Economic and Social Commission for Asia and the Pacific

CGPRT Centre Monograph No. 43

Coping against El Nino for Stabilizing Rainfed Agriculture: Lessons from Asia and the Pacific

Proceedings of a Joint Workshop
Held in Cebu, the Philippines
September 17-19, 2002

United Nations

Seasonal Climate Forecasts and Decision Support Systems for Drought Prone Agriculture: A Case Study Based on the Development and Application of the Rainman Climate Analysis Software

Jeff F. Clewett[*]

Abstract

This paper considers the role of decision support systems to apply seasonal climate information in agriculture by documenting the development and application of the Australian Rainman computer package as a case study. Rainman aims to develop knowledge and skills for managing climate variability in agriculture by analysing effects of the El Nino/Southern Oscillation (ENSO) on rainfall to derive probability-based seasonal climate forecasts. The two main seasonal forecast tools used in Rainman are the Southern Oscillation Index (SOI) and an index of Sea Surface Temperature (SST). The Rainman version 4 prototype is due for release and has improved seasonal forecast analyses and capacity for world-wide mapping of seasonal rainfall information at district and regional scales. There has also been interest in applying seasonal forecast technology to water supplies and irrigation systems and has led to developing the StreamFlow supplement for analysis of streamflow and run-off data.

A central principle used in developing Rainman has been to include only seasonal forecast methods that have been well established and accepted by the scientific community and national organizations with responsibility in seasonal climate forecasting. Thus, the participative process to define and review Rainman has been an important element in the development of Rainman as a decision support product. Peer review is a necessary part of the quality assurance process in developing decision support systems.

In communicating knowledge of risk, we have found that cumulative probability distributions work well for scientists. However, in communicating with the farming community, other ways of expressing risk have been more effective such as frequency plots, pie charts, box plots and time series. Rainman analyses follow accepted scientific conventions by applying several statistical tests to seasonal forecasts so that: (a) users have some guidance regarding the statistical reliability of the forecast information, and (b) duty of care is discharged in providing forecast information to users.

The Rainman case study shows that software is an effective way to provide people with climatic information because it can be detailed but easy to use, comprehensive and locally relevant. Learning to use ENSO information is maximised by combining “hands-on” learning with the software with participation in a workshop where people share ideas and experiences. Benefits of using Rainman include improved knowledge and skills about the variable climate and seasonal climate forecasts, enhanced agriculture and resource management decisions, and reduced climate risk exposure.

---

[*] Principal Scientist, Queensland Centre for Climate Applications, DPI, Toowoomba, Australia.

Introduction

The El Nino/Southern Oscillation (ENSO) component of climate variability has large and often severe impacts on both agricultural production and the livelihood of many people (Nicholls, 1985; White, 2000; Hammer *et al*., 2001), and in 1997/98, the impacts of El Nino in SE Asian countries caused widespread drought and fires with estimated losses exceeding $20 billion. While ENSO has impacts on a global scale (Stone *et al*., 1996), the timely knowledge of expected rainfall at a local level is an essential part of decision-making for farmers, resource managers and business people. Organizations in Australia involved with disseminating climatic information have recognised that people gain information, knowledge and skills in many ways, and have thus sought to build a rich diversity of information and decision support pathways. These pathways range from raising awareness, attitudes and aspirations of people to more comprehensive development of knowledge and skills through a breadth of decision support systems such as:

- Printed resources (books, pamphlets) eg. *Will It Rain?* (Partridge, 1991, 2002a, 2002b)
- Subscription services eg. Seasonal Climate Outlook (National Climate Centre)
- Mass media eg. TV services, radio, newspaper, magazines and journals
- Phone and fax services eg. Weather by Fax, FarmWeather, SOI Hotline, Farmfax
- PC Software eg. Grassman (Scanlan and McKeon, 1990 and Clewett *et al.*, 1991), Wheatman (Woodruff, 1992), DroughtPlan (Stafford-Smith *et al*., 1998; Cobon and Clewett, 1999), StreamFlow (Clarkson *et al.*, 2000), Whopper Cropper (Nelson *et al*., 2002)
- Web sites eg. LongPaddock (www.LongPaddock.qld.gov.au) Met Net (www.bom.gov.au), SILO (www.bom.gov.au/silo/), CVAP (Climate Variability in Agriculture Program) (www.cvap.gov.au), Qld Centre for Climate Applications (www.dpi.qld.gov.au/climate/).
- Education processes eg. The *Climate and Your Farm* Home Study Course (Brouwer and George, 1995; Bayley, 2000), *Managing for Climate* workshops (O'Sullivan and Paull, 1995) and *Developing Climate Risk Management Strategies* (ANTA, 2000).

While further analyses of the above are given by Clewett *et al*. (2000b), a general review of decision support systems is given by Stuth and Lyons (1993) and the text by Hammer *et al.* (2000) provides a recent review of the application of seasonal climate forecasting in Australian agriculture and natural ecosystems. In this latter text, the paper by White (2000) highlights the potential value of seasonal climate forecasts to agriculture, but also recognises the substantive difficulties that people have in applying probability-based information to management decisions. The papers by Hammer (2000) and Nelson *et al.* (2002) present the view that a major function of decision support systems is in the role of discussion support, designed to facilitate dialogue about management practices.

The purpose of this paper is to discuss the development and application of the Rainman package as a specific case study in the more general theme of developing decision support systems for the application of probability-based seasonal climate forecasts in agriculture. The following sections discuss:

- the challenge and historical factors leading to development of Rainman
- participative processes necessary for development of decision support
- presentation of results that recognise the needs of different users
- the scientific basis of seasonal forecast methods used in Rainman
- tests on seasonal forecast skill
- peer review and adoption

- benefits from development and application of Rainman

The challenge for rainman and its history of development

The challenge in developing Rainman as a decision support package was to find a practical way to lift the capacity of people to achieve better management of climatic risks so that opportunities for sustainability and profit in agricultural systems were enhanced. The key parts of this challenge were:

- developing a collaborative ethos and a participative problem-solving style so that Rainman represented the collective views of the scientific community and the needs of industry
- raising awareness of climate variability issues including the atmospheric and oceanic processes causing the El Nino/Southern Oscillation (ENSO) phenomenon
- enhancing knowledge of seasonal climate forecast technology and raising skills to apply this knowledge in agricultural decisions
- raising awareness and appreciation for the role of computer software in agricultural management, and successfully developing and marketing a software package and educational processes.

Rainman version 1 (Clarkson and Owens, 1991; Clewett *et al*., 1993) with its companion book *Will It Rain?* (Partridge, 1991) was developed in response to demand from many people concerning access to climate records and analyses of rainfall concerning the effects of ENSO. While this first publication was developed to meet the needs of Queensland, the popularity of the package and demand from other states soon led to development of version 2 for all of Australia (Clewett *et al*., 1994; Clewett *et al.* 1996). This was released in October 1994 with a second edition of *Will It Rain?* Further demand then led to release of a Windows version (Australian Rainman version 3) in June 1999 which also included a large the reference section and many improvements to the analyses and graphics (Clewett *et al*., 1999). The Rainman version 4 prototype is due for release and has improved seasonal forecast analyses and capacity for world-wide mapping of seasonal rainfall information at district and regional scales. It is being developed through the ACIAR-funded project "*Capturing the benefits of seasonal climate forecasts in agricultural management*" and has been used as a decision support resource in a series of workshops with strong support from participants in this project in Indonesia, Zimbabwe and India (George and Selvaraju , 2002). The project aims to:

- evaluate a range of seasonal climate forecast signals and statistical methods
- identify relationships between climate indicators and impacts on agriculture
- assess the value of the forecasts at key decision points in the agricultural system
- develop and evaluate (within case studies) a range of decision support systems; including participative workshops and learning packages, agricultural models, and an international version of the Australian Rainman software package
- publish and disseminate results from the case studies on ways to improve farm management so that potential benefits from forecasts are captured.

