Agricultural climate research and services in Australia

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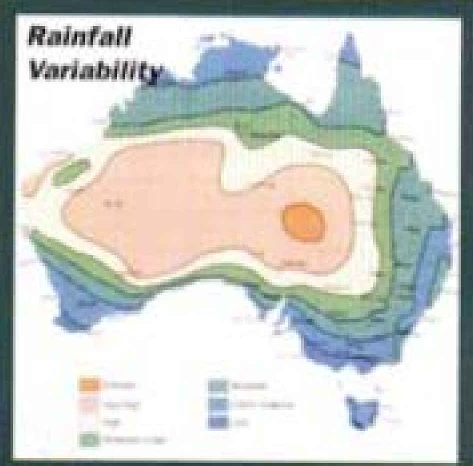

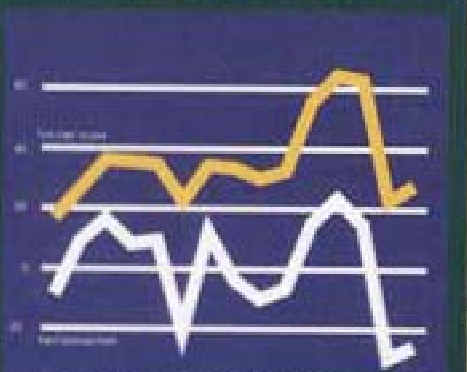

Climate Variability Series

CVAP

Climate Variability in Agriculture R&D Program

Agricultural climate research and services in Australia

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Contents

Acronyms and Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACIAR	Australian Centre for International Agricultural Research
ACRES	Australian Centre for Remote Sensing
ACT	Australian Capital Territory
ADAM	Australian Data Archive for Meteorology
AGCM	Atmospheric general circulation model
AFFA	Agriculture, Fisheries and Forestry—Australia
AgWA	Agriculture Western Australia
ANU	Australian National University
APSIM	Agricultural Production Systems Simulator
APSRU	Agricultural Production Systems Research Unit
AQIS	Australian Quarantine and Inspection Service
ARC	Australian Research Council
ASIT	Agro-ecological Systems and Information Technology
Aussie GRASS	Australian Grassland and Rangeland Assessment by Spatial Simulation
AVHRR	Advanced Very High Resolution Radiometer
AWRAPO	Australian Wool Research and Promotion Organisation
AWS	Agricultural Weather Services
BAM	Bureau of Meteorology Atmospheric Model
BMRC	Bureau of Meteorology Research Centre
BoM	Bureau of Meteorology
BRS	Bureau of Rural Sciences (formerly Bureau of Resource Sciences)
CCISR	Centre for Catchment and In-stream Research, Griffith University
CLIMARC	Climate Archives
CMR	CSIRO Marine Research
COARE	Coupled Ocean–Atmosphere Response Experiment
CRC	Cooperative Research Centre
CRES	Centre for Resource & Environmental Studies
CRYIS	Climate Risk and Yield Information Service
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVAP	Climate Variability in Agriculture Program
DAR	CSIRO Atmospheric Research
DAWA	Department of Agriculture, Western Australia (AgWA)
DCV	Decadal climate variability
DEC	Drought exceptional circumstances
DEST	Department of Environment, Sport and Territories
DISR	Department of Industry, Science and Resources
DNR	Queensland Department of Natural Resources
DLP	Drought Landcare Program
DLWC	Department of Land and Water Conservation, NSW
DPI	Queensland Department of Primary Industries
DPIE	Commonwealth Department of Primary Industries and Energy
DRDC	Dairy Research and Development Corporation
DSS	Decision support system
EA	Environment Australia
EC	Exceptional Circumstances
ENSO	El Niño–Southern Oscillation
EOC	Earth Observation Centre (CSIRO)
ERIN	Environmental Resources Information Network
ET	Evapotranspiration
Fax	Facsimile
FMD	Foot-and-mouth disease
GCM	General (global) circulation model
GIS	Geographic information system
GMS	Geostationary Meteorological Satellite

