An assessment of the impact of climate change on the nature and frequency of exceptional climatic events

DROUGHT

exceptional circumstances

Australian Government
Bureau of Meteorology

CSIRO

An assessment of the impact of climate change on the nature and frequency of exceptional climatic events

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SUMMARY

Background

The Australian Government is conducting a comprehensive national review of drought policy. The review includes three separate assessments. The first examines the implications of future climate change for the current exceptional circumstances (EC) standard of a one in 20-25 year event and is provided in this report. The others cover economic and social aspects.

This study analyses changes in the areal extent and frequency of exceptionally high temperatures, low rainfall and low soil moisture for seven Australian regions (see Figure 1): Queensland (Qld); New South Wales (NSW); Victoria and Tasmania (Vic&Tas); the northwest (NW); the southwest (SW); the southwest of WA (SW WA); and the Murray-Darling Basin (MDB). The analysis uses observed and simulated data covering varying periods from 1900 to 2040. Low, mean and high projections are given for future years.

The uncertainties associated with the historical data and the climate projections are noted, including the qualitative assessment that the temperature data have the lowest uncertainty, that there is higher uncertainty with the rainfall data, and that the soil moisture data – being derived from a combination of rainfall data, low resolution observations of evaporation, and modelling – are the least reliable.

Results

The analysis shows that the areal extent and frequency of ***exceptionally hot years*** have been increasing rapidly over recent decades and that trend is expected to continue. Further, over the past 40 years (1968-2007), exceptionally hot years are typically occurring over 10-12% of the area in each region, i.e. about twice the expected long-term average of 5%. By 2010-2040, the mean area is likely to increase to 60-80%, with a low scenario of 40-60% and a high scenario of 80-95%. On average, exceptionally high temperatures are likely to occur every one to two years.

Observed trends in ***exceptionally low rainfall years*** are highly dependent on the period of analysis due to large variability between decades. If rainfall were the sole trigger for EC declarations, then the mean projections for 2010-2040 indicate that more declarations would be likely, and over larger areas, in the SW, SW WA and Vic&Tas regions, with little detectable change in the other regions. Under the high scenario, EC declarations would likely be triggered about twice as often and over twice the area in all regions. In SW WA the frequency and areas covered would likely be even greater.

Projected increases in the areal extent and frequency of ***exceptionally low soil moisture years*** are slightly clearer than those for rainfall. If soil moisture were the sole criterion for EC declarations, then the mean projections indicate that more declarations would be likely by 2030, particularly in the SW, SW WA and Vic&Tas regions. Under the high scenario, EC declarations would be triggered almost twice as often in most regions and almost four times as often in SW WA.

Appropriateness of the current one in 20-25 year EC event trigger

The current EC trigger, based on historical records, has already resulted in many areas of Australia being drought declared in more than five per cent of years, and the frequency and severity are likely to increase. The principal implication of the findings of this study is that the existing trigger is not appropriate under a changing climate.

Future information needs and areas for more detailed assessment

Farmers and their suppliers need user-friendly, reliable and up-to-date location-specific information on historical climatic conditions and future climate variability. Key here is the risk of drought on timescales from seasons to decades. This report identifies a number of activities and areas of research for improving existing information, including:

- further improvement of drought monitoring capability and maintenance of networks for rainfall and other key climate observations;
- an online climate information system which readily integrates climate change projections with the historical database;
- participatory studies to more accurately identify the climate change information needs of the different rural sectors;
- research to improve climate change projections and seasonal-to-interannual forecasts, particularly with respect to specific rural sectors and a localised scale; and
- more detailed analyses of projected changes in exceptional climatic events in smaller regions and beyond the next 20-30 years.

1. Drought in Australia

Australia has one of the most variable climates in the world[1]. Internal and external factors drive climate variability on a range of timescales.

Internal factors are natural and arise from complex interactions within the climate system[2] such as the El Niño–Southern Oscillation, the Indian Ocean Dipole, the Southern Annular Mode and the Inter-decadal Pacific Oscillation.

Natural external factors include the Earth's rotation, variations in the energy from the Sun, volcanic eruptions and changes in the Earth's orbital parameters. Some external factors, such as changes in land-use, concentrations of greenhouse gases, aerosols and stratospheric ozone, are human-induced. Most of the global and Australian warming since the mid-20th century is very likely due to increases in greenhouse gases[3]. About 50 per cent of the rainfall decrease in southwestern Australia since the late 1960s is likely to be due to increases in greenhouse gases[4]. The autumn rainfall decline in southeastern Australia since the late 1950s may be partly due to increases in greenhouse gases[5]. Rainfall deficiency is just one of the ways in which drought can be defined (Box 1). Recent Australian droughts have been accompanied by higher temperatures[6].

Through the past century, major droughts have been associated with episodes of regional degradation in inland Australia[8]. Since the early 1990s, drought has formally been recognised as a natural characteristic of Australia's variable and changing climate. Successful management of climate risk is recognised as a definitive characteristic of farming excellence[9].

As stated in the Terms of Reference (Appendix 1): Government assistance for drought events is guided by the current National Drought Policy (NDP). Under the NDP, drought assistance or support is intended to be a short-term measure to help farmers prepare for, manage and recover from drought. The objectives of the NDP are to:

- encourage primary producers and other sections of rural Australia to adopt self-reliant approaches for managing within a changing climate;
- maintain and protect Australia's agricultural and environmental resource base during periods of extreme climate stress; and
- ensure early recovery of agricultural and rural industries, consistent with long-term sustainable levels.

Although self-reliance is a key objective, the NDP also recognises that there are rare and severe events that may be beyond the ability of even the most prudent farmer to manage. The Australian Government provides support to farmers and rural communities under the exceptional circumstances arrangements and other drought programs. The State and Territory Governments also participate in the NDP and provide support measures of their own.

Box 1: Drought definitions

Drought can be experienced and hence defined in different ways. There are essentially four types[7]:

- ***Meteorological drought:*** a period of months to years when atmospheric conditions result in low rainfall. This can be exacerbated by high temperatures and high evaporation, low humidity and desiccating winds;
- ***Agricultural drought:*** short-term dryness in the surface soil layers (root-zone) at a critical time in the growing season. The start and end may lag that of a meteorological drought, depending on the preceding soil moisture status;
- ***Hydrological drought:*** prolonged moisture deficits that affect surface or subsurface water supply, thereby reducing streamflow, groundwater, dam and lake levels. This may persist long after a meteorological drought has ended;
- ***Socio-economic drought:*** the effect of elements of the above droughts on supply and demand of economic goods and human well-being.

In deciding whether to declare a region as affected by EC, the National Rural Advisory Council and the Minister for Agriculture, Fisheries and Forestry must decide whether[10]:

1. the event is rare and severe, occurring on average once in 20 to 25 years, and on a significant scale in terms of the area and proportion of farm businesses affected;
2. the event has resulted in a rare and severe downturn in farm income over a prolonged period;
3. the event was not predictable or part of a process of structural adjustment.

Since inception of the NDP, most of Australia's agricultural regions have been drought declared[11] at some time. However, modelling has shown that most realistic criteria result in drought being declared for more time than suggested by a 1 in 20-25 year event[12]. This outcome is reflected by some regions having been continuously drought-declared for 13 of the past 16 years (Appendix 1).

Given the likely increase in the area of the globe affected by droughts in future[3], this assessment examines how climate change may affect the concept of a one in 20-25 year event into the future for Australia. The purpose of this assessment is to provide scientific input into the Australian Government's review of drought policy, and to assist farmers and local communities prepare for climate change. Key results are presented in this report, with Supplementary Information available at:

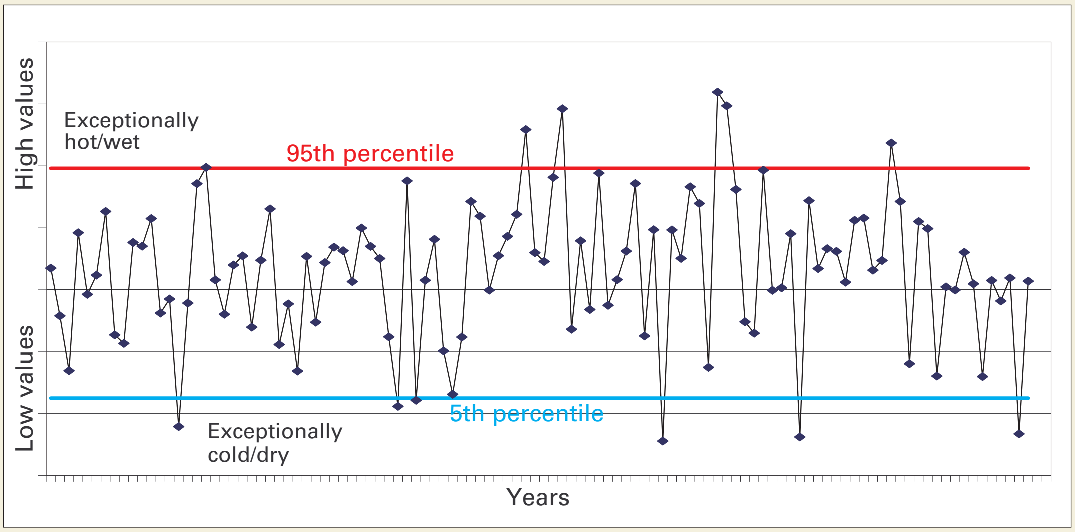
www.bom.gov.au/climate/droughtec

Regional summaries are provided in Appendix 2.

Box 2: Exceptional events

For the purpose of this study, exceptional events are defined as being of one year duration and occurring once every 20 years, on average. Therefore the return period is 20 years. In simple terms the probability of an event occurring in any single year is then one in 20, or 5%. If there were a hundred years of rainfall data that were sorted from the driest to the wettest, the five driest years would fall below the 5th percentile and the five wettest above the 95th percentile. The critical threshold values are defined as the 5th percentile for exceptionally low rainfall and soil moisture and the 95th percentile for exceptionally high temperature (see Supplementary Information).

If the length of the dataset were a multiple of 20 years, then exactly 5% of values would fall below the 5th percentile (or above the 95th percentile). However, the lengths of our datasets are not multiples of 20 years, hence there are small differences in the base rates and return periods for each dataset.



2. Historical changes in exceptional climatic events

2.1 Methods and data

We have undertaken an historical analysis of exceptional climatic events using three variables: temperature, rainfall and soil moisture.

- Temperature: annual data[13,14] with additional data from the National Climate Centre's climate database for 1910-2007 on a 25 km grid.
- Rainfall: monthly data[15] for 1900-2007 on a 25 km grid.
- Soil moisture: daily data for 1957-2006 on a 25 km grid.

The temperature and rainfall datasets have been specifically constructed for the monitoring of climate variability and climate change. These two datasets have been used very widely for historical analyses, including in the report *Climate Change in Australia*[2]. The rainfall data start in 1900 and the temperature data in 1910, because earlier measurements are either unreliable and/or insufficiently widespread across the country for analyses of the type undertaken in this study.

Since long-term, direct measurements of soil moisture for the whole of Australia are not available, soil moisture was computed using a daily rainfall-runoff model, called SIMHYD[16]. This model was driven by daily gridded rainfall and potential evaporation data from the SILO climate database[17]. Daily soil moisture estimates were calculated for 1957-2006. Prior to 1957, potential evaporation data are considered unreliable, and daily data for 2007 were not available at the time of analysis. This approach to calculating soil moisture is consistent with the methods used in the Murray-Darling Basin Sustainable Yields project[18], but will need further validation before it can be considered to give data of the same quality as that for temperature and rainfall.

If exceptional events are defined as occurring, on average, once every 20 years then in simple terms the probability of an event occurring in any single year is one in 20, or 5 per cent. For drought, the critical threshold value is defined as the 5th percentile for rainfall and soil moisture, based on all years of available data. For exceptionally high temperatures, the critical threshold is the 95th percentile. Further details are given in Box 2. The analyses are based on annual (Jan-Dec) data.

For simplicity, the assessment considers seven regions (Figure 1):

1. Queensland (Qld);
2. New South Wales (NSW);
3. Victoria and Tasmania (Vic&Tas);
4. The northwest (NW); all of the NT and the northern half of Western Australia;
5. The southwest (SW): all of SA and the southern half of WA, including the southwest of WA;
6. The southwest of WA (SW WA);
7. The Murray-Darling Basin (MDB).

