications when assessing GCM performance. For example, a low resolution GCM may be able to reproduce synoptic-scale features of the climate system and may thus be assessed as performing well on larger scales, but it may exhibit significant biases at regional scales. Adjusting for these biases can be difficult, particularly if the output data are to be used for hydrological modelling purposes, where it is important to preserve features of the rainfall distribution, rather than just the mean rainfall.

3.3 Assessment of general circulation models

The ability of GCMs to simulate historical climate may be used as an indicator of the level of confidence associated with their projections of the future climate (CSIRO & BOM 2007). GCMs can be assessed in terms of their ability to reproduce features of the present-day climate, such as: long-term average values, long-term average spatial patterns, seasonal cycles (based on long-term average monthly values), interannual variability (e.g. ENSO), and recent long-term trends which may (or may not) be the result of anthropogenic greenhouse gas forcing of the global climate system. Reichler and Kim (2008a, b) recently assessed 21 4AR models and used annual average values of 14 atmospheric and oceanic variables to assess model performance. Their results clearly demonstrated that the errors of the poorer performing models can be up to twice those of the better performing models.

Several studies have been published which describe the development of projections for Australia, with each of them adopting different methods for combining the results from different GCMs based on some measure of performance. Moise et al. (2005) assessed the performance of 18 coupled models which participated in the global Coupled Model Intercomparison Project, which provided simulations of climate change in response to increasing GHG levels. These models pre-dated the IPCC's 4AR models, but even so, it was apparent that: (i) there were significant model errors associated with simulations of Australian rainfall, particularly summer monsoon rainfall; and (ii) projections for the latter part of the 21st Century were very uncertain.

Suppiah et al. (2007b) assessed the performance of 23 4AR models with respect to how well they reproduced observed seasonal patterns of temperature, mean sea level pressure and rainfall over the Australian continent. They reduced the sample to 15 by rejecting those models which frequently failed to meet certain root mean square error and spatial correlation thresholds across the four seasons. They then generated climate change projections based on the mean and range of the 15-member sample, without discriminating between the results from individual models.

Watterson et al. (2007) and Hennessy et al. (2007a) have described a method for generating projections using PDFs. Their method weights the output from each model by its "M" skill measure (Watterson 1996) which is determined by comparing maps of simulated and observed seasonal mean temperature, rainfall and sea level pressure over the Australian continent. A single M value between 1 (perfect match) and 0 (no-skill) was obtained for each of the 23 4AR models, based on pattern correlations and root mean square errors. This methodology was used to derive the Climate Change in

Australia Projections described in Chapter 2.

Perkins et al. (2007) evaluated 14 of the 23 4AR models based on their ability to simulate daily rainfall and daily minimum and maximum temperatures for 12 regions in Australia. Model skill was assessed by the ability of the model to reproduce the frequency distribution functions of the three aforementioned variables. The authors noted that some of the models exhibited considerable skill, and that it was possible to identify relatively poorly performing models. Maxino et al. (2007) extended this approach, focusing on a single, relatively large and important sub-region of Australia - the Murray Darling Basin (MDB). They assessed 16 models (14 of the 23 4AR models, plus two additional models) for which daily data were available. Their analysis showed that some models were clearly flawed, with only four models recommended for use in impact assessments in the MDB region

Charles et al. (2007) also assessed model performance over the MDB region but focused on a model's ability to simulate both daily mean surface level pressure and the seasonal cycle of monthly average mean surface level pressure. Of the 11 models assessed (9 of the 23 4AR models, plus two additional models), four were clearly superior.

If one is interested in the effects of co-varying long-term changes in the atmosphere and ocean, then it is important to also assess models on their ability to simulate the ENSO phenomenon, which involves co-varying changes over several years. Van Oldenborgh et al. (2005) considered how well models were able to realistically simulate a number of important ENSO features, and surprisingly, of the 19 (4AR) models which were assessed, only six were judged to be acceptable.

In a recent study, Smith and Chandler (2008) identified a small (five) subset of models judged to be most suitable for deriving rainfall projections for Australia. The assessment was based on the full set of 23 4AR models whose results are available from the Program for Climate Model Diagnosis and Intercomparison web site (PCMDI 2008). The technique adopted was closely related to that used by Suppiah et al. (2007b). Suppiah et al. (2007b) assessed the performance of these models with respect to how well they reproduced observed seasonal patterns of temperature, mean surface level pressure and rainfall over the Australian continent. They argued that a multivariate assessment is important, as it can help identify those models which may be able to provide a good simulation of present-day rainfall (for example), but for the wrong reasons, especially if they cannot reproduce the correct mean surface level pressure patterns. Smith and Chandler (2008), however, assessed model performance with respect to rainfall only. They argued that it is highly unlikely that a model can provide a credible simulation of rainfall without having a credible simulation of humidity, temperature, winds, mean surface level pressure and other variables. In other words, Smith and Chandler (2008) assert that rainfall most likely serves as a good proxy for overall model performance.

For similar reasons, Smith and Chandler (2008) focused only on the Australian region, arguing that it was not useful to include a model which performs well over northern Europe (for example), but not locally. They also argued that, because the Australian continent as a whole is sufficiently large, the Australian climate provides a good test bed for assessing the performance of models. It comprises a wide range of climate regimes including the very dry interior compared to the very wet tropics; the dry west compared to the wetter east; a summer regime dominated by monsoon circulations, tropical cyclones, Madden-Julian Oscillations and thunderstorms, compared to a winter regime dominated by frontal events, cut-off lows and other winter season phenomena. Australia is also unique in that the climate is strongly affected by both the Pacific Ocean (via ENSO events) and, to a lesser extent, the Indian Ocean. It is highly unlikely that any model which provides a credible simulation of all these features will perform poorly over other parts of the globe (Smith and Chandler 2008).

Smith and Chandler (2008) identified 10 GCMs which satisfied their rainfall criteria, but also took into consideration other studies which assessed the performance of GCMs at simulating ENSO. According to the assessment of Van Oldenborgh et al. (2005), 4 of the 10 identified models did not provide credible representations of ENSO. While the Van Oldenborgh assessment did not include the ECHO-G model, the assessment by Min et al. (2005) indicated that this model also had difficulty reproducing the ENSO phenomenon. In particular, the amplitude of the simulated sea surface temperature anomalies was almost twice that observed, while the frequency spectrum was dominated by a 2-year peak, compared to the observed 3 to 7-year peak, possibly as a result of relatively poor horizontal resolution (400 km) (Guilyardi et al. 2004). Thus Smith and Chandler (2008) concluded that only five of the models provided good representations of both Australian rainfall patterns and ENSO.

While critical analysis of GCM performance is a necessary component of the scientific process, model selection can also have significant implications for policy planning. For example, projections for the Murray Darling basin from the selected GCMs indicated significantly drier conditions in the future than those indicated by the full set of GCMs.

3.4 Selection of general circulation models

The climate change projections for rainfall and temperature produced by the CSIRO and the Bureau of Meteorology (see Chapter 2 and CSIRO & BOM 2007) are accompanied by estimates of their ranges from all models. Such information is not always useful for hydrological modelling, as rainfall, temperature and potential evapotranspiration changes are not independent. Consequently, the range of possible climate change conditions is likely to be less than the range indicated by the individual variables. A more appropriate approach in these situations is to directly analyse the outputs for all variables of interest from the same model. Therefore a different dataset has been used in this chapter.

Model-specific climate change information for Australia can be obtained from OzClim (Ricketts & Page 2007). Ozclim is an on-line software tool developed by the CSIRO (OzClim 2008) that allows the user to choose from eight climate models, eight emissions scenarios and three climate sensitivities. At present OzClim only provides access to rainfall and temperature variables, however evapotranspiration is a key variable required for hydrological modelling. To support this study, QCCCE acquired an extended version of the OzClim datasets under licence from the CSIRO. Projections from 11 models were used to provide monthly rainfall, surface temperature and potential evapotranspiration input for hydrological modelling. The choice of models used in this report was driven by the availability of monthly data for potential evapotranspiration, rainfall and surface temperature, as well as the overall performance of various models in the Queensland context (see Smith & Chandler 2008; Suppiah et al. 2007b).

3.4.1 Rainfall projections

Projections for annual and seasonal rainfall for the Wide Bay-Burnett region are shown in Table 3-1. The projections were taken from the 11 GCMs for which OzClim data were available, and which are believed to provide robust simulations of present-day climate in the Australian region. For each model, a range of outputs are shown, incorporating three values of climate sensitivity: low, medium and high. Climate sensitivity is the global average warming in response to a doubling of the atmospheric concentration of carbon dioxide from 280ppm to 560ppm. The pre-industrial (before ~1750) concentration of CO_2 was around 280ppm, the concentration in 2006 was 380ppm, and a concentration of 560ppm is within the IPCC projected range for the mid-to-late 21st century. The outputs for each variable are tabulated as follows: *low* sensitivity corresponds to a global warming of 1.7°C, *medium* sensitivity corresponds to a global warming of 2.6°C, and *high* sensitivity corresponds to a global warming of 4.2°C; all for a doubling of CO_2 from 280ppm to 560ppm. Projections are only provided for the A1B and A1FI emissions scenarios, as recent evidence suggests that the lower emissions scenarios are less likely to eventuate. Note that there is very little difference between the A1B and A1FI emissions scenarios by 2030, thus only the outputs for the A1B emissions scenario are shown for 2030.

Correct utilisation of climate change projections requires the information to be interpreted in the context of historical variability. To facilitate contextual use of the rainfall projections shown in Table 3-1 (and also those in Table 2-1), a comparison of the mean and range of historical rainfall with the median and range of projected rainfall is shown in Figures 3-1 and 3-2. The median and range of annual rainfall projections derived from both: (i) all 23 4AR models; and (ii) the selected (11 member) subset of models, are shown in Figure 3-1. As shown, the range of projections under all scenarios considered for 2030, 2050 and 2070 is considerably less than the hitherto observed range in historical rainfall. The analogous comparison for summer rainfall is shown in Figure 3-2 and again, the range of projections is small relative to the historical range. The preceding comparisons should serve as a warning that the range in climate model projections is a reflection of differences between climate models and may not be an adequate indicator of the variability in future rainfall, which should be carefully considered when using the datasets for hydrological modelling.

Table 3-1: Climate change projections for annual and seasonal rainfall in 2030 (A1B emissions scenario) and 2050 (A1B and A1FI emissions scenarios) for the Wide Bay-Burnett region. The data are shown as the percentage change from the 1980–1999 model base period. For each scenario, models are ranked from the largest decrease to the largest increase. Model projections are ranked on annual rainfall, and the 10th, 50th (median) and 90th percentile values are highlighted in bold. DJF denotes summer (December–February), MAM denotes autumn (March–May), JJA denotes winter (June–August) and SON denotes spring (September–November). Models identified by Smith and Chandler (2008) are denoted by asterisks. Source: CSIRO 2008.