GRASP	GRASs Production
GRDC	Grains Research and Development Corporation
GSR	Growing Season Rainfall
HI	Harvest Index
IPM	Integrated Pest Management
IRI	International Research Institute
IWS	International Wool Secretariat
JE	Japanese encephalitis
LAI	Leaf Area Index
LWRRDC	Land and Water Resources Research and Development Corporation
MLA	Meat and Livestock Australia
MRC	Meat Research Corporation
MSS	Multi-spectral scanner
MIDAS	Model of an Integrated Dryland Agricultural System
MUDAS	Model of an Uncertain Dryland Agricultural System
NAB	National Australia Bank Ltd
NCC	National Climate Centre
NCEP	National Centres for Environmental Prediction at NOAA
NCVP	National Climate Variability Program
NDTI	Normalised Difference Temperature Index
NDVI	Normalised Difference Vegetation Index
NFF	National Farmers Federation
NHT	Natural Heritage Trust
NIR	Near-infrared
NLP	National Landcare Program
NOAA	National Oceanic and Atmospheric Administration (USA)
NSW	New South Wales
NT	Northern Territory
NZ	New Zealand
NWCB	Northwest Cloudbands
PIRSA	Primary Industries and Resources South Australia
PMP	Property Management Planning
PYCAL	Potential Yield Calculator
QCCA	Queensland Centre for Climate Applications
QDPI	Queensland Department of Primary Industries
QDNR	Queensland Department of Natural Resources
Qld	Queensland
R&D	Research and development
RAFCOR	Rural Adjustment Finance Corporation
RASAC	Rural Adjustment Scheme Advisory Council
RCM	Regional Climate Models
RIRDC	Rural Industries Research and Development Corporation
SA	South Australia
SARDI	South Australian Research and Development Institute
SCARM	Standing Committee on Agriculture and Resource Management
SILO	Special Information for Land Owners
SLUIS	Sustainable Land Use Information System
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
SWF	Screwworm fly
T	Temperature
TACT	Tactical decision aid
TAFE	Technical and Further Education
TAS	Tasmania
TM	Thematic Mapper
TOGA COARE	Tropical Ocean–Global Atmosphere Coupled Ocean–Atmosphere Response Experiment
UCSD	University of California, San Diego
UNE	University of New England
UNSW	University of New South Wales
UQ	University of Queensland
USA	United States of America
UWA	University of Western Australia
WA	Western Australia
WRI	Weighted Rainfall Index
WUE	Water Use Efficiency

Introduction

The aim of this publication is to provide a contemporary reference to Australia's research, development, education and extension activities in climate variability in relation to agriculture. This is to increase the awareness of scientific groups, and the general public, to work in this area, enabling a better appreciation of what is being done, and to improve the prioritisation, targeting and integration of the various research, development and service activities.

National overview—climate and agriculture

Australia is an island continent with ancient, fragile soils and a predominantly arid climate. Rainfall above 600 mm per annum is confined to the northern, eastern and south-eastern coastal regions and the south-western tip. The south is characterised by a Mediterranean-type climate with cold, wet winters and hot, dry summers. Annual pastures in the south usually germinate between March and May in response to autumn rains, growth being most active in spring before senescence in October to November. The north experiences a monsoonal climate, most of the rainfall occurring in late summer–autumn.

There is substantial variability in the rainfall between years, this variability increasing in general with distance inland from the coast. With climate variability there is inevitably drought. Australia therefore has the reputation of being a land of droughts and flooding rains.

Agriculture in Australia is predominantly extensive. In the limited area where high rainfall occurs, above 800 mm a year, agriculture in southern and eastern Australia is characterised by dairy and beef cattle, horticulture, and prime lamb production. Most wheat production, in association with sheep, is located in the south-east and south-west, between the 300 and 600 mm annual rainfall isohyets, though wheat production further north moves to higher rainfall areas. The balance of Australia's wool and beef production takes place in the pastoral zone, most of which has considerably less than 600 mm rainfall a year. A large part of the centre of Australia is desert or very arid rangelands that in most years are able to support relatively few grazing animals.