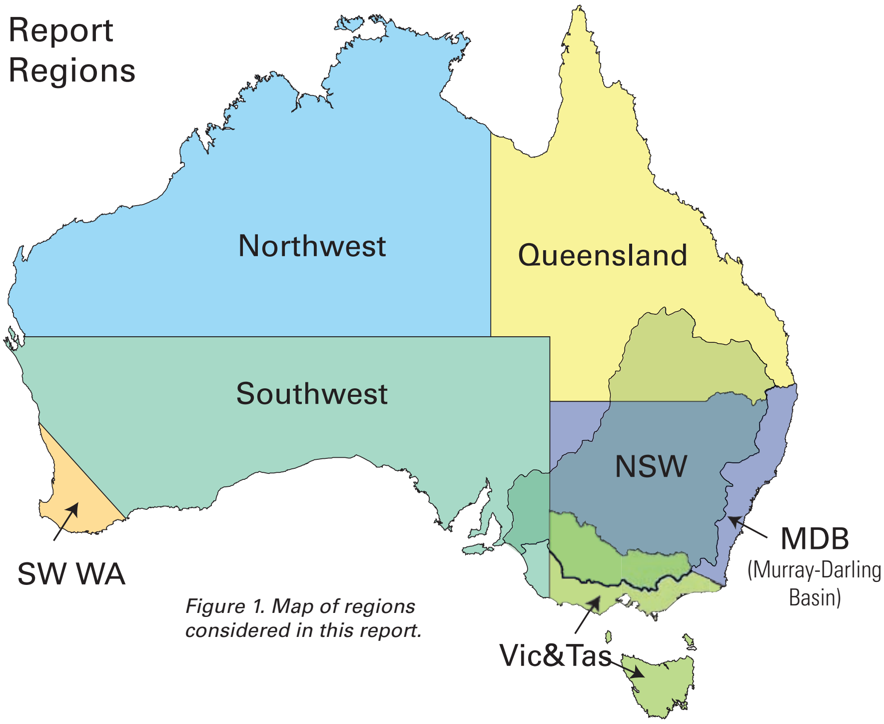


Figure 1. Map of regions considered in this report.

2.2 Exceptionally hot years

Australian average annual mean temperatures have increased by 0.9°C since 1910 (Figure 2a). Most of this warming has occurred since 1950, with the greatest warming in central and eastern parts and the least warming in the far northwest (Figure 2b). The warmest year for Australia since 1910 was 2005, while 2007 was the warmest year for much of southern Australia[19]. The number of hot days and nights has increased and the number of cold days and nights has declined.

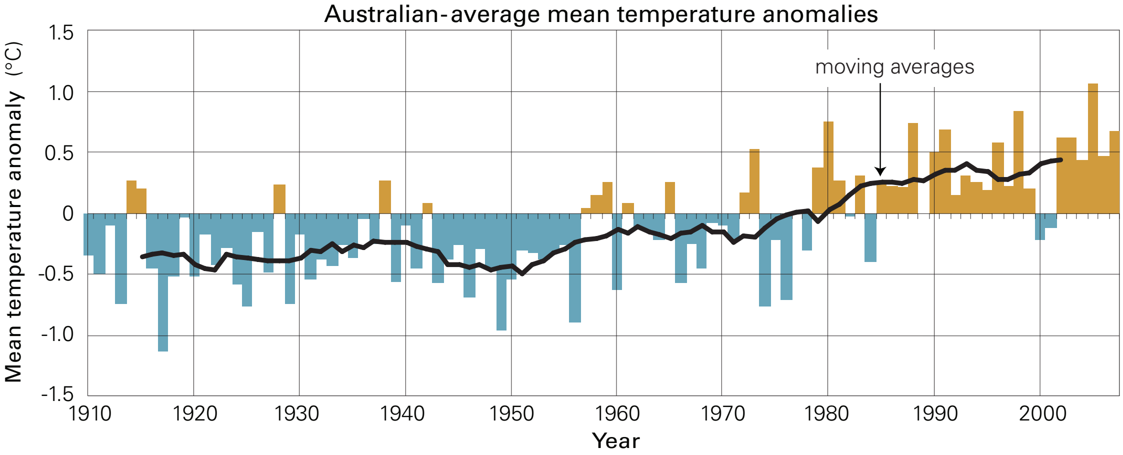
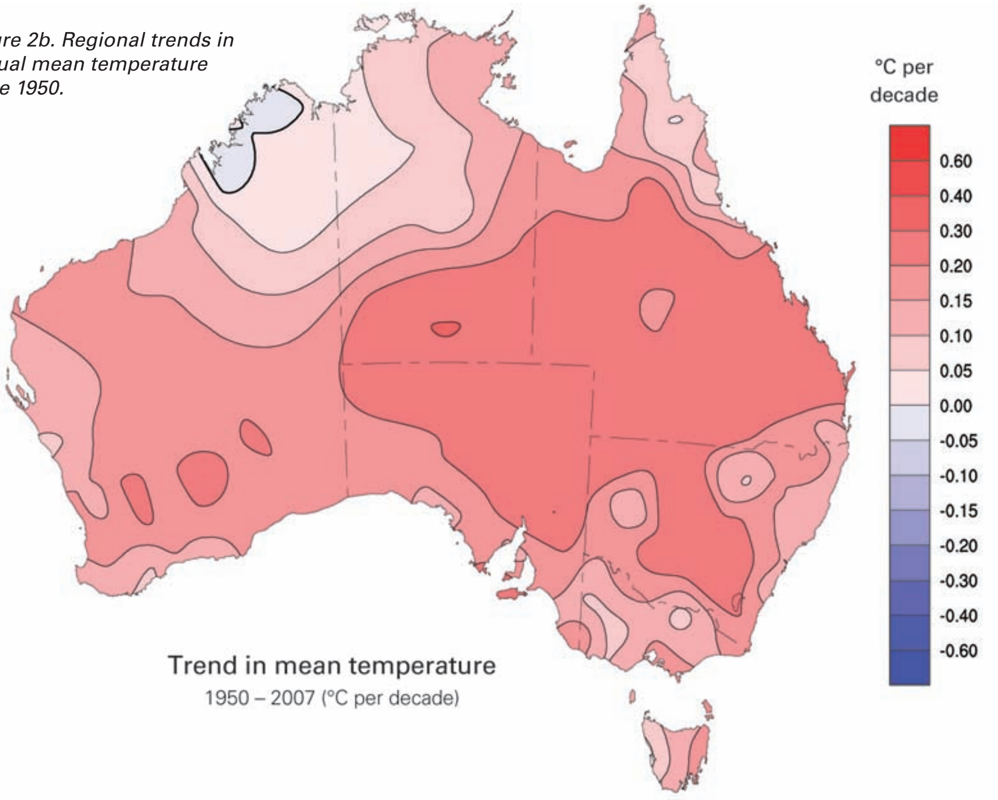


Figure 2a. Time series of Australian-average annual mean temperature anomalies (1910-2007) relative to 1961-1990 with an eleven-year moving average.

Figure 2b. Regional trends in annual mean temperature since 1950.



Region	Change in annual maximum temperature (°C)	Change in annual mean temperature (°C)	Change in annual minimum temperature (°C)	Change in annual total rainfall (mm)
Qld	0.91	1.20	1.48	–107
NSW	1.08	1.08	1.08	–92
Vic&Tas	0.80	0.74	0.63	–109
SW	1.20	1.08	0.97	42
NW	0.68	0.68	0.80	170
MDB	1.14	1.08	1.08	–76
SW WA	0.86	0.80	0.80	–62
Australia	0.91	0.97	1.03	33

Table 1. Change in regionally averaged annual maximum, mean and minimum temperature and annual total rainfall over the period 1950-2007.

Table 1 shows the regional trends in annual maximum, mean and minimum temperature, and annual rainfall, for the period 1950-2007. Warming has occurred in all regions, with minimum temperatures increasing slightly more than maximum temperatures. The strongest warming has occurred in the Queensland region, where rainfall has also declined markedly (see Section 2.3).

The percentage area of each region in which exceptionally hot years occurred is shown in Table 2. There has been a strong tendency for more exceptionally hot years. The results for annual minimum and maximum temperature are similar, and can be found in the Supplementary Information. A trend towards fewer exceptionally cold years is evident in the past century. In the past 40 years (1968-2007), the area experiencing exceptionally hot years has been 10-12%, which is at least twice the long-term average of 5% for all the study regions – including the MDB (Figure 3).

Region	1910-1949 % area	1920-1959 % area	1930-1969 % area	1940-1979 % area	1950-1989 % area	1960-1999 % area	1968-2007 % area
Qld	1.3	0.7	0.5	1.0	2.9	5.3	11.2
NSW	3.0	0.8	0.8	0.9	2.5	3.1	9.6
Vic&Tas	1.4	0.3	1.4	1.4	5.6	6.5	10.2
SW	0.6	0.1	0.4	0.8	2.4	6.7	11.7
NW	0.7	1.3	0.9	1.4	3.0	8.8	11.3
MDB	2.5	0.4	0.5	0.9	2.9	3.5	10.0
SW WA	0.0	0.0	0.0	2.4	5.1	11.3	12.7
Australia	1.1	0.7	0.7	1.1	2.8	6.7	11.2

Table 2. Average percentage area having exceptionally hot years for selected 40-year periods.

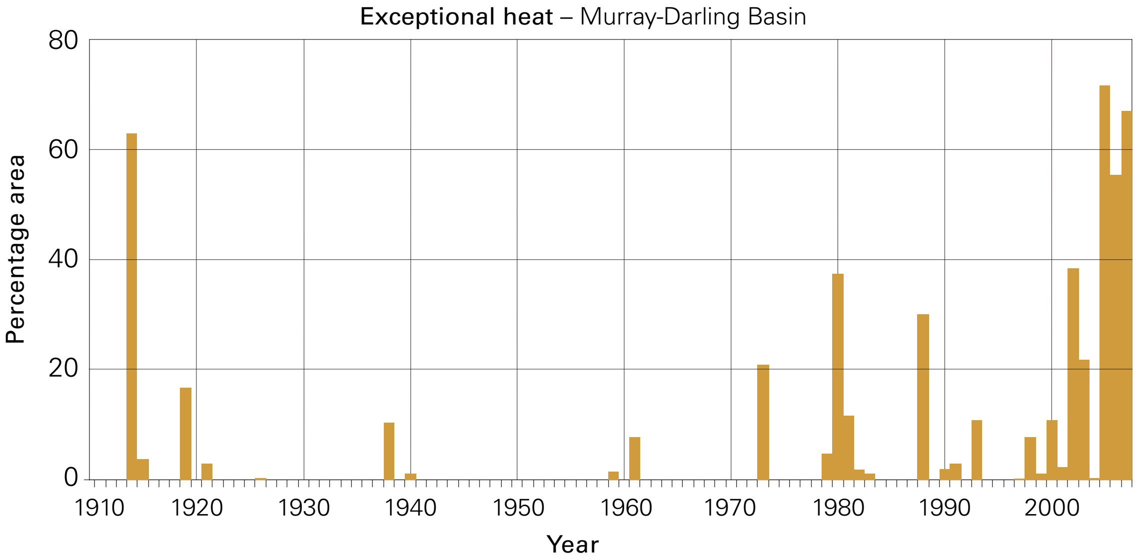


Figure 3. Percentage area of the MDB experiencing exceptional heat for 1910 - 2007.

2.3 Exceptionally low rainfall

In Australia, the twentieth century was characterised by frequent droughts around 1900 and again in the 1930s and 1940s, with wet conditions becoming widespread in the 1950s and 1970s (Figure 4a).

However, since 1950, most of eastern and southwestern Australia has become drier (Figure 4b and Table 1). Across NSW and Queensland, the rainfall trends are significantly influenced by very wet periods around the 1950s and 1970s. In contrast, northwestern Australia has become substantially wetter over recent decades, mostly during summer and autumn. Recent years, however, have been unusually dry in the east and southwest.

Trends are highly dependent on the period of analysis due to large variability between decades. This is particularly true for changes in exceptionally low rainfall. For example, since 1900, across most of Australia, the area experiencing exceptionally low

Region	1900-1939 % area	1910-1949 %area	1920-1959 %area	1930-1969 %area	1940-1979 %area	1950-1989 %area	1960-1999 %area	1968-2007 %area	1998-2007 %area
Qld	9.5	6.5	5.5	4.1	3.3	3.1	2.7	2.6	4.7
NSW	5.7	6.9	5.7	6.2	5.8	4.3	4.0	3.8	6.4
Vic&Tas	5.3	6.0	4.2	6.1	5.1	5.0	5.3	5.2	8.5
SW	5.2	7.1	7.2	6.9	7.9	5.9	4.9	4.4	3.4
NW*	6.3	5.3	6.5	7.5	6.5	6.1	4.7	3.5	3.3
MDB	6.1	7.2	5.8	6.4	5.7	4.1	3.5	3.5	6.9
SW WA	2.5	4.7	4.1	6.5	8.3	6.1	6.3	8.5	8.9
Australia	6.4	6.4	6.6	6.4	6.3	5.3	4.6	3.5	3.1

*A July to June year is used for the NW region to capture the complete wet season.

Table 3. Average percentage area having exceptionally low rainfall years for selected 40-year periods and the most recent decade (1998-2007).

