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ORIGINAL ARTICLE

Dangerous climate change and water resources in Australia

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Abstract Water resources in Australia are sensitive to changes in rainfall. Ongoing droughts in south-west and south-east Australia are stressing water resources in the major cities and in agricultural regions. Climate change scenarios for Australia include reasonable prospects of long-term drying, which would exacerbate these issues. The dryer scenarios would entail major readjustments and costs on natural and human systems.

Keywords Climate change · Water resources · Australia · Risk assessment · Climate variability

Introduction

Water resource issues in Australia are intimately related to the prevailing rainfall distribution, which governs the pattern and types of habitation and agriculture. The major cities are situated on the coastal fringes where much of the rainfall occurs. Agricultural production follows the rainfall regions and the major river valleys that spring from these regions. Major agriculture thus favors the east, west, and south coasts and inland regions such as the Murray-Darling basin. The high variability of rainfall in Australia leads to large variations in agricultural output and places stress on water management systems in the major cities. This is particularly apparent during major drought episodes such as that which gripped much of the continent in 2002 (Karoly et al. 2003).

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While Australia is already sensitive to existing variability in water resources, it may also be particularly vulnerable to climate change. That is because dry continents like Australia tend to dry out further in climate change scenarios. Thus, water resources may be the 'Achilles heel' of Australia under climate change and pose the most significant dangers. In this article, we begin by outlining the existing rainfall and water resource distribution and examine current trends in rainfall and temperature. Then, we summarize projections of climate change for the Australian region. This provides the context for examining changes in water resources and their likely impacts.

Current climate of Australia

The continent of Australia spans a tropical (monsoonal) climate regime in the north through an arid interior and a southern coast on the fringe of the southern ocean mid-latitude storm tracks. This produces the characteristic rainfall distribution shown in Fig. 1 with rainfall in the northern and southern coastal fringes of the continent. There is also significant rainfall along the eastern coastal fringe associated with storm systems and their interaction with the Great Dividing Range. The major cities are located inside the coastal fringes where rainfall occurs. The interior of the continent receives very little rainfall, because it sits beneath the descending branch of the subtropical ridge, as is characteristic of the planet's desert regions.

These features of rainfall in Australia make it particularly sensitive to greenhouse-driven climate changes. Though rainfall is hard to project in models, one of the consistent results that emerge is that the dry regions tend to

