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PII: S2212-0947(14)00003-6
DOI: http://dx.doi.org/10.1016/j.wace.2014.02.001
Reference: WACE19

To appear in: *Weather and Climate Extremes*

Received date: 18 December 2013
Revised date: 2 February 2014
Accepted date: 4 February 2014

Cite this article as: Roger C. Stone, Constructing a Framework for National Drought Policy: The Way Forward - The way Australia developed and implemented the National Drought Policy, *Weather and Climate Extremes,* http://dx.doi.org/10.1016/j.wace.2014.02.001

Constructing a Framework for National Drought Policy: The Way Forward
- The way Australia developed and implemented the National Drought Policy.

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Key words: climate variability, causality; national drought policy.

Abstract.

Australia has the world's highest levels of climatic variability with drought a naturally occurring component of this variability, but which may also occasionally persist for many years. Over the past 40 years climate science has provided a major contribution to improved understanding of the reasons for this high level of climatic variability with advances in seasonal forecasting research providing incentives for primary producers to adopt a more self-reliant approach to their farming operations, including drought preparedness. Over 20 major scientific publications pointed to aspects of the key climatic mechanisms – mainly associated with the El Niño phenomenon - that were now known to be responsible for drought events in Australia. Some of these publications also pointed to the means of forecasting such extreme climate events which implied the potential to prepare for drought events. . Coincident enhancement of farming technologies over this period further enabled producers to create more drought resilient systems. Australian Governments have also provided many incentives to improve self-reliance and farm management and so assist preparedness for the poorer (drought) seasons and years when they occur. Government policy development over this period has been conducted with an awareness of all these factors and has therefore been able to provide changes in drought assistance through new policy endeavours that are probably unequalled in the world. This paper presents insights to the scientific, technological, and policy aspects of managing drought in Australia

1.0 Introduction.

Australia has the highest levels of naturally occurring, year-to-year, rainfall variability in the world (Love, 2005). Yet, drought in Australia had long been regarded by policy makers as an aberration to an otherwise long-term 'normal' climate pattern (Botterill, 2005; Botterill and Wilhite, 2005). Further, Botterill (2005) and Botterill and Wilhite (2005) pointedly note that from the time of European settlement, Australian Governments "responded to the concept of drought being a natural disaster through various Commonwealth-State natural disaster relief arrangements which treated drought in a similar manner to disasters such as tropical cyclones or floods" (Botterill, 2005; Botterill and Wilhite, 2005).

In Australia, it has been suggested that "the best single indicator of drought has been a measurement of total rainfall" (Gibbs and Maher 1967). However, some consider this indicator to be insufficient in itself and White and Walcott (2009) point out that it is soil moisture derived from rainfall that is commonly the factor that is most limiting to plant growth, although rainfall is the most easily measured meteorological aspect, with many data available for over 100 years. With rainfall data easily categorised into percentiles, drought has generally been defined in Australia as occurring when rainfall for a specified period is below a certain percentile. Gibbs and Maher (1967) observed that the occurrence of annual rainfall in the first decile range on annual maps of Australia for the period 1885–1965 corresponded well with descriptions of drought occurrence recorded by Foley (1957).

White and Walcott (2009) continued that most policy makers, as well as drought-affected producers in Australia, sought a simple and transparent system for assessing drought but to include aspects associated with rainfall effectiveness in crop and pasture production. Interestingly, many agronomic simulation studies in Australia suggested that grassland or agricultural droughts usually coincided with meteorological droughts, identified through rainfall deficits, but the severity and duration of agricultural drought depended very much on the timing and distribution of the rainfall events and other climatic factors. White and Walcott (2009) suggest this means a minor rainfall deficiency could also have major consequences in terms of agricultural production, whereas a moderate rainfall deficiency may not always seriously reduce crop and pasture growth.

After many decades of provision of drought relief payments and subsidies under the definition of 'natural disaster relief', expenditure on drought relief dominated relief arrangements in Australia, compared to all other forms of natural disaster relief payments. In April, 1989, a Commonwealth Government Minister announced that drought was to be removed from these arrangements. This decision also followed the tabling in the national Commonwealth Parliament of a "leaked report" emanating from one of Australia's State Governments – Queensland - that had suggested considerable misuse of the drought relief payments scheme (Walsh 1989; Daly, 1994). There were also allegations that a Queensland State Minister had used his discretion to overrule a departmental decision to deny drought relief to a relative of the State Premier (Koch 1989).

Botterill (eg: Botterill, 2003; Botterill and Fisher, 2003; Botterill, 2004; Botterill and Wilhite, 2005), in particular, has been responsible for much of the progress gained in Australia in obtaining a more thorough understanding of drought policy developments in this country. Together with others (eg White et al., 2005) she began articulating the remarkable and more recent change in drought policy direction by Australian Governments. However, little has been provided to the global community that would allow further understanding of the climate science developments that have contributed to drought policy development.in Australia. This paper seeks to further elucidate and explain these contributing elements that led to the development towards national drought policy formulation.in Australia.