In addition to interest in analysis of rainfall, there has also been interest in the application of seasonal forecast technology to water supplies and irrigation systems. This has led to development of the StreamFlow supplement to Australian Rainman for analysis of streamflow and run-off data (Clarkson *et al*., 2000; Clewett *et al*., 2000a, 2000c, and Clarkson *et al*., 2001). The following is a summary description of the current version of Rainman.

Short description of Australian Rainman

Australian Rainman (Clewett *et al.*, 1999) is a comprehensive climate analysis and resource package for farmers, business people, researchers and education. The latest release (version 3.3) is easy to use and innovative in presenting a rich suite of information about Australia's climate and management of climatic risk in three editions: Standard, Educational and Professional. The menus, maps, graphs, tables, text and pictures make the information easy to understand, and the substantive analytical capabilities ensure that it can be used as a powerful research tool.

Australian Rainman is produced on CD ROM and enables people to rapidly evaluate the characteristics of daily, monthly and seasonal rainfall for their location. This includes seasonal forecasts of the amount, timing and frequency of rainfall based on phases and averages of the Southern Oscillation Index (SOI) and Sea Surface Temperatures (SST). There is also information on drought, humidity, temperature and evaporation. Monthly rainfall can be updated each month via the Internet, and users can enter and update rainfall records for their own property. The CD is packaged with a 16-page *"Getting Started"* booklet and includes:

- All of Australia's long-term historical daily and monthly rainfall records from more than 3,870 locations (45 per cent of locations with more 100 years of data,) with scientific details of the data set on the CD from the paper by Owens et al. (1996). (Version 4 of Rainman will also have monthly rainfall data from an additional 9,579 locations throughout the world that have been provided by the National Climate Data Centre, USA. Some 60 per cent of these locations have more than 50 years of good data and 10 per cent have more than 100 years of good data.)
- Analyses of monthly and daily rainfall to characterise the climatology of a location, and to provide drought analyses and seasonal forecasts (amount of rainfall, on-set dates of the wet season, frequency of rainfall events) presented as frequency and time series distributions.
- An interactive multi-media book *Will it Rain?* for understanding the El Nino/Southern Oscillation as the basis of seasonal forecasting and its application to management. While this electronic version has animated diagrams (e.g. of the Walker circulation) to enhance learning processes, a full colour printed version of the book (64 pages) is also available (Partridge, 1994).
- A CD version of the popular Long Paddock Internet site
- A suite of interactive tutorials by George and Brouwer (1999) on managing climate risk and application of seasonal forecast information in the context of agricultural decision-making including several case studies of how farmers and business people are using climate information in their management.
- A library of resource information including: a suite of ready-to-use diagrams that are suited to teaching principles about issues such as the mechanism of ENSO and climate risk management, a list of 80 scientific references for further reading and several scientific papers about Rainman and the data (Clewett *et al.*, 1993, 1996 and Owens *et al.*, 1996).

Participative processes involved in development

The need to develop and release the original Rainman decision support software package (Clarkson *et al*., 1991), and to produce the book *Will It Rain?* (Partridge, 1991) arose from:

- recognition of climatic risk as a major factor influencing decision-making in rural industries, coupled with the lack of easy access by the rural community in the 1980s to climate data upon which risk management strategies could be developed
- the enthusiastic interest shown by farmers and pastoralists at field-days in the late 1980s to climate data and analyses of seasonal rainfall for their own location. (The risk analyses on seasonal rainfall with durations of 1 to 12 months were pertinent to decision-making and were made available via modem connection to a program called CLIMATE (Willcocks and Lloyd 1988) held on central main frame computer run by the Queensland Department of Primary Industries.)
- severe drought in Central Queensland during the 1982/83 and 1986/87 El Nino events followed by the 1988/89 La Nina
- the influential work of key scientists in Australia during the mid 1980s (especially Dr Neville Nicholls, Dr Greg McKeon and Dr Graeme Hammer) and pivotal publications such as McBride and Nicholls (1983), Nicholls (1985, 1986), McKeon et al. (1986, 1990) and Hammer et al. (1991a, 1991b), and the realisation by the author of the powerful opportunities for better management of climatic risk provided by the combination of new advances in: (a) ENSO-based seasonal forecasts, (b) systems analysis methodology, and (c) development of PC computer technology and decision support software (e.g. Clewett et al., 1991a, 1991b).
- the lack of information in an easy-to-understand form describing the El Nino/Southern Oscillation and its effects on both climate and opportunities to improve management decisions
- high levels of interest shown by farmers, business people and agricultural professionals in the Central Highlands region of Queensland at seminars describing the potential of ENSO for seasonal rainfall forecasting (eg Coughlan, 1989 and Clewett *et al*., 1989)
- a decision by industry representatives, researchers and extension staff at a participative problem-solving workshop on the application of ENSO information (Queensland Department Primary Industries, Emerald, 29 Aug 1989) to embark on a range of initiatives to remedy the situation.

The participative processes used to initiate the Rainman package were continued in the production of the package through testing of Beta software, and in the proposal, development and testing stages of Rainman versions 2, 3 and 4. These participative processes involving industry, RD&E organizations and funding bodies have been fundamental to the *"success"* of Rainman. The name "Rainman" was derived by David Gramshaw in December 1989 from the phrase *"rainfall information for better management.* This was in keeping with the focus on management that was also used for other components of the "Beefman" series of decision support software for the beef industry of northern Australia (Ludwig *et al.*, 1993).

Effective networks of people and organizations were formed in the early stages of developing the proposal for Rainman version 2 to achieve ownership and sense of purpose. Importantly the network included users such as primary producers and agribusiness people and scientists from the Queensland Department of Primary Industries (and now the Dept of Natural Resources and Mines), the Bureau of Meteorology, the West Australian and other State Departments of Agriculture, universities and CSIRO. This was achieved through the development of formal partnerships in both the R&D implementation phase and the marketing phase, and by the direct contribution of people from other organizations in the project proposal for version 2 in January 1992, and their further participation in two workshops in Melbourne to: (a) review use of seasonal forecasting tools, and (b) decide the content of the Rainman package (Clewett, 1995b). The above network has been maintained through the development and application of Rainman version 3 and expanded on an international basis for development of version 4 through the current ACIAR-funded project "*Capturing the benefits of seasonal climate forecasts in agricultural managemen*t". The several funding organizations as described in the acknowledgements have played a key role as part of the participative process for achieving success with Rainman in terms of the wider goal of better management of climatic risk.

Presentation of results

People as individuals have different needs and learning styles, and thus respond to information in different ways. For example, in communicating knowledge of risk we have found that cumulative probability distributions provide an effective mechanism for scientists to communicate with each other. However, in communicating with the farming community we have found that other diagrams and ways of expressing risk are more effective such as frequency plots, pie charts, box plots and time series. The simplest statement for communicating risk has been the percent chance that seasonal rainfall will be above or below the median rainfall (or above or below the average) (Stone *et al*., 1996). While this very simple statement of risk is now widely used in the agricultural media in Australia, the research by Coventry (2001) shows that this statement can be easily misinterpreted by some people because of confusion about probability issues and thus on-going education processes are needed.

The next level for communicating risk is to consider the chance that seasonal rainfall will be: above average (highest 30 per cent), about average, or below average (lowest 30%). The Bureau of Meteorology has used this tercile method in their seasonal forecasts for many years and it is implemented in Rainman as pie charts which can clearly and rapidly show shifts in the chances of rain.

