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IPCC AR6 Working Group 1 report: conclusions on the evolving risk of drought

A special briefing by the ARC Centre of Excellence for Climate Extremes

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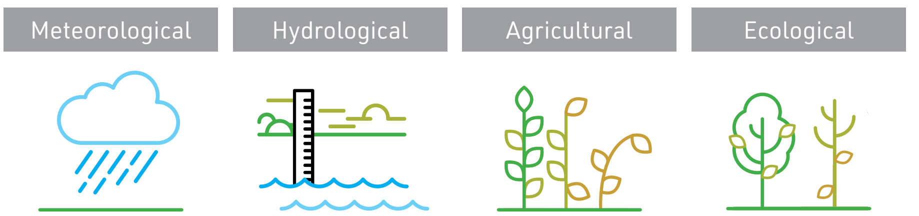
Drought is a major risk to Australia with extended periods of drought affecting our social, economic and environmental systems. The newly released report by the Intergovernmental Panel on Climate Change contains significant new assessments of the science and future projections of drought[1].

- Droughts are increasing over parts of south-east and south-west areas of Australia and are projected to continue to increase in the future.
- Some types of drought have decreased in northern Australia associated with increased wet season rainfall.
- No definitive links have been made between most recent Australian droughts and climate change due to high natural variability in rainfall.
- Climate model projections are consistent in suggesting an increase in many types of drought, in particular over southern Australia.
- Some attributes of drought (e.g. intensity) are not well simulated in global climate models, pointing to areas requiring further scientific development.

Droughts in Australia based on observations

There are many different types of drought. *Meteorological* drought is the result of a prolonged reduction in rainfall, while *hydrological* drought is where water reserves become depleted. Hydrological droughts are affected by climate change, as well as human activities such as water management and changes in land use. *Agricultural* and *ecological* drought occur when there is insufficient soil moisture available for plant growth.

TYPES OF DROUGHT



Environmental
Environmental drought, tree mortality, fire, habitat loss, erosion, water quality.

Socioeconomic
Crop failure, livestock mortality, low water supply, less hydropower.

Figure 1: Types of drought

Using observations, the IPCC note that hydrological droughts are increasing in the south-east and south-west areas of Australia[1,2,3,4]. These increases in drought are very much limited to the southern parts of the continent, and associated with declining cool season rainfall. Observations also show increases in agricultural and ecological droughts in southern Australia[5]. Agricultural and ecological droughts have decreased in northern Australia.

Our confidence in the past changes in different types of drought vary as a consequence of the quality and spatial coverage of observed data which is much richer and longer-term for meteorological drought than for ecological drought. The IPCC reports provide an assessment of the science of these changes, and provides detailed references to the key papers. We have gone back to those key papers to summarise the evidence the IPCC used in their assessment.

Meteorological drought: Most studies of meteorological drought are analyses based on changes in annual or seasonal rainfall. The IPCC reports *decreases* in meteorological drought frequency and intensity in northern Australia. This is supported by multiple lines of evidence including decreases in drought frequency and intensity between 1911-2009 and 1960-2009[5], an increase in average wet season rainfall in this region[6,7,8] and decreasing trends in consecutive dry days[9] . Reductions in average autumn and winter rainfall have been observed over southwestern Australia from 1900–2018[8]. Declines in cool season (April-October) rainfall were reported in parts of southeastern Australia since at least the mid-1970s[12,13], but longer-term decreasing trends over these regions since 1900 are not statistically significant[14,8] in part due to the short duration of the recent trend relative to natural variability. Summer rainfall is increasing over southern Australia[8].

Hydrological drought: The IPCC report an increasing drying signal in the southeast and particularly the southwest of Australia. A strong negative trend in southern Australia is identified for all indices of streamflow (low, median & high flows) over the period 1971-2010[4]. Using a longer analysis period (1950-2014) decreases in annual flow and various quantiles of streamflow have been noted in southeast Australia[2] including a significant decreasing trend in annual streamflow for most monitoring stations in New South Wales, Victoria, southeast South Australia, southwest Western Australia and northwest Tasmania. The majority of flow monitoring stations in the southern parts of Australia were characterised by rapid declines[2].