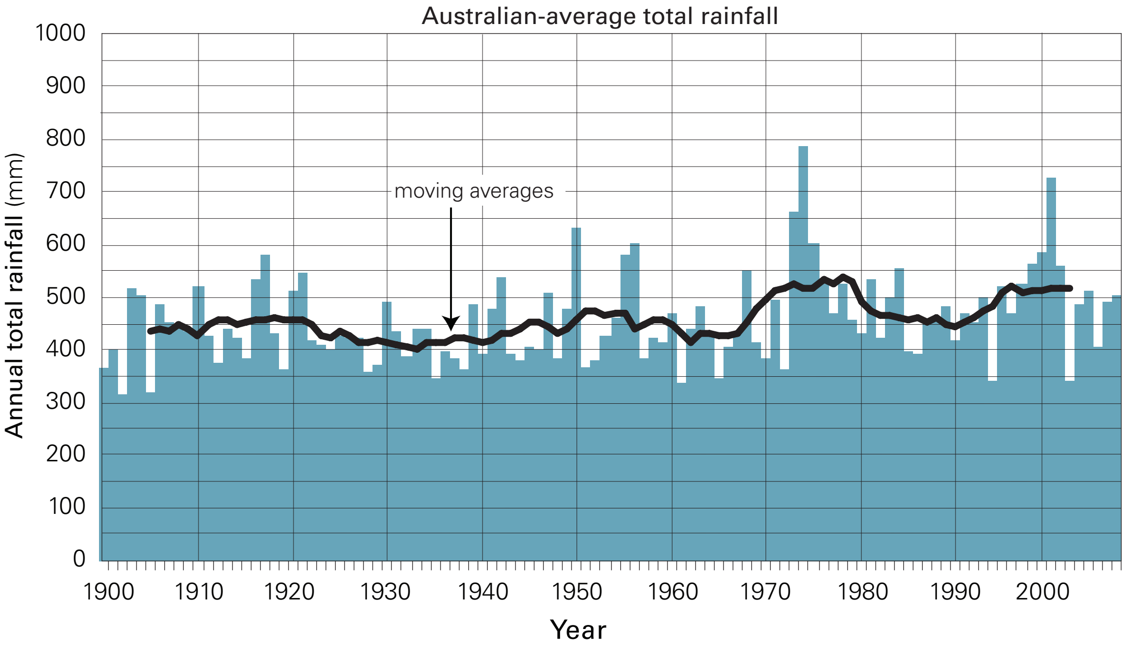
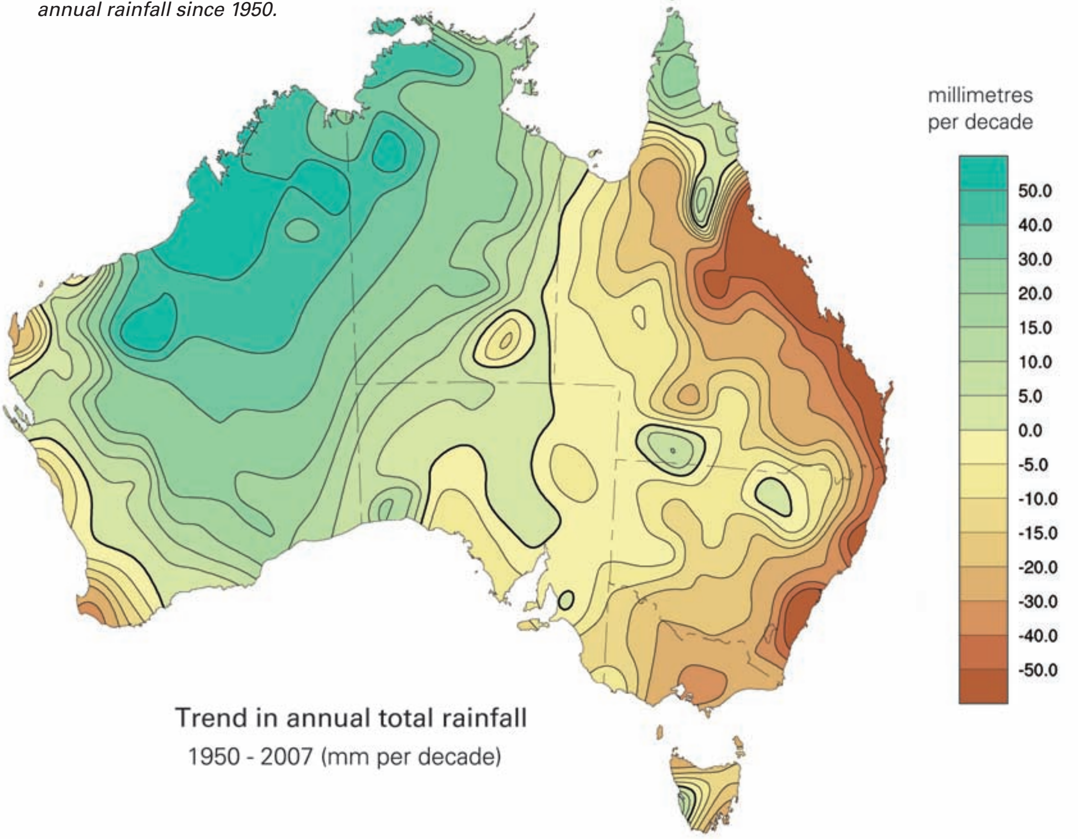


Figure 4a. Time series of Australian-average annual rainfall (1900 - 2007) with an eleven-year moving average (black line).

Figure 4b. Regional trends in annual rainfall since 1950.



rainfall has decreased slightly. However, the NSW, Vic&Tas, MDB and SW WA regions had above-average percentage areas of exceptionally low rainfall in 1998-2007 (Table 3). Important regional trends of note since 1900 include Queensland (see Figure 5a), where there has been a large decrease in the area experiencing exceptionally low rainfall, and SW WA (see Figure 5b) where there has been a large increase.

Typically, an increasingly dry climate tends to be associated with more exceptionally dry years (e.g. SW WA), while an increasingly wet climate tends to be associated with fewer exceptionally dry years (e.g. the NW region). Overall the trends in exceptionally low rainfall are not as strong as the trends in exceptionally high temperatures.

However, the absence of exceptionally wet years, as opposed to an escalation in dry years, can be important for hydrological and agricultural drought. For example, in both the far southwest and the southeast of Australia, the recent hydrological drought is significantly characterised by a near absence of very wet years, giving rise to drying soil profiles and low dam inflows.

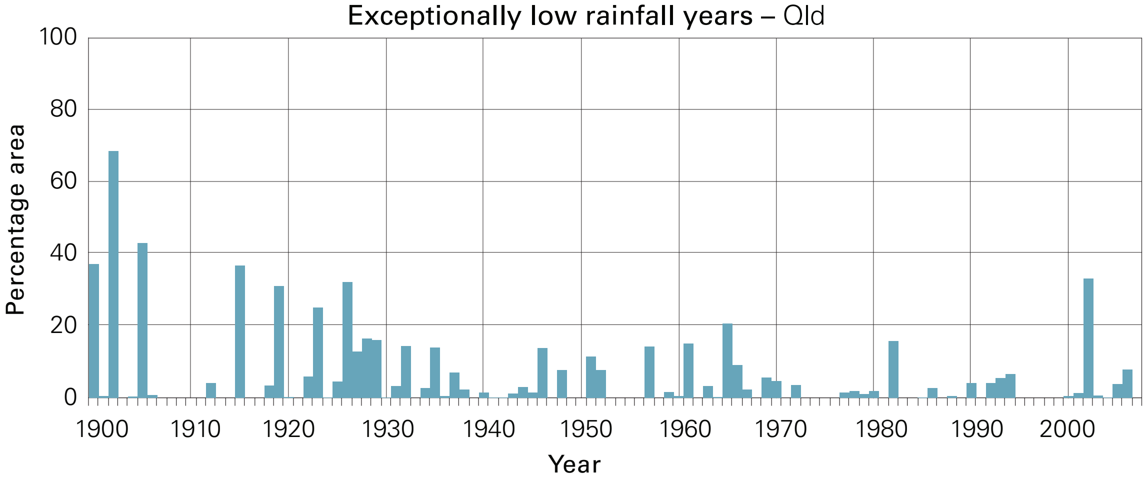


Figure 5a. Percentage area experiencing exceptionally low rainfall in each year (1900-2007) in Queensland.

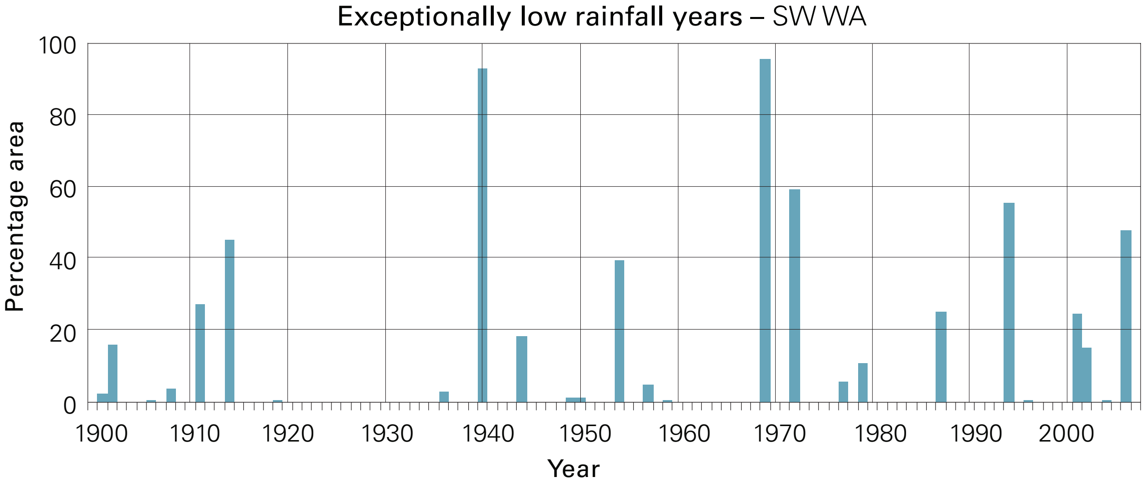


Figure 5b. Percentage area experiencing exceptionally low rainfall in each year (1900-2007) in SW WA.

2.4 Exceptionally low soil moisture years

The amount of moisture in the soil is influenced by rainfall, temperature and evaporation. There are no trends in exceptionally low soil moisture for the fifty years of available data (1957-2006). This is a consequence of the small pool of data, the large variation between decades, and the possible uncertainties introduced by the application of SIMHYD on a large scale.

Soil moisture deficiency typically lags rainfall deficiency by quite a few months. The exceptionally low soil moisture in 1968, 1983 and 2003 (Figure 6) in NSW and Vic&Tas, followed exceptionally low rainfall years in those regions in 1967, 1982 and 2002.

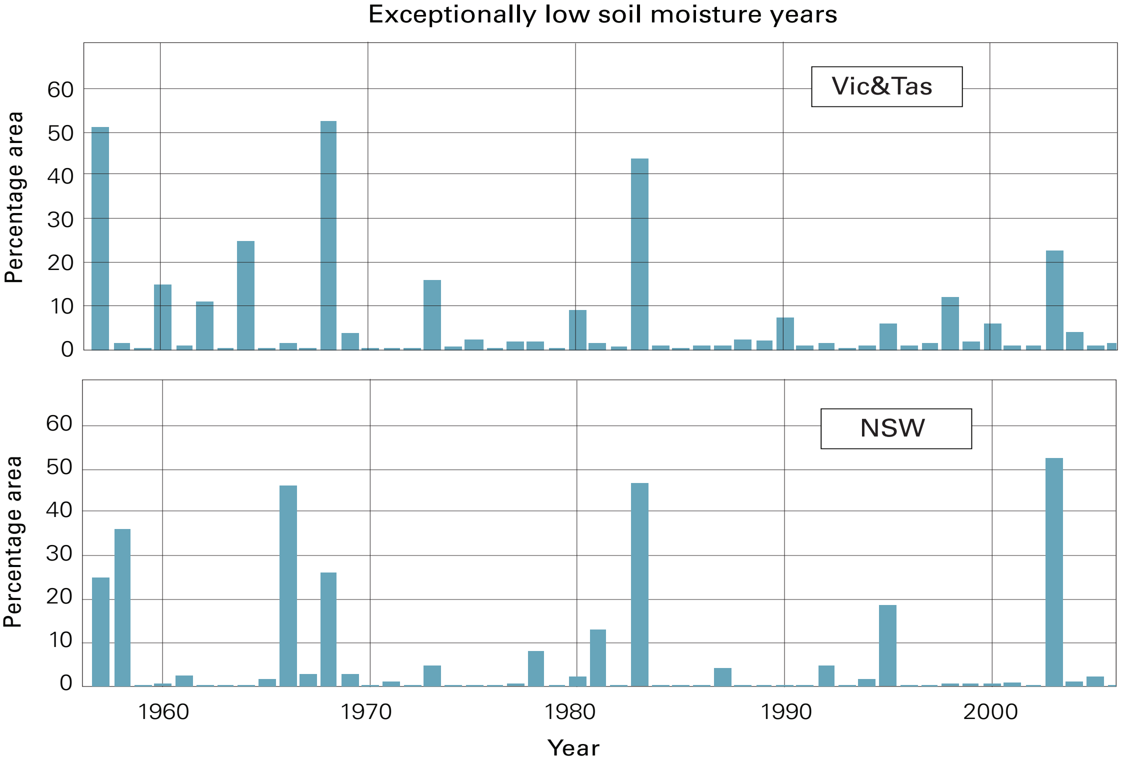


Figure 6. Percentage area having simulated exceptionally low soil moisture years for 1957-2006 in Vic&Tas and NSW.