2.0 Climate science input informs drought policy.

By the 1990s, it was becoming increasingly untenable to support the currently existing drought policy in the light of on-going and improved understanding of Australia's climate patterns, especially its high natural levels of year-to-year climatic variability - an improved understanding, it is here suggested, that has not received the due recognition that it should. In this respect, and as a summary of Table 1, it is proposed the output of Troup (1965), Heathcote (1973, 2000); Pittock (1975), McBride and Nicholls (1983), Allan (1985; 1988); Allan and Heathcote (1987), Drosdowsky (1988), Hunt (1985), Hammer et al. (1987), and particularly Nicholls (1977; 1979; 1983a,b; 1984; 1985a,b; 1987a,b; 1988a,b; 1989; 1990; 1991a,b) are indicative of major, comprehensive inputs provided to the advances in the understanding of extreme climate variability in Australia – and hence relationships between this high amount of climatic variability and drought. Table 1 provides an overview of this level of scientific activity and subsequent contribution to the understanding of the reasons behind Australia's high levels of climatic variability. Above all, these authors have been instrumental in providing critical evidence in regards to the extraordinarily high naturally occurring levels of year-to-year rainfall/climatic variability in Australia in the 10-20 years leading up to 1992 and therefore, it is argued, were also to provide fundamental insight into the potential predictability of much of this variability, at least on a seasonal basis.

In particular, researchers in the 1970s and 1980s, especially Robert Allan, Neville Nicholls, and Barrie Pittock provided fundamental and far-reaching insight into the core role played by the El Niño/La Niña/Southern Oscillation phenomenon (ENSO) in causing and driving much of the high levels of year to year climatic variability, and especially, drought events in Australia. Furthermore, McBride and Nicholls (1983), Williams (1987) and Drosdowsky (1998) paved the way for the development of seasonal climate forecasting in Australia - and hence opportunity for enhanced preparedness for climatic extremes and drought and the further development of operational seasonal climate forecasting in the 1990s (eg: Stone and Auliciems, 1992; Stone et al., 1996a,b; Stone and deHoedt, 2000; Drosdowsky and Chambers, 2001). Finally, linkages between improved understanding of seasonal climate variability, drought, and major climatic mechanisms such as ENSO with improved understanding of variation in Australia's crop and pasture yields and associated crop modelling capabilities that resulted in yield forecasting were led by crop physiologists such as Graeme Hammer (Hammer et al, 1987; 1988; 1996; 2000) and Holger Meinke (Meinke et al., 1996; 1998) which further resulted, in subsequent years, to major advances in development of fully integrated seasonal climate forecasting-crop modelling-decision systems in Australia, also of critical importance in improved farm management and drought preparedness (eg Hammer et al, 1996; 2000; Meinke and Stone, 2005) .

Thus, it is suggested here, that it was, by 1992 and in subsequent years, becoming increasingly difficult in Australia to argue that drought was an aberration and extreme level of disaster and not a normal feature of Australia's notably high - and to some extent predictable – aspect of year-to-year climatic variability. It is also noteworthy that many of these authors – now known as 'climate scientists' – participated in policy/science seminars, conferences and national and regional meetings that provided additional momentum to the shift to more self-reliance in farming in Australia and, importantly, provided impetus to policy shifts that led to Australia's national drought policy. This type of interaction resulted in the following example extract from Australia's National Drought Policy document prepared in 1992 (White et al, 2003; White et al., 2005) which stated, as a result of the interaction between policy agencies andclimate scientists of the day (including the author), that "drought research for a profitable and sustainable rural sector is wide ranging, and *includes whole farm management systems that integrate climate prediction* (italics provided here), technical, biological, and financial information; control strategies for weeds and pests; social-economic factors and the needs of rural communities and farm families in times of stress; and research on-farm and off-farm investment strategies for farmers" (Australia's National Drought Policy, 1992, in White et al., 2003; White et al, 2005). It is clear that climate science had a major role in providing critical information in to the drought policy framework that simply had not existed before this period.

TABLE 1 HERE

Additionally, it is further pointed out, that in terms of extreme climatic events for future years in Australia, it is noteworthy that there are potentially likely changes to drought occurrence and severity when modelled using the Hadley Centre (GloSea) model or associated 11 model ensemble, especially in regards to increases in moderate drought (Burke and Brown, 2007). . In this vein, in 2008, the Australian Government commissioned a national review of drought policy to help inform decisions on how it could better support farmers. The review included:

- an economic assessment of drought support measures by the Productivity Commission
- an assessment by an expert panel of the social impacts of drought on farm families and rural communities
- a climatic assessment by the Bureau of Meteorology and CSIRO.

The review found that drought conditions in Australia were likely to occur more often and be more severe under climate change. It also recommended that drought assistance programs be restructured to help farmers prepare for drought rather than waiting until they are in crisis to offer assistance. Aspects related to future drought policy under long-term climate change are considered outside the scope of this paper.

3.0 Climate variability links to production variability.

In a further understanding of the linkages between climate variability, climate mechanisms, and agricultural management systems in Australia, Meinke and Stone (2005) and Stone and Meinke (2005) provided a description of the main, and many, climate drivers that exist across temporal scales and which can be linked to drought occurrence and other extremes of climate variability in Australia. Importantly, they described the relationships that exist between these many climatic mechanisms and agricultural management practices, also operating at these scales (Figure 1). This type of approach demonstrated that clear relationships could then be established between an understanding of the many modes of climatic variability and the many modes of 'real' farm and agricultural value chain decisions.