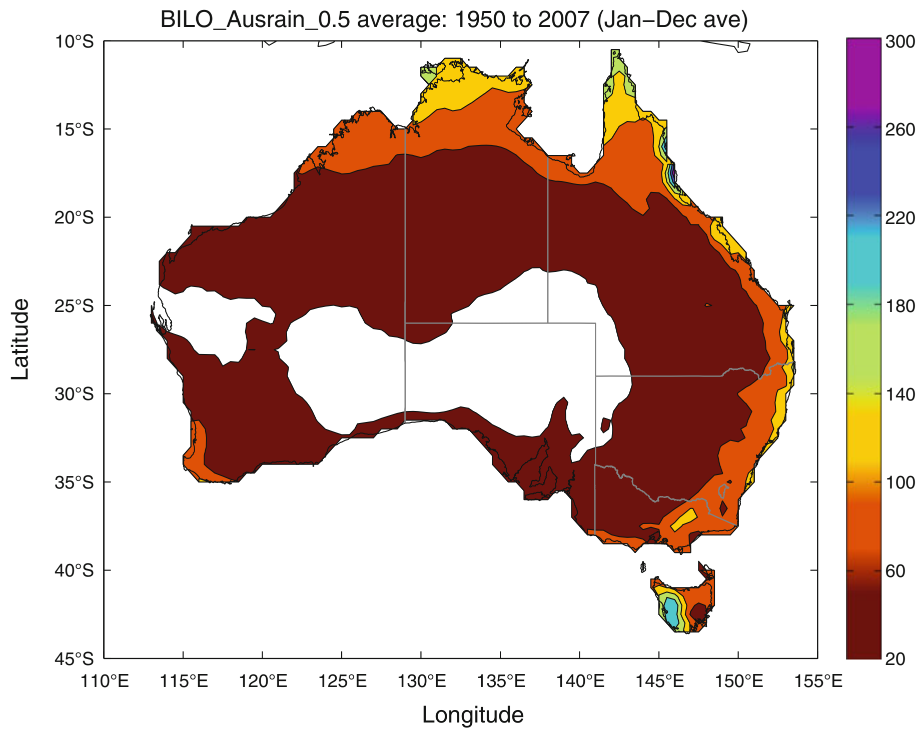


Fig. 1 Australian annual rainfall (mm). The rainfall data are described in Jones et al. (2009)

get dryer and wet regions wetter under greenhouse scenarios (Hansen et al. 1998; IPCC 2001, 1996, 2007). This result is also supported on dynamical and thermodynamical grounds (Held and Soden 2006). As a dry continent, Australia tends to dry out further in the models (except in the tropical north) as we shall see in the next section. An additional concern is that the southern coast and cities (Perth, Adelaide, Melbourne, Hobart, Sydney) are dependent on the passage of frontal and cutoff systems to provide much of their rainfall (Pook et al. 2006; Risbey et al. 2009). If these systems were to contract to the south as a result of greenhouse or ozone forcing of the climate (Hartmann et al. 2000; Karoly 2003), there is potential for major rainfall reductions in these regions. This is a particular concern in light of studies that indicate a contraction of the southern ocean storm track in recent decades (Thompson and Solomon 2002; Frederiksen and Frederiksen 2007).

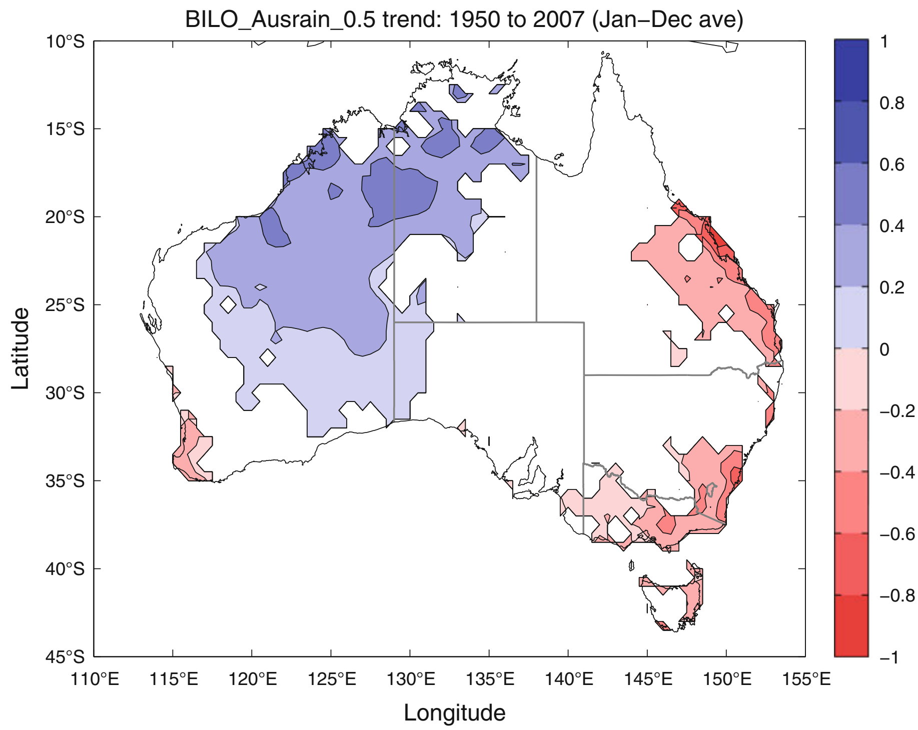
Though the link between climate change, circulation changes, and rainfall trends in Australia is not yet well established (Karoly 2003), the circulation trends are worrying in light of the observed rainfall declines in the southwest and southeast of Australia in recent decades (Gallant et al. 2007). Figure 2 shows rainfall trends over the past half century and indicates a drying of the southwest and southeast of the continent. The figure also shows increases over northwest and central Australia and decreases over all the eastern states.