3. Likely changes in climate averages

To provide a basis for estimating future climate change, 40 greenhouse gas and sulphate aerosol emission scenarios were prepared for the 21st century, based on a variety of assumptions about demographic, economic and technological factors likely to influence future emission[20]. The climatic effects of projected changes in emissions can be simulated using climate models, which are mathematical representations of the Earth's climate system.

Uncertainties in projected regional climate to 2030 are mostly due to differences between the results of the climate models rather than the different emission scenarios. Beyond 2040 the emission scenarios become more important. Observations since 1990 show that we are tracking the highest IPCC emission scenario, called A1FI[21], but climate simulations have not been performed using that scenario. Most climate research institutes around the world ran simulations using the mid-range emission scenarios, called A1B and A2. Hence, in this report, projections for the next 20 to 30 years are based on simulations using mid-range emission scenarios.

Over Australia, a warmer and drier climate is expected. Median estimates for 2030 indicate a warming of about 1°C, relative to 1990, with less warming near the coast and more warming inland, a 3 to 5% decrease in rainfall, with slightly larger decreases in central and southwestern areas and little change in the far north, and a 2 to 4% increase in potential evaporation (Figure 7). The range of uncertainty is larger when allowing for differences between climate model results: a warming of 0.6 to 1.5°C for most of Australia, rainfall changes of -10% to +5% in northern areas and -10% to little change in southern areas, and potential evaporation increases of 0 to 8%[2].

Generally modellers have high confidence in the broadscale projected temperature patterns due to consistency between models. There is less confidence concerning rainfall projections and potential evaporation.

Changes in average climate will be superimposed on large daily, seasonal and yearly variability, leading to significant changes in extreme events. The climatic anomalies of an individual year will be determined by a combination of natural variability and climate change due to global warming.

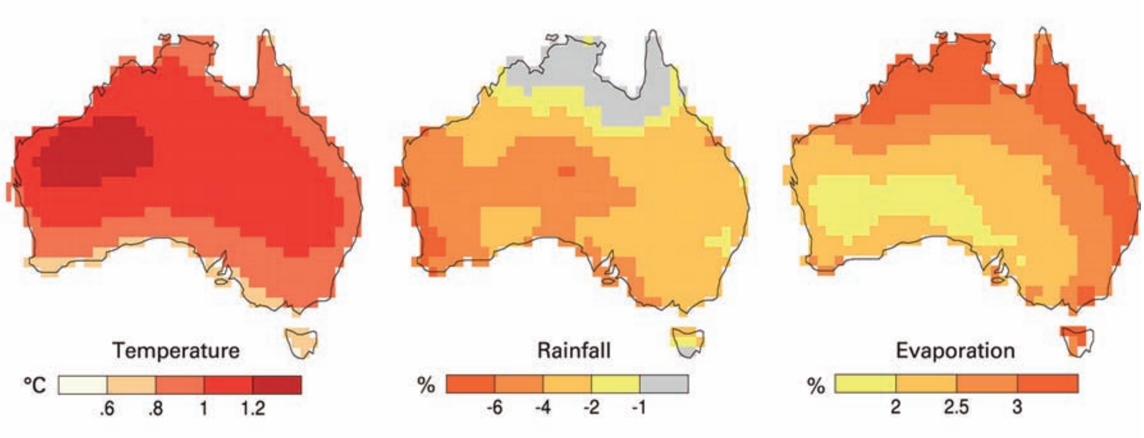


Figure 7. Median projected changes in annual-average temperature, rainfall and potential evaporation by 2030, relative to 1990, for the mid-range A1B emission scenario.

4. Likely changes in exceptional climatic events

Given that Australia is likely to become warmer, and drier in the south, it is likely there will be changes in the nature and frequency of exceptionally hot years, low rainfall years and low soil moisture years. There will also be significant regional variation. This study has estimated the changes in these factors for the next 20-30 years, as specified in the Terms of Reference (Appendix 1), because previous studies [22,23,24,25,26,27] have not adequately done this analysis. Some of these studies used the Palmer Drought Severity Index, in its original or slightly modified form. However, since this index is known to have significant limitations[28,29], it is not used in our analysis.

4.1 Methods and data

Our projections are based on simulations from 13 climate models that perform acceptably well in the Australian region and for which potential evaporation data exist. The models are described in the Supplementary Information.

For projected changes in temperature and rainfall, annual data for 1900-2040 were derived from simulations using observed atmospheric emissions of greenhouse gases and sulphate aerosols for 1900-2000, and the A1B emission scenario for 2001-2040. For three models, simulations with A1B emissions were unavailable, so simulations with A2 emissions were used instead. All data were projected on to a 25 km grid over Australia. For each grid cell, the thresholds for exceptionally hot years and exceptionally low rainfall years were calculated for the period 1900-2007. Projected changes for the next 20-30 years were calculated relative to these thresholds.

Soil moisture was estimated using the SIMHYD model[16], which has been used extensively, particularly to simulate river flows in Australian catchments. The model requires daily rainfall and potential evaporation data. Since only monthly rather than daily data were available from the climate models, we follow a method very similar to that from the Murray-Darling Basin Sustainable Yields project[18]. An Australian grid of projected changes in monthly mean rainfall and potential evaporation, per degree of global warming, was created for each climate model. To generate projections, these data were multiplied by A1B global warming estimates for 2030. The changes were applied to the observed daily data for 1957-2006 to create daily data for 50 years centred on 2030. SIMHYD was then driven by the modified data, allowing the calculation of annual average soil moisture data centred on 2030. Projected days with exceptionally low soil moisture for 2030 are calculated relative to the thresholds based on 1957-2006 (Box 2).

We have considered historical and projected variations in the intensity and frequency of exceptional events, where intensity is the percentage area of a region affected by an event and frequency is the regional-average number of years between events. Low, mean and high scenarios are given, where the mean is the 13-model average, and the low and high scenarios are the lowest and highest 10% of the range of model results, respectively.

4.2 Exceptionally hot years

Projected increases in mean temperature are likely to lead to more exceptionally hot years. This is shown in Figure 8, in which the observed data for 1910-2007 (from Section 3.2) are overlaid on the simulated data from 1900-2040.

Simulations show that, in each region, about 4.5% of the area has exceptionally hot years over the period 1900-2007 (Table 4). By 2010-2040, the mean area increases to 60-80%, with a low scenario of 40-60% and a high scenario of 80-95%. The observed increase in exceptionally hot years from 1900-2007 is generally consistent with the simulated mean change in all regions.

Simulated changes in the frequency of exceptionally hot years are shown in Table 5. The frequency is expressed as the average return period, in years. In each region, the return period is about 22 years for 1900-2007. By 2010-2040, the mean return period falls to about 1.5 years, with a low scenario of about 2 years (about 1.5 years in SW WA and Vic&Tas) and a high scenario of about 1 year.

In summary, the analysis clearly shows that the areal extent and frequency of exceptionally hot years have been increasing rapidly over recent decades and this trend is expected to continue in future.

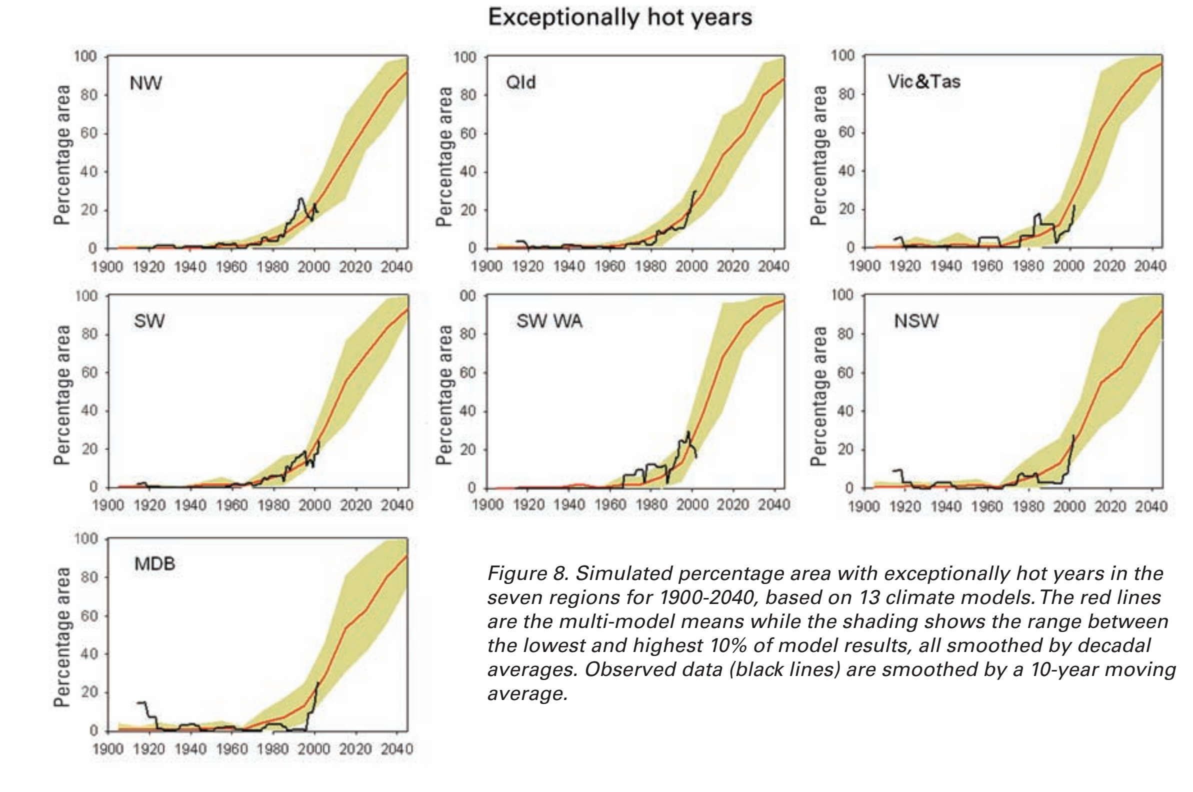


Figure 8. Simulated percentage area with exceptionally hot years in the seven regions for 1900-2040, based on 13 climate models. The red lines are the multi-model means while the shading shows the range between the lowest and highest 10% of model results, all smoothed by decadal averages. Observed data (black lines) are smoothed by a 10-year moving average.

Temperature - percentage area

Region	1900-2007	2010-2040 low	2010-2040 mean	2010-2040 high
Qld	4.6	48.9	62.2	73.8
NSW	4.5	43.5	62.1	81.0
Vic&Tas	4.6	60.5	76.1	95.0
SW	4.6	49.1	68.4	86.3
NW	4.6	50.0	63.5	82.0
MDB	4.5	45.2	64.9	90.1
SW WA	4.6	63.1	81.9	97.1

Table 4. Simulated percentage area having exceptionally hot years for 1900-2007 and 2010-2040, based on 13 climate models. The low and high scenarios represent the lowest and highest 10% of the range of model results.

Temperature - return periods

Region	1900-2007	2010-2040 low	2010-2040 mean	2010-2040 high
Qld	21.9	2.1	1.7	1.3
NSW	22.2	2.2	1.6	1.1
Vic&Tas	21.8	1.6	1.3	1.0
SW	21.9	2.0	1.5	1.1
NW	21.9	2.0	1.5	1.2
MDB	22.1	2.0	1.6	1.1
SW WA	21.6	1.5	1.2	1.0

Table 5. Simulated average return periods (years) for exceptionally hot years for 1900-2007 and 2010-2040, based on 13 climate models. The low and high scenarios represent the lowest and highest 10% of the range of model results.

Box 3: Statistical estimates of future exceptionally low rainfall

The range of changes in exceptionally low rainfall in response to projected reductions in mean rainfall can be estimated statistically (see Supplementary Information). In Figure 9, the probability of future exceptionally low rainfall (relative to the historical record) is graphed against the percentage reduction in mean annual rainfall (see also selected results in Table 6).

A 10 per cent decrease in mean annual rainfall across most of Australia is a possible scenario by 2030 (see Section 3). This decrease roughly doubles the risk of exceptionally low rainfall in five of the study regions, and almost triples the risk for the Vic&Tas and SW WA regions. A 20 per cent mean rainfall decrease triples the risk of exceptionally low rainfall in the same five regions and increases by more than six-fold the risk for the Vic&Tas and SW WA regions.