Ecological and agricultural drought: Multiple lines of evidence point to decreasing drought in northern Australia[10,5,11,12] which is to be expected given the observed increase in warm season rainfall. In southern Australia there is a drying trend in some regions, although this depends to a degree on how drought is measured and over what timescales the trends are calculated. There is some limited evidence that the intensity of drought has increased in southwest Australia[21,22], and the duration of drought has in increased in southeast Australia from 1911-2009[23]. However, a lack of observed data early in the 20th century makes robust trends difficult to discern.

Recent and severe droughts in most parts of Australia cannot be definitively connected to human influence, including southeastern Australia[13]. Recent and severe droughts in Australia have been linked to tropical climate variability (El Niño-Southern Oscillation and the Indian Ocean Dipole[14]) but the large variability in the climate makes extracting a clear climate change signal difficult. The one major exception is the winter rainfall decline in southwestern Australia which has been linked to human-induced climate change[6] causing a southward migration of the mid-latitude storm track.

Projections of future drought over Australia

Future projections of drought are regionally variable, though the most recent IPCC report makes it clear that these regional changes become more extreme with every additional fraction of a degree of global warming. Hydrological drought is expected to increase in southern Australia at global climate warming levels of 2°C or higher[15]. Agricultural and ecological droughts are expected to increase in southern and eastern Australia at global warming levels of 2°C or higher[3,16,17]we developed new information on drought projections for Australia and four sub-regions based on the natural resources management (NRM.

These projections rely on climate model simulations which can capture the duration of observed short-term meteorological droughts seen in Australia but do not capture the intensity of observed droughts well[18]. The IPCC state that for several regions, including southern Australia, more frequent and severe meteorological droughts will be experienced with climate warming[4]. Much of the increase in drought is associated with a poleward shift in the storm tracks that tends to reduce rainfall in the far south of the continent. This poleward shift may reverse, and the rainfall recover, if climate is stabilised[19] although this is uncertain and requires further study.

Climate projections show changes to regional-scale weather and climate systems (e.g. anticyclones and the sub-tropical ridge), and large-scale phenomena (e.g. El Niño and positive Indian Ocean Dipole events[20]) that are related to elevated drought risk in Australia. Climate models project changes to circulation patterns that lead to the types of climatic conditions that suppress rainfall over southern Australia[21]. More El Niño-like conditions are expected in the future[22], although there is considerable uncertainty in these projections[23] and rain-promoting La Niña event may also become stronger. There is evidence that positive Indian Ocean Dipole events may become stronger and more common[24], and the positive trend in the Southern Annular Mode continue in winter. Both of these are associated with cool season drying over southern Australia. However, the impact of these changes on Australian drought has not yet been directly examined.

Global Changes in drought

Global changes in drought are important to Australia as they can impact global food security, the supply of some agricultural crops to Australia, or add significantly to the cost of imports. Droughts may also cause significant social dislocation with security concerns, although linking these phenomena is not straightforward[25].

Globally, the frequency and severity of droughts has increased over the last few decades in the Mediterranean, western North America, and southwestern Australia and this can be attributed to human induced climate warming[26,6]. Meteorological droughts, associated with deficits in precipitation, have also increased in parts of Africa and South America. Human induced climate change has affected observed changes in meteorological droughts in southwestern South America (increase) and northern Europe (decrease). Agricultural and ecological droughts, associated with a lack of sufficient soil moisture, show stronger changes than meteorological droughts due, in