The Climate Variability in Agriculture Research and Development (R&D) Program (CVAP), funded primarily by the Commonwealth Government, together with contributions from several R&D Corporations and managed by the Land and Water Resources Research and Development Corporation (LWRRDC), has its basis in the National Drought Policy (NDP). CVAP evolved from the former National Climate Variability R&D Program (NCVP). The NDP was developed to encourage primary producers and other sections of rural Australia to adopt self-reliant approaches to managing for climatic variability, to maintain and protect Australia's agricultural and environmental resource base during periods of extreme climate stress, and to ensure early recovery of agricultural and rural industries, consistent with long-term sustainable industries (White *et al.* 1993; O'Meagher *et al.* 1998, in press).

The National Drought Policy therefore sees climate variability and drought as part of the Australian environment. The policy recognises that drought is only one of several sources of uncertainty affecting farm businesses and is part of a farmer's normal operating environment. However, its effects can be minimised through good management practices. The main focus is on farm management that takes into account the risks associated with a variable climate and adheres to the principles of sustainable agriculture. Commonwealth and State initiatives to encourage Property Management Planning are consistent with this approach.

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Climate and agriculture in the States and Territories

WESTERN AUSTRALIA

Western Australia spans a latitude band from about 14 to 35 degrees south and covers an area of some 2.5 million sq km. Latitude, distance from the sea, and local topography largely shape the State's wide range of climates, with different rain-producing systems important in different parts. In the winter rainfall belt near the south-west corner, and also in the monsoonal north-west Kimberley, there are areas that average over 1,400 mm of rain per year. In between, a large area averages less than 250 mm of annual rainfall.

The Kimberley wet season extends on average from late December to March. The monsoon is marked by alternating active and 'break' periods, related in part to the Intraseasonal Oscillation or 30–60 day wave, which, however, affords very limited predictability. In the transition period of about three months prior to the wet season there is gradually increasing rainfall, mostly related to thunderstorms that develop inland diurnally. Seasonal rainfall predictability based on lagged correlations with the Southern Oscillation Index (SOI) is strongest in spring but mostly poor for the peak summer months. The SOI and its interannual changes are used to predict features of the WA tropical cyclone season, relating mostly to spring and autumn cyclone activity (not just for the Kimberley).

In the broad arid zone stretching approximately WNW to ESE across central WA, and also extending into less arid areas in the south-west Kimberley and the wheatbelt, a major contribution to the annual rainfall comes from Northwest Cloudbands (NWCBs). NWCB activity peaks in late autumn and early winter, May being wetter than April over most of the area. Diurnal thunderstorm activity contributes much of the area's summer rainfall, though individual tropical cyclones have been known to generate daily totals in excess of the annual mean. There are significant lagged relationships, at least over parts of the area, with Indian Ocean Sea Surface Temperature (SST) patterns as indicated by the Indian Ocean Index of Drosdowsky (1993). The correlations have opposite signs in summer and winter. Seasonal predictability based on the SOI is mainly poor, though less so for summer rainfall in the north and west Pilbara.

Towards the south-west corner, the relative influence of NWCBs decreases as cold fronts and other mid-latitudinal disturbances become predominant. Even so, a significant proportion of annual rainfall involves tropical interactions, particularly in the form of rainbands as tropical air is steered southward and lifted in advance of cold fronts in the westerlies. Over most of the south-west the rainfall peaks in June on average, with the westerlies at their farthest northward extent. The wettest six months are generally May to October, yielding over 80% of the annual total over a wide area. In the north and north-east wheatbelt, however, the wettest period is earlier, Bencubbin's wettest six months being March to August. Weak but significant simultaneous correlations exist between the SOI and rainfall over south-west WA, while the SOI change from one winter to the next is significantly related to the May to October rainfall in the second year. However, seasonal predictability based on SOI lagged correlations is considerably weaker than for much of Australia and is especially limited for winter rainfall. It is strongest for autumn rain, but does not permit an accurate forecast of the date of the agriculturally important 'break of season', usually in April or May. Indian Ocean SST patterns allow some limited predictability of the rainfall, mainly for spring and summer.