Rainfall variability in the eastern Australian states is closely related to the El Niño Southern Oscillation (ENSO), with dryer years typical during El Niño episodes (Nicholls et al. 1997). Trends in ENSO are thus also a concern in regard to rainfall trends in Australia. There appears to have been a shift towards more frequent, intense El Niño episodes since about 1970 (Folland et al. 2001)—which is consistent with the drying trend over the eastern states. The reality of this shift and any links to greenhouse climate forcing will take longer to unravel unfortunately. Some climate models do project increases in El Niño under greenhouse forcing, though not all models agree (Risbey et al. 2002). Rainfall variability across southern Australia is also related to the Indian Ocean Dipole (IOD), Southern Annular Mode (SAM), and blocking events (Risbey et al. 2009). The declining trend in southern Australian rainfall has been linked to each of these features to some degree (Murphy and Timbal 2008), though none are definitive.

Temperature trends in Australia over the past century are consistent with global trends in showing a more or less steady warming, which is uniform across the continent, with the exception of small region in the northwest. The cooling region is coincident with the area of largest rainfall increase shown in Fig. 2 and is probably associated with the increased rainfall and cloudiness there.

There have been various studies of changes to climate extremes in Australia, with a good summary of past changes provided by Nicholls et al. (2000). These show mixed trends (increases and decreases) for various measures of extreme regional rainfall and no trend in the percentage of the country in extreme rainfall (drought or wet) conditions since 1910—though at subcontinental scales, there is a drying in the east and moistening in the

Fig. 2 Trend in rainfall based on 1950–2007 period (mm yr^{-1})



northwest. At a global scale, the percentage of the earth's surface experiencing extreme dry conditions has increased over the past century, with a more marked increase in the past half century (Dai et al. 2004). This is driven in part by the increase in temperature, which increases potential evaporation and contributes to drying at the surface (Dai et al. 2004). Extreme temperatures in Australia exhibit increases in the number of hot days (Nicholls et al. 2000; Tryhorn and Risbey 2006). Warmer temperatures tend to exacerbate droughts when they occur and were cited as contributing factors to the severity of the 2002 Australian drought (Nicholls 2004; Risbey et al. 2003).

Beyond these episodic droughts, sustained droughts are ongoing over parts of southwestern and southeastern Australia. In the southwest, there has been a sustained drop in rainfall of about 10–15% since the 1970s (Timbal 2004). This has led to a reduction in inflows into Perth's dams by about half (IOCI 2002). This is a severe shock to the water system in the major city in the region. The cause of the rainfall decline in southwestern Australia is the subject of ongoing research (IOCI 2002), but will be difficult to establish unequivocally. It may be a natural decline (Cai et al. 2005), or it may be associated with changes in greenhouse gases and/or ozone (Karoly 2003).

The number of storms passing through this region has declined in recent decades (Frederiksen and Frederiksen 2007; Simmonds and Keay 2000). Though storm tracks fluctuate naturally, there is concern that this is consistent with the poleward contraction of southern hemisphere storm tracks posited by Hartmann et al. (2000) and others. That contraction is said to occur in conjunction with an ozone-greenhouse induced cooling of the lower stratosphere in high southern latitudes. Thus, human-induced climate change may already be affecting this region. The long-term nature of the rainfall decline in Perth and the possibility that it is greenhouse driven have led Perth's water resource managers to assume that the reduced rainfall is now the new norm for planning purposes (Sadler 2000). In response, Perth Water Corporation has brought forward a range of projects to develop additional supply (including desalinization) at a cost of hundreds of millions of dollars.

The problems in Perth may extend to other cities in the south, if the poleward shift in storm tracks extends across the continent. The other major cities in southern Australia (Brisbane, Sydney, Melbourne, Adelaide) are also enduring drought, with reservoir supply levels near record lows in recent years. All have instituted major water restrictions, with Melbourne and Adelaide declaring some of them permanent. The water supply problems across southern Australia are primarily related to reductions in rainfall, with warming playing a much smaller role so far (though it does exacerbate the problems). Water managers for all these cities are concerned about climate change, and we turn to projections of climate change in the following section.