		Annual			DJF			MAM			JJA			SON		
2030 A1B		LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
GFDL_cm2_1	*	-6.6	-11.1	-17.7	-2.3	-3.8	-6.1	-8.9	-14.8	-23.7	-9.6	-16.1	-25.7	-5.8	-9.6	-15.4
UKMO_HADGEM1	*	**-5.1**	**-8.5**	**-13.7**	**-1.7**	**-2.9**	**-4.6**	**-5.8**	**-9.6**	**-15.3**	**-6.4**	**-10.7**	**-17.2**	**-6.6**	**-11.0**	**-17.6**
MPI_ECHAM5	*	-3.4	-5.7	-9.1	-0.6	-1.0	-1.6	-3.2	-5.3	-8.5	-4.5	-7.5	-12.0	-5.3	-8.9	-14.2
CSIRO_Mark 3.5		-3.3	-5.5	-8.8	-0.5	-0.8	-1.3	-1.5	-2.5	-4.0	-5.7	-9.5	-15.3	-5.5	-9.1	-14.6
UKMO_HADCM3	*	-3.2	-5.4	-8.7	0.1	0.1	0.1	-3.5	-5.9	-9.4	-4.0	-6.6	-10.5	-5.6	-9.3	-14.8
IAP_FGOALS1_0_g		**-1.9**	**-3.2**	**-5.1**	**0.2**	**0.3**	**0.4**	**-2.3**	**-3.8**	**-6.1**	**-3.5**	**-5.9**	**-9.4**	**-2.0**	**-3.3**	**-5.2**
CSIRO_Mark 3.0		-1.7	-2.8	-4.5	1.7	2.8	4.5	-1.3	-2.1	-3.4	-3.4	-5.7	-9.2	-3.7	-6.1	-9.8
NCAR_CCSM3_0		-0.7	-1.1	-1.7	1.6	2.7	4.3	-3.0	-5.0	-7.9	-2.5	-4.1	-6.6	1.2	2.0	3.2
MIROC3_2_hires	*	-0.5	-0.8	-1.2	1.7	2.9	4.6	2.7	4.5	7.2	-3.3	-5.6	-8.9	-2.9	-4.8	-7.7
MIUB_echo_g		**-0.2**	**-0.3**	**-0.5**	**4.4**	**7.4**	**11.8**	**1.7**	**2.8**	**4.4**	**-4.1**	**-6.8**	**-10.9**	**-2.7**	**-4.5**	**-7.2**
MIROC3_2_medres		2.4	4.0	6.4	3.2	5.3	8.6	7.0	11.7	18.8	0.9	1.4	2.3	-1.5	-2.4	-3.9
2050 A1B		LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
GFDL_cm2_1	*	-11.3	-18.8	-30.2	-3.9	-6.5	-10.4	-15.2	-25.2	-40.4	-16.4	-27.3	-43.7	-9.8	-16.3	-26.1
UKMO_HADGEM1	*	**-8.7**	**-14.5**	**-23.3**	**-2.9**	**-4.9**	**-7.8**	**-9.8**	**-16.3**	**-26.1**	**-11.0**	**-18.3**	**-29.2**	**-11.2**	**-18.7**	**-29.9**
MPI_ECHAM5	*	-5.8	-9.6	-15.4	-1.0	-1.7	-2.8	-5.4	-9.0	-14.4	-7.6	-12.7	-20.3	-9.1	-15.1	-24.2
CSIRO_Mark 3.5		-5.6	-9.4	-15.0	-0.8	-1.4	-2.2	-2.6	-4.3	-6.8	-9.8	-16.2	-26.0	-9.3	-15.5	-24.8
UKMO_HADCM3	*	-5.5	-9.2	-14.7	0.1	0.2	0.2	-6.0	-10.0	-16.1	-6.7	-11.2	-17.9	-9.5	-15.7	-25.2
IAP_FGOALS1_0_g		**-3.3**	**-5.4**	**-8.7**	**0.3**	**0.4**	**0.7**	**-3.9**	**-6.5**	**-10.5**	**-6.0**	**-10.0**	**-16.1**	**-3.3**	**-5.6**	**-8.9**
CSIRO_Mark 3.0		-2.9	-4.7	-7.6	2.9	4.8	7.7	-2.2	-3.6	-5.7	-5.9	-9.8	-15.6	-6.3	-10.4	-16.7
NCAR_CCSM3_0		-1.1	-1.8	-3.0	2.8	4.6	7.4	-5.1	-8.4	-13.5	-4.2	-7.0	-11.2	2.1	3.4	5.5
MIROC3_2_hires	*	-0.8	-1.3	-2.1	3.0	4.9	7.9	4.6	7.6	12.2	-5.7	-9.5	-15.2	-4.9	-8.2	-13.2
MIUB_echo_g		**-0.3**	**-0.5**	**-0.8**	**7.5**	**12.5**	**20.1**	**2.8**	**4.7**	**7.5**	**-6.9**	**-11.6**	**-18.5**	**-4.6**	**-7.6**	**-12.2**
MIROC3_2_medres		4.1	6.8	10.9	5.5	9.1	14.5	12.0	19.9	31.9	1.5	2.5	3.9	-2.5	-4.2	-6.7
2050 A1F1		LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
GFDL_cm2_1	*	-13.3	-22.2	-35.5	-4.6	-7.6	-12.2	-17.8	-29.7	-47.5	-19.3	-32.1	-51.4	-11.5	-19.2	-30.7
UKMO_HADGEM1	*	**-10.3**	**-17.1**	**-27.3**	**-3.4**	**-5.7**	**-9.2**	**-11.5**	**-19.2**	**-30.7**	**-12.9**	**-21.5**	**-34.4**	**-13.2**	**-22.0**	**-35.2**
MPI_ECHAM5	*	-6.8	-11.3	-18.1	-1.2	-2.0	-3.3	-6.4	-10.6	-17.0	-9.0	-14.9	-23.9	-10.7	-17.8	-28.5
CSIRO_Mark 3.5		-6.6	-11.0	-17.6	-1.0	-1.7	-2.6	-3.0	-5.0	-8.0	-11.5	-19.1	-30.6	-11.0	-18.3	-29.2
UKMO_HADCM3	*	-6.5	-10.8	-17.3	0.1	0.2	0.3	-7.1	-11.8	-18.9	-7.9	-13.2	-21.1	-11.1	-18.5	-29.6
IAP_FGOALS1_0_g		**-3.8**	**-6.4**	**-10.2**	**0.3**	**0.5**	**0.8**	**-4.6**	**-7.7**	**-12.3**	**-7.1**	**-11.8**	**-18.9**	**-3.9**	**-6.5**	**-10.5**
CSIRO_Mark 3.0		-3.3	-5.6	-8.9	3.4	5.6	9.0	-2.5	-4.2	-6.7	-6.9	-11.5	-18.4	-7.4	-12.3	-19.6
NCAR_CCSM3_0		-1.3	-2.2	-3.5	3.3	5.4	8.7	-5.9	-9.9	-15.9	-5.0	-8.3	-13.2	2.4	4.0	6.4
MIROC3_2_hires	*	-0.9	-1.5	-2.4	3.5	5.8	9.3	5.4	9.0	14.3	-6.7	-11.1	-17.8	-5.8	-9.7	-15.5
MIUB_echo_g_		**-0.3**	**-0.6**	**-0.9**	**8.8**	**14.7**	**23.6**	**3.3**	**5.5**	**8.8**	**-8.2**	**-13.6**	**-21.8**	**-5.4**	**-9.0**	**-14.3**
MIROC3_2_medres		4.8	8.0	12.9	6.4	10.7	17.1	14.1	23.5	37.5	1.7	2.9	4.6	-2.9	-4.9	-7.8

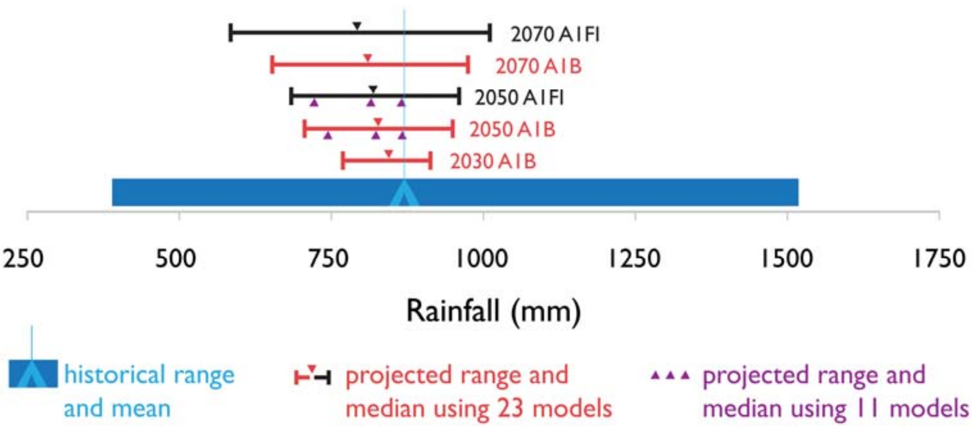

Figure 3-1: Climate change projections for annual rainfall for the Wide Bay-Burnett region. Projections are shown as a median and range (10th and 90th percentiles). Results were derived using data for both the A1B and A1FI emissions scenarios, from: (i) all 23 IPCC 4AR models for (2030, 2050 and 2070); and (ii) the subset of 11 selected models (2050). The observed mean and range (1971–2000) in this region are also shown. Data source: CSIRO & BOM 2007.

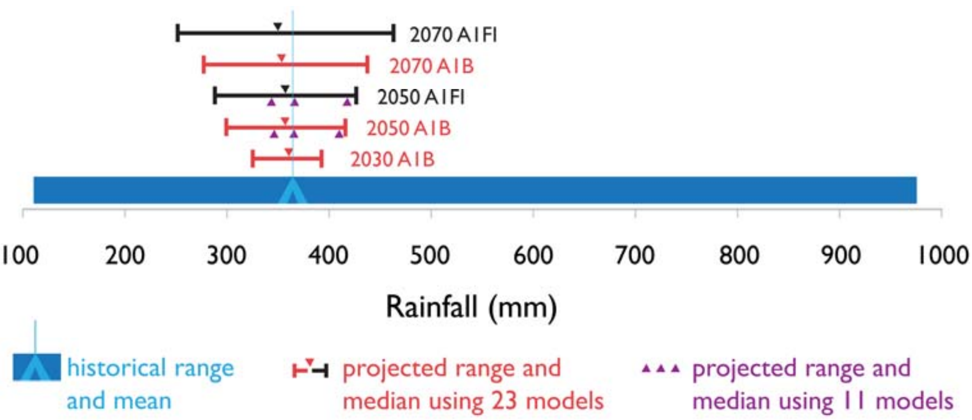

Figure 3-2: Climate change projections for summer rainfall for the Wide Bay-Burnett region. Projections are shown as a median and range (10th and 90th percentiles). Results were derived using data for both the A1B and A1FI emissions scenarios, from: (i) all 23 IPCC 4AR models for (2030, 2050 and 2070); and (ii) the subset of 11 selected models (2050). The observed mean and range (1971–2000) in this region are also shown. Data source: CSIRO & BOM 2007.

3.4.2 Potential evapotranspiration projections

Projections for annual and seasonal potential evapotranspiration for the Wide Bay-Burnett region are shown in Table 3-2. The projections were derived from the extended OzClim datasets. The reader should note that only six models were used as 5 of the selected models did not provide all the datasets required for the calculation of potential evapotranspiration.

Table 3-2: Climate change projections for annual and seasonal potential evapotranspiration in 2030 (A1B emissions scenario) and 2050 (A1B and A1FI emissions scenarios) for the Wide Bay-Burnett region. The data are shown as the percentage change from the 1980–1999 model base period. For each scenario, models are ranked from the smallest to largest increase. DJF denotes summer (December–February), MAM denotes autumn (March–May), JJA denotes winter (June–August) and SON denotes spring (September–November). Source: CSIRO 2008.

	Annual			**DJF**			**MAM**			**JJA**			**SON**		
2030 A1B	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
MIROC3_2_medres	1.4	2.3	3.7	1.3	2.1	3.4	1.3	2.2	3.6	1.7	2.8	4.5	1.3	2.1	3.4
IAP_FGOALS1_0_g	1.7	2.9	4.6	1.4	2.4	3.8	2.1	3.6	5.7	1.9	3.2	5.1	1.5	2.5	4.0
MIROC3_2_hires	1.9	3.1	5.0	1.8	3.0	4.9	2.2	3.6	5.8	1.9	3.1	5.0	1.6	2.7	4.4
NCAR_CCSM3_0	2.0	3.4	5.4	1.8	2.9	4.7	2.6	4.4	7.1	2.6	4.3	6.8	1.1	1.9	3.0
CSIRO_Mark 3.5	2.6	4.4	7.0	2.6	4.3	6.8	3.1	5.1	8.2	2.7	4.5	7.2	2.1	3.6	5.7
CSIRO_Mark 3.0	4.2	7.0	11.2	4.3	7.2	11.5	4.5	7.5	12.0	4.6	7.6	12.2	3.4	5.7	9.1
2050 A1B	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
MIROC3_2_medres	2.4	4.0	6.3	2.2	3.6	5.8	2.3	3.8	6.1	2.9	4.8	7.7	2.2	3.6	5.8
IAP_FGOALS1_0_g	3.0	4.9	7.9	2.4	4.0	6.4	3.6	6.0	9.7	3.3	5.4	8.7	2.6	4.3	6.8
MIROC3_2_hires	3.2	5.3	8.5	3.1	5.2	8.3	3.7	6.1	9.8	3.2	5.3	8.5	2.8	4.6	7.4
NCAR_CCSM3_0	3.4	5.7	9.2	3.0	5.0	8.0	4.5	7.5	12.0	4.4	7.2	11.6	1.9	3.2	5.0
CSIRO_Mark 3.5	4.5	7.4	11.9	4.4	7.2	11.6	5.3	8.7	14.0	4.6	7.6	12.2	3.7	6.1	9.8
CSIRO_Mark 3.0	7.2	11.9	19.1	7.3	12.2	19.5	7.7	12.8	20.5	7.8	13.0	20.8	5.8	9.7	15.5
2050 A1F1	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
MIROC3_2_medres	2.8	4.6	7.4	2.5	4.2	6.8	2.7	4.5	7.1	3.4	5.6	9.0	2.6	4.3	6.8
IAP_FGOALS1_0_g	3.5	5.8	9.3	2.8	4.7	7.6	4.3	7.1	11.4	3.8	6.4	10.2	3.0	5.0	8.0
MIROC3_2_hires	3.7	6.2	10.0	3.6	6.1	9.7	4.3	7.2	11.5	3.8	6.3	10.0	3.3	5.5	8.7
NCAR_CCSM3_0	4.0	6.7	10.8	3.5	5.9	9.4	5.3	8.8	14.1	5.1	8.5	13.6	2.2	3.7	5.9
CSIRO_Mark 3.5	5.2	8.7	14.0	5.1	8.5	13.6	6.2	10.3	16.5	5.4	9.0	14.4	4.3	7.2	11.5
CSIRO_Mark 3.0	8.4	14.0	22.4	8.6	14.3	22.9	9.0	15.1	24.1	9.1	15.2	24.4	6.8	11.4	18.2

3.4.3 Surface temperature projections

Projections for annual and seasonal temperature for the Wide Bay-Burnett region are shown in Table 3-3. Data are presented for all GCMs for which OzClim projections were available, and estimates of the 10th, 50th (median) and 90th percentiles are highlighted in bold. In this case the projections are absolute changes (°C) from the mean for the model base period (1980–1999).

Table 3-3: Climate change projections for annual and seasonal temperature in 2030 (A1B emissions scenario) and 2050 (A1B and A1FI emissions scenarios) for the Wide Bay-Burnett region. The data are shown as the absolute change (°C) from the 1980–1999 model base period. For each scenario, models are ranked from the smallest to largest increase. Model projections are ranked on annual temperature, and the 10th, 50th (median) and 90th percentile values are highlighted in bold. DJF denotes summer (December–February), MAM denotes autumn (March–May), JJA denotes winter (June–August) and SON denotes spring (September–November). Source: CSIRO 2008.