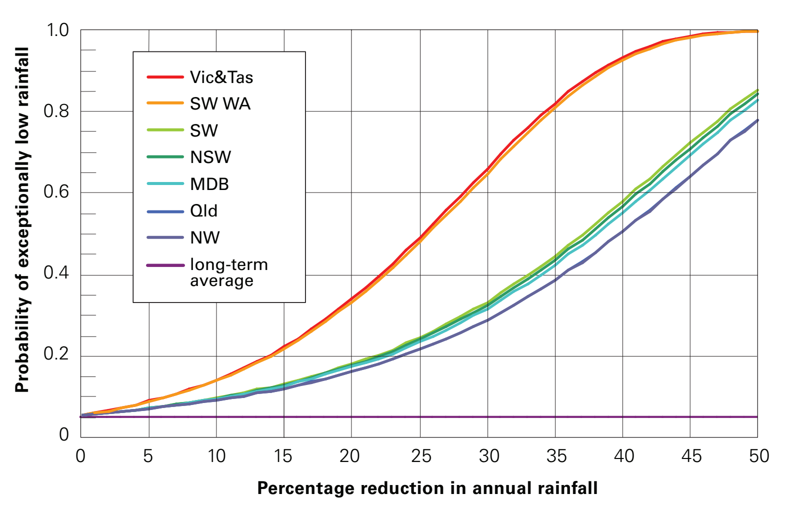
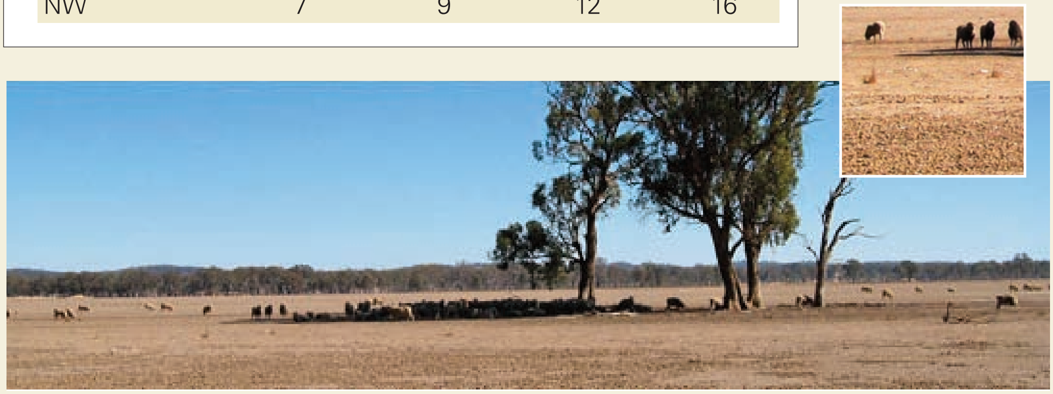


Figure 9. Probability of exceptionally low rainfall for mean rainfall decreases of up to 50% in the seven regions. The results for the Qld and NW regions are almost identical and overlap.

Region	Reduction in annual rainfall 5% Probability	10% Probability	15% Probability	20% Probability
Vic&Tas	9	14	22	34
SW WA	9	14	22	33
SW	7	10	13	18
NSW	7	10	13	18
MDB	7	9	13	17
Qld	7	9	12	16
NW	7	9	12	16

Table 6. Probability (%) of exceptionally low rainfall for mean rainfall decreases of 5, 10, 15 and 20%.



4.3 Exceptionally low rainfall

Projected decreases in annual average rainfall are likely to lead to fewer exceptionally wet years and more exceptionally dry years. Changes in the latter have been estimated in two ways: (a) a statistical modification of the observed rainfall data (Box 3); and (b) analysis of simulations from 13 climate models.

The areal extent of exceptionally low rainfall years is shown for each region in Figure 10, in which the observed data for 1900-2007 (from Section 3.3) are overlaid on the simulated data from 1900-2040. The observations are generally within the range of individual model results. In each region, about 5.5% of the area (Box 2) has exceptionally low rainfall over the period 1900-2007 (Table 7). By 2010-2040, the mean area shows little change in the Qld, MDB and NW regions. However, the mean area increases to 8-10% in the SW and Vic&Tas regions and to over 18% in SW WA. The low scenario is 2-5% (9% in SW WA) and the high scenario is 8-12% (14% in Vic&Tas and 26% in SW WA).

Simulated changes in the frequency of exceptionally low rainfall years are shown in Table 8. In each region, the return period (Box 2) is about 18 years for 1900-2007. By 2010-2040, the mean return period falls slightly to 16-18 years in most regions (around 13 years in SW and Vic&Tas, 6.5 years in SW WA), with a low scenario of 20-22 years (25-27 years in Qld, NSW and MDB, 11 years in SW WA) and a high scenario of 8-11 years (7 years in Vic&Tas, 4 years in SW WA).

In summary, if rainfall were the sole trigger for EC declarations, then the mean projections indicate that more declarations would be likely, over larger areas, in the SW, SW WA and Vic&Tas regions for 2010-2040, with little detectable change in the other regions. Under the high scenario in all regions, EC declarations would likely be triggered about twice as often (at least four times as often in SW WA) and over double the areas (quadruple the area in SW WA).

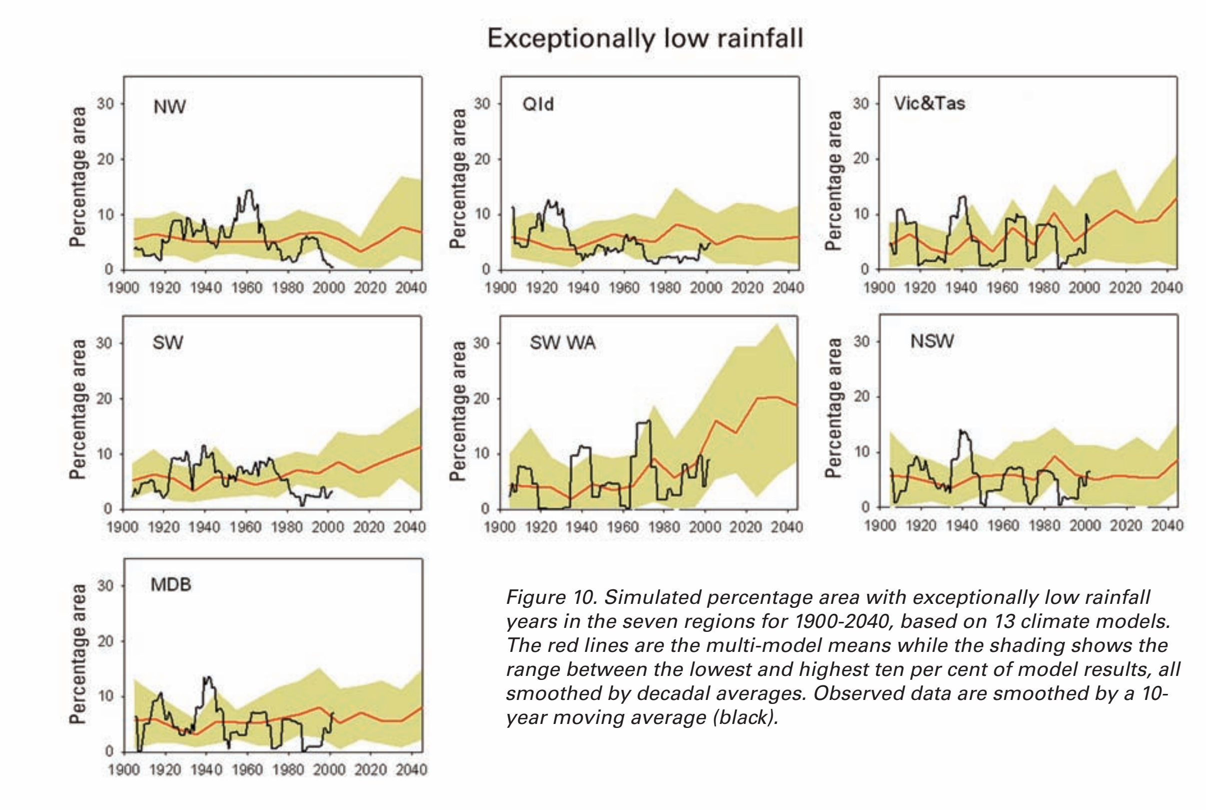


Figure 10. Simulated percentage area with exceptionally low rainfall years in the seven regions for 1900-2040, based on 13 climate models. The red lines are the multi-model means while the shading shows the range between the lowest and highest ten per cent of model results, all smoothed by decadal averages. Observed data are smoothed by a 10-year moving average (black).

Rainfall – percentage area

Region	1900-2007	2010-2040 low	2010-2040 mean	2010-2040 high
Qld	5.5	1.7	5.8	9.7
NSW	5.6	2.2	5.6	10.9
Vic&Tas	5.4	3.0	9.7	13.9
SW	5.6	5.0	8.4	12.1
NW	5.6	1.8	5.3	8.0
MDB	5.6	2.7	6.0	11.1
SW WA	5.5	9.0	18.4	26.5

Table 7. Simulated percentage area having exceptionally low annual rainfall for 1900-2007 and 2010-2040, based on 13 climate models. The low and high scenarios represent the lowest and highest ten per cent of the range of model results.

Rainfall – return periods

Region	1900-2007	2010-2040 low	2010-2040 mean	2010-2040 high
Qld	18.1	26.3	16.0	9.8
NSW	18.0	27.6	18.0	8.4
Vic&Tas	18.3	20.4	12.4	6.9
SW	18.0	22.4	13.7	8.1
NW	18.0	21.9	16.2	10.9
MDB	18.0	25.0	17.3	8.9
SW WA	18.1	10.7	6.5	3.7

Table 8. Simulated return periods (years) for exceptionally low annual rainfall for 1900-2007 and 2010-2040, based on 13 climate models. The low and high scenarios represent the lowest and highest ten per cent of the range of model results.

Soil moisture – percentage area

Region	1957-2006	50 years centered on 2030		
		Low	Mean	High
Qld	6.5	4.4	7.4	10.6
NSW	6.3	4.5	7.1	10.0
Vic&Tas	6.6	7.0	11.0	15.2
SW	6.2	6.0	8.5	11.3
NW	6.3	4.4	7.0	10.0
MDB	6.2	4.6	7.3	10.2
SW WA	6.1	12.8	15.9	20.0

Table 9. Simulated percentage area having exceptionally low annual-average soil moisture for 1957-2006 and 50 years centred on 2030, based on 13 climate models. The low and high scenarios represent the lowest and highest ten per cent of the range of model results.

Soil moisture – return periods

Region	1957-2006	50 years centered on 2030		
		Low	Mean	High
Qld	16.5	19.4	12.6	9.3
NSW	16.4	22.0	14.0	10.2
Vic&Tas	16.8	14.3	9.4	7.5
SW	16.3	15.1	11.5	8.8
NW	16.3	21.7	13.5	10.3
MDB	16.2	19.8	13.4	9.6
SW WA	17.0	7.0	6.0	4.9

Table 10. Simulated return periods (years) for exceptionally low annual-average soil moisture for 1957-2006 and 50 years centred on 2030, based on 13 climate models. The low and high scenarios represent the lowest and highest ten per cent of the range of model results.

4.4 Exceptionally low soil moisture

Table 9 shows that, over the past 50 years, about 6% of each region had exceptionally low soil moisture (Box 2). The simulations for 50 years centred on 2030 indicate a mean increase to around 7% in most regions. The low scenario is around 4.5% in most regions and the high scenario is around 10% in most regions. Larger percentage areas are simulated in the SW, Vic&Tas and SW WA regions.

Table 10 shows that, over the past 50 years, the mean return period between exceptionally low soil moisture years was around 16 years (Box 2). The simulations for 50 years centred on 2030 indicate a mean decrease to 12-14 years in most regions. The low scenario is around 19-22 years in most regions and the high scenario is 9-10 years in most regions. Shorter return periods are simulated in the SW, Vic&Tas and SW WA regions.

In summary, projected increases in the areal extent and frequency of exceptionally low soil moisture are more evident than those for rainfall, notwithstanding the different calculation methods. If soil moisture were the sole criterion for EC declarations, then the mean projections indicate that more declarations would be likely by 2030, particularly in the SW, SW WA and Vic&Tas regions. Under the high scenario, EC declarations would likely be triggered almost twice as often in most regions, compared with the historical record, and almost four times as often in SW WA. As stated earlier, the soil moisture datasets and analysis have higher levels of uncertainty than those for temperature and rainfall.

Box 4: Uncertainties and assumptions

There are four main sources of uncertainty in climate change science: (1) the projected increase in greenhouse gases; (2) the relationship between greenhouse gas emissions and their atmospheric concentrations; (3) the global warming for a given change in concentrations; and (4) regional climate change.