The fullest understanding of climate risk often occurs where people have been able to view all of the historical rainfall (eg. 100 years of data) as a time-series histogram. Time series can be particularly useful because they give an analogue representation of people's chronological memory patterns. Research (Coventry, 2001) has shown that people are more able to assimilate statements about frequency (eg. 7 years in 10) than the more abstract probability statement (eg. 70 per cent chance). Understanding is maximised where different colours are assigned to different year types (such as using red bars for El Nino year types and blue bars in the histogram for La Nina year types). Such a diagram clearly shows the relative frequency and spatial separation of El Nino and La Nina events. The time-series analogue also shows how often above and below median (or above and below average) rainfall occurs without recourse to frequency distribution data or abstract mathematical/statistical representations. Simplicity is often the key to comprehension. Comprehension empowers people with ownership of the forecast and thus confidence in moving towards using it in their decision-making. Technical aspects of the seasonal forecast analyses are given in the following sections.

Scientific basis of seasonal forecast methods used in Rainman

The two main seasonal forecast tools used in Rainman are the Southern Oscillation Index (SOI) and an index of Sea Surface Temperature (SST). The historical values of the SOI (1876 to present) are based on the work of Troup (1965) and Allan *et al.* (1996) and represent standard deviations (times 10) of differences in air pressure anomalies between the central Pacific (Tahiti) and Indonesian region (Darwin). The SOI is provided by the Bureau of Meteorology and is updated and periodically revised on their website. The SST index is also provided by the Bureau and is based on the work of the Bureau of Meteorology Research Centre as described below.

The seasonal forecast analysis method in Rainman version 1 was based on established relationships derived and substantiated from the work of McBride and Nicholls (1983), Nicholls (1984a, 1984b, 1986, 1991), Allan (1988), Ropelewski and Halpert (1987, 1989), Clewett *et al.* (1989, 1991b), Hastings (1990), Drosdowsky and Williams (1991). The evidence in these studies showed strong statistical relationships between seasonal values of the SOI (typically averaged over 3 months) and rainfall in eastern Australia and other parts of the world. Analysis of ENSO impacts on user-defined rainfall seasons in Rainman version 1 were confined to assessing historical rainfall data using the average seasonal (3 month) SOI as the predictor with zero lead-time. Analyses of rainfall data (typically 70 years or more) at a location of the user's choice were presented in tables as frequency and time-series distributions for 3 classes of the SOI using the method of Clewett *et al.* (1989, 1991b). The class boundaries defaulted to: negative (below -5), neutral (-5 to +5), and positive (above +5) for normally distributed data such as monthly values of the SOI, this gives approximately equal values of the monthly SOI in each class. These boundaries were user-adjustable to enable assessment of changes in risk at extreme values of the SOI in a way that is comparable to examining extreme values in regression analyses such as that used at the time by the Bureau of Meteorology (NCC 1991, Nicholls, 1991). Others have also found it useful to examine the extremes of the Southern Oscillation (Hastings 1990, White 2000). Separation of the historical data into several classes and plotting resulting frequency distributions was a relatively new approach in communications that enabled users to rapidly and easily compare likely outcomes from different seasonal forecast scenarios.

The workshop to review the seasonal forecast analyses in Rainman was convened by the National Climate Centre, Bureau of Meteorology in March 1993 and was attended by climatologists (from the Bureau, universities and CSIRO), industry representatives and agricultural scientists from state and national organizations. This provided a rigorous peer review (Clewett, 1995b) of the data and analytical methods published in Rainman version 1 (Clarkson and Owens, 1991). The 2-day review was thorough and concluded that Rainman version 2 (Clewett *et al.*, 1994) should expand the geographic coverage of the rainfall data set to all locations in Australia, expand the analytical and presentation methods used, and develop a national marketing plan. The review concluded that the analyses described above for Rainman version 1 should be retained and expanded to include:

- variable lead time and duration of the SOI predictor
- trends in the SOI
- use of the SST as a predictor
- "break of season" analyses using daily rainfall data

The reasons for these conclusions are described below. Other predictors such as sea level (Mitchell, 1994) and persistence of north-west cloud bands were to be excluded until clear methodologies were resolved. Other analyses such as the 40-day wave were considered to have too many unresolved issues for inclusion. Further development of drought analyses were recommended as were analyses of temperature data, including frost.

Lead-time in Rainman is defined as the gap in time between the end of the predictor period and the start of the rainfall period that is forecast (i.e. the predictand). Several studies highlight the considerable value and need for longer lead-time forecasts for decision making (e.g. Nicholls, 1986; Stafford-Smith, 1998; Ash *et al.*, 2000, Everingham *et al.*, 2002 and Park *et al.*, 2002). Hartman *et al.* (2002) report the legitimate criticisms of resource managers and decision makers of seasonal forecast information that do not target the needs of users. Inclusion of variable lead time as an integral part of the seasonal forecast capability in Rainman versions 2 and 3 is based on:

(a) the need to target as early as possible the rainfall season that is relevant to the decision-making need of the user

(b) conclusions of the 1993 review of Rainman version 1 described above.

(c) findings that the mechanism of the southern oscillation supports longer lead-time forecasts particularly during southern hemisphere winter/spring/early summer period (McBride and Nicholls, 1983; Allan, 1988; Allan *et al.*, 1996; Drosdowsky and Williams, 1991; Simmonds and Hope, 1997; and Stone and de Hoedt, 2000).

Use of variable lead-times using the SOI and SST is well established in the literature and variable lead-time analyses have been used in several seasonal forecast analyses (Nicholls, 1985; Nicholls, 1986; Allan, 1988; and Ropelewski and Halpert, 1989; Drosdowsky and Chambers, 2001; and Everingham *et al*., 2002). In assessing use of seasonal forecasts for land, pasture and animal production in Northern Australia, McKeon et al (2000) and Ash et al (2000) conclude that the key component was the need for long-lead forecasts (e.g. a June forecast for the November - March season).

The studies by McBride and Nicholls (1983), Allan (1988) and others reported above also document the value of concurrent or simultaneous analyses for understanding the relationships that have occurred in history between the predictor and the predictand. Users of Rainman are encouraged as part of the philosophy on application of decision support software (Stuth and Lyons, 1991) to explore concurrent and longer lead-time relationships to achieve understanding and an appreciation of the strengths, weaknesses and uncertainties in seasonal climate forecasts. When first investigating relationships for a location or season, it is often best to begin with a concurrent analysis before investigating the strengths and weaknesses of the forecast analysis.

The recommendation of the 1993 peer review to include the trend in the SOI as a seasonal forecast tool was achieved by implementing the SOI Phase system (Stone and Auliciems, 1992 and Stone *et al.*, 1997) in version 2 and it is now used in versions 3 and 4 with zero lead-time as the default forecast method. The SOI Phase system was derived from cluster analysis which revealed 5 phases as follows: 3 phases describing the state of the SOI (positive, neutral and negative), and 2 phases describing the change in the SOI (rapidly Rising and Falling phases). The SOI 5 Phase system is based on just two values of the monthly average SOI (eg. this month, and last month) and can thus respond quickly to changing SOI conditions. The rapid response of the SOI Phase can, in some circumstances, cause instability in the seasonal forecast (e.g. July 2001 to March 2002) however, the rapid response of the SOI is an advantage in the southern hemisphere autumn (April-May) because the rise or fall in the SOI can be a useful indicator of developing El Nino and La Nina conditions and this can be used to advantage in winter cropping decisions (Hammer *et al.*, 1996 and Carberry *et al.*, 2000).

Seasonal forecasts with Indian Ocean SST anomalies with variable lead time were included in versions 2 and 3 based on the research of Drosdowsky (1993c), and importantly, the consensus of scientific opinion at the Melbourne peer review in 1993. It is now proposed that this SST system derived by Drosdowsky (1993c) be upgraded in version 4 with the SST 9 Phase system of Drosdowsky (2002). This is similar to the SST-based operational forecast system now used by the Bureau of Meteorology (Grant Beard, National Climate Centre pers. comm.) and is based on the research of Drosdowsky and Chambers (2001). The SST 9 Phase system is slightly simpler than the Bureau's operational system and is a factorial of 3 Pacific Ocean phases (cool, neutral, warm) by 3 Indian Ocean phases (cool, neutral, warm) calculated from EOFs. To enhance understanding of Pacific Ocean and Indian Ocean relationships with rainfall, the Rainman version 4 prototype enables the Indian and Pacific Ocean main effects to be calculated separately or combined as the 9 phases.