FIGURE 1 HERE

Clear production links in Australia to key climate drivers could also now be clearly demonstrated. Complementary with the increasing understanding of the role that a high natural level of climate variability plays in the almost cyclical recurrence of drought in Australia has been the increased understanding of the associated aggregate year-to-year variability in crop yields (Figure 2, courtesy R. B. Hansen). Indeed, in a comparison of Australian crop yield variability with that of other OECD countries, notable extreme levels of variability for key commodities, wheat, barley, and oilseeds exist (Figure 3) (see Kimura and Anton, 2011). Further, within Australia, grains and oilseed production has the highest levels of value volatility compared to other agricultural industries in Australian farm production (Figure 4) (see Hatt et al., 2012).

FIGURE 2 HERE

In addition to higher yield volatility, Australian agricultural industries are exposed to greater systemic production risks than are other countries (compared with, for example, European countries including Estonia, Italy, and the United Kingdom). This is the risk that can be experienced by a large number of farmers and farm businesses at one time due to the widespread nature of many Australian droughts that can impact the entire nation, simultaneously.

FIGURE 3 HERE

Compared to other industries, Australian agriculture has greater volatility in production with the Australian Bureau of Agricultural and Resource Economics and Sciences **(**ABARES,2003**)** suggesting Australian farmers experience a higher degree of production risk than other sectors of the Australian economy, and they expect that this will further increase with a changing climate in important agricultural regions (ABARES, 2003).

Additionally, while production variability is common to all agricultural industries in Australia, the level of volatility differs across agricultural industries. In recent decades volatility in the value of production - which is strongly correlated to yields - for the grains and oilseeds sector has been much greater than that experienced by other industries". Figure 4 demonstrates the high level of volatility in the grains and oilseeds industry compared to other crops and livestock (National Rural Advisory Council, 2012).

FIGURE 4 HERE

3.1 Coincident evolution and diversification of Australian agriculture - acknowledgement of the 'changing face' of Australian agriculture.

In the face of high levels of year-to-year climatic variability in Australia, land use and farming systems have nevertheless evolved and diversified, especially in the past four decades, largely responding to commodity prices, market arrangements, and, importantly, variability in natural resource conditions (including climate). Over the past four decades (since the early 1970s), livestock industries have reached a plateau, but with areas under cotton, sugar cane, potato, rice, viticulture and horticulture increasing, especially since 1983. In addition, consolidation in farm industries and farm holdings have occurred with the numbers of farms decreasing from 178,000 in 1982 (coincidentally, a major El Niño-induced drought year in Australia) to 145,000 agricultural holdings in 1996/97. There has also been an increase in average property size in the cropping and grazing industries (Australian Natural Resources Atlas, 2010).

Coincident technological advances have resulted in improved cereal grain yields in many Australian regions between 1982 and 1997, notably where crops have been more diversified in regions of somewhat more reliable rainfall. However, in regions with less reliable rainfall "yield trends have been less spectacular" (Australian Natural Resources Atlas, 2010). Key technological advancements have been achieved through improved nitrogen management and subsequent strong productivity gains and in reducing annual variations in wheat yields (where wheat yields were highly subject to seasonal climate variability) through the development of drought-tolerant species and disease control (Australian Natural Resources Atlas, 2010).

Also likely the result of a determination to better manage climatic extremes in Australia, the area of *irrigated agricultural land* has increased by 26% in the last 20 years. Two-thirds of all irrigated land in Australia is now in the Murray-Darling Basin of eastern Australia where nearly half is used for pasture production. Additionally, irrigated areas across Australia under cotton, sugar cane, pasture and fruit have all increased during this period (Department of Sustainability, Environment, Water, Population and Communities, 2010).

It is further suggested a major technological advancement, in addition to the improved understanding of key climatic mechanisms over this period in Australia, has been the realisation of the key value of the use of crop simulation modelling to aid *planning* for agricultural drought purposes. In particular, the Agricultural Production Systems Simulator (APSIM) (Keating at al, 2004) provides simulated historical and future yields of crops and pastures, incorporating climate information, especially seasonal climate forecasting information, as an integral component of the output. In this, APSIM assimilates key soil processes (water, nitrogen, carbon) and surface residue dynamics and erosion to provide a range of management options that can involve selected crop rotations and fallowing options. A further associated technological advancement has been the capability to provide pre-run APSIM outputs as a form of decision support (decision support systems - DSS) to aid in the preparedness for extremes in climate variability, including likely low rainfall periods that can be coupled with very low antecedent soil moisture conditions. Such a DSS, known as 'WhopperCropper' (Cox et al., 2004), can provide support to such decisions as "when to sow my sorghum crop with an impending low rainfall period (and potential drought), given poor starting conditions".

3.2 Development of risk management capabilities and key policy initiatives.

In 1990, in a major advance in policy, a drought policy review task force (DPRTF) argued that 'drought was a relative concept, not some absolute condition: *"It reflects the fact that current agricultural production is out of equilibrium with prevailing seasonal conditions', and: 'managing for drought is about managing for the risks involved in carrying out an agricultural business, given the variability of climate"* (DPRTF, 1990). Also noteworthy was that the Task Force rejected the construct of drought as a disaster and recommended that a national drought policy be implemented 'as a matter of urgency' (DPRTF, 1990).