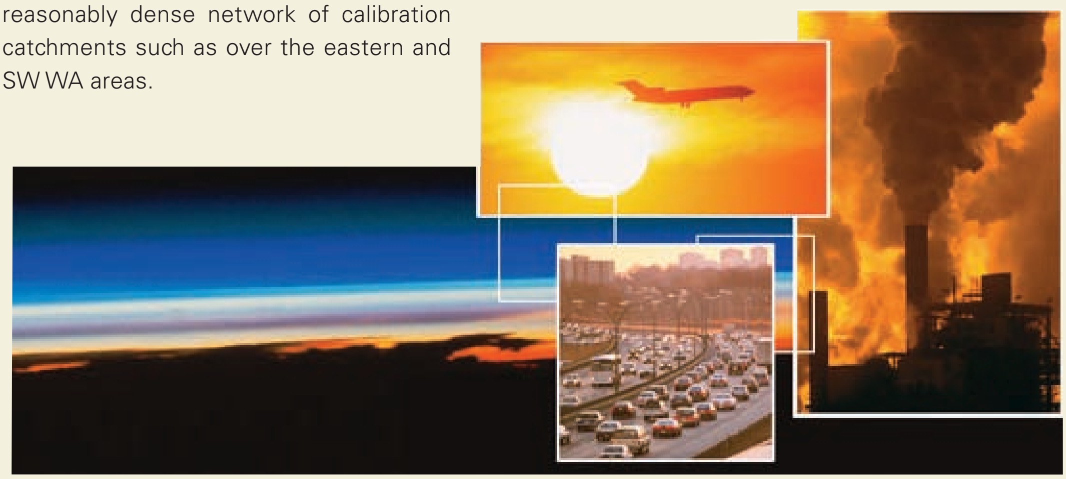
The emission scenarios depend on assumptions about future demographic changes, economic development and technological improvements[20]. These uncertainties become greater further into the future, but the emission scenarios are fairly similar up to 2030.

Greenhouse gas concentrations in the atmosphere depend not only on the emissions, but also on the rates at which the gases are removed from the air by various processes. Most gases are removed by chemical reactions or ultraviolet radiation, but carbon dioxide is removed by absorption into the oceans, vegetation and soils. Higher carbon dioxide concentrations and larger changes in climate tend to reduce the absorptive efficiency, resulting in even higher concentrations, as observed in recent years[30].

Increasing concentrations of greenhouse gases and changes in aerosol emissions affect the average surface temperature of the Earth. The warming effect of greenhouse gases is well understood. The contribution from aerosols (microscopic particles in the air) is less well understood, but is believed to lead to a net cooling effect[3]. There are significant uncertainties associated with factors that may enhance or suppress global warming, e.g. melting of polar ice or changes in cloud properties. Global warming projections take account of these uncertainties by expressing outcomes in terms of a range. The estimated global warming in 2030 for the mid-range A1B emission scenario[20] is 0.54-1.44°C, but as little as 0.45-1.20°C for the B1 scenario and as much as 0.6-1.6°C for the A1T scenario[2] (see Section 3).

Regional changes in climate have been derived from 13 climate models, most of which were driven by the A1B emission scenario[20]. Of the 13 models, six are considered to be slightly less reliable than the other models, according to various criteria[31]. We examined whether rainfall projections would be biased by excluding these six models. Since nearly all models show decreased rainfall in the south, with mixed results in the north, the model selection did not bias the rainfall projections. Using all 13 models represented a conservative approach. Ten of the 15 models used in the Murray-Darling Basin Sustainable Yields project[18] are amongst the 13 models used in our study. There is significant overlap between models used in both projects, and the non-overlapping models have a typical range of rainfall projections, so there is broad consistency between the two studies.

Soil moisture was estimated using a model called SIMHYD, which has been calibrated over 331 catchments across Australia[16] and used successfully for various applications. In this study, soil moisture for each 25 km grid cell is estimated using optimised parameter values from the closest calibration catchment. The further a catchment is away from a calibrated catchment, the larger the uncertainty in soil moisture estimates. This becomes less significant over areas with a reasonably dense network of calibration catchments such as over the eastern and SW WA areas.



5. Conclusions

Our conclusions address the Terms of Reference (Appendix 1) which require: (1) assessment of the place of past exceptional climatic events in the context of the likely frequency and severity of future climatic events; and (2) comments on the appropriateness of the current one in 20-25 year EC event trigger based on the historical record.

5.1 The likely frequency and severity of future climatic events

Temperature

The analysis clearly shows that the areal extent and frequency of exceptionally hot years have been increasing rapidly over recent decades and this trend is expected to continue in future. Further, over the past 40 years (1968-2007), exceptionally hot years are typically occurring over 10-12% of the area in each region, i.e. about twice the long-term average of 5%. By 2010-2040, the mean area is likely to increase to 60-80%, with a low scenario of 40-60% and a high scenario of 80-95%. Exceptionally hot years are likely to occur every 1-2 years, on average, over the period 2010-2040.

Rainfall

Trends are highly dependent on the period of analysis due to large variability between decades. This is particularly true for changes in exceptionally low rainfall. Since 1900, across most of Australia, the area experiencing exceptionally low rainfall has decreased slightly. However most regional trends since 1990 show increasing areas of exceptionally low rainfall in southern Australia. For 2010-2040, if rainfall were the sole trigger for EC declarations, then the mean projections indicate that more declarations would be likely, over larger areas, in the SW, SW WA and Vic&Tas regions, with little detectable change in the other regions. Under the high scenario in all regions, EC declarations would likely be triggered about twice as often (at least four times as often in SW WA) and over double the area (quadruple the area in SW WA).

Soil moisture

Soil moisture data – being derived from a combination of rainfall data, low-resolution observations of evaporation, and modelling – are less reliable. Projected increases in the areal extent and frequency of exceptionally low soil moisture years are slightly clearer than those for rainfall, notwithstanding the different calculation methods. If soil moisture were the sole criterion for EC declarations, then the mean scenarios indicate that more declarations would be likely by 2030, particularly in the SW, SW WA and Vic&Tas regions. Under the high scenario, EC declarations would likely be triggered almost twice as often in most regions compared with the historical record, and almost four times as often in SW WA.

5.2 The appropriateness of the one in 20-25 year EC event trigger

The current EC trigger, based on historic records, has already resulted in many areas of Australia being drought declared in more than 5% of years[12]. Further, on the measures of extreme events considered here, this frequency is likely to increase in the future without a change in the trigger (Section 5.1).

Could the trigger level be adjusted to track the changing nature of a one in 20-25 year event? It would be possible to design an operational trigger based on a moving window instead of the total historical record. However, this approach has already been modelled (based on 20, 30 or 40-year moving 'training windows')[12] and shown to result in no useful improvement. This is partly due to the lags in responses, since operationally the 'training windows' have to be historic. Moreover, such an approach also introduces new criteria (such as the duration of the 'training window') which may create contention in the same way that 'lines on maps' issues have in the past. Alternatively, to avoid depending on past data, trigger levels could be updated on the basis of future projections. However, such a system would require continual changes since projections are updated every few years.

In summary, this study suggests that the existing EC trigger definition is not appropriate under a changing climate. Future drought policy may be better served by avoiding the need for a trigger at all.

5.3. Future information needs and areas for more detailed assessment

Farmers and their suppliers need user-friendly, reliable and up-to-date information specific to their location regarding climatic conditions and future climate variability. Key here is the risk of drought on timescales from the current year out to some decades in the future. Changes to the frequency of good years, in which most farm profits are made, is also critical information. A sound understanding is also needed of the uncertainties associated with seasonal forecasts and decadal projections.

Some of this information is available on websites and in computer software provided by various agencies, e.g. the Bureau of Meteorology website (including SILO and Water and the Land: WATL); the Climate Change in Australia website; RAINMAN software; MetAccess software; the Queensland Government 'longpaddock' website; the Australian Water Availability Project website; and the National Agricultural Monitoring System website.

Improving this information will require:

- further improvement of drought monitoring capability, particularly through the integration of various data sources (e.g. satellites, stations, radars, etc.) and maintenance of the quality and distribution of networks for rainfall and other key climate observations;
- an online climate information system that readily integrates climate change projection information with the historical database is needed by farmers and others. Such infrastructure does not exist at present, but if it did it would allow farmers to assess climate projections in their region against the background of the historical climate.
- a better understanding of how local, regional and national decision making about climate variability and climate change in agriculture best contributes to farmer risk management and to industry adaptation to climate change;
- a national re-analysis of Australia's climate observations, using modern computational tools that can fill gaps in the observed record and can blend observations from a variety of sources including weather stations, satellites and weather balloons;
- participatory studies to more accurately identify the climate change information needs of different sectors of rural Australia;
- research to improve climate change projections and seasonal-to-interannual forecasts and their relevance to decision-makers in different sectors and regions of rural Australia.The development of seamless prediction systems on relevant timescales (e.g. Australian Community Climate and Earth System Simulator: ACCESS) is a critical step in this direction.

The benefit of this information will be enhanced by improved knowledge of:

- what information on climate and associated production and natural resource management variables will hasten or impede adoption of self-reliant approaches in the face of climate change, and of how different incentives affect this adoption; and
- how sustainable levels of production are likely to change with future climate change.

Critically, this climate information needs to be translated into the variables that matter for farmers and their suppliers, such as yields and farm economics. Consequently, tools will be required for this integration of climate information so as to contribute to agricultural risk management processes and decision-making. There is a suite of existing tools which in some cases are supported by social learning processes, e.g. Yield Prophet, National Crop Outlook website and FARMSCAPE. These can increase awareness and understanding, particularly with regard to seasonal climate outlooks, climate change projections, uncertainties and probabilistic information.

More detailed assessment of exceptional climatic events is likely to be needed for specific purposes within some sub-regions, e.g. southeast Queensland. An assessment of impacts beyond the next 20-30 years would be prudent, given the long-term planning horizons of some enterprises and the focus on sustainability.

APPENDIX 1 Terms of Reference

Assessment of the impact of climate change on the nature and frequency of exceptional climatic events

Background

Government assistance for drought events is guided by the current National Drought Policy (NDP). Under the NDP, drought assistance or support is intended to be a short-term measure to help farmers prepare for, manage and recover from drought. The objectives of the NDP are to:

- encourage primary producers and other sections of rural Australia to adopt self-reliant approaches for managing a changing climate;
- maintain and protect Australia's agricultural and environmental resource base during periods of extreme climate stress; and
- ensure early recovery of agricultural and rural industries, consistent with long-term sustainable levels.

Although self-reliance is a key objective, the NDP also recognises that there are rare and severe events that are beyond the ability of even the most prudent farmer to manage. The Commonwealth Government provides support to farmers and rural communities under the Exceptional Circumstances (EC) arrangements and other drought programs. The state and territory governments also participate in the NDP and provide support measures of their own.

To be classified as an EC event, the event must be rare, that is, it must not have occurred more than once on average in every 20-25 years. Australia is experiencing a drought that has been unprecedented in its geographic extent, length and severity. Some areas have been drought declared for 13 of the last 16 years, leading to some recipients receiving EC assistance since 2002.

Climate change will bring significant challenges for Australian agriculture. Climate change is expected to increase the frequency, severity and length of drought periods in future.

Australian primary industries ministers have agreed that current approaches to drought and EC are no longer the most appropriate in the context of a changing climate. They agreed that drought policy must be improved to create an environment of self-reliance and preparedness and encourage the adoption of appropriate climate change management practices.

To improve drought policy, ministers agreed to consider:

- relevant social dimensions and policy responses to drought and Exceptional Circumstances;
- the provision of accessible social welfare support, including eligibility criteria;
- the effectiveness of business support payments;
- the effectiveness of financial risk management strategies, including Farm Management Deposits;
- the effectiveness of preparedness policies; and
- cost-benefit analysis of State and Federal drought assistance.

This scientific assessment will be undertaken by the Bureau of Meteorology (BoM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and will examine the effect of climate change on the likely nature and frequency of exceptional climatic events. It will be presented in a form that will enable it to be used in future drought policy discussions, including stakeholder consultation, and it will articulate the assumptions made in undertaking the scientific assessment.

This assessment, as part of a review of drought policy, will support:

- Productivity Commission inquiry into the appropriateness of current Government drought business support and income support measures; and
- an expert panel's assessment of the social dimensions of the impacts of drought and the extent and range of current Government and non-government social support services available to farm families and rural communities.

This scientific assessment will provide a basis for longer term studies on the impact that climate change will have on the agricultural and environmental resource base.