In general, the seasons of maximum predictability vary according to how the predictors are used. SOI phases and trends over various periods have been shown in many cases to provide better predictive skill than simple lagged SOI-rainfall correlations. Additional skill has also been demonstrated by methods involving a combination of predictors, and particularly using SST anomaly patterns covering the Pacific and Indian Oceans. These latter patterns also allow useful predictability of seasonal temperatures.

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SOUTH AUSTRALIA

The climate of South Australia varies from hot and dry in the interior to the milder and wetter climates of the southern Mount Lofty Ranges and the south-east coast of South Australia. Median annual rainfall ranges from about 100 mm in the area east of Lake Eyre to more than 1,000 mm on the higher parts of the Mount Lofty ranges.

During the warmer half of the year (November to April), high pressure systems (anticyclones) generally move eastward south of the Great Australian Bight. Consequently, the most frequent air stream across most of South Australia during this period is from the south-east to east. Most cold fronts during this period fail to produce much useful rain. Warm moist air occasionally moves south from the tropics during summer, and thunderstorms may develop.

During the colder half of the year (May to October) the anticyclones tend to be centred over the Great Victoria Desert and central New South Wales. The most frequent winds are from the north-west to south-west. Frontal systems associated with depressions travelling eastwards travelling across the ocean have a significant influence on the weather in southern Australia during this season.

Annual field crop production is restricted to southern districts of the State where median annual rainfall exceeds 275–300 mm, and extends up to about 550–600 mm annual rainfall. These winter crops depend almost entirely on incident rainfall received from April to October, although on some soils there is the opportunity to store limited subsoil moisture from the previous year or from heavy rain events in the summer–autumn preceding the crop.

North of the wheatbelt, annual rainfall is too low and erratic to support annual crop or pasture production. Extensive livestock grazing (sheep and cattle) is the major agricultural pursuit on these semi-arid to arid rangelands.

In the southernmost districts of the State, and in the higher regions of the Mount Lofty Ranges, rainfall is either excessive (more than 550–600 mm) and/or the topography not suited to annual cropping. Agricultural activity in these regions includes extensive livestock grazing of improved annual/perennial pastures for sheep, beef and dairy production, and intensive horticulture (annual vegetable crops, perennial tree and vine crops).

Yields of annual field crops (winter cereals, pulses and oilseeds) and pastures are largely determined by total April to October rainfall, although the distribution of this rainfall through the growing season can also influence the efficiency with which it is utilised for crop and pasture production. Timing of the autumn break (ie. the first significant rainfall event which causes germination of winter crop, pasture and weed species) is a critical factor in determining length of growing season and hence yield. This generally occurs in May or June, but can vary greatly between years. An early break to the season (April or earlier) provides an opportunity for above average yields and the sowing of longer growing season crops, especially in lower rainfall districts. But an early break has a risk of being a false break, ie. where sufficient rain falls to stimulate germination early in the season, but the delay to follow-up rains results in severe moisture stress and plant death. A late break (July or later) means a greater risk of low yields or even total crop failure, unless spring conditions are sufficiently favourable to compensate. Optimum time of sowing for wheat is generally accepted to be early to mid-May in low rainfall districts, ranging to late May to mid-June in higher rainfall districts where favourable spring conditions are more assured. The risk of frost damage to crops in spring in some districts causes crop sowing to be deliberately delayed to reduce the likelihood of frost at the critical crop flowering period.

The high potential for wind erosion on the lighter mallee soils of much of the State's lower rainfall districts poses an additional risk in the wheatbelt. Seasonal climatic conditions that can accentuate this risk include low rainfall/poor crop and pasture production in the previous year resulting in low residual soil cover, false breaks that promote crop sowing but subsequent poor growth or crop death, late breaks that provide little or no new season growth for soil cover, and extreme wind events with extended periods of high velocity/low humidity winds (generally from the north and north-west, preceding cold fronts, from May through to July).