The Drought Policy Review Task Force aimed to:

1. identify policy options which encourage primary producers and other segments of rural Australia to adopt self-reliant approaches to the management of drought;
2. consider the integration of drought policy with other relevant policy issues; and
3. advise on priorities for Commonwealth Government action in minimising the effects of drought in the rural sector (DPRTF, 1990).

Importantly, the Australian Drought Policy Review Task Force Review team identified its focus as: "The concept of risk management is central to the philosophy of this review" (DPRTF, 1990) - and it set out its vision of the role of both government and farmers in achieving a sound drought response. It argued that any government assistance should:

- be provided in an adjustment context
- be based on a loans-only policy
- permit the income support needs of rural households to be addressed in more extreme situations (DPRTF, 1990).

A subsequent step was that, in 1992, the Australian Senate set up an inquiry into an appropriate government response to the Drought Policy Review Task Force report. Importantly, this Senate inquiry endorsed a self-reliant approach to drought and, like the DPRTF, rejected the reinstatement of drought in the natural disaster relief arrangements. Finally, Australian Government Ministers announced in July 1992 that they had reached agreement on the National Drought Policy, explicitly based on principles of self-reliance, risk management and an acceptance that drought was a natural feature of Australian climate. However, it was further agreed that 'in circumstances of severe and exceptional drought' an appropriate response would be considered that would 'not compromise the principles and objectives' of the National Drought Policy (Australian Agricultural Council, 1992).

The formalised objectives of the National Drought Policy thus developed were to:

- encourage primary producers and other sections of rural Australia to adopt self-reliant approaches to managing for climate variability;
- facilitate the maintenance and protection of Australia's agricultural and environmental resource base during periods of increasing climate stress, and;
- facilitate the early recovery of agricultural and rural industries, consistent with long-term sustainable levels (Agricultural Council of Australia and New Zealand, 1992).

Botterill (2005) noted that these policies and arrangements have been amended a number of times since their inception but the basic structure still remains. A key point in this policy is that farmers have been asked 'to assume greater responsibility for managing the risks arising from climatic variability'- while the government would 'create the overall environment which is conducive to this whole farm planning and risk management approach'.

3.3 Removal of drought from natural disaster relief arrangements.

Thus, a critical and fundamental shift in Australian drought policy occurred with the removal of drought from the natural disaster relief arrangements with the view then developed from increasingly convincing sources (as noted above), that drought and high levels of variability in agricultural production in Australia was actually a 'normal part of a farmer's operating environment' and should be managed like any other business risk. However, an additional important step was that an accompanying package of programs was put in place to support farmers as they improved their risk management skills. This policy also introduced the concept of 'exceptional circumstances' to cover events of such severity that they would be considered beyond the scope of good risk management (White et al., 1993; Wilhite, 1997). In this respect, it has been noted that meanwhile, in the United States, individual States were the policy innovators for drought management (Wilhite, 1991a), in contrast to Australia, where the Federal Government has provided most of the leadership, in concert with the States, for the development of a national drought policy (White et al., 1993; Wilhite, 1997).)

Therefore, in parallel with core focussed agricultural research and development activities emanating from notable research institutions, there have been valuable developments in Australian state and territory government policies and programs that have sought to assist Australian farm businesses to manage their risks, especially the coincident financial risks such as:

- Farm Management Deposits which have assisted farmers better manage the financial variability that can arise from climate variability and market fluctuations,
- Tax relief measures – farm income averaging, fuel rebates,
- A suite of decision support systems and tools, many with links to seasonal climate forecasting – includes the notable Bureau of Meteorology web-based services and outputs (eg "Water and the Land"), State-based and State industry focussed outputs such as 'the Long Paddock' (Queensland) monthly seasonal updates, industry specific services..
- Training and farm business planning – eg: 'Plan, Prepare, and Prosper' workshops for farm planning management (State of Western Australia), 'ProFarm' courses (State of New South Wales), 'Managing for Climate and Weather Workshops' (State of Queensland's Department of Primary Industries in cooperation with the Bureau of Meteorology).
- Many government programs that influence drought preparedness.
- Initiation and incorporation of research and development corporations ("RDCs") that have ensured a research and development commitment to user engagement and farmer uptake. These include the Grains Research and Development Corporation, the Sugar Research and Development Corporation, the Cotton Research and Development Corporation, the Rural Industry Research and Development Corporation, and the Managing Climate Variability Program – which are mostly funded by a levy placed on yearly crop production for each agricultural industry sector in Australia.

It should also be pointed out that there has been a developing acknowledgement of the commercial risk management strategies available to Australian farmers and agricultural businesses:

- Price hedging – used as a price risk management tool – incorporating futures contracts, options and swaps in commodity markets to offset gains or losses made in physical markets or in foreign exchange markets,
- Financially-focussed decision support systems and tools – eg 'GrassGro'; Yield Prophet (CSIRO).
- Purchase of insurance – primarily for 'named perils' such as hail, fire, frost.
- Aspects of some general insurance products such as 'drought clauses under livestock policies'.