	Annual			DJF			MAM			JJA			SON		
2030 A1B	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
MIUB_echo_g	0.4	0.7	1.1	0.3	0.5	0.8	0.4	0.6	1.0	0.5	0.8	1.2	0.5	0.8	1.2
IAP_FGOALS1_0_g	**0.4**	**0.7**	**1.1**	**0.4**	**0.7**	**1.1**	**0.4**	**0.7**	**1.2**	**0.4**	**0.7**	**1.1**	**0.4**	**0.7**	**1.2**
MIROC3_2_medres	0.5	0.8	1.2	0.4	0.7	1.2	0.5	0.8	1.3	0.5	0.9	1.4	0.4	0.7	1.1
UKMO_HADGEM1	0.5	0.9	1.4	0.6	0.9	1.5	0.5	0.9	1.4	0.5	0.8	1.3	0.6	0.9	1.5
NCAR_CCSM3_0	0.5	0.9	1.4	0.5	0.8	1.3	0.5	0.9	1.4	0.6	1.1	1.7	0.5	0.8	1.3
MIROC3_2_hires	**0.6**	**0.9**	**1.5**	**0.6**	**0.9**	**1.5**	**0.5**	**0.9**	**1.4**	**0.6**	**0.9**	**1.5**	**0.6**	**0.9**	**1.5**
MPI_ECHAM5	0.6	1.0	1.6	0.6	1.0	1.6	0.6	1.0	1.6	0.7	1.1	1.8	0.6	0.9	1.5
UKMO_HADCM3	0.6	1.0	1.6	0.6	1.1	1.7	0.6	0.9	1.5	0.6	1.0	1.6	0.6	1.1	1.7
CSIRO_Mark 3.0	0.6	1.1	1.7	0.6	1.0	1.7	0.6	0.9	1.5	0.7	1.2	1.8	0.6	1.1	1.7
CSIRO_Mark 3.5	**0.7**	**1.1**	**1.8**	**0.7**	**1.1**	**1.8**	**0.6**	**1.1**	**1.7**	**0.7**	**1.1**	**1.8**	**0.7**	**1.2**	**1.9**
GFDL_cm2_1	0.7	1.1	1.8	0.6	1.0	1.6	0.7	1.1	1.8	0.7	1.2	1.9	0.7	1.1	1.8
2050 A1B	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
MIUB_echo_g	0.7	1.1	1.8	0.5	0.9	1.4	0.6	1.1	1.7	0.8	1.3	2.0	0.8	1.3	2.1
IAP_FGOALS1_0_g	**0.7**	**1.2**	**1.9**	**0.7**	**1.1**	**1.8**	**0.8**	**1.2**	**2.0**	**0.7**	**1.2**	**1.9**	**0.7**	**1.2**	**2.0**
MIROC3_2_medres	0.8	1.3	2.1	0.7	1.2	2.0	0.8	1.3	2.1	0.9	1.5	2.4	0.7	1.2	1.9
UKMO_HADGEM1	0.9	1.5	2.4	0.9	1.6	2.5	0.9	1.5	2.3	0.8	1.4	2.2	1.0	1.6	2.5
NCAR_CCSM3_0	0.9	1.5	2.4	0.8	1.4	2.2	0.9	1.5	2.4	1.1	1.8	2.9	0.8	1.4	2.2
MIROC3_2_hires	**0.9**	**1.6**	**2.5**	**0.9**	**1.6**	**2.5**	**0.9**	**1.5**	**2.4**	**1.0**	**1.6**	**2.6**	**0.9**	**1.6**	**2.5**
MPI_ECHAM5	1.0	1.7	2.8	1.0	1.7	2.7	1.0	1.7	2.7	1.1	1.9	3.0	1.0	1.6	2.6
UKMO_HADCM3	1.0	1.7	2.8	1.1	1.8	2.9	0.9	1.6	2.5	1.0	1.7	2.8	1.1	1.8	2.9
CSIRO_Mark 3.0	1.1	1.8	2.9	1.1	1.8	2.9	1.0	1.6	2.5	1.2	2.0	3.1	1.1	1.8	2.9
CSIRO_Mark 3.5	**1.1**	**1.9**	**3.0**	**1.1**	**1.9**	**3.0**	**1.1**	**1.8**	**2.9**	**1.1**	**1.9**	**3.0**	**1.2**	**2.0**	**3.2**
GFDL_cm2_1	1.1	1.9	3.0	1.0	1.7	2.8	1.1	1.9	3.0	1.2	2.1	3.3	1.2	1.9	3.1
2050 A1F1	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
MIUB_echo_g	0.8	1.3	2.1	0.6	1.0	1.7	0.8	1.3	2.0	0.9	1.5	2.4	0.9	1.5	2.4
IAP_FGOALS1_0_g	**0.8**	**1.4**	**2.3**	**0.8**	**1.3**	**2.1**	**0.9**	**1.5**	**2.3**	**0.8**	**1.4**	**2.2**	**0.9**	**1.4**	**2.3**
MIROC3_2_medres	0.9	1.6	2.5	0.9	1.4	2.3	0.9	1.6	2.5	1.1	1.8	2.8	0.9	1.4	2.3
UKMO_HADGEM1	1.1	1.8	2.8	1.1	1.9	3.0	1.0	1.7	2.7	1.0	1.6	2.5	1.1	1.9	3.0
NCAR_CCSM3_0	1.1	1.8	2.9	1.0	1.6	2.6	1.1	1.8	2.8	1.3	2.1	3.4	1.0	1.6	2.5
MIROC3_2_hires	**1.1**	**1.8**	**2.9**	**1.1**	**1.9**	**3.0**	**1.0**	**1.7**	**2.8**	**1.1**	**1.9**	**3.0**	**1.1**	**1.9**	**3.0**
MPI_ECHAM5	1.2	2.0	3.2	1.2	2.0	3.2	1.2	2.0	3.2	1.3	2.2	3.6	1.1	1.9	3.0
UKMO_HADCM3	1.2	2.0	3.3	1.3	2.1	3.4	1.1	1.9	3.0	1.2	2.0	3.3	1.3	2.2	3.5
CSIRO_Mark 3.0	1.3	2.1	3.4	1.3	2.1	3.4	1.1	1.9	3.0	1.4	2.3	3.7	1.3	2.2	3.4
CSIRO_Mark 3.5	**1.3**	**2.2**	**3.5**	**1.3**	**2.2**	**3.5**	**1.3**	**2.1**	**3.4**	**1.3**	**2.2**	**3.5**	**1.4**	**2.3**	**3.8**
GFDL_cm2_1	1.3	2.2	3.6	1.2	2.0	3.2	1.3	2.2	3.6	1.4	2.4	3.9	1.4	2.3	3.6

The range in projected annual and summer temperatures from: (i) all 23 of the IPCC 4AR models; and (ii) the 11-member selected subset of models, are compared with the observed historical variability in Figures 3-3 and 3-4, respectively. In contrast to rainfall, the historical variability in temperature is relatively small, and model projections indicate significant and systematic deviations from the present-day climate.

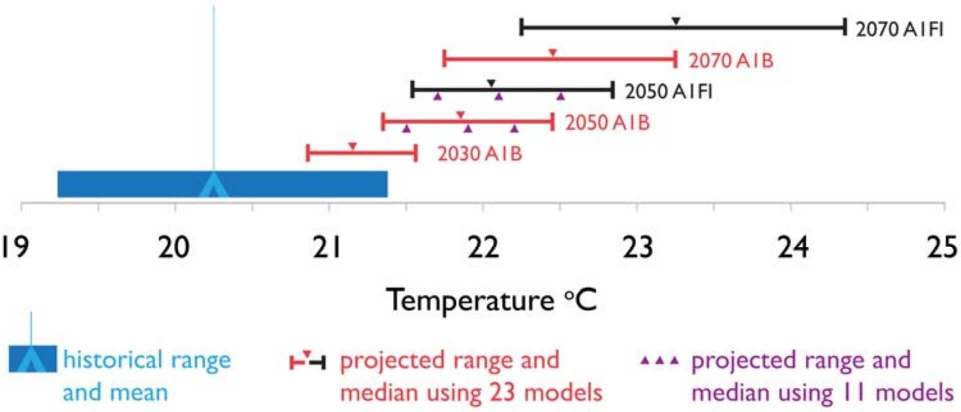

Figure 3-3: Climate change projections for annual average temperature for the Wide Bay-Burnett region. Projections are shown as a median and range (10th and 90th percentiles). Results were derived using data for both the A1B and A1FI emissions scenarios, from: (i) all 23 IPCC 4AR models for (2030, 2050 and 2070); and (ii) the subset of 11 selected models (2050). The observed mean and range (1971–2000) in this region are also shown. Data source: CSIRO & BOM 2007.

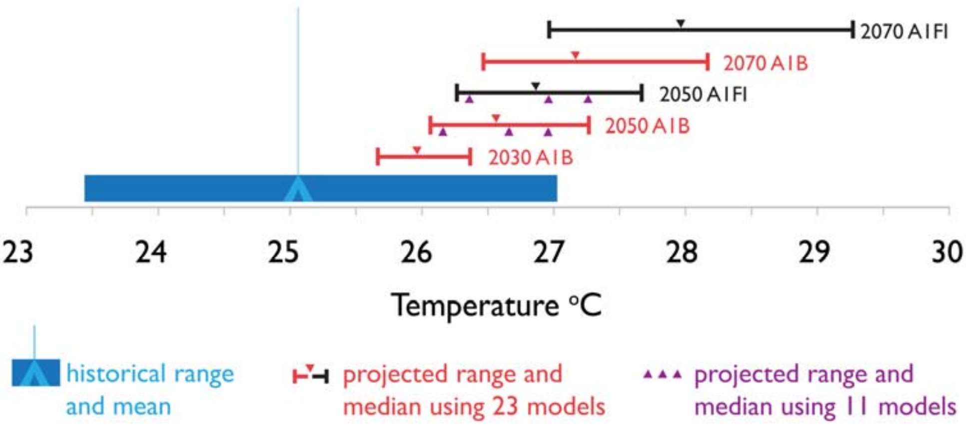

Figure 3-4: Climate change projections for summer average temperature for the Wide Bay-Burnett region. Projections are shown as a median and range (10th and 90th percentiles). Results were derived using data for both the A1B and A1FI emissions scenarios, from: (i) all 23 IPCC 4AR models for (2030, 2050 and 2070); and (ii) the subset of 11 selected models (2050). The observed mean and range (1971–2000) in this region are also shown. Data source: CSIRO & BOM 2007.

3.5 Summary

In this chapter we have presented projections for key climate variables relevant to hydrological modelling of the Wide Bay-Burnett region. The projections were extracted from a subset of IPCC AR4 models which have been shown to provide credible simulations of rainfall in the Australian region. Climate change projections were provided for 2030, based on the A1B emissions scenario, and for 2050, based on the A1FI and A1B emissions scenarios. The A1B and A1FI emissions scenarios were chosen as they track the current actual emissions more closely than the other major SRES scenarios. Again it should be noted that in recent years actual emissions have been higher than those predicted by both the A1FI and A1B scenarios (see Figure 2-3). It is essential to understand that if emissions continue to track higher than those predicted under the A1FI scenario, then the accompanying climate projections may significantly underestimate the impact of climate change.

The projections tabulated in this chapter (Tables 3-1 to 3-3) usually have a narrower range of uncertainty (as represented by the 10th and 90th percentile values) than those previously derived using all 23 of the IPCC AR4 models (see Table 2-1). A comparison of projections derived from the full set of IPCC AR4 models and those derived from the subset of 11 models is shown in Table 3-4.

Table 3-4: Comparison of climate change projections derived from all 23 IPCC 4AR models with data derived from the subset of models (assuming medium sensitivity) identified for hydrological modelling. Data are presented for annual rainfall and temperature in 2030 (A1B emissions scenario) and 2050 (A1B and A1FI emissions scenarios) for the Wide Bay-Burnett region. The projections are shown as changes in rainfall (%) and temperature (°C) relative to the 1980–1999 model base period.

	10th Percentile	Median	90th Percentile
Annual rainfall: 2030			
11 selected models: A1B	-9%	-3%	0%
23 4AR models: A1B	-12%	-3%	+5%
Annual surface temperature: 2030			
11 selected models: A1B	+0.7 °C	+0.9 °C	+1.1 °C
23 4AR models: A1B	+0.6 °C	+0.9 °C	+1.3 °C
Annual rainfall: 2050			
11 selected models: A1B	-15%	-5%	-1%
23 4AR models: A1B	-19%	-5%	+9%
11 selected models: A1FI	-17%	-6%	-1%
23 4AR models: A1FI	-22%	-6%	+10%
Annual surface temperature: 2050			
11 selected models: A1B	1.2 °C	1.6 °C	1.9 °C
23 4AR models: A1B	1.1 °C	1.6 °C	2.2 °C
11 selected models: A1FI	1.4 °C	1.8 °C	2.2 °C
23 4AR models: A1FI	1.3 °C	1.8 °C	2.6 °C

A number of conclusions can be drawn from the comparison of the projections from the two sets of models. Firstly, projections from the subset of models display similar median values as those from the full set of models, but narrower ranges. Secondly, there is greater agreement between the two sets of temperature projections, as compared to the two sets of rainfall projections, consistent with the assertion that there is more confidence in temperature projections than in rainfall projections. Thirdly, projections from the subset of models indicate: (i) a lower likelihood of rainfall increasing; and (ii) smaller decreases in rainfall, compared to the projections based on all 23 of the IPCC 4AR models.

In general, model projections for temperature indicate a significant and systematic shift towards warmer conditions, which lie outside the range observed historically. In contrast, the projected changes in rainfall are within the range of observed historical variability.

It should also be noted that there is more confidence in broad scale average projections than in local projections (IPCC 2007). In addition, there is more uncertainty about climate change projections for 2050, than about those for 2030, as the uncertainty relating to emissions scenarios is known to increase with time (CSIRO & BOM 2007).

4. Climate change impacts and implications

4.1 Introduction

The climate change projections in the preceding chapters indicated that rainfall in the coming decades may be significantly reduced under the scenarios considered. To identify the potential implications that a reduction in rainfall may have on the Wide Bay-Burnett region, a workshop was held in Brisbane on the 26th of June 2008. At this workshop, future climate change projections were presented to a panel of experts representing government and stakeholder groups. The workshop was coordinated by Mr. Paul Hope (Queensland Department of Natural Resources and Water), and this chapter records the outcomes arising from the workshop.

The QCCCE had provided NRW with climate change projections to support hydrological modelling of the Wide Bay-Burnett region. The purpose of the workshop was to review the results of the hydrological studies, and given that background, consider the potential implications of climate change for various sectors within the region. The desired outcome from the modelling was an approximate measure of reductions in inflow to regional water storages under median changes in rainfall and potential evapotranspiration by 2050, for the A1FI emissions scenario.

4.2 Climatic effects on water supplies

Climate change impact studies are important in identifying the possible risks and benefits associated with climate change, so that adaptation and mitigation strategies can be developed. Several studies have already been completed on the effects of climate change on run-off (and thus water resources) including those by Chiew (2006), Durack et al. (2005), Jones and Durack (2005) and Hennessy (2003). The main implication for changes in rainfall is that there is a non-linear effect on runoff. For example, a 10% reduction in rainfall can lead to a 30% reduction in runoff (Chiew 2006). Likewise, a 10% change in forest cover can result in a 40 mm change in water yield (coniferous and eucalypt cover types; Bosch and Hewlett 1982). Changes in temperature also directly affect evaporation from soil and water stores, plant water use and human consumption. All of these factors can reduce inflows into water storages, which in turn raises the prospect of water resources being over-allocated.

It is difficult to prepare future projections of water balances due to the uncertainties involved in predicting climatic and anthropogenic responses to climate change adaptation and mitigation strategies. For example, it is important to note that there is a considerable time-lag between CO_2 emissions and the resulting global average CO_2 concentration. In addition, most current projections are based on the two highest SRES emission scenarios; however the reality is that actual emissions are already tracking above the highest SRES emissions scenario (A1FI). It was therefore advised that the projections contained in this report be revised in five years to reflect updated climatic and hydrological modelling outputs. Such an update may enable the inclusion of outputs generated by newer, high resolution GCMs using updated emissions scenarios. Currently, most GCMs operate on a 100 to 200 km horizontal grid, thereby missing the substantial effects that topography and land cover heterogeneity can have on local wind speeds and mesoscale air circulations.