Seasonal forecasts of the "*Break of Season*" as recommended by the 1993 review were implemented in Rainman version 2 as several new analyses to assess the timing, frequency and amount of rain in user-defined rainfall events, and were then upgraded in version 3 to assess the effects of ENSO has on these characteristics. A rainfall event is defined in these analyses by some minimum amount of rain occurring within a maximum period of time (eg. at least 50 mm of rain falling within a 7-day period). The analyses require daily rainfall data and were developed by the Agriculture Department in Western Australia to assess opportunities to better manage wheat production. Through collaborative agreements with Dr Doug Abrecht the West Australia daily rainfall analysis software was adapted for use within Rainman version 2 and then upgraded later for version 3.

Upgraded analyses were developed in Rainman version 3 to assess the influence of ENSO on the characteristics of rainfall events within a season and were: date of first event, date of second event, number of events, and amount of effective rain. These analyses are useful to define the date of on-set of the wet season (Nicholls, 1984c), the chance of follow-up rainfall (Park *et al.*, 2001), and the substantial influence of ENSO on these and other characteristics of rainfall such as *when* and *how often* planting rains for cropping might occur in a season (Nicholls and Kariko, 1993). The analyses can also be used to assess the likelihood of large-scale flooding events as might be associated with the effects of ENSO on tropical cyclonic activity (Nicholls, 1984b, 1992; Hastings, 1990; and Evans and Allan, 1992).

Tests on seasonal forecast skill

Rainman analyses follow accepted scientific conventions by applying several statistical tests to seasonal forecasts so that: (a) users have some guidance regarding the statistical reliability of the forecast information, and (b) there is duty of care in providing forecasts information to users. While this latter point is of value to professional advisors and organizations in terms of risk management, the review of statistical tests in seasonal forecast analyses by Nicholls (2001) clearly shows that there are several significant deficiencies in null hypothesis statistical test procedures and thus complete reliance or over-emphasis on these tests should be avoided. As Rainman is a decision support package, the forecast skill tests are also seeking to minimise risks associated with artificial skill and this is dealt with in more detail later.

The statistical tests used in Rainman are: (1) the Kruskal-Wallis (KW) test as used by Stone and Auliciems (1992), the Kolmogorov-Smirnov (KS) test as described by Conover (1971) for comparing two probability distributions, and (3) the LEPS (Linear Error in Probability Space) skill score test as proposed by Ward and Folland (1990). The non-parametric KW and KS tests are used in preference to Analysis of Variance F tests because rainfall data is often skewed. These tests are calculated using the methods of Conover (1971) and are applied as follows:

- the KW probability is calculated for the 'all years data' but not for each SOI/SST group.
- the KS probability is calculated for each SOI/SST group but not the 'all years' data

The KW test is given precedence over the KS test and in the prototype for version 4 results are *"greyed out"* if they are not statistically significant (threshold value used for KS and KW test values is 0.90). If the KW test is less than 0.90, it is recommended that the long-term climatology (i.e. the data in the 'all years' column) be used to assess climate risks. In calculating the KS test values, the cumulative probability distribution of each SOI (or SST) group is compared against the combined cumulative probability distribution formed from the pooled data in all other groups. For example, the KS test for the SOI negative phase compares the probability distribution for the SOI negative phase against the probability distribution formed from the combined data from the positive, falling, rising and neutral phases. Further details on the KS and KW tests are given in the Rainman *"Help"* notes.

To further assist users to identify seasonal forecast information that is skilful and not just due to chance relationships in the historical data, Rainman version 4 also provides cross-validated LEPS (Linear Error in Probability Space) skill score tests (Ward and Folland, 1990; and Wilks, 1996). The "continuous" method based on equation 12 of Potts *et al.* (1996) is used for calculating the skill score with results presented as tables, graphs and maps. The mapping capabilities of the Rainman version 4 prototype enable comparison of cross-validated skill scores at multiple locations. A significance level for the "continuous" LEPS skill score was identified using a random forecast method similar to that of Drosdowsky and Chambers (2001). A LEPS Skill Score of 7.0 equated with the 0.90 KW test value for these forecasts and the upper 15th percentile of 26,000 random forecasts.

Peer review and adoption

The purpose of this section in the Rainman case study is to highlight the importance of peer review as a necessary part of the quality assurance process in developing decision support systems. In addition to the 1993 Melbourne review, Rainman has been peer-reviewed on many occasions from different perspectives (science, decision-support, communication, education, marketing). Rainman has been presented for review at major International and national conferences (Clewett *et al*., 1993; Clewett, 1995b; Clewett *et al.*, 1996; and George *et al.*, 2000) and this has included independent review processes (White and Stynes 1996, Power *et al.* 2001). The papers by Clewett *et al.* 1993 and 1996 are reproduced in full in Rainman version 3. Examples of external and independent peer reviews are as follows.

- Three separate funding bodies have reviewed previously published versions of Rainman from scientific and decision support perspectives and found in favour of further R&D support on five separate occasions, and on two of those occasions external reviews were commissioned by the funding organization.
- Rainman has been independently reviewed by climatologists and agricultural scientists in several major RD&E organizations in Australia and has been: (a) cleared for purchase of a site licence, (b) adopted as an accredited package for training staff (eg. Bureau of Meteorology Training Centre, South Australia Dept of Agriculture, NSW Agriculture), and (c) adopted for use in research and extension by professional staff.
- Education institutions including universities, schools, agricultural colleges and geography professionals have reviewed Rainman and recommended and/or adopted it for use in teaching programmes (eg. for the courses Weather and Climate in Farming (Bayley, 2000) and Developing climate risk management strategies (ANTA, 2000)).
- Farm journals have given it four and half star ratings as a decision-support package (eg. Buckley, 2000) and national software competitions have awarded honours to Rainman on several occasions for excellence (eg. First prizes at The Australian Farm

Software Competition in 1992 and 1995, and the Asia Pacific Information Technology and Telecommunications software competition in 2000).

- Most importantly some thousands of people have reviewed the overall value of Rainman to their situation and have demonstrated their support by purchasing a copy.

Continuing quality assurance processes and peer review in the development of Rainman version 4 have recently raised several questions concerning artificial skill and multiplicity in the seasonal forecast analyses and have precipitated several improvements. Nicholls (1991) defined multiplicity as *"the statistical problem that arises when a large number of statistical hypotheses are tested (e.g. when many cross correlations are calculated)"* and the effect of multiplicity as *"the probability of incorrectly rejecting at least one null hypothesis increases geometrically as more hypotheses are tested"*.

Artificial skill is described by Nicholls (1991) in two ways. Firstly by "the tuning effect of fitting a model in which the parameters need to be estimated from the available data. This will lead to "artificial" skill, which may disappear when the prediction model is used on new, independent data". Use of cross-validation techniques to measure forecast skill as implemented in the Rainman version 4 prototype (described above) is the recommended approach to avoid these artificial skill problems (Drosdowsky and Allan, 2000; and Tashman 2000). The second source of artificial skill described by Nicholls (1991) and by Wilks (1996) is more relevant to dangers in multiple regression techniques where extra and unnecessary predictors are sometimes included in forecast methods. This second source of artificial skill is not an issue for Rainman because multiple predictors in the one forecast equation are not used.