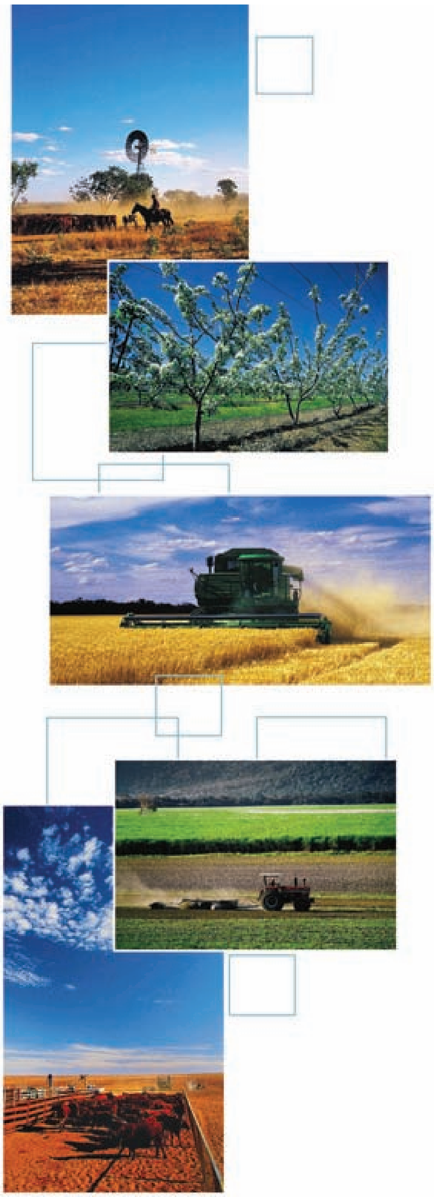
Scope of the assessment

The BoM and CSIRO are requested, on the basis of current knowledge of climate change science, to assess:

1. Likely changes to temperature regimes over the next 20-30 years across significantly sized regions (for example, northern Australia), such as consecutive sequences of unusually warm months or seasons.
2. Likely changes in the nature and frequency of severe rainfall deficiencies over the next 20-30 years, in comparison to severe rainfall deficiencies defined by the available instrument records. Severe rainfall deficiency is defined as an event in the lowest 5th percentile of historical records persisting for prolonged periods and over significantly sized regions.
3. The likely effect of projected climate changes on integrated measures of drought such as soil moisture, water availability, or an appropriate drought index, such as the Palmer Drought Severity Index, over the next 20-30 years.
4. The place of past exceptional climatic events in the context of the likely frequency and severity of future climatic events.

Based on this assessment, the BoM and CSIRO are requested to comment on the appropriateness of the current one in 20-25 year EC event trigger based on the historic record.

BoM and CSIRO are also requested to provide a preliminary assessment of future information needs and areas for more detailed assessment.



Nature of the assessment

BoM and CSIRO will provide a final report to the Minister for Agriculture, Fisheries and Forestry in June 2008. BoM and CSIRO's report will be released by the government.

APPENDIX 2 Regional summaries

Queensland summary

In Queensland, the frequency and areal extent of exceptionally hot years and exceptionally low soil moisture years are likely to increase in the future (Figure A1, Table A1). The mean projections indicate that:

- by 2010-2040, exceptionally hot years are likely to affect about 60% of the region, and occur every two years on average;
- by 2010-2040, little change is likely in the frequency and areal extent of exceptionally low rainfall years;
- by 2030, exceptionally low soil moisture years are likely to affect about 7% of the region and occur about once every 13 years on average.

Qld	1900-2007	2010-2040* low	2010-2040* mean	2010-2040* high
Percent area (T)	4.6	48.9	62.2	73.8
Percent area (R)	5.5	1.7	5.8	9.7
Percent area (S)	6.5	4.4	7.4	10.6
Return period (T)	21.9	2.1	1.7	1.3
Return period (R)	18.1	26.3	16.0	9.8
Return period (S)	16.5	19.4	12.6	9.3

*Table A1. Observed and simulated percentage areas and return periods (years) having exceptionally hot years (T), low rainfall years (R) and low soil moisture years (S) for 1900-2007 for 2010-2040, with projections based on 13 climate models. The low and high scenarios represent the lowest and highest 10% of the range of model results. *For soil moisture the projections are for 50 years centred on 2030, not 2010-2040.*

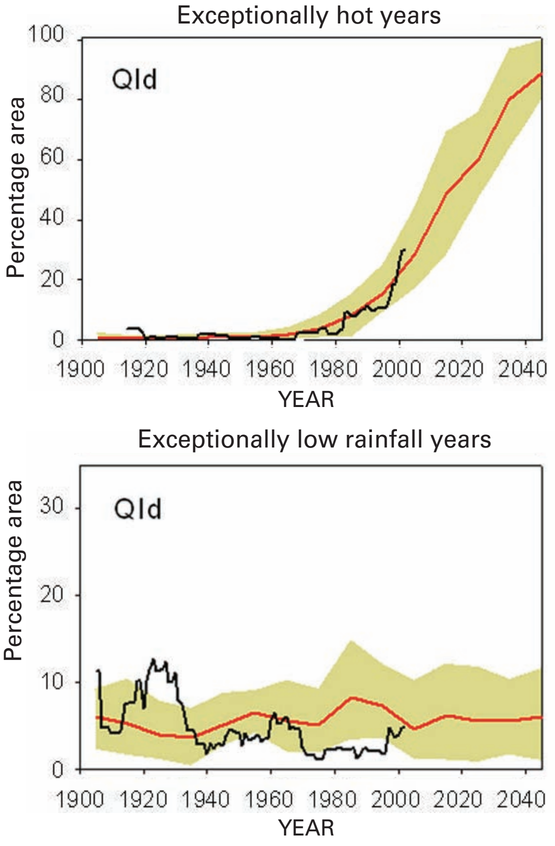


Figure A1. Observed and simulated percentage area with exceptionally hot years (upper) and exceptionally low rainfall years (lower) in Queensland for 1900-2040, with projections based on 13 climate models. The red lines are the multi-model means while the shading shows the range between the lowest and highest 10% of model results, all smoothed by decadal averages. Observed data are smoothed by a 10-year moving average (black).

New South Wales summary

In NSW, the frequency and areal extent of exceptionally hot years and exceptionally dry years are likely to increase in the future (Figure A2, Table A2). The mean projections indicate that:

- by 2010-2040, exceptionally hot years are likely to affect about 60% of the region, and occur every 1.6 years on average;
- by 2010-2040, no change is likely in the frequency or areal extent of exceptionally low rainfall years;
- by 2030, exceptionally low soil moisture years are likely to affect about 7% of the region and occur about once every 14 years on average.

Qld	1900-2007	2010-2040* low	2010-2040* mean	2010-2040* high
Percent area (T)	4.5	43.5	62.1	81.0
Percent area (R)	5.6	2.2	5.6	10.9
Percent area (S)	6.3	4.5	7.1	10.0
Return period (T)	22.2	2.2	1.6	1.1
Return period (R)	18.0	27.6	18.0	8.4
Return period (S)	16.4	22.0	14.0	10.2

*Table A2. Observed and simulated percentage areas and return periods (years) having exceptionally hot years (T), low rainfall years (R) and low soil moisture years (S) for 1900-2007 for 2010-2040, with projections based on 13 climate models. The low and high scenarios represent the lowest and highest 10% of the range of model results. *For soil moisture the projections are for 50 years centred on 2030, not 2010-2040.*

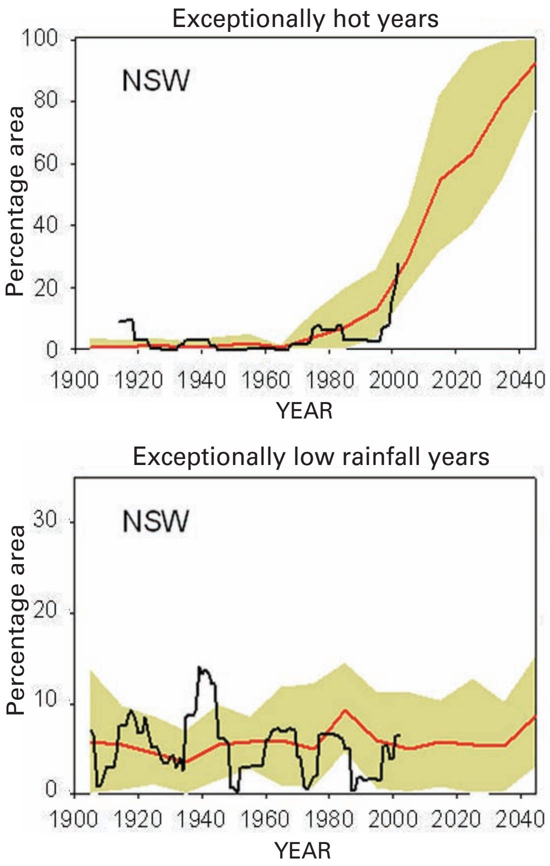


Figure A2. Observed and simulated percentage area with exceptionally hot years (upper) and exceptionally low rainfall years (lower) in NSW for 1900-2040, with projections based on 13 climate models. The red lines are the multi-model means while the shading shows the range between the lowest and highest 10% of model results, all smoothed by decadal averages. Observed data are smoothed by a 10-year moving average (black).

Victoria and Tasmania summary

In Victoria and Tasmania (Vic&Tas), the frequency and areal extent of exceptionally hot years and exceptionally dry years are likely to increase in the future (Figure A3, Table A3). The mean projections indicate that:

- by 2010-2040, exceptionally hot years are likely to affect about 75% of the region, and occur every 1.3 years on average;
- by 2010-2040, exceptionally low rainfall years are likely to affect about 10% of the region and occur about once every 12 years on average;
- by 2030, exceptionally low soil moisture years are likely to affect about 11% of the region and occur about once every 9 years on average.

Qld	1900-2007	2010-2040* low	2010-2040* mean	2010-2040* high
Percent area (T)	4.6	60.5	76.1	95.0
Percent area (R)	5.4	3.0	9.7	13.9
Percent area (S)	6.6	7.0	11.0	15.2
Return period (T)	21.8	1.6	1.3	1.0
Return period (R)	18.3	20.4	12.4	6.9
Return period (S)	16.8	14.3	9.4	7.5

*Table A3. Observed and simulated percentage areas and return periods (years) having exceptionally hot years (T), low rainfall years (R) and low soil moisture years (S) for 1900-2007 for 2010-2040, with projections based on 13 climate models. The low and high scenarios represent the lowest and highest 10% of the range of model results. *For soil moisture the projections are for 50 years centred on 2030, not 2010-2040.*

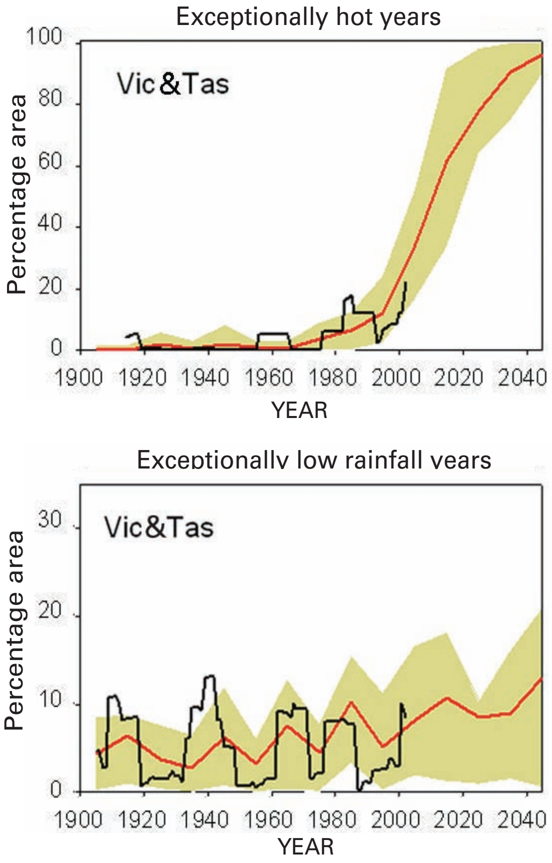


Figure A3. Observed and simulated percentage area with exceptionally hot years (upper) and exceptionally low rainfall years (lower) in Vic&Tas for 1900-2040, with projections based on 13 climate models. The red lines are the multi-model means while the shading shows the range between the lowest and highest 10% of model results, all smoothed by decadal averages. Observed data are smoothed by a 10-year moving average (black).

Northwest summary

In the northwest (NW) region, the frequency and areal extent of exceptionally hot years and exceptionally dry years are likely to increase in the future (Figure A4, Table A4). The mean projections indicate that:

- by 2010-2040, exceptionally hot years are likely to affect about 65% of the region, and occur every 1.5 years on average;
- by 2010-2040, exceptionally low rainfall years are likely to occur about once every 16 years on average, with no change in areal extent;
- by 2030, exceptionally low soil moisture years are likely to affect about 7% of the region and occur about once every 14 years on average.