4.3 Summary of changes per sector

4.3.1 Urban/Residential use

Projections for the Wide Bay-Burnett region include a decline in rainfall, along with increases in temperature and evapotranspiration. Such changes could potentially lead to increased use of air conditioners in residential homes. In addition, there may be an increase in the use of private swimming pools to reduce the discomfort resulting from hotter and longer summer periods, leading to additional evaporation from pool surfaces, and hence more water being used to maintain them. While domestic rainwater tanks may help alleviate pressures on major water storages, the possibilities of reduced rainfall, greater variability in rainfall, and more prolonged periods between rainfall events, could together make rainwater tanks an insecure source of water.

4.3.2 Commercial use

Projected increases in surface temperature may result in increased use of evaporative cooling systems in commercial buildings. Increased evapotranspiration may also contribute to increased water demand, as playing fields and golf courses may require more water in order to be maintained to acceptable conditions.

4.3.3 Industrial use

Water use in cooling towers at major industrial sites may also increase, due to the extra load on equipment incurred through increased air temperatures. Furthermore, the incoming water temperature may be higher, imposing a need to cool the water further than at present.

Consequently, power demand may increase due to the enhanced need for cooling across all sectors.

4.3.4 Agricultural use

The IPCC's 4AR (Hennessy et al. 2007b; IPCC 2007a) acknowledged that the Australian agriculture sector has a high level of vulnerability to climate change. Climate change is very likely to have a number of negative impacts on agriculture, including the volume and quality of produce, the reliability of production systems, and the natural resource base on which it depends (Stokes et al. 2008). Adapting to such changes will require the development of a suitable and comprehensive range of strategies.

Within the agricultural sector there are many factors, other than climate variability and change, which can also contribute to either an increase or decrease in demand for water. These include:

- changing land use, such as urban encroachment
- competing water consumer demands, such as industrial and mining developments
- changes in domestic and international trade policies which impact on economic viability, and
- changes in government policy.

Existing climate change adaptation strategies for the agricultural sector may also contribute to changing water demands. These include:

- developments in biotechnology and plant breeding, aimed at developing climate change-resilient species, such as drought tolerant crop varieties
- improved farming practices such as controlled traffic, minimum tillage and trash/stubble retention systems
- improved irrigation efficiency, through the development of economical on-farm delivery systems, optimisation of irrigation scheduling and reductions in water seepage and evaporation losses from storage and delivery channels, and
- use of seasonal climate forecasting systems to manage production and supply risks.

An increase in the atmospheric concentration of carbon dioxide has the potential to increase photosynthesis and water use efficiency, which may result in higher crop yields. However, such benefits may be offset by declines in rainfall and increases in temperature and/or atmospheric evaporative demand (McRae et al 2007). Additional research is required to investigate the combined effects of reduced water availability, higher temperatures, increased evaporative demand and higher concentrations of atmospheric greenhouse gases on plant physiology in Australia (McRae et al 2007).

At present it is difficult to accurately determine how the agricultural sector's demand on water supply may change in the future, as a result of climate change. Furthermore, insufficient research has been undertaken to critically evaluate the economic costs and benefits of differing adaptation strategies. It can therefore be argued that currently, the best option available to manage climate change in any production system is to improve its resilience, sustainability and profitability. It is irrelevant whether changes in management systems and water use are driven by climate change, or the need to remain economically viable, so long as suitable options are developed (McRae 2007).

4.4 Estimated change in water demand for the Wide Bay-Burnett Region

The potential impacts of 'likely' climate change on water balances in the Wide Bay-Burnett region are summarised in Tables 4-1 and 4-2. The workshop participants considered the A1FI emissions scenario to be the most likely outcome of all the emissions scenarios considered, and consequently the data in Tables 4-1 and 4-2 were derived using the median (50th percentile) climate projections for 2050, based upon the A1FI emissions scenario. Under this scenario, annual average rainfall is projected to decrease by approximately 53mm, annual average temperature is projected to increase by 1.8^{o}C, and annual average evapotranspiration is projected to increase by 110mm (see Tables 2-1, 3-2 and 3-4).

Table 4-1: Estimated impact of climate change on urban water demand in 2056.

Sector	Potential % change in demand	Proportion of total demand affected	Overall % change in demand
Residential	+15% to +25%	35%	+5.3% to +8.8%
Commercial	+15% to +25%	15%	+2.3% to +3.8%
Industrial	+15% to +25%	15%	+2.3% to +3.8%

Table 4-2: Estimated impact of climate change on rural water demand in 2056.

Sector	Crop	% change in demand
Agricultural	Sugarcane - including efficiency gains - no efficiency gains	 -10% per ha +10% per ha
	Vegetables	+5% per ha
	Grains	+7% per ha
	Tree crops	Negligible

The estimated potential impacts of climate change on surface water flows in the Burrum River catchment are as follows:

- An average change of -15% for inflows into Lenthalls Dam (ranging from -39% to +17%)
- An average change of -17% for end of system flows of the Burrum River (ranging from -43% to +18%).

Urban Sector

Climate change is expected to place upward pressure on a proportion of urban residential water demand (particularly external discretionary water use), with approximately 35% of total residential consumption being affected. A 1.8°C warming will likely increase demand from the affected component by 15 to 25%, predominantly due to extra cooling, evaporative losses from swimming pools and the watering of gardens. Current urban residential water use in the Wide Bay-Burnett region is approximately 270 L/person/day, representing about 35% of total urban/reticulated water consumed within the region. The net result is estimated to be an increase in demand of up to 8.8% by 2056 (Table 4-1).

About 15% of the current regional water demand for the commercial sector is likely to be impacted by climate change. The demand in this area is projected to increase by 15 to 25%, due to additional water use on golf courses, parks and gardens, and for evaporative cooling. Commercial water use accounts for about 25% of the total urban/reticulated water consumed within the region. The net result is estimated to be an overall 3.8% increase in demand from the commercial sector by 2056 (Table 4-1).

Similarly, about 15% of the current regional water demand for the industrial sector is likely to be affected by climate change. Demand from this component is projected to increase by 15 to 25%, due to additional water that will be needed by cooling towers at major industrial sites (such as Tarong Power Station), and the operation of sugar mills. Industrial water use accounts for about 15% of the total urban/reticulated water used within the region. The net result is estimated to be an overall 3.8% increase in demand from the industrial sector by 2056 (Table 4-1).

Rural Sector

The workshop participants considered it unlikely for there to be any great change in the area of irrigated tree crops e.g. fruit trees. Industry trends would however, depend on the impact of the likely introduction of a carbon Emissions Trading Scheme (ETS) by the Federal Government. Furthermore, the participants considered that the effects of any such scheme were likely to impact on all of Queensland's irrigation regions.

The area planted with sugarcane is likely to decline, leading to reduced water consumption by this crop (Park et al 2007). The water demands from vegetable crops are about 10% those of sugar cane, and consequently, it is expected that there will be increase in area planted with vegetable crops. Water demand from vegetable crops is therefore estimated to increase by 5%. Grain crops are likely to show an approximate 7% increase in water demand, due to increased temperatures throughout the winter months, and decreases in spring rainfall. The changes in demand for the rural sector are summarised in Table 4-2.

The total impact of climate change on the regional water balance by 2056 can therefore be summarised as follows:

Supply: a 15% decrease in yield from existing surface storages.

Demand: a 7.5% increase in urban demand and a 10% increase in rural demand.

4.5 Summary

The uncertainty associated with both climatic events and potential changes in their seasonality and longer-term patterns, means that 'level of service' (water availability) from major storages may become more uncertain. This leads to possible future scenarios where the level of service provided includes uncertainty in water balances, and thus uncertainty in the security of water entitlements available to the various sectors.

To improve water planning, NRW, in conjunction with the QCCCE, have developed a methodology for undertaking systematic hydrological modelling which includes the effects of climate change on regional water supplies. The Integrated Quality and Quantity Modelling (IQQM) system will be used to model hydrological responses based on a stochastic 'probability' approach using 'low', 'medium' and 'high' climate change scenarios, and demand will be assessed against performance indicators for both current and future demand scenarios.

Bibliography

Abbs, D.J., Ayral, S., Campbell, E., McGregor, J.L., Nguyen, K.C., Palmer, M., Rafter, A.S., Watterson, I.G. & Bates, B.C. 2006: *Projections of extreme rainfall and cyclones: final report to the Australian Greenhouse Office*. C/0971.CSIRO Marine and Atmospheric Research, Aspendale, Australia. 97 pp.

Alexander, L., Hope, P., Collins, D., Trewin, B., Lynch, A. & Nicholls, N. 2007: Trends in Australia's climate means and extremes: a global context. *Australian Meteorological Magazine*, 56, 1-18.

Australian Bureau of Meteorology 2008: Cyclone information website. See http://www.BOM.gov.au/weather/cyclone/tc-trends.shtml.

Australian Bureau of Statistics (ABS) 2007: *Australian demographic statistics, Sep 2007*. Catalogue Number 3101.0, Australian Bureau of Statistics, Canberra, Australia.

Bosch, J. M. & Hewlett, J. D. 1982: A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology*, 55(1-4), 3-23.

Charles, S.P., Bari, M., Kitsios A. & Bates, B.C. 2007: Effect of GCM bias on downscaled precipitation and runoff projections for the Serpentine Catchment, Western Australia. *International Journal of Climatology*, 27, 1673-1690.

Chiew, F.H.S. 2006: *An overview of methods for estimating climate change impact on runoff*. 30th Hydrology and Water Resources Symposium, Launceston, Tasmania, December 2006.

Collins, D.A., Della-Marta, P.M., Plummer, N. & Trewin, B.C. 2000: Trends in annual frequencies of extreme temperature events in Australia. *Australian Meteorological Magazine*, 47, 277-292.

CSIRO & Bureau of Meteorology (CSIRO & BOM), 2007: *Climate change in Australia – technical report 2007*, Pearce, K.B., Holper, P.N., Hopkins, M., Bouma, W.J., Whetton, P.H., Hennessy, K.J. & Power, S.B. (eds). CSIRO and Australian Bureau of Meteorology. 140 pp. See http://www.climatechangeinaustralia.gov.au.

Durack, P., Jones, R., Page, C. & Ricketts, J. 2005: *Climate change impacts on the water resources of the Fitzroy Basin*. In "Climate Change in Queensland under enhanced greenhouse conditions. Final Report 2004-2005", CSIRO and Australian Bureau of Meteorology. 81 pp.

Fitzmaurice, L. & Beswick, A. 2005: *Sensitivity of the FAO56 crop reference evapotranspiration to different input data*. Queensland Department of Natural Resources and Mines, Brisbane, 16pp.

Garnaut, R. 2008: *Garnaut climate change review. Final Report*. Cambridge University Press, Melbourne. See http://www.garnautreview.org.au.

Guilyardi, E., Slingo, J., Cole, J., Delecluse, P., Gualdi, S., Navarra, A., Madec, G., Roberts, M., Latif, M. and Terray, L. 2004: Representing El Niño in coupled ocean atmosphere GCMs: the dominant role of the atmosphere component. *Journal of Climate*, 17, 4623-4629.

Hennessy, K. 2003: Climate change and its projected effects on water resources. In: *Water the Australian dilemma*, Proceedings of the 2003 Invitation Symposium: water - the Australian dilemma, Australian Academy of Technological Sciences and Engineering. Melbourne, pp 174-191.

Hennessy, K., Colman, R., Watterson, I.G. & Jones, R. 2007a: Global climate change projections. In: *Climate change in Australia –technical report 2007.* K.B. Pearce, P.N. Holper, M. Hopkins, W.J. Bouma, P.H. Whetton, K.J. Hennessy & S.B. Power (eds). CSIRO and Australian Bureau of Meteorology, pp 36-48.

Hennessy, K., Fitzharris, B., Bates, B.C., Harvey, N., Howden, S.M., Hughes, L.S.J. & Warrick, R. 2007b: In *Climate change 2007 - impacts, adaptation and vulnerability - contribution of Working Group II to the Fourth Assessment Report of the International Panel on Climate Change*. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., & and Hanson, C.E. (eds). Cambridge University Press, Cambridge.

Hennessy, K.J., Suppiah, R. & Page, C.M. 1999: Australian rainfall changes, 1910-1995. *Australian Meteorological Magazine*, 48, 1-13.

Intergovernmental Panel on Climate Change (IPCC) 2007a: *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Pachauri, R.K & Reisinger, A.(eds). IPCC, Geneva, Switzerland, 104 pp.

Intergovernmental Panel on Climate Change (IPCC) 2007b: *Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., & Miller, H.L. (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Jeffrey, S., Carter, J., Moodie, K. & Beswick, A. 2001: Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling and Software*, 16, 309-330.

Jones, D. & Durack, K. 2005: *Estimating the impacts of climate change on Victoria's runoff using a hydrological sensitivity model.* CSIRO Atmospheric Research, Aspendale, Australia.

Jovanovic, B., Jones, D.A. & Collins, D. 2008: A high quality monthly pan evaporation dataset for Australia. *Climatic Change*, 87(3-4), 517.

Leslie, L.M., Karoly, D.J., Leplastrier, M. & Buckley, B.W. 2007: Variability of tropical cyclones over the southwest Pacific Ocean using a high-resolution climate model. *Meteorology and Atmospheric Physics*, 97(1-4), 171-180.

Local Government Association of Queensland (LGAQ). 2007: *Adapting to climate change: a Queensland local government guide*. Local Government Association of Queensland, Brisbane.

Local Government, Planning, Sport and Recreation (LGPSR) 2007: *Wide Bay-Burnett Regional Plan 2007–2026: The principal regional strategy for guiding growth and sustainability in the Wide Bay-Burnett region.* Department of Local Government, Planning, Sport and Recreation, Queensland Government, Brisbane, 118 pp.

Lough, J. M. 1991: Rainfall variations in Queensland, Australia 1891-1986. *International Journal of Climatology*, 11, 745-768.

Lough, J.M. 1997: Regional indices of climate variation: Temperature and rainfall in Queensland, Australia. *International Journal of Climatology*, 17, 55-66.

Maxino, C.C., McAvaney, B.J., Pitman, A.J. & Perkins, S.E. 2007: Ranking the AR4 climate models over the Murray-Darling Basin using simulated maximum temperature, minimum temperature and precipitation. *International Journal of Climatology*, 28(8), 1097-1112.

McAlpine C.A., Syktus, J., Deo, R.C., Lawrence, P.J., McGowan, H.A., Watterson, I.G. & Phinn, S.R. 2007: Modelling the impact of historical land cover change on Australia's regional climate. *Geophysical Research Letters*, 34, 1-6.