Climate projections for Australia

Climate projections are generally more robust at the largest spatial scales. Thus, it is worth considering first the global-

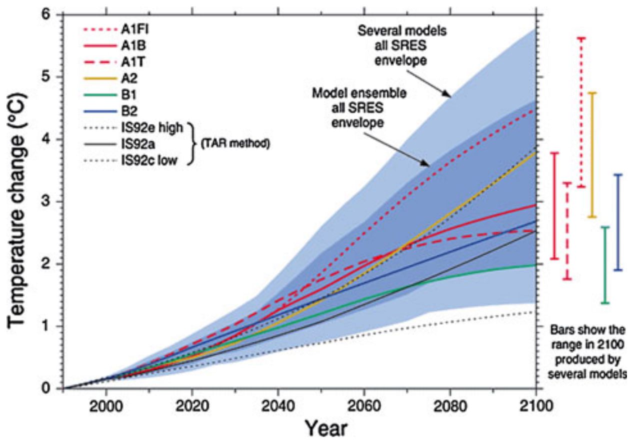


Fig. 3 Temperature projections from a range of climate models. Source: IPCC (2001)

scale projections of temperature changes from climate models. Figure 3 shows a spread of temperature projections from a suite of models running a spread of emissions projections. Both the emission pathways and use of different models contribute to the spread of temperature projections. Model spread is contributed by both model uncertainty and climate variability. The spread in the figure provides a measure of the overall uncertainty in temperature projections. Temperatures in the Australian region would tend to loosely follow the global projections shown here, though would also be amplified because land areas warm faster than ocean areas.

The amplification of warming over land areas is illustrated in Fig. 4. This figure shows the warming averaged over many models at a time equivalent to the end of the century. The model-average warming in the Australian region at this point is about 3 or 4°C, though this warming could be considerably smaller or larger (perhaps 1–6°C) based on the spread shown in Fig. 3.

Multi-model ensembles provide a means to average out the random changes in model simulations and emphasize the changes that occur in common across models. This can be quite useful for rainfall, which has higher spatial variability than temperature changes. The multi-model ensemble rainfall changes for the current suite of climate models are shown in Fig. 4. The figure shows that there are indeed spatially coherent areas of rainfall change across models. The pattern of change shows that the driest regions of the planet in the descending branches of the subtropical ridge tend to dry out further, while the wetter regions in the tropics and poleward of the subtropical ridge tend to get wetter. This result is consistent across models and also with earlier generation climate models. This increases the robustness of the result, though there are always circulation changes in the models possible that might change this picture. The result is not encouraging for Australia as much of the continent (except the tropical North) is located in the vicinity of the subtropical ridge and is projected to dry. The magnitude of the drying shown is on the order of 5–10%, though there would be a large range of uncertainty about this value (even as to sign). For individual models, the ranges projected include more substantial drying (CSIRO 2001; CSIRO and Bureau of Meteorology 2007).

In this review of climate projections for Australia, it is apparent that greenhouse climate change can affect rainfall