Research, extension and regulatory programs conducted within Primary Industries and Resources SA (PIRSA) seek to ensure sustainable management of the State's natural resources for profitable agricultural production. This is being achieved through, *inter alia*, the development and promotion of farming practices and farming systems to minimise seasonal climate risks to agriculture and to capitalise on the opportunities presented by favourable seasonal conditions. Training and skills development programs to improve self-reliance in the agricultural sector through the ability to manage all manner of risks, including those presented by seasonal climate variability, are a priority within PIRSA. These include Property Management Planning and TOPCROP. There is also concern about a declining rainfall trend in recent years, particularly over the southern part of the State, this being explored through the Indian Ocean Climate Initiative with the Bureau of Meteorology, CSIRO and the Western Australia government. Where extreme climatic events do result in major loss, damage or disruption in the State's agricultural industries, PIRSA provides advice and support to the State Minister in assessing and presenting the case for Federal Government assistance under the Exceptional Circumstances provisions, and in managing the disbursement of any such funds provided.

VICTORIA

The climate of Victoria is characterised by a range of different climate zones, from the hot, dry Mallee region of the north-west to the alpine snowfields in the north-east of Victoria. To the west and north of the Great Divide the land flattens out to the dry inland plains. It is in the Mallee where the hottest temperatures in the State most commonly occur during summer, and where the annual median rainfall drops below 250 mm.

The climate changes across the State are reflected by marked changes in vegetation. Vegetation ranges from the mallee scrub country in the north-west, through irrigated plains in the Northern Country and the wetter grazing lands of the south to the forested mountainous country of eastern Victoria and the winter snow-covered alpine regions in the north-east.

North of the Great Divide there is not only a marked decline in mean annual rainfall, but also a marked increase in the variability of the amount of rainfall from year to year. It is a winter rainfall or quasi-Mediterranean environment with typically dry summers. In the north of the State autumn rains that initiate the growth of the predominantly annual pastures, either native or typically annual ryegrass and subterranean clover, may occur any time from February to June. Early autumn rains that are not followed up result in the top soil drying out and seedlings dying, leading to a false autumn break. Annual pastures typically dry off in late October and November leaving standing dry feed for the summer.

Many of the farms of the Wimmera, Mallee, northern and north-east Victoria are devoted to both cereal crop and livestock production. The latter is dominated by either Merinos for wool production, or Merino ewes crossed with Border Leicester rams to produce First Cross Ewes as dams for prime lamb production in either the irrigation areas or in the south of the State. The irrigation areas are concentrated along the Murray River, and in the Goulburn Valley near Shepparton and Kyabram. Soil salinity is a major problem in many of the irrigation areas, particularly between Kerang and Swan Hill, and in dryland country where excessive tree clearing has occurred.

The mountains of the Great Divide in Victoria attain a maximum height of 1,986 m at Mt. Bogong near the town of Mt. Beauty. There are several peaks in excess of 1,500 m in the north-east of Victoria. Median annual rainfall ranges in some of the mountainous regions can be in excess of 1,800 mm. The Great Divide extends westwards almost to the South Australian border, with most peaks below 600 m except in the mountainous area called the Grampians, near Stawell, where Mt. William's summit is 1,167 m.

The coastal strip, south of the ranges, is generally wetter except in the far east where the Strezlecki ranges shelter East Gippsland from the moisture laden south-westerly winds. The probability of early autumn and late spring rains is considerably higher than north of the divide. Pastures in the south-west of the State are typically perennial ryegrass and subterranean clover, whereas perennial grasses and white clover dominate in Gippsland. The south-west of the State is dominated by Merinos for wool production, crossbred sheep (e.g Merino x Border Leicester ewes to Dorset Horn rams) for prime lamb production, or cattle. Dairying is more evident in Gippsland.

TASMANIA

Tasmania enjoys for the most part a 'temperate maritime' climate. The sea, never more than 115 km distant, suppresses temperature extremes. The prevailing westerly airstream leads to a marked variation of cloudiness, rainfall and temperature. The result is a west coast and highlands that are cool, wet and cloudy and an east coast and lowlands that are milder, drier and sunnier.