Multiplicity is however an issue that needs to be appropriately addressed. Rainman can calculate several independent forecasts for the one locality because it can apply several predictors (average SOI, SOI Phase and SST Phase) at several lead times at several locations in the one locality. One in 10 of these forecast results can be expected to be *"statistically significant"* just due to chance because the statistical test significance levels are set at 0.90. The occurrence of 1 in 10 statistically significant forecasts due to just chance is also true when forecasts are routinely assessed every month. Thus, there is need to emphasise the value of spatial and temporal coherence in seasonal forecasts to help weed out the occurrence of "rogue" forecasts that are an artefact of the historical data. Multiplicity is an important issue that must be dealt with in an effective way and is done so in the Rainman package by:

- always providing seasonal forecasts as frequency-based information that are derived from historical data, thus the forecast information is never "wrong" and this provides corporate protection
- providing data in a variety of ways that clearly demonstrates the strengths, weaknesses and riskiness of seasonal forecast information
- guiding users through the "Help" and "Tutorial" systems that: (a) identify appropriate methods to approach seasonal forecast analyses, (b) reveal uncertainties about the forecasts in ways that are consistent with the risk management conclusions of Clark and Brinkley (2001), (c) bring attention to the cognitive biases and difficulties that people have in using probabilistic information (Nicholls, 1999; White, 2000; and Coventry, 2001) and (d) encourage users to identify a priori hypotheses concerning the target management decision and thus avoid "engaging in haphazard fishing expeditions which will almost certainly find some statistically significant relationship" (Drosdowsky and Allan, 2000). The prominent "Chance result or Real Skill" red button in the Rainman version 4 prototype draws attention to and displays the following text:

> *All seasonal analyses in Rainman are based on historical data and thus use of Rainman for forecasts of seasonal rainfall is dependent on the statistical relationships in the historical data. These relationships may be a guide to the future. Statistical tests on the skill of seasonal forecasts are useful because they help to weed out erroneous results in the data, and to reveal where tools such as the Southern Oscillation Index (SOI) and Sea Surface Temperature (SST) have "real" rather than "artificial" skill as indicators of future events. When statistically "not significant" relationships between ENSO indicators and rainfall are observed in the data, then users should reject use of the ENSO indicator for that location/season, and use the all-years climate information for the seasonal forecast. The following practices should be adopted in assessing seasonal forecast analyses from Rainman:*
>
> - *firstly define the purpose (e.g. the agricultural decision being made) for using the seasonal analysis information in Rainman, and then use the purpose to define the rainfall season*
> - *use climatology (i.e. data in the all-years column) as the primary seasonal forecast method*
> - *consider the mechanisms of ENSO (e.g. read Will It Rain ?) and if convinced that there is sound reason for impacts of ENSO on the location and season of choice then proceed to examine relationships of ENSO indicators with seasonal rainfall*
> - *examine the statistical significance and variability of relationships (examine data in different ways e.g. use of tables, pie charts, box plots and importantly the historical time-series plots)*
> - *examine the reliability of the ENSO signal by examining results for different periods of time (see the historical time-series plots), adjacent seasons and lead-times (use the Period of Skill analysis), neighbouring locations (use the mapping analysis) and different forecast tools (Average SOI, SOI Phases and SST Phases).*

Independent and competing forecasts are common place in meteorology and occur in most other disciplines (finance, commodity and labour markets), and thus dealing with competing and sometimes misleading information is a common circumstance in the every day life of farmers, business people and resource managers. Issues concerning decisions about choosing between forecasts or combining results from several forecasts are examined by Clemen *et al.* (1995); Nicholls (2000); and Armstrong (2001). Rainman does not attempt to deal with these issues. However, there is an emerging view that use of quantitative and objective methods to combine forecasts and thus prepare ensemble forecasts has merit (Armstrong, 2001 and Drosdowsky, 2002).

Some 3000 copies of Rainman and approximately 6300 copies of *Will It Rain?* have been distributed throughout Australia. A further 1500 copies of the Indonesian version of *Will it Rain?* (Partridge and Ma'Shum, 2002) are being distributed through the University of Mataram. The distribution of Rainman includes several hundred copies being used through site licences in 5 major organizations. Many packages are used by groups of people and thus total usage is estimated to be in excess of 10,000 people. Users include: primary producers across a wide range of industries; extension services (government and private consultants); business people from the agricultural, construction, tourism, health, mining and financial sectors; researchers across a variety of disciplines; and educational institutions from secondary, tertiary and vocational fields.

Benefits from the development and application of Rainman

Climate variability has large influences on the sustainability of land use practices and on the profitability of businesses in the food and fibre chain. Better climatic information can lead to better business decisions and land management. Rainman has made a significant contribution to land management practices by providing a high-quality and easily accessible suite of information about climatic risk and the application of seasonal forecasts including several examples as case studies in the tutorials. This enables people to build their knowledge and skills to make better decisions. Examples include: improved choice of crops and fertiliser use; matching stocking rates to expected feed supplies; more efficient use of irrigation water; and smarter financial decisions.

Rainman has raised awareness of climate forecasting as a land management tool and awareness of the Southern Oscillation as a major factor-influencing climate in many parts of the world. There was little knowledge of ENSO in the Australian community when Rainman was first produced in 1991. Since then a marked improvement in climate knowledge and management of climate risk has occurred, and while several major educational campaigns have contributed to this improvement, some significant part is due to the use of Rainman by many people. While quantitative assessment of overall impacts is not possible, there are many anecdotal accounts now available of how climate risk and ENSO information has helped large numbers of people in their business decisions (George *et al*., 2000).

Several factors have contributed to the success of Australian Rainman including:

- Meeting the needs of people by producing a package that is comprehensive, easy to use, locally relevant, and addressing the problems that people face in managing climatic risk by:
    (a) targeting the required location, season and lead-time
    (b) providing clear information about risk and whether forecast skill is present or not
    (c) providing interpretive tutorial processes and materials.
- Seasonal climate forecasts are perceived to be very useful in agricultural management and thus Rainman is seen as useful because it empowers people with the necessary knowledge and skills to apply seasonal forecasting technology to their management decisions.
- The CD technology used enables fast, reliable and comprehensive delivery of information, the computer programming software is at the forefront of technology, the combination of data, analytical capacity, tutorials and reference information give the product balance, and the package mix can grow to take on new information (eg. streamflow and runoff) and new climate forecasting methods as the science improves.
- The marketing and communications program has been effective and the package has been promoted and sold at an affordable price through a range of outlets and with standard, educational, professional and network options to suit different user groups. Gaining national recognition through achieving several prestigious awards in national IT competitions has been an important element of the communications strategy.

Conclusion

The seasonal forecast capabilities of Rainman have been developed from results of soundly based research on the characteristics of ENSO. This development has occurred over quite some time in a truly participative problem-solving framework that has involved collaboration with industry and several organizations.

The Rainman case study shows that software is an effective way to provide people with climatic information because it can be detailed but easy to use, comprehensive and locally relevant. Providing information in different formats is useful because people learn in different ways, however, the most effective method for communicating the risk dimension in seasonal forecasts is with frequency information displayed as the time series distribution.

People gain confidence in probabilistic seasonal forecasts when they understand the physical basis of ENSO and thus the reasons for its influence on global, regional and local climate patterns. The relationships of ENSO with changes in the characteristics of seasonal rainfall (timing, frequency of events and amount) at their own location and consequent impacts on agriculture are important.

Learning to use ENSO information in management is maximised by combining "hands on" learning with the software with participation in a workshop situation where people can test their ideas and also listen to the knowledge and experience of others (Clewett *et al.*, 2000b).

Current research is extending the application of Rainman to other countries including Indonesia, Zimbabwe and India in the collaborative project entitled " *Capturing the Benefits of Seasonal Climate Forecasts in Agricultural Management*" funded by the Australian Centre for International Agricultural Research.

There is continuing demand from users for a Rainman suite of information on a website.