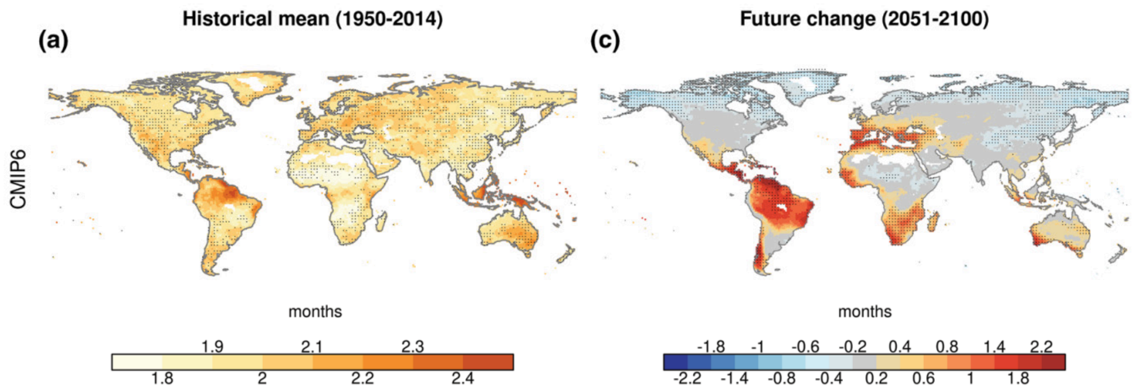


Figure 2: Projected changes in drought duration from the latest global climate models (CMIP6). The left panel (a) shows the simulation of drought duration over the historical period (1950-2014). The stippling shows where >75% of the models are within 10% of the observed mean. The left panel shows projected changes (2051-2100) relative to the historical period. Stippling indicates where the magnitude of the multi-model mean future changes exceeds the inter-model standard deviation (source[18]).

part, to increases in atmospheric evaporative demand[16]. Large reductions in runoff are projected over southern Africa, the Mediterranean and northern North America, but large increases are projected over northern North America, Eurasia, and the Indian sub-continent[16]. Hydrological droughts are affected by climate change, as well as human activities such as water management and changes in land use.

An analysis[18] of future meteorological drought duration risk shows that climate models can capture observed drought duration well (as shown by the stippling in the figure below, left). These same models agree on increases in drought duration in the future (as shown by the stippling in the figure below, right), giving confidence in these projections.

The IPCC report also highlights new understanding around concurrent heat waves and droughts (compound events)[27]. These have increased in frequency over the last century at the global scale due to human influence[28].

Why is projecting future drought so challenging?

First and foremost, drought is a regional phenomenon driven by rainfall which in turn responds to many drivers on many timescales. In Australia, rainfall is affected by the large-scale modes of variability (such as El Niño-Southern Oscillation). Rainfall is also affected by the location of the storm tracks south of Australia which are moving poleward with major implications for southern Australian rainfall. In northern parts of Australia, and the eastern states, the sea surface temperatures that influence cyclones and east coast low formation are also important sources of rainfall. Finally, a lot of rainfall is associated with smaller-scale features such as fronts and deep convection. This leads to the need for models to capture many phenomena, operating on many timescales and spatial scales, and the interactions between these phenomena.

Despite the challenge, the evidence is that global models have skill in capturing the duration of meteorological droughts, particularly on shorter timescales. The models also consistently simulate future droughts lasting longer over many regions of Australia.

Our models are currently less skilled in simulating drought intensity; although this has only been evaluated for meteorological droughts it is likely true of other types of drought. This is linked with multiple challenges including those associated with land surface processes[29]. For example, changes in the water use efficiency of plants and plant growth will occur at higher CO_2 concentrations. These changes have the potential to affect future changes in agricultural and ecological droughts, which are not fully understood[1,26].

A further issue is that the models used to represent hydrological processes, and human management of hydrological processes are not fully developed in global climate models. This has led to the evolution of methods to explore hydrological droughts where data are taken from climate models and used to force hydrological models. Evidence has emerged that this is not a robust approach in a changing climate and tends to overestimate how droughts will intensify[30].

Resolving how droughts will change in the future in Australia is extremely challenging. The ARC Centre of Excellence for Climate Extremes is pursuing multiple strategies, in collaboration with our partners, including much higher resolution climate models, improved representation of rainfall processes, and improved hydrological and ecological processes in our models. Our goal is to provide more reliable scientific foundations for efforts to adapt to future droughts. For the foreseeable future, and for most of Australia, adaptation to drought will have to accommodate deep uncertainty on the future frequency, magnitude and duration of all types of drought. The exceptions to this are the drying trends in south west Western Australia and the far south of Victoria and South Australia, and the wetting trends in the far north of Australia which may become attributed to human activities soon.

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Figure 1 Types of drought designed by A Crimp

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