McRae, D., G. Roth, and M. Bange. 2007: *Climate change in cotton catchment communities - A scoping study*. Cotton Catchment Communities CRC, for the Australian Greenhouse Office, Department of Environment and Heritage, Canberra.

Meneghini, B., Simmonds, I. & Smith, I.N. 2007: Association between Australian rainfall and the Southern Annular Mode. *International Journal of Climatology*, 27, 109-121.

Meyers, G., McIntosh, P., Pigot, L. & Pook, M. 2007: The years of El Niño, La Niña and interactions with the tropical Indian Ocean. *Journal of Climate*, 20, 2872-2880.

Min, S-K., Legutke, S., Hense, A. & Kwon, W-T. 2005: Internal variability in a 1000-year control simulation with the coupled climate model ECHO-G - II. El Niño Southern Oscillation and North Atlantic Oscillation. *Tellus A*, 57(4), 622-640.

Moise, A.F., Colman, R.A., Zhang H. 2005: Coupled model simulations of current Australian surface climate and its changes under greenhouse warming: an analysis of 18 CMIP2 models. *Australian Meteorological Magazine*, 54, 291-307.

Mpelasoka, F., Collier, M., Suppiah, R. & Pena Arancibia, J. 2007a: Application of Palmer drought severity index to observed and enhanced greenhouse conditions using CSIRO Mk3 GCM simulations, Proceedings of *MODSIM 2007 International Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, Christchurch, New Zealand, pp 539-545.

Mpelasoka, F., Hennessy, K., Jones, R. & Bates, B. 2007b: Comparison of suitable drought indices for climate change impacts assessment over Australia towards resource management. *International Journal of Climatology*, 28(10), 1283–1292.

Natural Resources and Water (NRW) 2007a: *ClimateSmart 2050 – Queensland Climate Change Strategy 2007*: *a low-carbon future*. Queensland Department of Natural Resources and Water, Queensland Government, Brisbane, 36pp.

Natural Resources and Water (NRW) 2007b: *ClimateSmart adaptation 2007–12: an action plan for managing the impacts of climate change.* Queensland Department of Natural Resources and Water, Queensland Government, Brisbane, 28pp.

Nicholls, N., Landsea, C. & Gill, J. 1998: Recent trends in Australian region tropical cyclone activity. *Meteorological Atmospheric Physics*, 65, 197–205.

Nicholls, N. 2004: The changing nature of Australian droughts. *Climatic Change*, 63, 323-336.

Nicholls, N. 2006: Detecting and attributing Australian climate change: a review. *Australian Meteorological Magazine*, 55, 199-211.

OzClim, 2008: CSIRO software tool for "Exploring climate change scenarios for Australia". See http://www.csiro.au/ozclim..

Park, S., Howden, M., Higgins, A., McRae, D., Horan, H. and Hennessy, K. 2007: Climate change: informing the Australian sugar industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D. In the final report of projects CSE019 and SRD011 by Park, S., Creighton, C. and Howden, M., Sugar Research and Development Corporation.

Parson, E., Burkett, V., Fisher-Vanden, K., Keith, D., Mearns, L., Pitcher, H., Rosenzweig, C. & Webster, M. 2007: Global change scenarios: their development and use. *Sub-report 2.1B, Synthesis and Assessment Product 2.1*, U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Energy, Office of Biological and Environmental Research, Washington, D.C., USA, 106 pp.

Perkins, S.E., Pitman, A.J., Holbrook N.J. & McAveney, J. 2007: Evaluation of the AR4 climate models: simulated daily maximum temperature, minimum temperature and precipitation over Australia using probability density functions. *Journal of Climate*, 20, 4356-4376.

Pittock, B. (ed.) 2003: *Climate change: an Australian guide to the science and potential impacts.* Australian Greenhouse Office, Canberra.

Plummer, N., Salinger, M.J., Nicholls, N., Suppiah, R., Hennessy, K.J., Leighton, R.M., Trewin, B., Page, C.M. & Lough, J.M. 1999: Changes in climate extremes over the Australian region and New Zealand during the twentieth century. *Climatic Change*, 42, 183-202.

Preston, B.L. 2007: Applications of climate projections in impacts and risk assessments. In: *Climate change in Australia –technical report 2007*. K.B. Pearce, P.N. Holper, M. Hopkins, W.J. Bouma, P.H. Whetton, K.J. Hennessy & S.B. Power (eds). CSIRO and Australian Bureau of Meteorology, pp 108-123.

Preston, B.L. & Jones, R.N. 2008: Evaluating sources of uncertainty in Australian runoff projections. *Advances in Water Resources*, 31(5), 758-775.

Program for Climate Model Diagnosis and Intercomparison (PCMDI) 2008: See http://www-pcmdi.llnl.gov/.

Queensland Climate Change Centre of Excellence (QCCCE) 2007: *The South East Queensland Drought to 2007,* Queensland Department of Natural Resources and Water, Queensland Government, Brisbane, 7pp.

Raupach, M., Briggs, P., King, E., Paget, M. & Trudinger, C. 2007: Trends in Australian water availability. *Proceedings of Greenhouse 2007*, CSIRO and Australian Bureau of Meteorology , Sydney.

Rayner D., Wall, C., Willcocks, J., Barley, R. & Prior, K. 2007: Chapter 3 in: *State of the environment, Queensland 2007.* Environmental Protection Agency, Queensland Government, Brisbane.

Reichler, T. & Kim, J. 2008a: How well do coupled models simulate today's climate? *Bulletin of the American Meteorological Society*, 89, 303-311.

Reichler, T. & Kim, J. 2008b: Uncertainties in the climate mean state of global observations, reanalyses, and the GFDL climate model. *Journal of Geophysical Research*, 113, D05106, DOI: 10.1029/2007JD009278.

Ricketts, J.H. & Page, C.M. 2007: A web-based version of OzClim for exploring climate change impacts and risks in the Australian region. Proceedings of *MODSIM 2007 International Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, Christchurch, New Zealand, pp 560-566.

Roderick, M.L. & Farquhar, G.D. 2004: Changes in Australian pan evaporation from 1970 to 2002. *International Journal of Climatology*, 24, 1077-1090.

SILO database 2008: Queensland Environmental Protection Agency, Queensland Government, Brisbane. See http://www.nrw.qld.gov.au/silo and references therein.

Smith, I. 2004: An assessment of recent trends in Australian rainfall. *Australian Meteorological Magazine,* 53, 163-173.

Smith, I. & Chandler, E. 2008: *Refining rainfall projections for the Murray Darling Basin of south-east Australia: the effect of sampling model results based on performance.* Submitted.

Stokes, C.J., Howden, S.M, Gifford, R.G, Meinke, H., Bange, M., McRae, D., Roth, G., Gaydon, D., Beecher, H.G., Reinke, R., Crimp, S., Park, S., Inman-Bamber, G., Webb, L., Barlow, E.W.R., Hennessy, K., Whetton, P.H., Booth, T.H., Kirschbaum, M.U.F., Battaglia, M., Stone, G., Cobon, D., Ash, A., McKeon, G., Miller, C.J., Jones, R.N., Hobday, A. J., and Poloczanska, E. S. 2008, *An overview* *of Climate change adaptation in Australian primary industries – impacts, options and priorities*, Prepared for Land and Water Australia by the CSIRO Climate Adaptation National Research Flagship. CSIRO, Canberra.

Stone, R., Nicholls, N. & Hammer, G. 1996: Frost in northeast Australia: trends and influences of phases of the southern oscillation. *Journal of Climate*, 9, 1896-1909.

Sturman, A.P. & Tapper, N.J. 1996: *The weather and climate of Australia and New Zealand.* Oxford University Press, Melbourne, 476 pp.

Suppiah, R. & Hennessy, K.J. 1998: Trends in total rainfall, heavy rain events and number of dry days in Australia, 1910–1990. *International Journal of Climatology*, 18, 1141-1164.

Suppiah, R., Hennessy, K.J. & Whetton, P.H. 2007a: A comparison of Australian climate change projections based on IPCC TAR and AR4 climate model simulations. Proceedings of *MODSIM 2007 International Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, Christchurch, New Zealand, pp 518-524.

Suppiah, R., Hennessy, K.J., Whetton, P.H., McInnes, K., Macadam, I., Bathols, J., Ricketts, J. & Page, C.M. 2007b: Australian climate change projections derived from simulations performed for the IPCC 4th Assessment Report. *Australian Meteorological Magazine*, 56, 131-152.

Tapper, N. & Hurry, L. 1993: *Australia's weather patterns: an introductory guide.* Dellasta Pty Ltd, Mt Waverley, Australia, 130 pp.

Thompson, D.W. & Wallace, J.M. 2000: Annular modes in the extratropical circulation. Part 1: month-to-month variability. *Journal of Climate*, 13, 1000-1016.

Van Oldenborgh, G.J., Philip, Y.S. & Collins, M. 2005: El Niño in a changing climate: a multi-model study. *Ocean Science*, 1, 81-95.

Watterson, I.G. 1996: Non-dimensional measures of climate model performance. *International Journal of Climatology*, 16, 379-391.

Watterson, I.G., Whetton, P., Moise, A., Timbal, B., Power, S., Arblaster, J. & McInnes, K. 2007: Regional climate change projections. In: *Climate change in Australia –technical report 2007*. K.B. Pearce, P.N. Holper, M. Hopkins, W.J. Bouma, P.H. Whetton, K.J. Hennessy & S.B. Power (eds). CSIRO and Australian Bureau of Meteorology, pp 49-107.

Whetton, P., MacAdam, I., Bathols, J. & O'Grady, J. 2007: Assessment of the use of current climate patterns to evaluate regional enhanced greenhouse response pattern of climate models. *Geophysical Research Letters*, 34, L14701, DOI: 10.1029/2007GL030025, 2007.

Appendix A: Ancillary datasets for temperature

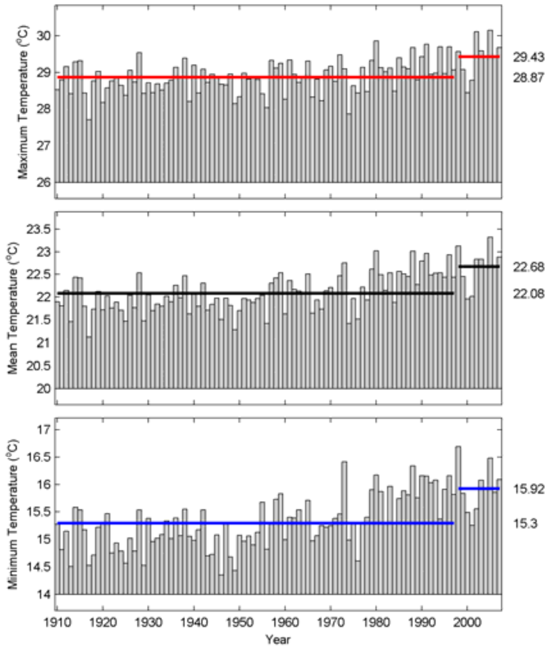

Figure A-1: Annual minimum (bottom), mean (middle) and maximum (top) temperatures during the 1910–2007 period for Australia. The horizontal lines show the average for last decade (1998–2007) compared to the average over the 1910–1997 period. The numbers on the right are the means for the 1910–1997 (bottom) and 1998–2007 (top) periods. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

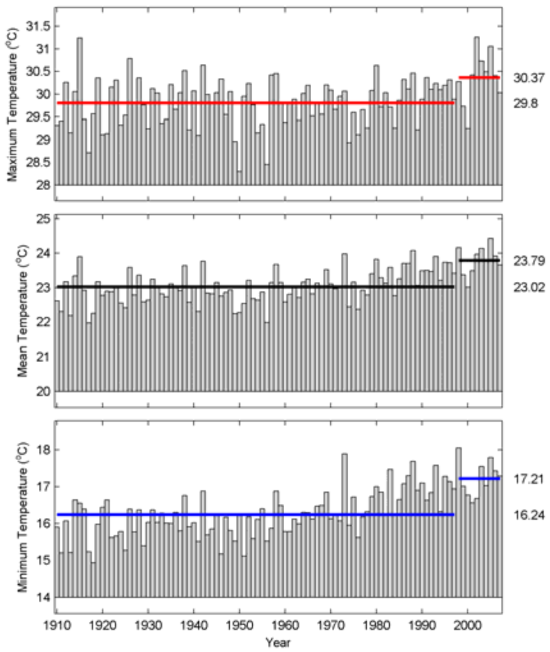

Figure A-2: Annual minimum (bottom), mean (middle) and maximum (top) temperatures during the 1910–2007 period for Queensland. The horizontal lines show the average for last decade (1998–2007) compared to the average over the 1910–1997 period. The numbers on the right are the means for the 1910–1997 (bottom) and 1998–2007 (top) periods. Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

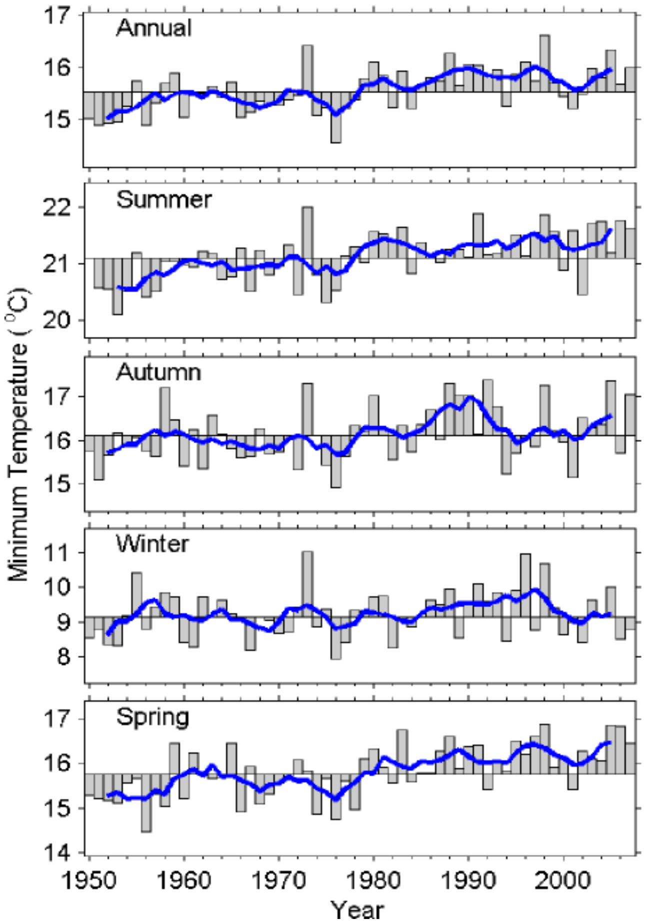

Figure A-3: Annual and seasonal minimum temperatures during the 1950–2007 period for Australia. The blue line shows the five-year running average. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