Qld	1900-2007	2010-2040* low	2010-2040* mean	2010-2040* high
Percent area (T)	4.6	50.0	63.5	82.0
Percent area (R)	5.6	1.8	5.3	8.0
Percent area (S)	6.3	4.4	7.0	10.0
Return period (T)	21.9	2.0	1.5	1.2
Return period (R)	18.0	21.9	16.2	10.9
Return period (S)	16.3	21.7	13.5	10.3

*Table A4. Observed and simulated percentage areas and return periods (years) having exceptionally hot years (T), low rainfall years (R) and low soil moisture years (S) for 1900-2007 for 2010-2040, with projections based on 13 climate models. The low and high scenarios represent the lowest and highest 10% of the range of model results. *For soil moisture the projections are for 50 years centred on 2030, not 2010-2040.*

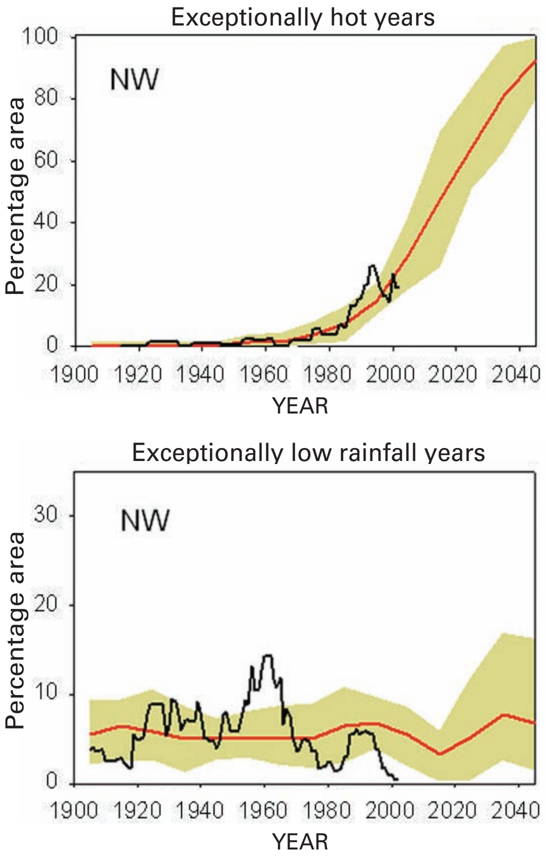


Figure A4. Observed and simulated percentage area with exceptionally hot years (upper) and exceptionally low rainfall years (lower) in the NW region for 1900-2040, with projections based on 13 climate models. The red lines are the multi-model means while the shading shows the range between the lowest and highest 10% of model results, all smoothed by decadal averages. Observed data are smoothed by a 10-year moving average (black).

Southwest summary

In the southwest (SW) region, the frequency and areal extent of exceptionally hot years and exceptionally dry years are likely to increase in the future (Figure A5, Table A5). The mean projections indicate that:

- by 2010-2040, exceptionally hot years are likely to affect about 70% of the region, and occur every 1.5 years on average;
- by 2010-2040, exceptionally low rainfall years are likely to affect about 8% of the region and occur about once every 14 years on average;
- by 2030, exceptionally low soil moisture years are likely to affect about 9% of the region and occur about once every 12 years on average.

Qld	1900-2007	2010-2040* low	2010-2040* mean	2010-2040* high
Percent area (T)	4.6	49.1	68.4	86.3
Percent area (R)	5.6	5.0	8.4	12.1
Percent area (S)	6.2	6.0	8.5	11.3
Return period (T)	21.9	2.0	1.5	1.1
Return period (R)	18.0	22.4	13.7	8.1
Return period (S)	16.3	15.1	11.5	8.8

*Table A5. Observed and simulated percentage areas and return periods (years) having exceptionally hot years (T), low rainfall years (R) and low soil moisture years (S) for 1900-2007 for 2010-2040, with projections based on 13 climate models. The low and high scenarios represent the lowest and highest 10% of the range of model results. *For soil moisture the projections are for 50 years centred on 2030, not 2010-2040.*

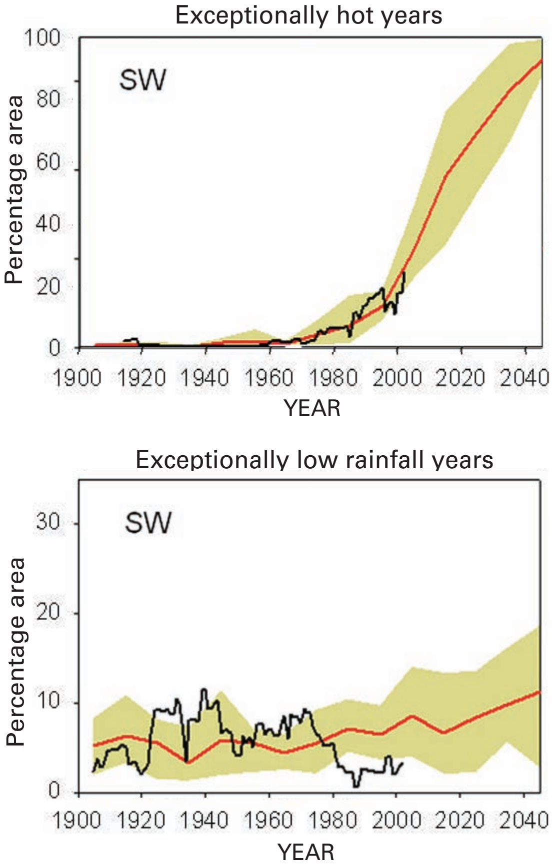


Figure A5. Observed and simulated percentage area with exceptionally hot years (upper) and exceptionally low rainfall years (lower) in the SW region for 1900-2040, with projections based on 13 climate models. The red lines are the multi-model means while the shading shows the range between the lowest and highest 10% of model results, all smoothed by decadal averages. Observed data are smoothed by a 10-year moving average (black).

Southwest WA summary

In southwest WA (SW WA), the frequency and areal extent of exceptionally hot years and exceptionally dry years are likely to increase in the future (Figure A6, Table A6). The mean projections indicate that:

- by 2010-2040, exceptionally hot years are likely to affect about 80% of the region, and occur every 1.2 years on average;
- by 2010-2040, exceptionally low rainfall years are likely to affect about 18% of the region and occur about once every seven years on average;
- by 2030, exceptionally low soil moisture years are likely to affect about 16% of the region and occur about once every six years on average.

SW WA	1900-2007	2010-2040* low	2010-2040* mean	2010-2040* high
Percent area (T)	4.6	63.1	81.9	97.1
Percent area (R)	5.5	9.0	18.4	26.5
Percent area (S)	6.1	12.8	15.9	20.0
Return period (T)	21.6	1.5	1.2	1.0
Return period (R)	18.1	10.7	6.5	3.7
Return period (S)	17.0	7.0	6.0	4.9

*Table A6. Observed and simulated percentage areas and return periods (years) having exceptionally hot years (T), low rainfall years (R) and low soil moisture years (S) for 1900-2007 and for 2010-2040, with projections based on 13 climate models. The low and high scenarios represent the lowest and highest 10% of the range of model results. *For soil moisture the projections are for 50 years centred on 2030, not 2010-2040.*

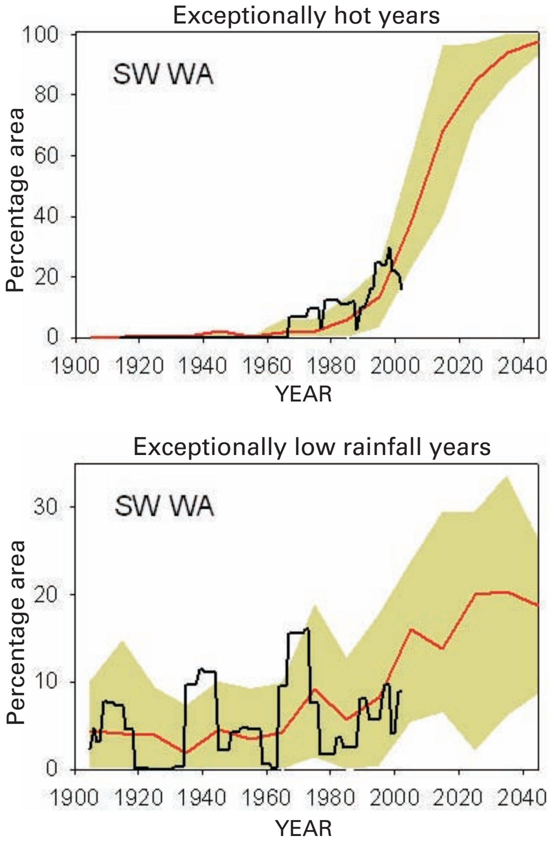
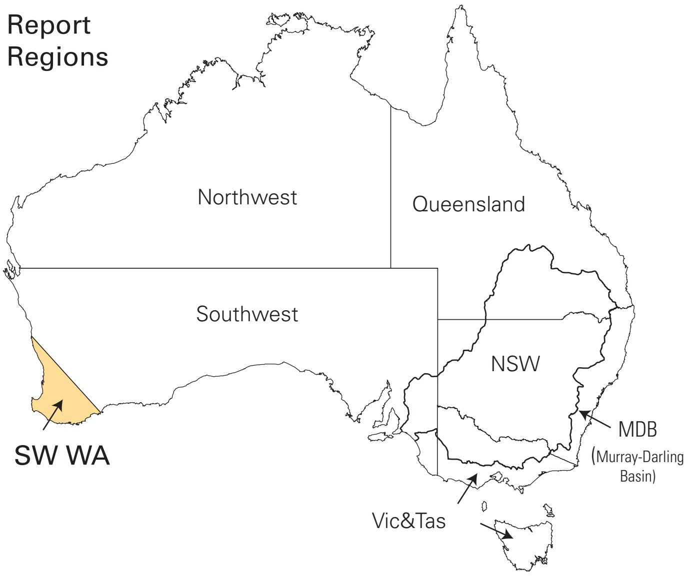


Figure A6. Observed and simulated percentage area with exceptionally hot years (upper), and exceptionally low rainfall years (lower) in SW WA for 1900-2040, with projections based on 13 climate models. The red lines are the multi-model means while the shading shows the range between the lowest and highest 10% of model results, all smoothed by decadal averages. Observed data are smoothed by a 10-year moving average (black).



Murray-Darling Basin summary

In the Murray-Darling Basin (MDB), the frequency and areal extent of exceptionally hot years and exceptionally dry years are likely to increase in the future (Figure A7, Table A7). The mean projections indicate that:

- by 2010-2040, exceptionally hot years are likely to affect about 65% of the region, and occur every 1.6 years on average;
- by 2010-2040, little change is likely in the frequency and areal extent of exceptionally low rainfall years;
- by 2030, exceptionally low soil moisture years are likely to affect about 7% of the region and occur about once every 13 years on average.

Qld	1900-2007	2010-2040* low	2010-2040* mean	2010-2040* high
Percent area (T)	4.5	45.2	64.9	90.1
Percent area (R)	5.6	2.7	6.0	11.1
Percent area (S)	6.2	4.6	7.3	10.2
Return period (T)	22.1	2.0	1.6	1.1
Return period (R)	18.0	25.0	17.3	8.9
Return period (S)	16.2	19.8	13.4	9.6

*Table A7. Observed and simulated percentage areas and return periods (years) having exceptionally hot years (T), low rainfall years (R) and low soil moisture years (S) for 1900-2007 for 2010-2040, with projections based on 13 climate models. The low and high scenarios represent the lowest and highest 10% of the range of model results. *For soil moisture the projections are for 50 years centred on 2030, not 2010-2040.*

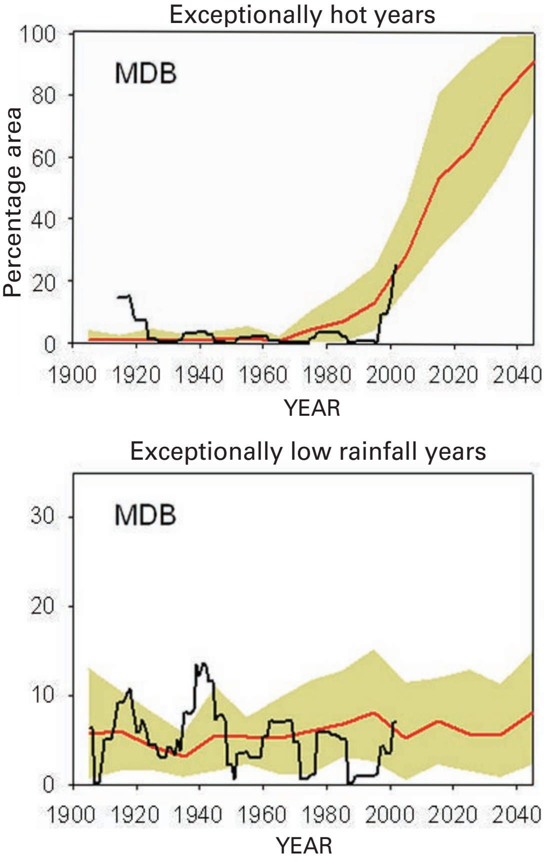


Figure A7. Observed and simulated percentage area with exceptionally hot years (upper) and exceptionally low rainfall years (lower) in the MDB for 1900-2040, with projections based on 13 climate models. The red lines are the multi-model means while the shading shows the range between the lowest and highest 10% of model results, all smoothed by decadal averages. Observed data are smoothed by a 10-year moving average (black).

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