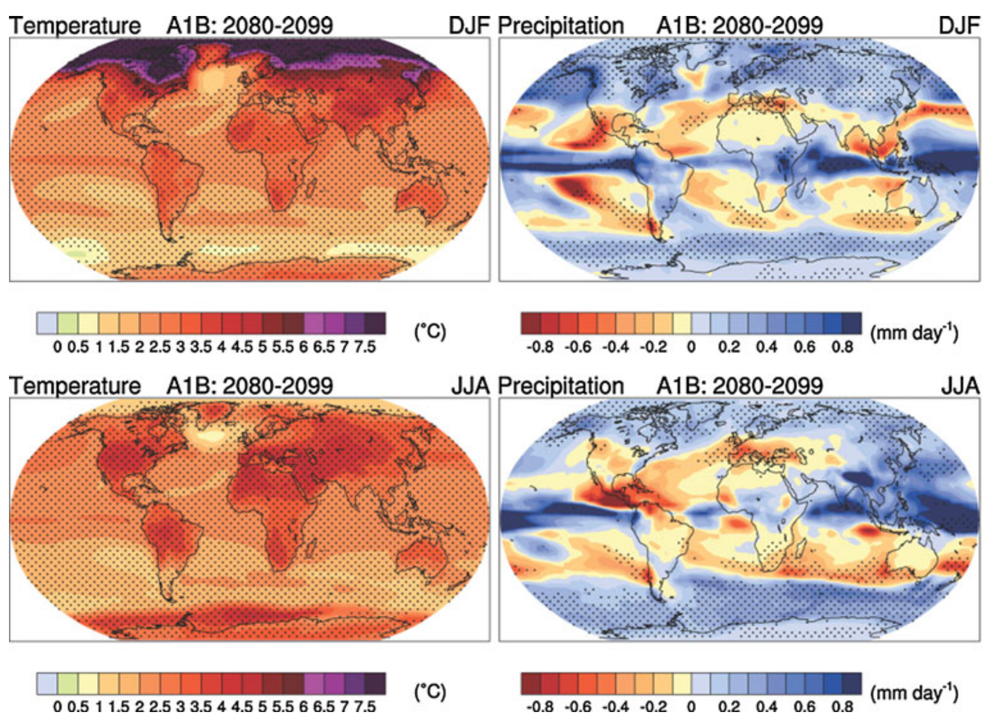


Fig. 4 Multi-model projections of temperature and rainfall for the December–February (DJF) and June–August (JJA) seasons. Source: IPCC (2007)

in a variety of different ways. First, it may lead to an intensification of the subtropical ridge over Australia, which would further dry the continent. The rain-bearing storm tracks that transit the southern fringes of the continent may also contract toward the poles in association with greenhouse and ozone forcing. The warming induced over the continent is bound to worsen droughts when they do occur. And there are some suggestions that greenhouse forcing might also increase the frequency or intensity of El Niño events, which are associated with the presence of drought. The picture that emerges is one of relatively small changes in the dynamics of climate in the region, potentially leading to large changes in rainfall regime. While there is considerable uncertainty surrounding these projections, greenhouse seems to be pushing all of them in the wrong direction—toward a drier continent.

Impacts on water resources

A further drying of the southern half of the Australian continent would place water stress on an existing water regime that is already stressed in a variety of ways. Some of the impacts that would be associated with a reduction in rainfall include:

- Loss of environmental flows in river systems. This would reduce water quality and exacerbate salinity stress on riverine ecosystems.
- Degradation of floodplain ecosystems such as the redgum forests on the Murray river.
- Reduced water for agriculture leading to severe shortfalls and transformation of agricultural activities.
- Transformation to a state of ongoing water shortfalls and restrictions for the southern cities.

These impacts are not controversial in that they are already the norm during current dry periods. Climate change of the type indicated would make these kinds of impacts more frequent and severe (Chiew and McMahon 2002). There may also be thresholds at which the changes become even more abrupt. One example would be the potential for a more permanent contraction of the storm tracks transiting the south of the continent. If this were to come to pass, the reductions in rainfall in the south would be more extreme and so too the drop in available water in southern rivers and dams. The threshold scenario of a sudden and prolonged drop in supply is speculative, but plausible and not without some possible precedent in the southwest of Australia.

For the threshold scenario of a more radical drop in rainfall, there would be correspondingly radical changes in the ways in which water is likely utilized. For a scenario in which flows in the Murray-Darling river system were halved (CSIRO 2001), the existing agricultural mix and practices in the basin would not be remotely sustainable. There would be no choice but to ration the water more severely and improve water practices. If the basin were to continue to be economically and ecologically sustainable in that scenario, then the largest and least productive users of irrigated water would have to change operations. That might imply an end to practices such as irrigated dairy, rice, and cotton in the Murray-Darling basin. For those irrigators remaining in the basin, there would still need to be extensive adaptation to cope with greatly reduced allocations.