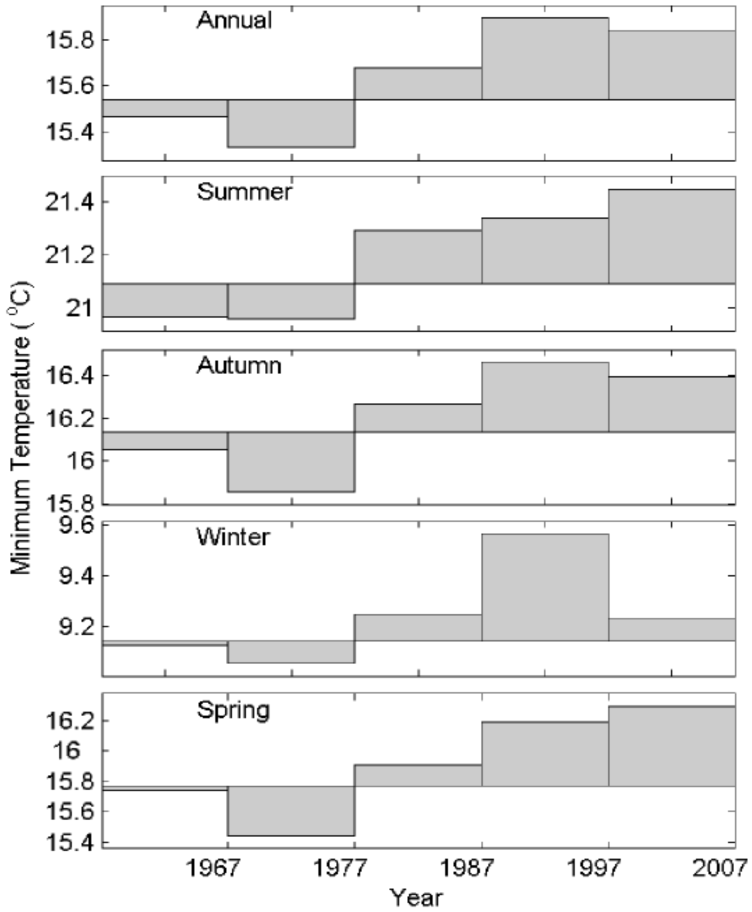

Figure A-4: Decadal average annual and seasonal minimum temperatures during the 1957–2007 period for Australia. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

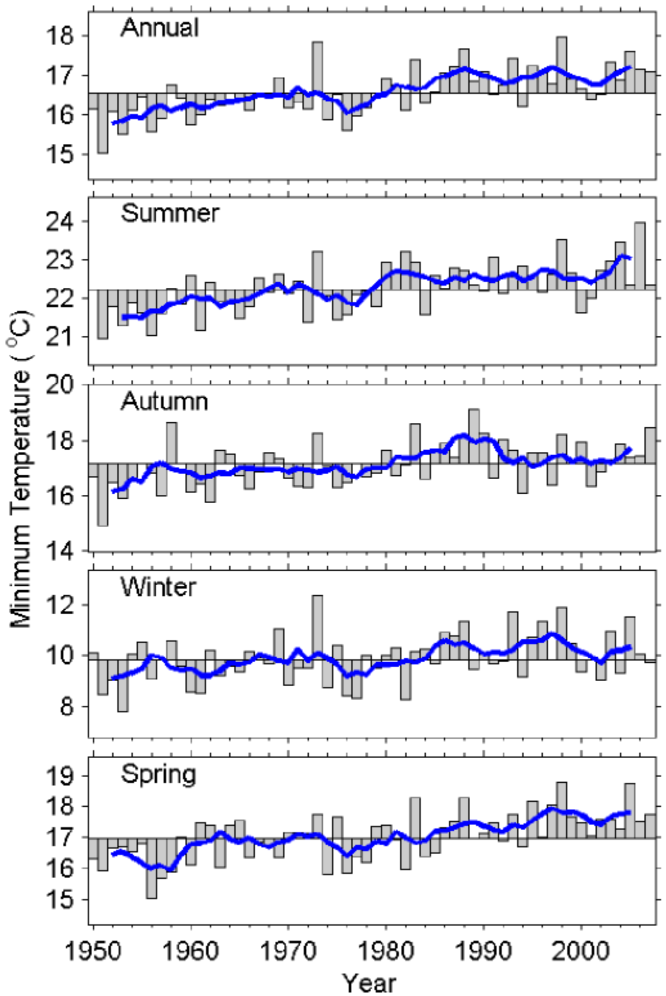

Figure A-5: Annual and seasonal minimum temperatures during the 1950–2007 period for Queensland. The blue line shows the five-year running average. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

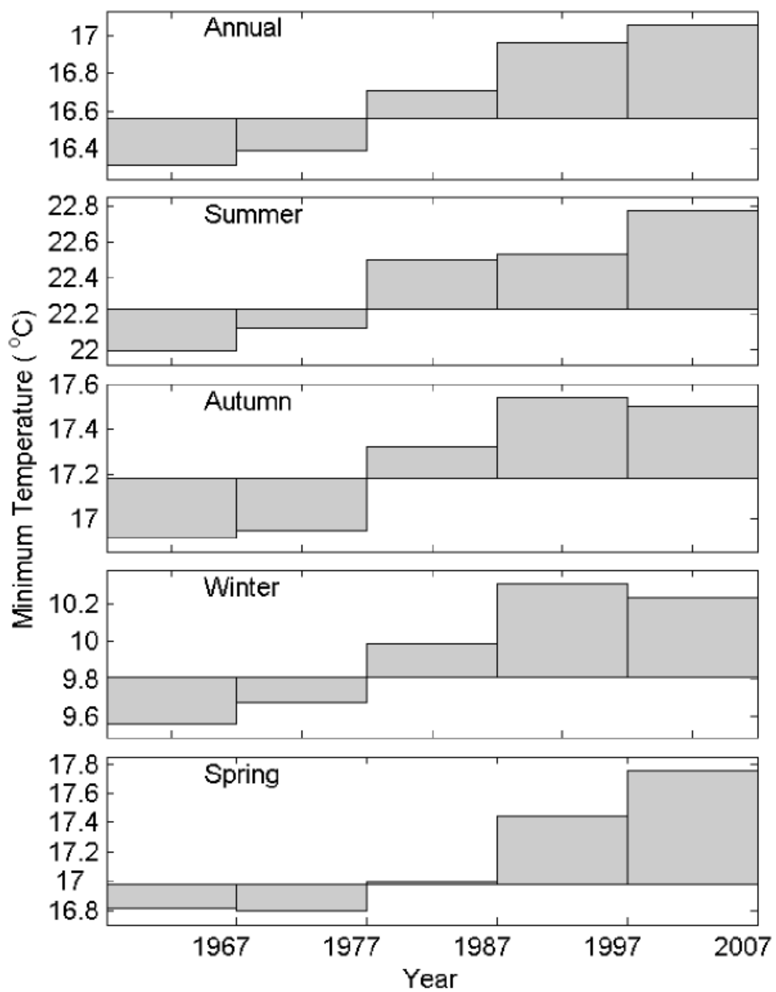

Figure A-6: Decadal average annual and seasonal minimum temperatures during the 1957–2007 period for Queensland. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

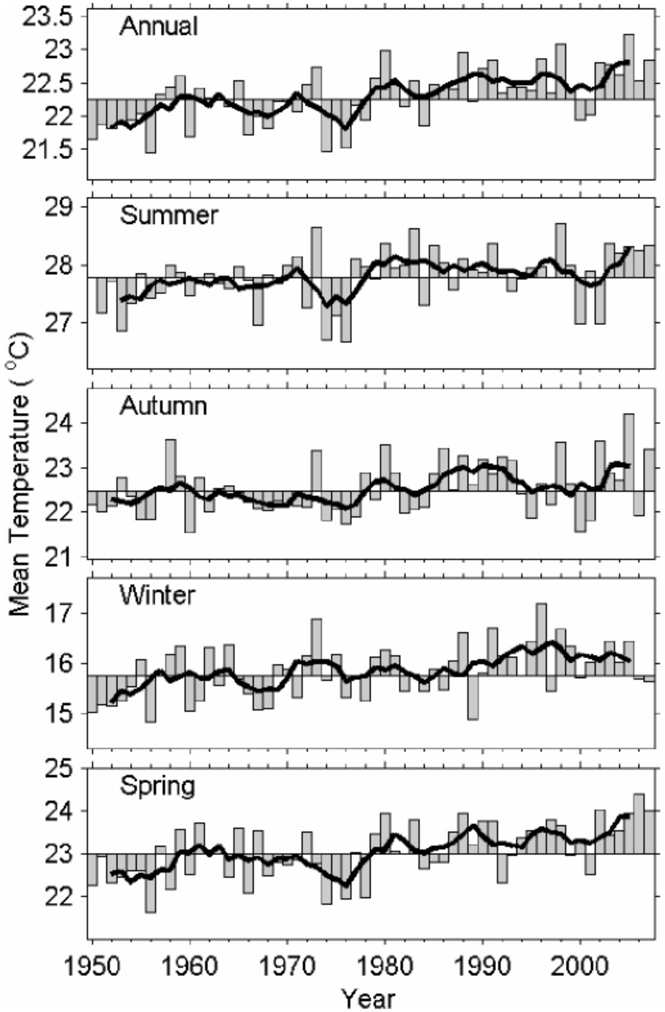

Figure A-7: Annual and seasonal mean temperatures during the 1950–2007 period for Australia. The black line shows the five-year running average. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

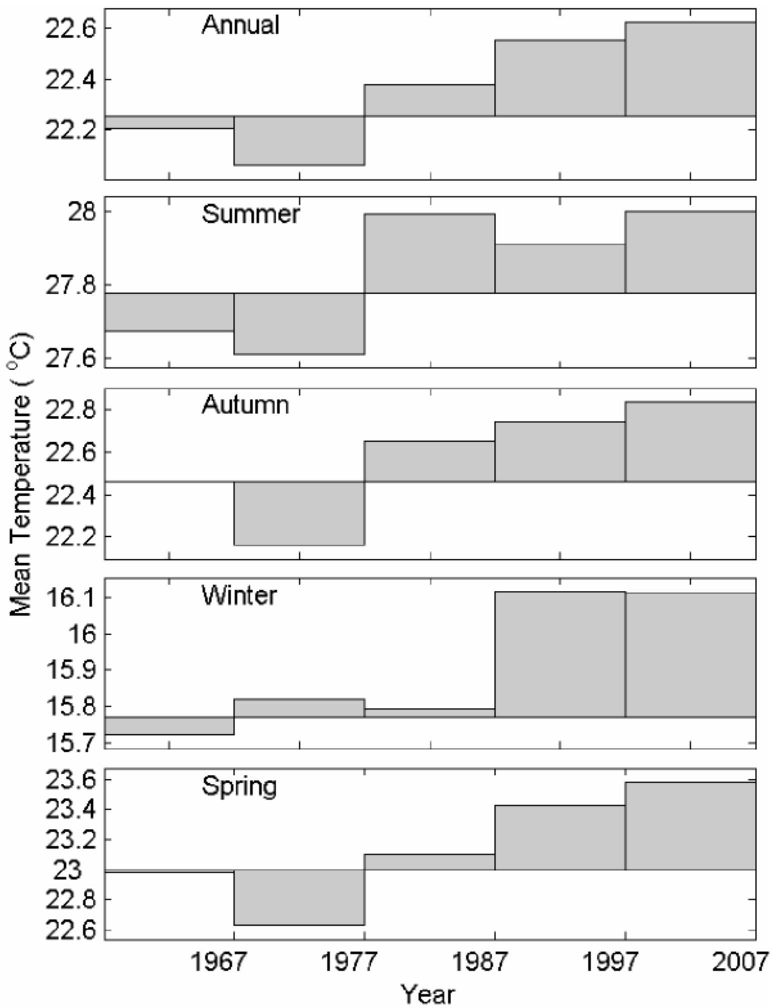

Figure A-8: Decadal average annual and seasonal mean temperatures during the 1957–2007 period for Australia. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

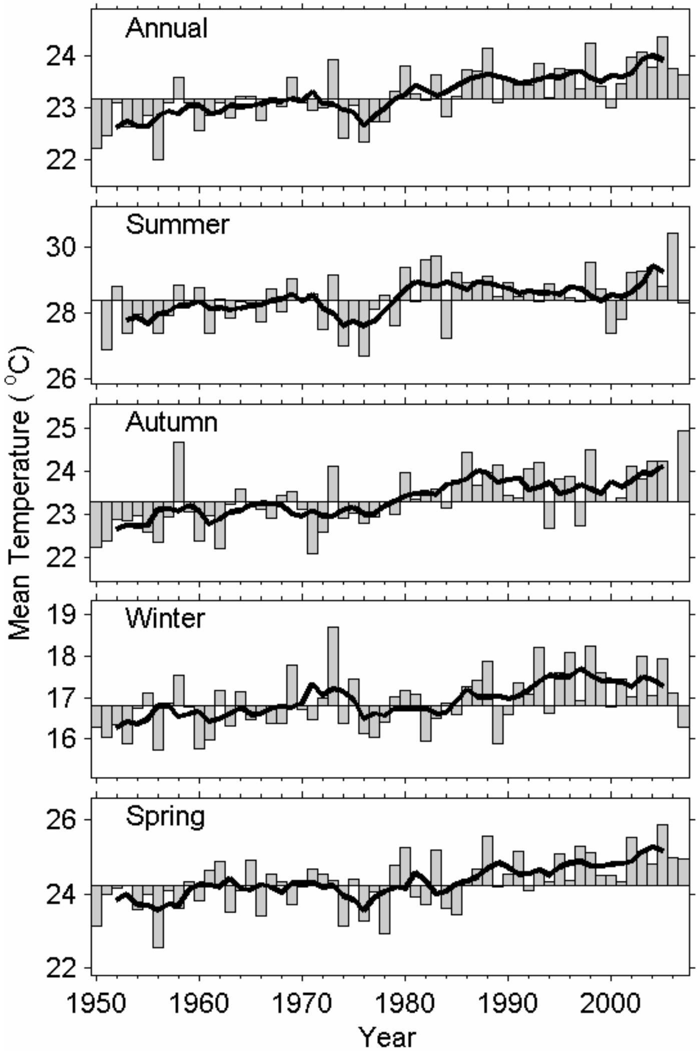

Figure A-9: Annual and seasonal mean temperatures during the 1950–2007 period for Queensland. The black line shows the five-year running average. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