It is further noted that "there is considerable evidence that Australian farm businesses now use these strategies to deal with a highly volatile operating environment. This has also been done with relatively low levels of government support. For example, during one of the most severe and prolonged dry periods in Australia (recorded since 1900) nearly 70 per cent of Australian broadacre and dairy farmers in drought areas received no government drought support during the drought period of 2002–03 to 2007–08" (National Rural Advisory Council, 2012). It has further been recognised that "the range of strategies available are implemented at the discretion of farmers and influenced by the agricultural industry, the farming system and the geographic location of the farming business. Table 2 outlines some of the impacts of drought on agricultural industries and how different strategies can and have been adopted on-farm to account for those specific risks" (National Rural Advisory Council, 2012).

TABLE 2 HERE

4.0 Summary and Conclusions.

. Recognising key aspects associated with Australia's exceptionally high levels of climatic variability, with drought a naturally occurring component of this variability, has provided a major contribution to advances in seasonal forecasting research and provided incentives for primary producers to adopt a more self-reliant approach to their farming operations, including drought preparedness.
It is recognised that major advances, especially in regards to provision of leading scientific publications in climate science, were made in Australia during the 1970 and 1980s in regards to improving understanding of climate variability and also climate forecasting research, with commencement of quasi-operational climate forecasting outputs by the Bureau of Meteorology and some State-based organisations, primarily focussed on the needs in management of primary industries.

Australian Governments, meanwhile, provided incentives to improve self-reliance and farm management and so assist preparedness for the poorer seasons and years when they occurred. Government policy development over this period was able to provide fundamental changes in drought assistance through new policy endeavours that are probably unequalled in the world. O'Meagher et al., (2000) further noted that there were a number of overarching key components in effective drought risk reduction strategy development in Australia, summarised as follows:

- the availability of timely and reliable information on which to base decisions;
- policies and institutional arrangements that encouraged assessment,
- communication, and application of that information;
- a suite of appropriate risk management measures for all key decision makers;
- actions by decision makers that were effective and consistent (also after Wilhite, 2005).

After many decades of provision of drought relief payments as natural disaster relief, expenditure on drought relief dominated natural disaster relief arrangements in Australia. However, in April, 1989, the Commonwealth Government announced that drought was to be removed from these arrangements. A critical and fundamental shift in Australian drought policy occurred with the removal of drought from the natural disaster relief arrangements. An additional step was that an accompanying package of programs was put in place to support farmers as they improved their risk management skills. This policy also introduced the concept of 'exceptional circumstances' to cover events of such severity that they would be considered beyond the scope of good risk management. Therefore, in Australia, in parallel with focussed agricultural/climate research and development activities, there have been valuable developments in Australian Government policies that have sought to assist Australian farm businesses to manage their risks, including financial risks.

Thus, development of major drought management and policy advances in Australia has additionally been facilitated through improved capabilities in climate modelling and forecasting, especially integrated climate-agricultural simulation modelling, on-farm financial forecasting and counselling, and establishing links to drought preparedness. There has also been a fundamental acknowledgement of the role played by leading farmers and agribusiness in utilising advances made in whole-farm modelling, farm management and improved understanding of drought preparedness.

5.0 Acknowledgements.

The authors are grateful to the organising committee of the High Level Meeting on National Drought Policy, through the World Meteorological Organisation's (WMO) Agricultural Meteorology Programme for the opportunity to present this paper at the meeting held in Geneva, 11-15 March, 2013. The authors are especially grateful to Dr M.V.K. Sivakumar (WMO), and the Australian Managing Climate Variability Program (MCVP) for their continued support for this work over many years. The authors are also grateful to Ms Lynda Brunton and Mr Robert Hansen for contribution to the figures supplied in this manuscript.