The threshold scenario would also have major impacts in the southern cities. These cities are already facing current droughts and projected growth in demand for water as population increases. A prolongation of these droughts would necessitate radical urban-use transformations that go well beyond anything currently in place to maximize water capture, reuse, and efficiency measures. Buildings, industry, and urban form would need to change to use much less water (Kenway et al. 2008).

Dangerous levels and responses

The question of whether the kinds of climate impacts envisaged for water resources in Australia are 'dangerous' is partly a matter of perspective (Risbey 2006). In the short term of the next few decades, climate change represents an additional stressor on existing stressed water resource systems. Thus, while the risk of large climate changes is smaller in the short term, the incremental stress may be sufficient to pose large risks and costs in some cases. This would be more likely for cities/regions already undergoing drought and already using water resources to capacity—cities in the southern part of the continent and irrigated agriculture inland of the Great Dividing Range.

An example of the potential for large costs from climate-induced water resource fluctuations in these regions is given by the widespread drought of 2002 (Karoly et al. 2003), which reduced national GDP by a percent or two and rural GRP by up to 20% (Adams et al. 2002). Hardest hit areas were in the Murray-Darling basin and in the southwest of Western Australia. That drought has continued throughout much of eastern and southern Australia through the present time and is threatening the viability of whole horticultural regions (Cart 2009).

In the longer term beyond the next few decades, climate changes may lead to a fairly significant drying of the southern portion of the continent. This would pose significant risks irrespective of the influence of non-climate-related factors on water resources. In many cases, these other factors (demand increases, overuse, salinity) are all working in the same direction to stress water resources. Given the size of the expected climate changes (CSIRO 2001; CSIRO and Bureau of Meteorology 2007) and the fundamental nature of water to the nation's economic and ecological prosperity, the expected changes seem dangerous by most reasonable perspectives. Since we can expect a spectrum of different impacts on different parts of the water resource sector, there is no single threshold that separates 'safe' from 'dangerous' climate changes. And even if we isolate particular applications, it is still difficult to separate out climate change impacts from those caused by other factors in assessing the overall risk faced. Given the uncertainties, we can only really say that the less forcing of climate, the better. This is underscored by the fact that many of the impacts in the shorter term are already 'locked-in' due to the inertia of the climate system (Meehl et al. 2005), and we are now looking to minimize the longer term impacts.

Beyond the issue of what is dangerous and what is not, we also seek in this volume to identify the level of danger (impact) corresponding to different amounts of temperature increase. This is difficult to do for water resource impacts, because they depend on changes in supply (rainfall) and demand (usage) that are only loosely related to changes in temperature. Whereas temperature tends to increase in most regions in greenhouse scenarios, rainfall may go up or down depending on shifts in circulation features. However, as noted in the section on "Climate projections for Australia", the Australian continent tends toward a reduction in rainfall in greenhouse scenarios. That reduction is roughly proportional to the increase in temperature, and thus, one can loosely say that the more temperature increases the greater the risk of rainfall decline for Australia. This is of course only a rough expectation that one might think of as the most likely expectation, but it is by no means certain.

With that rough heuristic and some scaling from modeling studies (CSIRO 2001), we can project decreases in rainfall ranging from a few percent for a 1°C warming, through to some tens of percent for a warming of 4°C or so. There is large uncertainty on these numbers (even as to sign), and it is not always meaningful to be more specific. But we can present more specific information as a scenario if taken in the right spirit. A scenario mapping temperature changes to rainfall changes is given in Table 1. The rainfall ranges given in the table are deliberately broad. The actual rainfall changes will depend heavily on the region within Australia and the precise nature of any circulation changes.