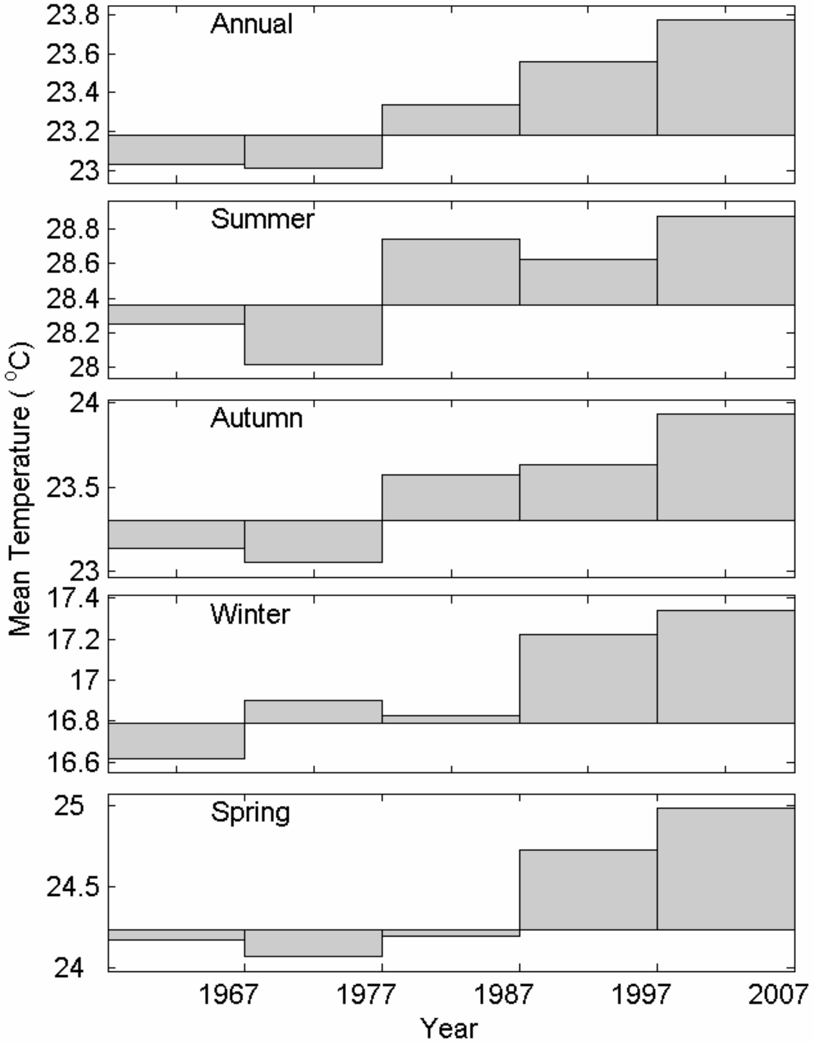

Figure A-10: Decadal average annual and seasonal mean temperatures during the 1957–2007 period for Queensland. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

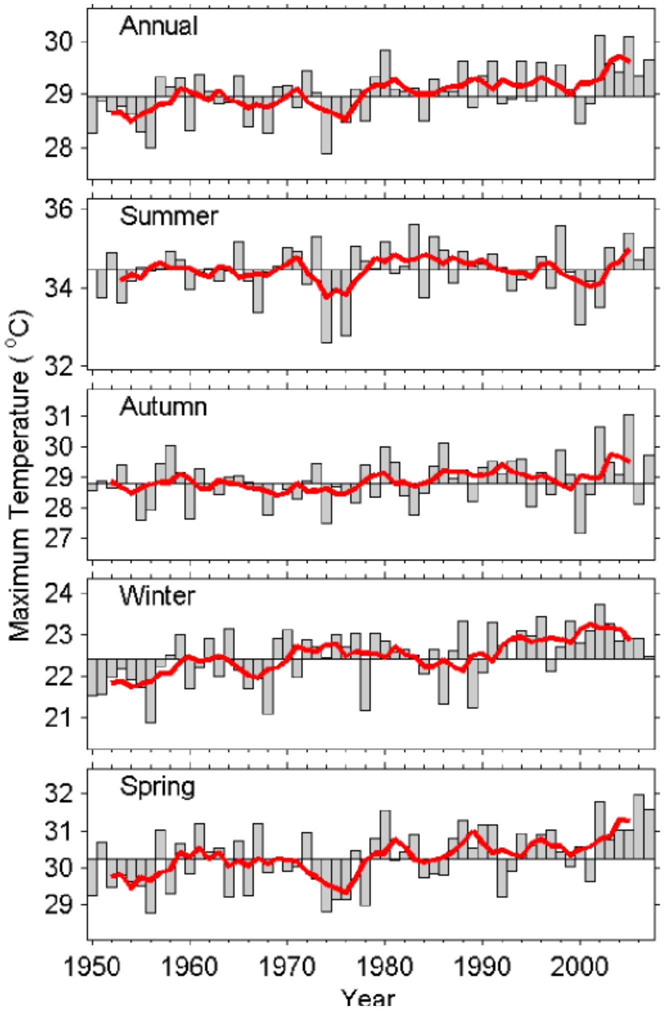

Figure A-11: Annual and seasonal maximum temperatures during the 1950–2007 period for Australia. The red line shows the five-year running average. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

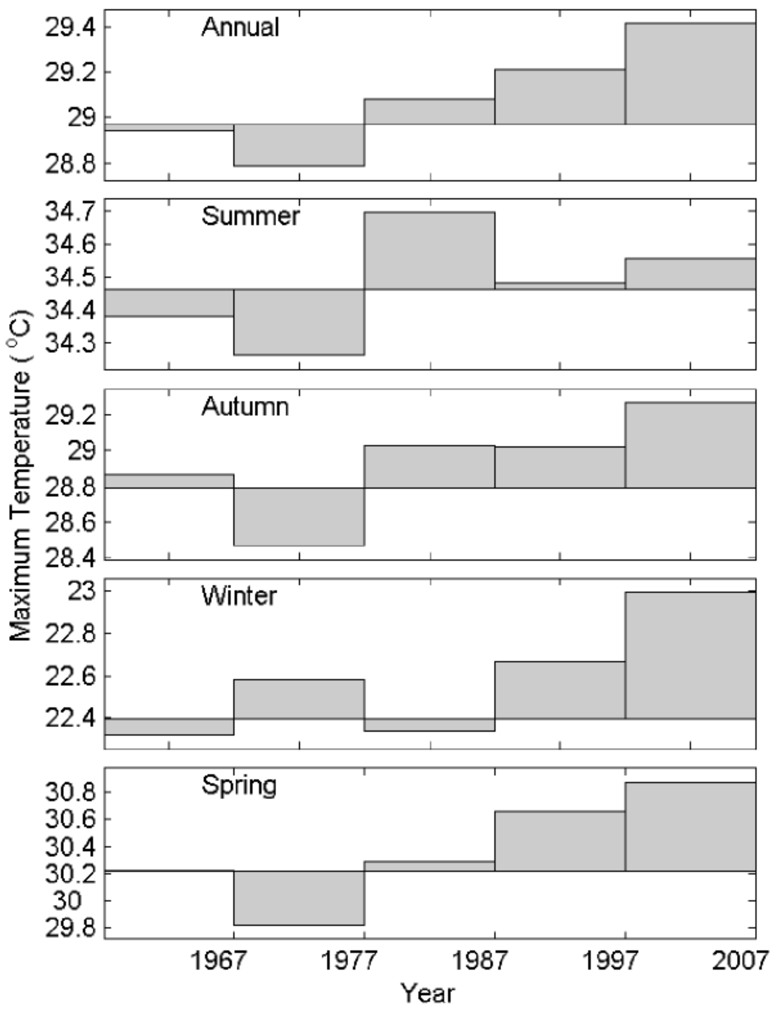

Figure A-12: Decadal average annual and seasonal maximum temperatures during the 1957–2007 period for Australia. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

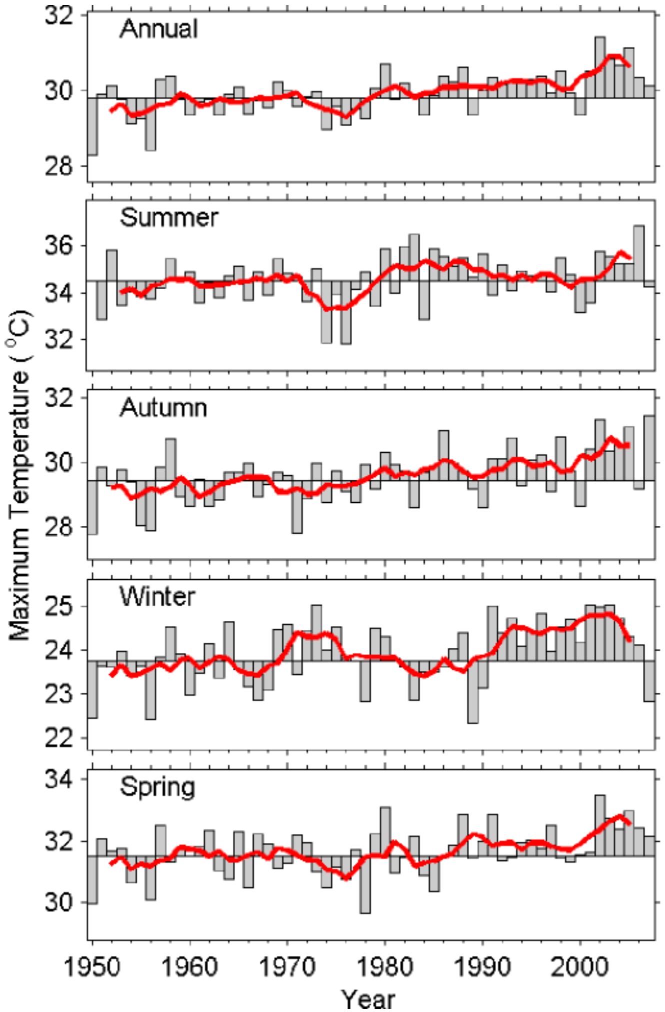

Figure A-13: Annual and seasonal maximum temperatures during the 1950–2007 period for Queensland. The red line shows the five-year running average. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

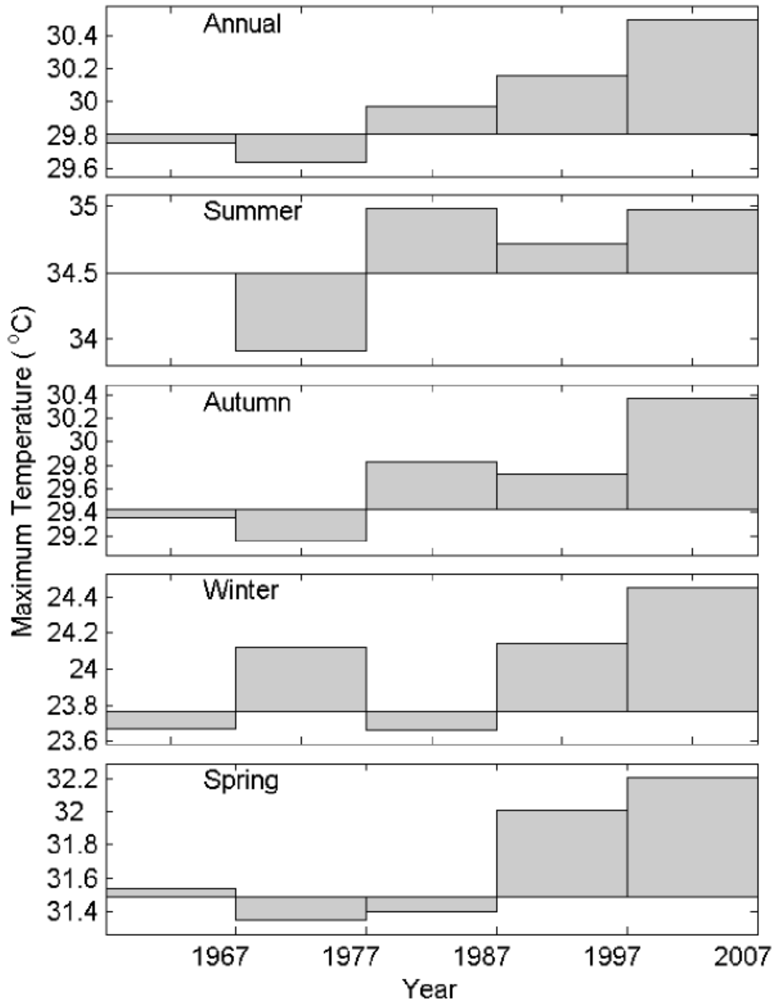

Figure A-14: Decadal average annual and seasonal maximum temperatures during the 1957–2007 period for Queensland. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