Contacts

Dr Jeff Clewett (jeff.clewett@dpi.qld.gov.au), Queensland Centre for Climate Applications, Queensland Department of Primary Industries, PO Box 102, Toowoomba Qld 4350. Ph: +61 7 4688 1348, Fax: +61 7 4688 1477. Further details on Rainman and *Will It Rain?* is available from the Queensland Department of Primary Industries (www.dpi.qld.gov.au/shop/).

Acknowledgements

Funding organizations have played a key role in the development and application of Rainman. Firstly, through the Australian Meat Research Corporation initiative in persuing the development of decision support software in the Beefman Project, and then through the Australian Rural Industries Research and Development Corporation support of versions 2 and 3. The support of Rainman projects and the Rainman Streamflow project by Land and Water Australia (formerly Land and Water Resources Research and Development Corporation) through the Climate Variability in Agriculture Program (White, 2000) has been vital. The current support of the Australian Centre for International Agricultural Research for development of Rainman version 4 with international data is much appreciated.

References

Allan, R.J., 1988. El Nino Southern Oscillation influences in the Australasian region. Prog. Physical Geograpghy 12: 4-40.

Allan, R.J. and Pariwono, J.I., 1990. Ocean-atmosphere interactions in low-latitude Australasia. Int. Journal of Climatology 10:145-178.

Allan, Rob, Lindsay, J. and Parker, D., 1996. El Nino Southern Oscillation and Climate Variability, Australia: CSIRO.

Allan, R.J., Beard, G., Close, A., Herczeg A.L., Jones, P.D. and Simpson, H.J., 1996. Mean sea level pressure indices of the El Nino-Southern Oscillation: relevance to stream discharge in south-eastern Australia. CSIRO Division of Water Resources Report 96(1).

ANTA, 2000. Developing climate risk management strategies. AG5215 BM Agriculture and Horticulture Vocational Training Package, Canberra: ANTA (Australian National Training Authority).

Armstrong, J.S. (ed), 2001. Principles of Forecasting: A handbook for researchers and practitioners. Kluwer Academic.

Ash, A., O'Reagain, P, McKeon, G.M. and Stafford-Smith, M., 2000. Managing climate variability in grazing enterprises: A case study of Dalrymple Shire, North Eastern Australia. *In* G.L. Hammer, N. Nicholls and C. Mitchell (eds.) Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems – the Australian Experience, The Netherlands: Kluwer Academic.

Bayley, D., 2000. Weather and Climate in Farming: Managing risk for profit. State of New South Wales, NSW Agriculture.

Brouwer, D. and George, D., 1995. Climate and Your Farm. New South Wales Agriculture Home Study Program, New South Wales Agriculture.

Buckley, D., 2000. Climate Risk – Forecasts help farmers to minimise losses. Farming Ahead Journal, Kondinin, September, 2000.

Carberry, P., Hammer, G.L., Meinke, H. and Bange, M., 2000. The potential value of seasonal climate forecasting in managing cropping systems. *In* G.L. Hammer, N. Nicholls and C. Mitchell (eds). Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems – the Australian Experience, The Netherlands: Kluwer Academic.

Clark, A.T. and Brinkley, T., 2001. Risk Management: for Climate Agriculture and Policy, Commonwealth of Australia: Bureau of Rural Sciences.

Clarkson, N.M. and Owens, D.T., 1991. RAINMAN - Rainfall Information for Better Management, Brisbane: Queensland Department of Primary Industries, (PC software on disk).

Clarkson, N.M., Clewett, J.F. and Owens, D.T., 2001. STREAMFLOW: a supplement to Australian Rainman to improve management of climatic impacts on water resources, Toowoomba: Queensland Government, Department of Primary Industries, (a PC software package on CD ROM).

Clarkson, N.M., Owens, D.T., James, R.A. and Chiew, F.H.S., 2000. Seasonal streamflow forecasts to improve management of water resources 3. Issues in assembling an adequate set of Australian historical streamflow data for forecasting. Proceedings of the 26th National and 3rd International Hydrology and Water Resources Symposium of The Institution of Engineers, 20-23 November 2000, Perth, Australia.

Clemen, R.T., Murphy, A.H. and Winkler, R.L., 1995. Screening probability forecasts: contrasts between choosing and combining. International Journal of Forecasting 11:133-146.

Clewett, J.F., Taylor, W.J., McKeon, G.M., Neal, J.A., Howden, S.M., Young, P.D., Rickert, K.G. and Wilson, R., 1988a. BEEFMAN: Computer systems for evaluating management options for beef cattle in northern Australia. Proceedings Australian Society Animal Production 17:367.

Clewett, J.F., Young, P.D. and Willcocks, J.R., 1989. Effect of climate change on agriculture in central Queensland: rainfall variability analysis. *In* E.R. Anderson (ed.). The changing climate and central Queensland Agriculture, Rockhampton: Australian Institute of Agricultural Science.

Clewett, J.F., Cavaye, J.M., McKeon, G.M., Partridge, I.J. and Scanlan, J.C., 1991a. Decision support software as an aid to managing pasture. Tropical Grasslands 25: 159-164.

Clewett, J.F., Howden, S.M., McKeon, G.M. and Rose, C.W., 1991b. Optimising farm dam irrigation in response to climatic risk. *In* R.C. Muchow and J.A. Bellamy (eds.) Climatic Risk in Crop Production: Models and Management for the Semi-arid Tropics and Subtropics, Wallingford, U.K.: CAB International.

Clewett, J.F., Clarkson, N.M., Owens, D.T. and Partridge, I.J., 1993. Rainman: Using El Nina and Australia's rainfall history for better management today. *In* S. Field (ed.), Harnessing Information for a Smarter Agriculture, Proceedings of the Australian Institute of Agricultural Science National Conference, Launceston, September 1992.

Clewett, J.F., Clarkson, N.M, Owens, D.T. and Abrecht, D.G., 1994. Australian Rainman: Rainfall Information for Better Management, Brisbane: Department of Primary Industries (PC software on disk).

Clewett, J.F., 1995a. Australian Rainman: A computer package for better decision-making. Proceedings of International Conference "Tropical Oceans Global Atmosphere", Melbourne: Bureau of Meteorology.

Clewett, J.F., 1995b. Review of Climate Prediction Tools. Proceedings from Rainman review workshop, National Climate Centre, Melbourne, 18-19 March 1993. *In* Final report on Project DAQ 141A "Rainman: Rainfall Information for Rural Communities" to Rural Industries Research and Development Corporation, 26 April 1995, Brisbane: Qld Dept Primary Industries.

Clewett, J.F., Clarkson, N.M., Partridge, I.J., and Abrecht, D.G., 1996. Australian Rainman: Progress and Prospects. *In* Proceedings of Managing with Climatic Variability Conference '*Of droughts and flooding rains*', 16-17 November 1995. Land and Water Resources Research and Development Corporation, Canberra. Occasional Paper CN03/96.

Clewett, J.F., Smith, P.G., Partridge, I.J., George, D.A. and Peacock, A., 1999. Australian Rainman Version 3: An integrated software package of Rainfall Information for Better Management, QI98071, Queensland: Department of Primary Industries (PC software on CD).

Clewett, J.F., Clarkson N.M. and Chiew, F.H.S., 2000a. Seasonal streamflow forecasts to improve management of water resources 2. Impact of climate variability and ENSO on streamflow and runoff in Australia. Proceedings of the 26th National and 3rd International Hydrology and Water Resources Symposium of the Institution of Engineers, 20-23 November 2000, Perth, Australia.

Clewett, J., George, D., Cliffe, J., Drosdowsky, W., O'Sullivan, D., Paull, C., Partridge, I., and Saal, R., 2000b. Building Knowledge and Skills to use Seasonal Climate Forecasts in Property Management Planning. *In* G.L. Hammer, N. Nicholls and C. Mitchell. (eds.) Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems – the Australian Experience", The Netherlands: Kluwer Academic.