Table 1 Climate scenarios matching temperature changes to rainfall changes for continental Australia (excluding the northern monsoon region)

Temperature increase (°C)	Rainfall decrease (%)
0 ↔ 1	Within natural variability ↔ 10
1 ↔ 2	Small reduction ↔ 20
2 ↔ 4	Small reduction ↔ 40

For the EU's critical level of 2°C warming, we might expect rainfall reductions from 0 to 20% (Table 1). While these numbers might not sound particularly large at the low end, we must bear in mind that rainfall reductions translate into much larger reductions in runoff in most of Australia (Chiew and McMahon 2002), as in the case of Perth cited earlier. Thus, there is a fairly reasonable expectation that a 2°C warming could be associated with the kinds of severe restrictions and impacts on the water sector outlined in the section on "Impacts on water resources". For a 2°C warming, we could expect degradation of ecosystems, considerable loss of agricultural capacity, and severe water restrictions on southern cities.

The rainfall reductions shown in the scenario are more likely to be larger in the south of Australia and thus apply more specifically to the southern cities (Perth, Adelaide, Melbourne, Sydney). As the example of Perth already shows, the costs in terms of developing additional supply runs into hundreds of millions of dollars, and that is just to adapt to the 10% drop experienced there to date. If longer sustained reductions of the order of 20% were to occur in the catchments of these major cities, the costs could run into billions of dollars, with major dislocations and wholesale restructuring of water use. Thus, even the 2°C warming scenario may pose very large risks to these cities. Risk is generally posed as probability time consequences. In this case, the consequences are large, while the probability is unknown. While we can not put rigorous probability distributions on the projected rainfall in these cities for a given time or temperature increase, reductions of this order are broadly plausible.

The prospects of these changes in water resources throw up difficult choices for water resource management. The climate-induced water resource transition in the rural sector heightens the need to end grossly unsustainable practices. In the urban sector, it may require that governments mandate aggressive efficiency, capture, and reuse programs and reorient the form of the city to minimize water requirements. The adaptation choice facing Australian governments (state and federal) is to either do these things sooner and thereby 'create' more water in the system, reducing the ultimate impacts, and provide alternatives for those people and industries in transition. Alternatively, the transition in the water sector will happen anyway, but will have bigger impacts. The risks can be reduced by reducing emissions of greenhouse gases, though such reductions need to commence now in order to be effective in this regard. Some 'danger' is inevitable, but how much is a question of political will.

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References

Adams PD, Horridge M, Masden JR, Wittwer G (2002) Drought, regions and the Australian economy between 2001–02 and 2004–05—Technical report. General paper G135. Monash University Centre of Policy Studies

Cai WJ, Shi G, Li Y (2005) Multidecadal fluctuations of winter rainfall over southwest Western Australia simulated in the CSIRO Mark 3 coupled model. Geophys Res Lett 32(12): 926–927

Cart J (2009) What will global warming look like? Scientists point to Australia. Los Angeles Times 9 April

Chiew FHS, McMahon TA (2002) Modelling the impacts of climate change on Australian streamflow. Hydrol Process 16(6):1235–1245

CSIRO (2001) Climate change projections for Australia. Technical report. CSIRO Australia

CSIRO and Bureau of Meteorology (2007) Climate change in Australia: technical report 2007. Technical report. CSIRO Marine and Atmospheric Research, Clayton South, VIC, Australia, p 148

Dai A, Trenberth KE, Qian T (2004) A global dataset of Palmer drought severity index for 1870–2002: relationship with soil moisture and effects of surface warming. J Hydrometeorol 5(6):1117–1130

Folland CK, Karl TR, Christy JR, Clarke RA, Gruza GV, Jouzel J, Mann ME, Oerlemans J, Salinger MJ, Wang S-W (2001) Observed climate variability and change. In: Houghton JT, Ding Y, Griggs DJ et al (eds) Climate change 2001: the scientific basis. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 99–181

Frederiksen JS, Frederiksen CS (2007) Interdecadal changes in southern hemisphere winter storm track modes. Tellus A 59(5):599–617. doi:10.1111/j.1600-0870.2007.00264.x

Gallant AJE, Hennessy KJ, Risbey J (2007) Trends in rainfall indices for six Australian regions: 1910–2005. Aust Meteorol Mag 56(4):223–239

Hansen J, Fung I, Lacis A, Rind D, Lebedeff S, Ruedy R, Russell G, Stone P (1998) Global climate changes as forecast by Goddard Institute for Space Studies three-dimensional model. J Geophys Res 93:9341–9364