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STONE ROBERTSON TABLES

Author/Manuscript title	Key climate variability/drought attribute and issue addressed	Comments
Allan, R.J. (1983) 'Monsoon and teleconnection variability over Australasia during the Southern hemisphere summers of 1973-77'. *Mon.Wea. Rev.* **111**, 113-142.	La Niña (including protracted La Niña) linkages to monsoon and teleconnection patterns over Australia during the 1973-1977 period.	Links between ENSO and the Australian monsoon.
Allan, R.J. (1985) 'The Australasian Summer Monsoon, Teleconnections and Flooding in the Lake Eyre Basin'. *South Australian Geographical Papers, Monograph* **No. 2**, 49pp.	La Niña and El Niño (ENSO) Australia links.	Critical aspects related to ENSO
Allan, R.J. and Pariwono, J.I. (1987) 'Aspects of large-scale ocean-atmosphere interactions in low latitude Australasia'. *Tropical Ocean-Atmosphere Newsletter*, **38**, 6-10	ENSO links to Australian climate variability	
Allan, R.J., and Heathcote, R.L. (1987) 'The 1982-83 drought in Australia' in Glantz, M., Katz., R., and Kranz., M (eds) The Societal Impacts Associated with the 1982-83 Worldwide Climatic Anomalies, UNEP, National Center for Atmospheric Research, Boulder, Colorado, 19-23	Detailed climatic mechanisms-drought occurrence aspects for Australia.	ENSO linked to drought.
Allan, R.J. (1988) 'El Niño Southern Oscillation influences in Australasia'. *Progress in Physical Geography*, **12**, 4-40.	ENSO influences/impacts across Australasia.	
Drosdowsky, W. (1988) 'Lag relations between the Southern Oscillation and the troposphere over Australia' BMRC Research Report No. 13 Bureau of Meteorology Research Centre, Melbourne, Australia.	Uncovering detailed tropospheric synoptic climatologies related to major climate variations in Australia.	Atmospheric drivers linked upper level dynamics to ENSO.
Glantz, M.H., Katz, R.W., and Nicholls, N. (1991a). *Teleconnections linking worldwide climate anomalies* Cambridge University Press.	Improving understanding of the role of atmospheric teleconnections in core climate systems.	
Hammer, G. L., Woodruff, D. R. & Robinson, J. B. (1987) 'Effects of climate variability and possible climatic change on reliability of wheat cropping—a modelling approach'. *Agric. Forest Meteorol*. 41, 123–142. (doi:10.1016/0168-1923(87)90074-8.)	Detailed investigation of seasonal climate variations and implications for the wheat industry in Australia	Clear links to grains industry management
Hammer, G.L., McKeon, G.M., and Clewett, J.F. (1988) 'Effect of climate change on agriculture in Central Queensland III: managing production under climatic variability' in: Anderson, E.R. (ed) *The Changing Climate and Central Queensland Agriculture – Proceedings of the Fifth Symposium of the Central Queensland Sub-Branch of the Australian Institute of Agricultural Science*, Rockhampton, Queensland, November, 1988, 61-68.	New approaches to utilisation of farm and pasture production through opportunities likely to be provided by seasonal climate forecasting – also links to enhancing capability to managing agricultural issues under climate change.	Pioneering (1988) integration of seasonal climate forecasting, pasture production for grazing and drought preparedness.
Heathcote, R L (1973) "Drought perception" in J V Lovett (Ed.) *The environmental, economic and social significance of drought* Sydney, Angus & Robertson**:** 17-40	Sociological and scientific understanding of drought perception in Australia at that time.	
Hunt, B.G. (1985) 'Drought research-the modelling approach' in *Report on Drought*	Developing aspects of sophisticated climate modelling approaches in	'Drought' is, to some extent,

Research in Australia, October, 1985, CSIRO Division of Atmospheric Research, Melbourne, Australia.	describing drought development in Australia.	predictable in Australia.
Nicholls, N. (1977) 'Tropical-extratropical interactions in the Australian region' *Mon. Wea. Rev*., 105, 826-832	El Niño/Southern Oscillation (ENSO) influences on circulation patterns in higher latitudes of the Australian region – and hence improved understanding of year to year climatic variability.	First clear linkages being established between ENSO and Australian climate variability.
Nicholls, N. (1979) 'A simple air-sea interaction model' *Quart J. Roy. Meteorol. Soc*., 105, 93-105.	Equatorial sea surface temperature variation and variation in Australian climate.	
Nicholls, N. (1983a) 'Predictability of the 1982 Australian drought' *Search*, 14, 5-6, 154-155.	Exploring the potential for drought prediction in Australia based on systems such as ENSO.	Clear linkages further established between ENSO and drought in Australia, including predictability of drought.
Nicholls, N. (1983b) 'The potential for long-range prediction of seasonal mean temperature in Australia' *Aust. Met. Mag*. 31, 4, 203-207.	Exploring the potential for temperature forecasts in Australia utilising knowledge of ENSO.	The value of seasonal forecasting becoming recognised.
Nicholls, N. (1984) 'A system for predicting the onset of the north Australian wet-season' *J. Climatol*., 4, 425-435.	Suggesting a capability for predicting the onset of the northern Australian wet season.	Practical application of seasonal forecasting strongly suggested.
Nicholls, N. (1985a) 'Impact of the Southern Oscillation on Australian crops' *J. Climatol*., 5, 553-560.	Crop production in Australia strongly related to climate variation which is, in turn, strongly related to ENSO and thus has inherent predictability.	
Nicholls, N, (1985b) 'Towards the prediction of major Australian droughts' *Aust. Met. Mag*., 33, 161-166.	Potential predictability of Australian droughts (ENSO relationships).	Drought predictability.
Nicholls, N. (1987a) 'The El Niño/Southern Oscillation phenomenon' in Glantz, M. (ed.) *Economic and Societal Impacts Associated with the 1982/83 World-Wide Climate Anomalies, Lugano Report*, UNEP, Geneva, Switzerland, 2-10.	Climate variability and ENSO connections.	
Nicholls, N. (1987b) 'Prospects for drought prediction in Australia and Indonesia' *Planning for Drought*………..	Potential for drought prediction due to enhanced knowledge of causes of extreme rainfall variability in Australia.	Drought predictability.
Nicholls, N. (1988a) 'El Niño-Southern Oscillation and rainfall variability' *J. Climat.* 1, 4, 418-421.	Strong relationship between ENSO and high rainfall variability.	
Nicholls, N. (1988b) 'El Niño-Southern Oscillation impact prediction' *Bull. Amer. Met. Soc.*, 60, 2, 173-176.	The role of ENSO and global/Australian climate variability and impact prediction.	
Nicholls, N. (1989) 'Sea-surface temperatures and Australian winter rainfall' *J Climate*, 2, 965-973.	Understanding the role of both Pacific and Indian Ocean sea-surface temperatures in Australian rainfall variability.	
Nicholls, N and Wong, K.K. (1990) 'Dependence of rainfall variability on mean rainfall, latitude, and the Southern Oscillation'. *J. Climate*, 3, 1, 163-	Improving understanding of rainfall variability (in Australia) and relationships with ENSO.	Key manuscript on Australian (and