Clewett, J.F., Thompson, P.J.M., George, D.A., Owens D.T., and Clarkson. N.M., 2000c. Seasonal streamflow forecasts to improve management of water resources: 4. Communicating results to improve knowledge and skills of clients in Australia. Proceedings of the 26th National and 3rd International Hydrology and Water Resources Symposium of the Institution of Engineers, 20-23 November 2000, Perth, Australia.

Cobon, D., and Clewett, J.F., 1999. DroughtPlan CD: a compilation of software packages, workshops, case studies and reports to assist management of climate variability in pastoral areas of northern Australia. Information Series QI99002, Brisbane: Queensland Department of Primary Industries.

Conover, W.J., 1971. Practical Non-Parametric Statistics. John Wiley and Sons.

Coughlan, M., 1989. *In*. E.R. Anderson (ed.) The changing climate and central Queensland Agriculture, Rockhampton: Australian Institute of Agricultural Science,

Coventry, W., 2001. Climate variability and farmers risk assessments and decision making. Post-graduate thesis, School of Psychology, University of Queensland

Drosdowsky, W., 1993a. An analysis of Australian seasonal rainfall anomalies: 1950-1987. I: Spatial patterns. Int. Journal Climatology

Drosdowsky, W., 1993b. An analysis of Australian seasonal rainfall anomalies 1950-1987. II: Temporal variability and teleconnection patterns. Int Journal Climatology 13:111-149.

Drosdowsky, W., 1993c. Potential predictability of winter rainfall over southern and eastern Australia using Indian Ocean sea-surface temperature anomalies. Aust Meteorologgy Magazine 42:1-6.

Drosdowsky, W., 1996. Variability of the Australian summer monsoon at Darwin: 1957-1992. Journal of Climate 9:85-96

Drosdowsky, W. and Williams, M., 1991. The southern oscillation in the Australian region. Part I: Anomalies at the extremes of the oscillation. Journal of Climate 4:619-638.

Drosdowsky, W., 2002. SST Phases and Australian Rainfall. Aust. Met. Mag. 51(1): 1-12.

Drosdowsky, W. and Allan, R., 2000. The potential for improved statistical seasonal climate forecasts. *In* G.L. Hammer, N. Nicholls and C. Mitchell (eds.) Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems – the Australian Experience, The Netherlands: Kluwer Academic.

Drosdowsky, W. and Chambers, L.E., 2001. Near-global sea surface temperature anomalies as predictors of Australian seasonal rainfall. Journal of Climate 14:1677-1687.

Evans, J.L. and Allan, R.J., 1992. El Nino/Southern O scillation modification to the structure of the monsoon and tropical cyclone activity in the Australasian region. Int. Journal of Climatology 12:611-623.

Everingham, Y.L., Muchow, R.C., Stone, R.C., Inman-Bamber, N.G., Singels, A. and Bezuidenhout, C.N., 2002. Enhanced risk management and decision-making capability across the sugarcane industry value chain based on seasonal climate forecasts. Agricultural Systems 74(3):459-477.

George, D.A., and Brouwer, D., 1999. Tutorials. *In* J.F. Clewett, P.G. Smith, I.J. Partridge, D.A. George, and A. Peacock, 1999. Australian Rainman Version 3: An integrated software package of Rainfall Information for Better Management, Brisbane: Queensland Department of Primary Industries.

George, D., Cobon, D., and Bayley, D., 1999. Developing Climate Education and Agriculture in Australia: Australian “Rainman”, “DroughtPlan”, and other educational resources. International Conference “Education: Weather, Ocean, Climate”, Aust. Met. and Oceanographic Society, 5 –9 July, 1999, Ballarat and Melbourne, Australia.

George, D., Clewett, J.F., McBride, J., Balusubramanian, T.N., Huda, A.K.S., Geethalakshmi, V., Selvaraju, R. and Mavi, H., 2000. Seasonal climate and weather forecasting: agricultural applications. *In* Managing Natural Resources for Sustainable Agricultural Production in the 21st Century, International. Conf. Proc., 14-18 Feb 2000, New Delhi: Indian Council of Agricultural Research.

George, D.A. and Selvaraju, R.N., 2002. Building knowledge and skills to apply seasonal climate forecasts in agriculture. *In* Applying seasonal climate forecasts in agriculture. Conference Proceedings, Tamil Nadu Agricultural University, India, 24-26 September 2002 (in press).

Halpert, M.S. and Ropelewski, C.F., 1992. Surface Temperature Patterns Associated with the Southern Oscillation. Journal of Climate 5:577-593.

Hammer, G.L. and Muchow, R., 1991a. Quantifying climatic risk to sorghum in Australia’s semi-arid tropics and sub-tropics: model development and simulation. *In* R.C. Muchow and J.A. Bellamy (eds.) Climatic Risk in Crop Production: Models and Management for the Semi-arid Tropics and Subtropics’, Wallingford, U.K.: CAB International.

Hammer. G.L., McKeon, G.M., Clewett, J.F. and Woodruff, D.R., 1991b. Usefulness of seasonal climate forecasts in crop and pasture management. Proceedings of First Australian Conference on Agricultural Meteorology, Bureau of Meteorology, Melbourne. .

Hammer, G.L., Holzworth, D.P. and Stone, R.C., 1996. The value of skill in seasonal climate forecasting to wheat crop management in a region with high climatic variability. Aust. Journal of Agricultural Research 47: 717-737.

Hammer, G.L., 2000. Applying seasonal climate forecasts in agricultural and natural ecosystems – a synthesis. *In* G.L. Hammer, N. Nicholls and C. Mitchell (eds.) Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems – the Australian Experience, The Netherlands: Kluwer Academic.

Hammer, G.L., Nicholls, N. and Mitchell, C. (eds), 2000. Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems – the Australian Experience, The Netherlands: Kluwer Academic.

Hammer, G.L., Hansen, J.W., Phillips, J.G., Mjelde, J.W., Hill, H., Love, A., and Potgieter, A., 2001. Advances in application of climate prediction in agriculture. Agric Systems 70:515-553.

Hartmann, H.C., Pagano, T.C., Sorooshian, S. and Bales, R., 2002. Confidence Builders: Evaluating Seasonal Climate Forecasts from User Perspectives. Bulletin of the American Meteorological Society. 83(5):683–698.

Hastings, P.A., 1990. Southern Oscillation Influences on Tropical Cyclone Activity in the Australian/South West Pacific Region. Int. Journal of Climatology 10: 291-298.

Haylock M. and McBride, J., 2001. Spatial coherence and predictability of Indonesian wet season rainfall. Journal of Climate 14:3882-3887.

Ludwig, J.A., Clewett, J.F. and Foran, B.D., 1993. Meeting the needs of decision support software users: Australian rangelands. *In* J.W. Stuth, and B.G. Lyons (eds.). Emerging Issues for Decision Support Systems for Management of Grazing Lands, Paris: Parthenon Publishing Group.

McBride, J.L. and Nicholls, N., 1983. Seasonal relationships between Australian rainfall and the Southern Oscillation. Monthly Weather Review 111:1998-2004.

McKeon, G.M. Rickert, K.G. and Scattini, W.J., 1986. Tropical pastures in the farming system: case studies of modelling integration through simulation. Proceedings of the Third Australian Conference on Tropical Pastures, Occasional Publication No. 3. Tropical Grassland Soc. of Australia.

McKeon, G.M., Day, K.A., Howden, S.M., Mott, J.J., Orr, D.M., Scattini, W.J. and Weston, E.J., 1990. Northern Australian savannas: management for pastoral production. Journal Biogeog. 17: 355-72.

Mielke, P.W., K. J. Berry, C. W. Landsea and W. M. Gray, 1996. Artificial skill and validation in meteorological forecasting. Weather Forecasting 11:153-169.