Hartmann DL, Wallace JM, Limpasuvan V, Thompson DWJ, Holton JR (2000) Can ozone depletion and global warming interact to produce rapid climate change? Prock Natl Acad Sci U S A 97(4):1412–1417

Held IM, Soden BJ (2006) Robust responses of the hydrological cycle to global warming. J Clim 19(21):5686–5699

IOCI (2002) Climate variability and change in south west Western Australia. Technical report. Indian Ocean Climate Initiative, Perth, Australia

IPCC, 1996: Climate Change 1995: The Science of Climate Change, J.T. Houghton, L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenburg, K. Maskell, Eds., Cambridge University Press, Cambridge, UK, p 572

IPCC, 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, C.A. Johnson, Eds., Cambridge University Press, Cambridge, UK, p 881

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, Eds., Cambridge University Press, Cambridge, UK and New York, NY, USA, p 996

Jones D, Wang W, Fawcett R (2009) High-quality spatial climate data-sets for Australia. Aust Meteorol Ocn J 58(12):233–248

Karoly DJ (2003) Ozone and climate change. Science 302(5643): 236–237

Karoly D, Risbey J, Reynolds A, Braganza K (2003) Global warming signature in Australia's worst drought. Australas Sci 24(3):14–17

Kenway S, Turner G, Cook S, Baynes T (2008) Water-energy futures for Melbourne: the effect of water strategies, water use, and urban form. Technical report. CSIRO Australia, p 40

Meehl GA, Washington WM, Collins WD, Arblaster JM, Hu AX, Buja LE, Strand WG, Teng HY (2005) How much more global warming and sea level rise? Science 307(5716):1769–1772

Murphy BF, Timbal B (2008) A review of recent climate variability and climate change in southeastern Australia. Int J Climatol 28(7):859–879

Nicholls N (2004) The changing nature of Australian droughts. Clim Change 63(3):323–336

Nicholls N, Drosdowsky W, Lavery B (1997) Australian rainfall variability and change. Weather 52(3):66–71

Nicholls N, Trewin B, Haylock N (2000) Climate extremes indicators for state of the environment monitoring. Australia: State of the environment. Second technical paper series. Department of the Environment and Heritage, Canberra, p 20

Pook MJ, McIntosh PC, Meyers GA (2006) The synoptic decomposition of cool-season rainfall in the Southeastern Australian cropping region. J Appl Meteorol Climatol 45(8):1156–1170

Risbey J (2006) Some dangers of 'dangerous' climate change. Clim Policy 6(5):527–536

Risbey JS, Lamb PJ, Miller RL, Morgan MC, Roe GH (2002) Exploring the structure of regional climate scenarios by combining synoptic and dynamic guidance and GCM output. J Clim 15(9):1036–1050

Risbey J, Karoly D, Reynolds A, Braganza K (2003) Global warming signature in Australia's worst drought. Bull Aust Meteorol Oceanogr Soc 16:6–11

Risbey JS, Pook MJ, McIntosh PC, Ummenhofer CC, Meyers G (2009) Characteristics and variability of synoptic features associated with cool season rainfall in southeastern Australia. Int J Climatol 29(11):1595–1613

Risbey J, Pook M, McIntosh P, Wheeler M, Hendon H (2009) On the remote drivers of rainfall variability in Australia. Mon Weather Rev 137(10):3233–3253

Sadler B (2000) Informed adaptation to a changed climate state Is south-western Australia a national canary? Report. Indian Ocean Climate Initiative, Australia

Simmonds I, Keay K (2000) Variability of southern hemisphere extratropical cyclone behavior, 1958–97. J Clim 13(3):550–561

Thompson DWJ, Solomon S (2002) Interpretation of recent southern hemisphere climate change. Science 296(5569):895–899

Timbal B (2004) Southwest Australia past and future rainfall trends. Clim Res 26(3):233–249

Tryhorn L, Risbey J (2006) On the distribution of heat waves over the Australian region. Aust Meteorol Mag 55(3):169–182