Appendix B: Ancillary datasets for rainfall

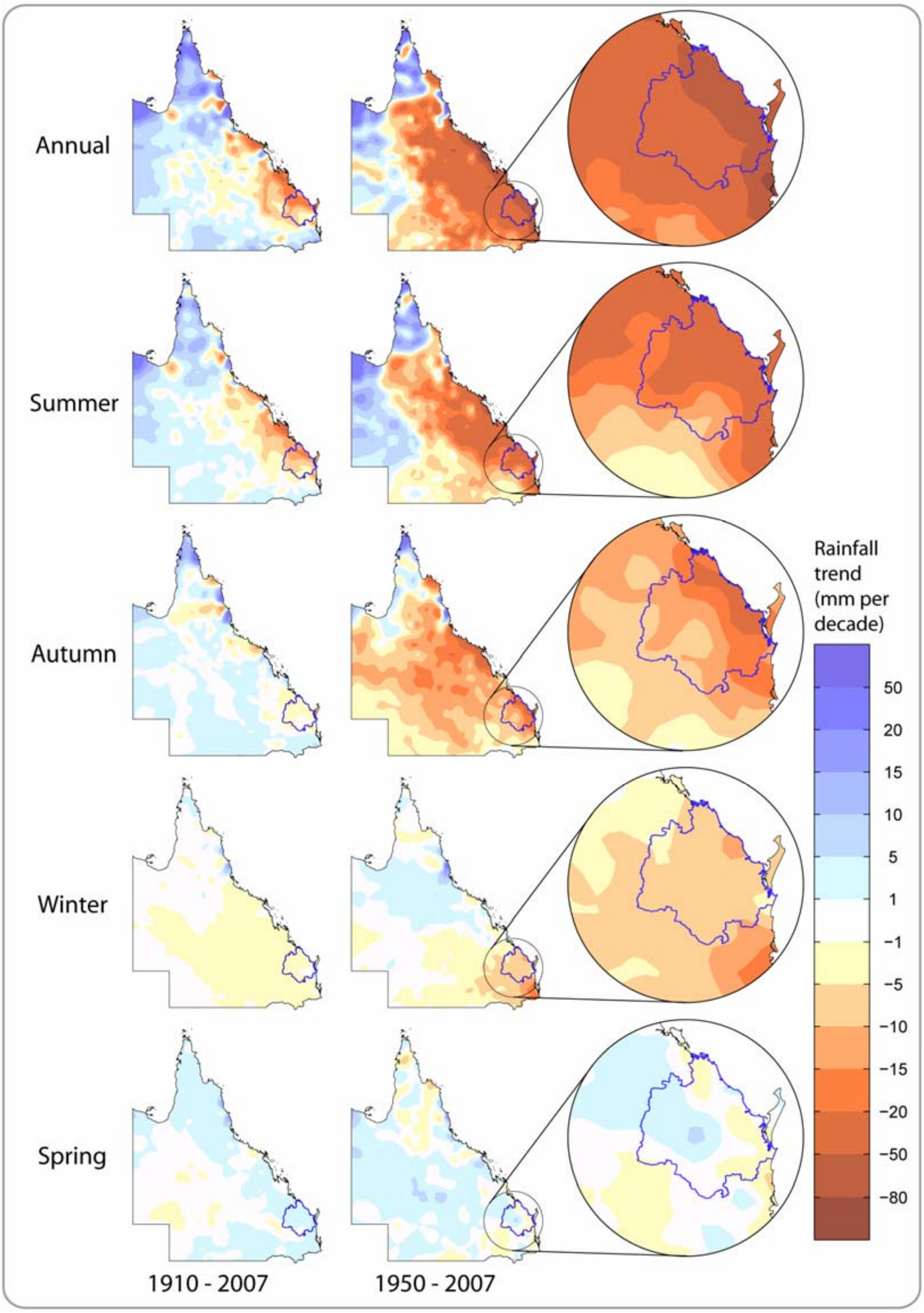

Figure B-1: Trends (mm per decade) in annual and seasonal rainfall during the 1910–2007 (left column), and the 1950–2007 (right column) periods for Queensland. The Wide Bay-Burnett region is enlarged for the 1950–2007 period. Source: Australian Bureau of Meteorology 2008.

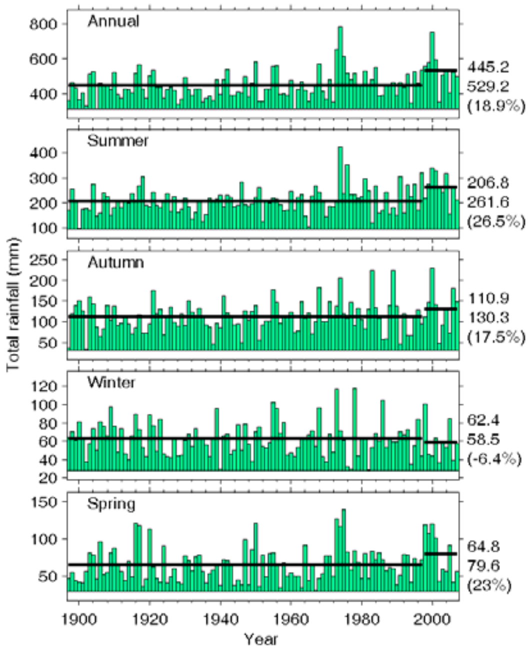

Figure B-2: Annual and seasonal rainfall during the 1897–2007 period for Australia. The horizontal lines show the average for the last decade (1998–2007) compared to the average over the 1897–1997 period. The numbers shown on the right are the means for the 1897–1997 (top value) and 1998–2007 (middle value) periods. The relative change (%) between the two periods is also shown (bottom value). *Data source: Australian Bureau of Meteorology 2008. Note: Vertical scales may differ between graphs.*

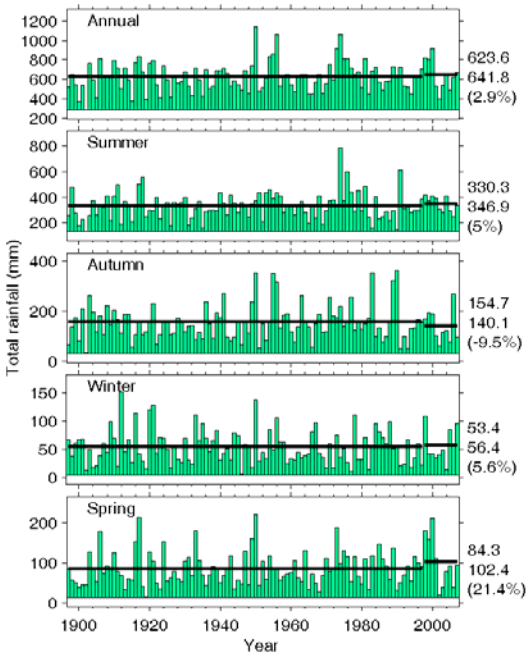

Figure B-3: Annual and seasonal rainfall during the 1897–2007 period for Queensland. The horizontal lines show the average for the last decade (1998–2007) compared to the average over the 1897–1997 period. The numbers shown on the right are the means for the 1897–1997 (top value) and 1998–2007 (middle value) periods. The relative change (%) between the two periods is also shown (bottom value). Data source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

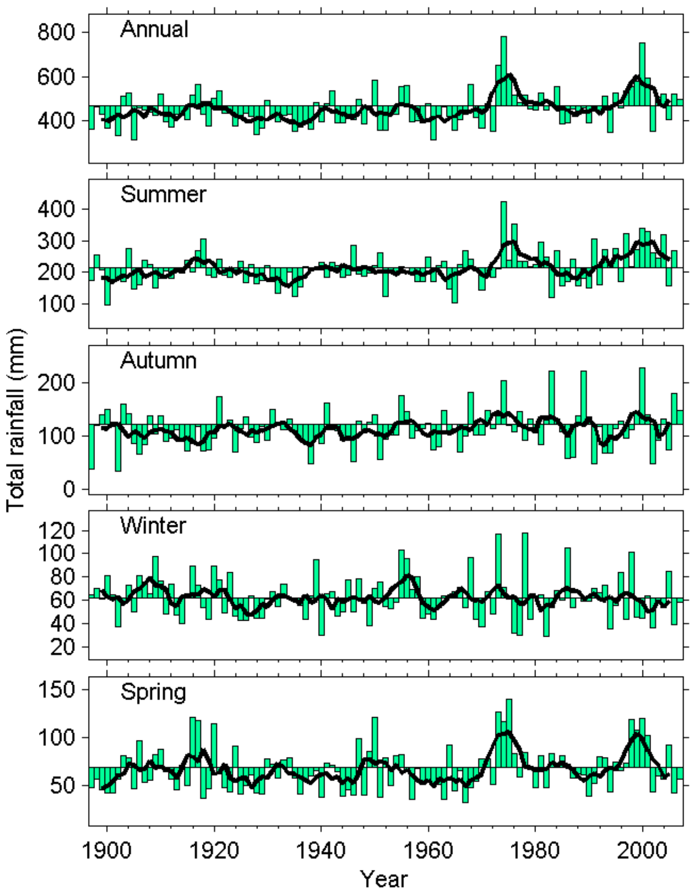

Figure B-4: Annual and seasonal rainfall during the 1897–2007 period for Australia. The black line shows the five-year running average. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

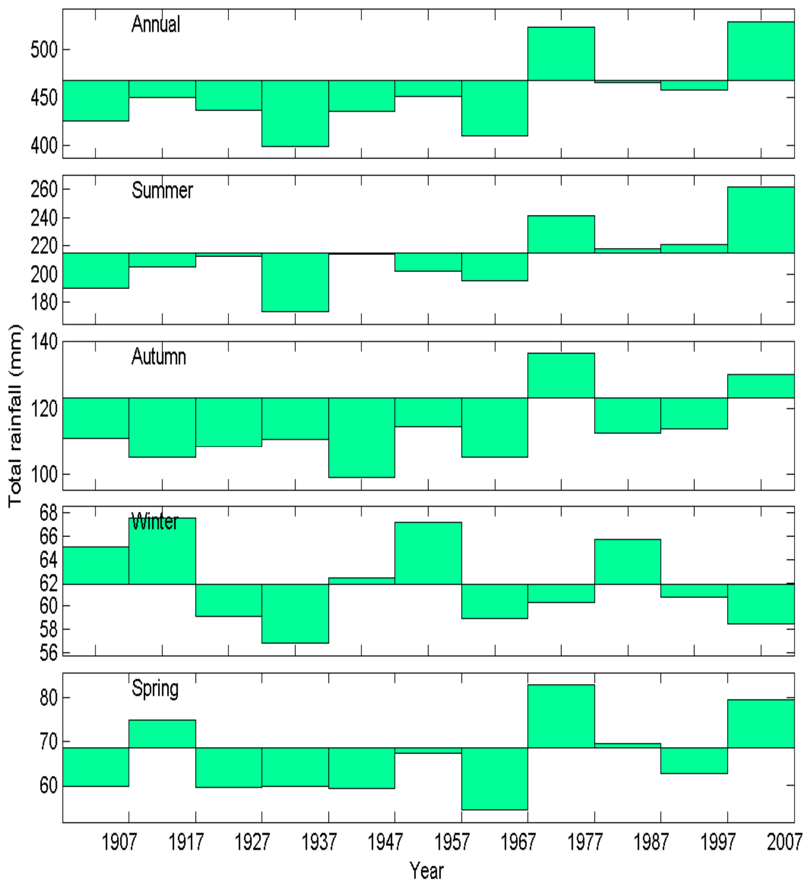

Figure B-5: Decadal average annual and seasonal rainfall during the 1897–2007 period for Australia. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

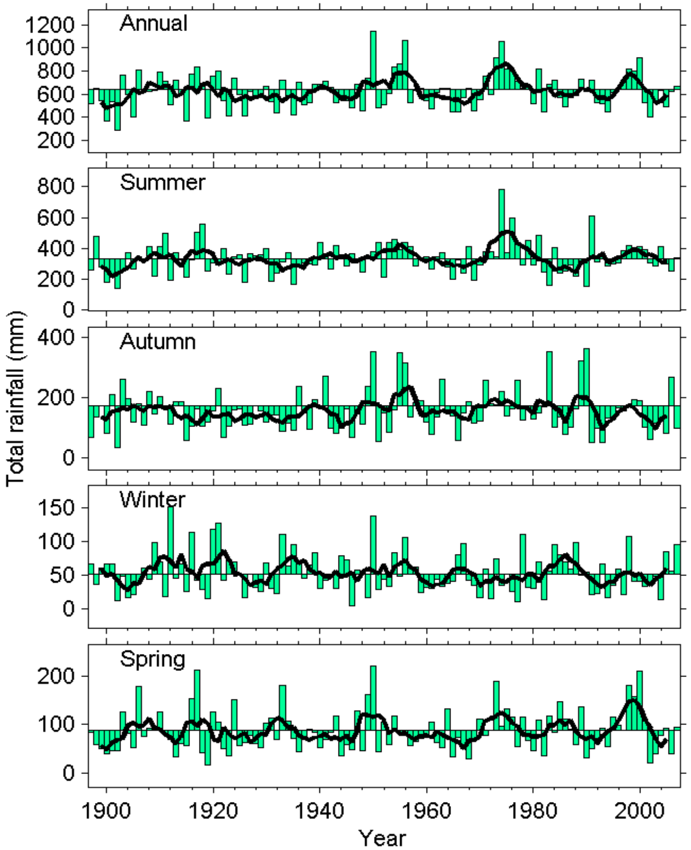

Figure B-6: Annual and seasonal rainfall during the 1910–2007 period for Queensland. The black line shows the five-year running average. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*

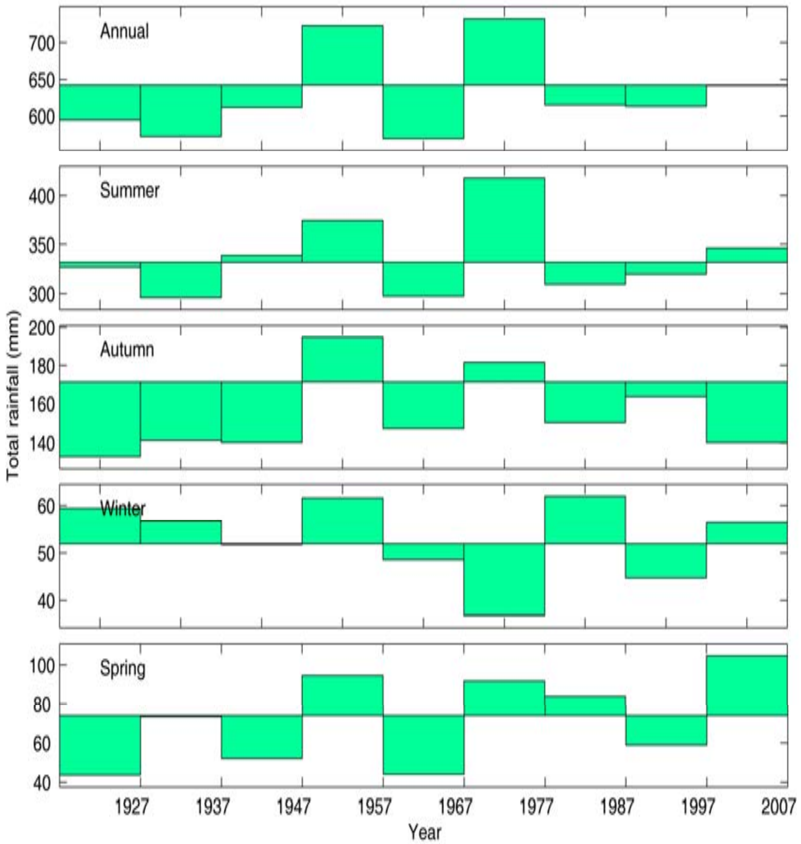

Figure B-7: Decadal average annual and seasonal rainfall during the 1910–2007 period for Queensland. Source: Australian Bureau of Meteorology 2008. *Note: Vertical scales may differ between graphs.*