170.		global) rainfall variability.
Nicholls, N. (1991a) 'The El Niño-Southern Oscillation and Australian Vegetation' *Vegetation and climate interactions in semi-arid regions* Springer, 23-36.	ENSO impacts on Australian rainfall and subsequent drought.	
Nicholls, N. (1991b)' Historical ENSO variability in the Australian region' in: *El Nino Historical and Paleoclimatic aspects of the Southern Oscillation*' HF Diaz and V. Markgraf (eds.), Cambridge Univ. Press, 151-173.	Improved understanding of the key role of ENSO in Australian climate variability.	
Pittock, A.B. (1975) 'Climate change and the patterns of variation in Australian rainfall' *Search*, 6, 11-12, 498-504.	Comprehensive overview of the major climate mechanisms responsible for seasonal climate variation in Australia.	Remarkable insight into key climate mechanisms responsible for climate variability in Australia.
Troup, A.J. (1965) 'The Southern Oscillation' *Q.J. Roy. Meteorol. Soc*. 91, 490-506.	Remarkable provision of a practical measure of the level of variation of the Southern Oscillation in terms of a useable index with application to climate variability and seasonal climate forecasting.	Remarkable insight into the value of quantifying ENSO states and hence predictability of climate impacts.
Williams, M. (1987) 'Relations between the Southern Oscillation and the troposphere over Australia' *BMRC Research Report No. 6*. Bureau of Meteorology Research Centre, Melbourne, Victoria, Australia.	Insight into the core driving mechanisms between ENSO and especially Southern Oscillation patterns and key tropospheric variability over Australia.	Enabled the provision of insight into the mechanisms that connected ENSO to, for example, low rainfall or drought periods in Australia – which also led to development of operational seasonal forecasting systems.

Table 1: Overview of climate research initiatives and inputs that provided major advances in the understanding of extreme climate variability, and relationships to drought, in Australia.

Industry	**Some impacts of drought**	**Farm-level management strategies**
Broadacre grazing	Reduced pasture growth; consequent reduced meat and wool production Reduced land carrying capacity	Destocking Supplementary feeding Containment paddocks Agistment
Dryland cropping	Quantity and timing of rain prior to and during the growing season influences	Variable use of inputs as season evolves Diversification of the farm business Change crop varieties and/or types, adjust planting dates, change fertiliser regimes
Irrigated Cropping	Water allocation reduced or nil allocation depending on drought severity	Choose not to plant Temporary switch to dry land production Diversification of the farm business
Horticulture	Reduced to low water allocation	Allow some plants to die Pruning to minimise water use
Dairy farming	Reduced pasture growth Heat stress	Increased supplementary feeding Animal shading sprinklers

Table 2. Impacts of drought on agricultural industries together with different strategies adopted on-farm to account for those specific risks in Australia (National Regional Advisory Council, 2012).

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Decision type (eg. only)	Climate system (year)
Logistics (eg. scheduling of planting / harvest operations)	Intraseasonal (>0.2)
Tactical crop management (eg. fertiliser/pesticide use)	Intraseasonal (0.2-0.5)
Crop type (eg. wheat or chickpeas)	Seasonal (0.5-1.0)
Crop sequence (eg. long or short fallows)	Interannual (0.5-2.0)
Crop rotation (eg. winter or summer crop)	Annual/biennial (1-2)
Crop industry (eg. grain or cotton, phase farming)	Decadal (~10)
Agricultural industry (eg. crop or pasture)	Interdecadal (10-20)
Landuse (eg. Agriculture or natural system)	Multidecadal (20+)
Landuse and adaptation of current systems	Climate change

Figure 1. Relationships identified between key climatic mechanisms (right hand side of figure) and examples of agricultural management practices (‘decision types’) (left hand side of figure) also operating at these scales in Australia (after Meinke and Stone, 2005; Stone and Meinke, 2005).