Mitchell, W.M, 1994. Using mean sea level anomalies as an indicator of regional climate variability. Agr. Sys. Info. Tech. 6:19-21.

NCC, 1991. Seasonal Climate Outlook Service: what it is and how to use it. National Climate Centre, Bureau of Meteorology.

Nelson, R.A., Holzworth, D.P., Hammer, G.L. and Hayman, P.T., 2002. Infusing the use of seasonal climate forecasting into crop management practice in North East Australia using discussion support software, Agric. Systems (submitted Dec 2001).

Nicholls, N., 1984a. The Southern Oscillation and Indonesian sea surface temperature. Monthly Weather Review 112:424-432.

Nicholls, N., 1984b. The Southern Oscillation, sea-surface-temperature, and inter-annual fluctuations in Australian tropical cyclone activity. Journal Climatology 4:661-670.

Nicholls, N., 1984c. A system for predicting the onset of the north Australian wet-season. Journal Climatology 4:425.

Nicholls, N., 1985. Impact of the Southern Oscillation on Australian crops. Journal Climatology 5:553-560.

Nicholls, N., 1986. Use of the Southern Oscillation to predict Australian Sorghum yield. Agricultural and Forest Meteorology 38:9-15.

Nicholls, N., 1989. Sea surface temperature and Australian winter rainfall. Journal Climatology 2:965-973.

Nicholls, N., 1991. Advances in long-term weather forecasting. *In* R.C. Muchow, and J.A. Bellamy (eds.) Climate risk in crop production: models and management for the semiarid tropics and subtropics. CAB International.

Nicholls, N., 1992. Recent performance of a method for forecasting Australian seasonal tropical cyclone activity. Australian Meteorological Magazine 40:105-110.

Nicholls, N., 1995. All-India summer monsoon rainfall and seas surface temperatures around northern Australian and Indonesia. Journal of Climate 8:1463-1467.

Nicholls, N., 1999. Cognitive illusions, heuristics, and climate prediction. Bulletin of the American Meteorological Society 80:1385-1397.

Nicholls, N., 2001. Commentary and analysis: the insignificance of significance testing. Bulletin of the American Meteorological Society 81:981-986.

Nicholls, N. and Kariko, A., 1993. East Australian Rainfall Events: International Variations, Trends, and Relationships with the Southern Oscillation. Journal of Climate 6:1141-1152.

Owens, D.T., Clarkson, N.M. and Flood, N., 1996. Development of a long-term Daily and Monthly Rainfall Collection for Australia. *In* The Impact of Weather and Climate on Agriculture Proceedings of the Second Australian Conference on Agricultural Meteorology, University of Queensland, Brisbane, 1-4 October 1996.

Park, J.N., Cobon, D.H. and Crabb, D.M., 2001. Integrating climate forecasts and geospatial systems to enhance grazing management in northern Australia. *In* Proceedings of Geospatial Conference, Sydney.

Park, J.N., Cobon D.H., Simpson G.B. and Clewett, J.F., 2002. The utility of forecasting summer rainfall and modelled pasture growth in the Mitchell grasslands of western Queensland. Proceedings of Australian Rangelands Society Conference, Kalgoolie, September 2002.

Partridge, I.J. (ed.), 1991. Will It Rain?: El Nino and the Southern Oscillation. Queensland Department of Primary Industries, Brisbane, Information Series QI91028.

Partridge, I.J. (ed.), 1994. Will It Rain? The effects of the Southern Oscillation and El Nino on Australia. Second Edition, Department of Primary Industries Queensland, Brisbane, Information Series QI94015.

Partridge, I. J. and Mansur Ma'shum, 2002a. Will it rain?: The effect of the Southern Oscillation and El Nino in Indonesia, Brisbane: Department of Primary Industries.

Partridge, I. J. and Mansur Ma'shum, 2002b. Kapan hujan turun? Dampak Osilasi Selatan dan El Nino di Indonesia, Brisbane: Department of Primary Industries.

Potts, J.M., Folland, C.K., Jolliffe, I.T. and Sexton, D., 1996. Revised "LEPS" scores for assessing climate model simulations and long-range forecasts. Journal of Climate 9:34-53.

Power, S., Wright, W. and Della Marta, P. (eds.), 2001. Cli-Manage 2000 - Conference on Managing Australian Climate Variability - Climate Variability in Agriculture National Conference Proceedings, 23-25 October 2000, National Climate Centre, Bureau of Meteorology, Melbourne.

Robinson, S. and Abrecht, D., 1993. TACT User Manual. A seasonal wheat sowing decision aid. Program version number 2.0. Western Australian Department of Agriculture.

Ropelewski, C.F. and Halpert, M.S., 1987. Global and regional scale precipitation patterns associated with the El Nino/Southern Oscillation. Monthly Weather Review 115:1606-1626.

Ropelewski, C.F. and Halpert, M.S., 1989. Precipitation patterns associated with the high index phase of the Southern Oscillation. Journal Climatology 2:268-284.

Scanlan, J.C. and McKeon, G.M., 1990. GRASSMAN: a computer program for managing native pastures in eucalypt woodlands, v. 1.0. Queensland Department of Primary Industries, Brisbane.

Simmonds, I. and Hope, P., 1997. Persistence characteristics of Australian rainfall anomalies. Int. Journal of Climatology 17:597-613

Stone, R.C. and de Hoedt, G., 2000. The development and delivery of current seasonal climate forecasting capabilities in Australia. *In* G.L. Hammer, N. Nicholls and C. Mitchell (eds.) Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems – the Australian Experience, The Netherlands: Kluwer Academic.

Stone, R.C. and Auliciems, A., 1992. SOI phase relationships with rainfall in eastern Australia. International Journal of Climatology 12:625-636.

Stone, R.C., Hammer, G.L. and Marcussen, T., 1996. Prediction of global rainfall probabilities using phases of the southern oscillation index. Nature 384:1896-1909.

Stafford-Smith, M., Clewett, J.F., Moore, A.D., McKeon, G.M. and Clark, R., 1998. DroughtPlan – building on grazier participation to manage climate variability. Land and Water Resources Research and Development Corporation, Canberra. Occasional Paper CV01/97, Canberra.

Stuth, J.W. and Lyons, B.G. (eds.), 1993. Decision Support Systems for the Management of Grazing Lands. Man and the Biosphere Series 11, Paris: The Parthenon Publishing Group.

Tashman, L.J., 2000. Out-of-sample tests of forecasting accuracy: an analysis and review. Int Journal of Forecasting 16:437-450.

Troup, A.J., 1965. The Southern Oscillation. Quart. Journal of the Royal Meteorology Society 91:490-506.

Ward, M.N. and Folland, C.K., 1990. Prediction of seasonal rainfall in the north nodeste of Brazil using eigenvectors of sea-surface temperature. International Journal of Climatology 11:711-743.

White, B.J., 2000. The importance of climate variability and seasonal forecasting to the Australian economy. *In* G.L. Hammer, N. Nicholls and C. Mitchell (eds) Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems – the Australian Experience, The Netherlands: Kluwer Academic.

White, B.J. and Stynes, B., 1996. In panel discussion of R&D priorities, Proceedings of Managing with Climatic Variability Conference 'Of droughts and flooding rains', 16-17 November 1995. Land and Water Resources Research and Development Corporation, Canberra. Occasional Paper CN03/96.

Wilks, D.S., 1996. Statistical methods in the atmospheric sciences. International Geophysics Series 59. Academic Press.

Willcocks, J.R. and Lloyd, P.L., 1988. The QDPI's Climate Data Bank. *In* Australia's Rangelands'. Australian Rangeland Society Conference Proceedings, Longreach, June 1988.

Woodruff, D.R., 1992. Wheatman a decision support system for wheat management in subtropical Australia. Aust. Journal Agric. Res. 43:1483-1499.