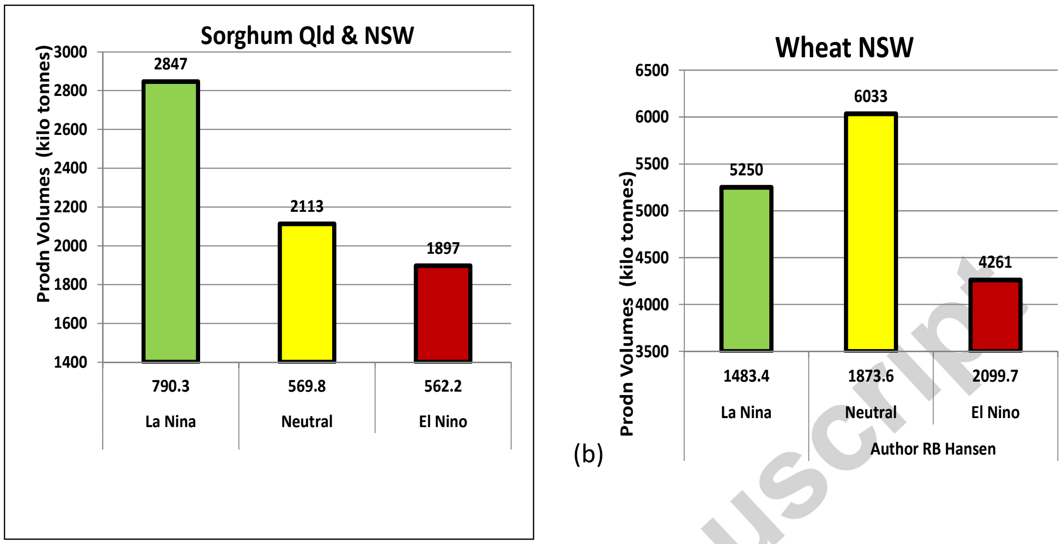

Figure 2. Variation in crop yields associated with El Niño, La Niña, and so-called 'neutral' years or seasons in the equatorial Pacific Ocean in relation to (a) total sorghum yields for the Australian states of Queensland (Qld) and New South Wales (NSW) and (b) wheat crops in the Australian State of New South Wales (courtesy B. Hansen, University of Southern Queensland) (Values at the top of each bar denote mean average yields while those at the bottom of each bar denote the mean yield standard deviation).

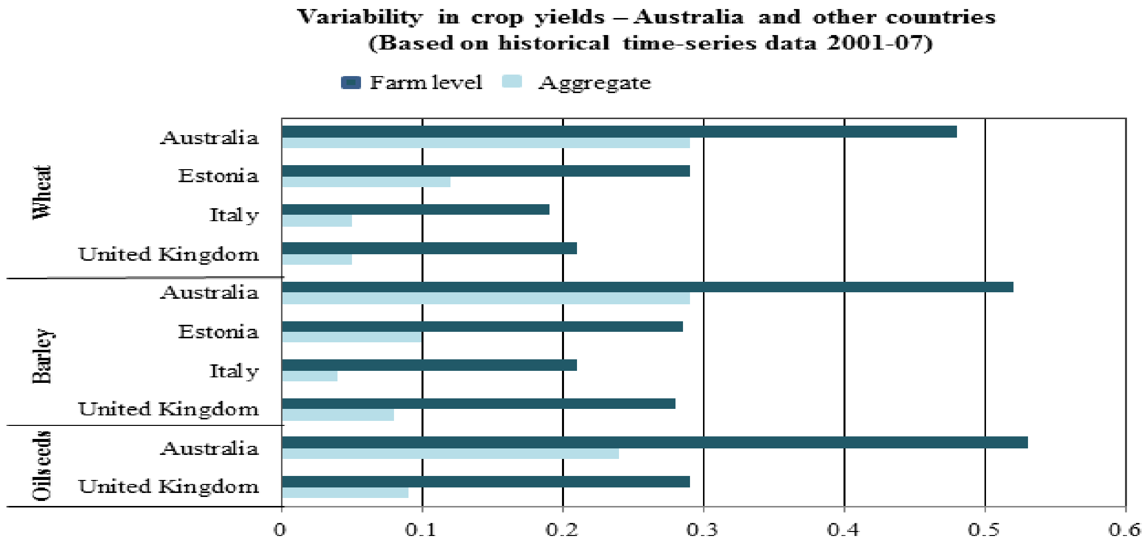

Figure 3. Variability in crop yields and other OECD countries for comparison at farm level and aggregate level (courtesy Kimura and Anton, 2011).

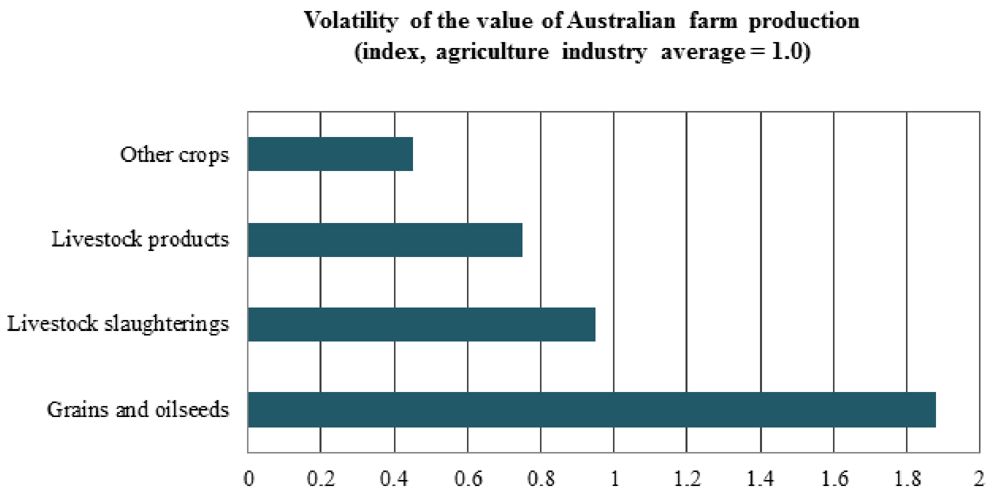

Figure 4. Volatility in the value of Australian farm production (courtesy Hatt et al, 2012, in National Rural Advisory Council, 2012).