The interaction of airstream and topography is the main factor governing rainfall in Tasmania. Consequently the annual rainfall varies markedly across the State, averaging less than 600 mm in the Midlands but over 3,500 mm in some part of the mountainous west. The highest rainfalls occur in remote, unpopulated regions. In the highlands, above the 900 metre level, snow can occur at any time of the year. Heaviest snowfalls tend to occur in July and August.

There are three main influencing temperature regimes in Tasmania. Proximity to the sea ensures coastal locations will have a milder temperature regime than inland ones. Temperature decreases with altitude (by about 0.7°C for every 100 m), making elevated locations generally cooler than low level ones. Finally, cloudiness in the west (a result of the persistent westerly winds) suppresses daytime temperatures there.

Summers are mild, with any hot periods rarely lasting more than a few days. Rainfall is generally lower (in both amount and frequency) in summer, most notably in the west and north-west. Afternoon sea breezes are common along the coasts.

Winters are not excessively cold, especially compared to places at similar latitudes in the northern hemisphere that do not have the sea's moderating influence. Westerly winds with embedded cold fronts often cross the State, and these can bring cold weather and snow to low levels. Every so often winds will be light, the skies clear and the mornings cold and frosty.

Climate variability tends to be less than most mainland States, but is nevertheless an integral part of agriculture in Tasmania. The Tasmanian government is therefore a signatory to the National Drought Policy, and related policies that aim to improve the business and risk management skills of farm managers, and promote the identification and implementation of sustainable agricultural systems. This includes the FarmWi$e Program, part of the national program on Property Management Planning. Research aimed at meeting these policy objectives is targeted to enhance the management and decision making skills of property managers and their advisers to ensure sustainable agriculture.

NEW SOUTH WALES

New South Wales is entirely in the temperate zone. The climate is generally mild, equable and mostly free from extremes of heat and cold, but very high temperatures occur in the north-west and very cold temperatures on the southern tablelands. The Great Dividing Range, running approximately north to south in the east of New South Wales, has a large impact on the climate, creating four distinct climate zones; the coastal strip, the highlands, the western slopes and the flatter country to the west.

The climate of the coastal strip is influenced by the warm waters of the Tasman Sea, which in general keep the region free from extremes of temperature and provide moisture to increase rainfall, the annual median of which ranges from about 750 mm in the south to 2,000 mm in the north. The mountains of the Great Divide attain a maximum height of 2,228 m at Mt. Kosciuszko, and there are several peaks in excess of 1,500 m, extending up to northern NSW. Travelling from east to west across the range, the elevation abruptly increases away from the coastal plain, and then west of the divide it gradually descends onto the western plains. Consequently, winter snowfalls are experienced over what are aptly called the Tablelands regions.

On the Western Slopes the rainfall gradually decreases, together with the frequency of winter snowfalls. Average maximum temperatures gradually increase as height above sea level decreases. Further to the west the land slowly flattens out to the dry inland plains, marked by cold nights. It is in the far north-west where the hottest temperatures in the state most commonly occur during summer, and where the annual mean rainfall drops below 200 mm.

The way in which the climate changes across the State is reflected by marked changes in vegetation, which ranges from the sub-tropical rainforests of the north-east to the fragile alpine heath lands in the southern Alps, through the dry forests and undulating pasture lands of the Midwest to the dry plains of the north-west. The more arid west is dominated by increased variability in rainfall and native grasslands. Sub-tropical grasses dominate in northern New South Wales, whereas annual pastures and crops are widespread in the wheat-sheep country throughout the centre and south of the State. Perennial pastures are more typical in the higher rainfall areas on the south coast where more dairying occurs.

The recurrence of drought is a common feature of the NSW climate. Numerous droughts have occurred during the 20th century and had devastating effects on the rural economy of the State. The last severe drought occurred in 1982–83 when few farms remained unaffected. The droughts in the State occur because of very high variability of rainfall and very high rates of evaporation and evapotranspiration. The amount of annual evaporation always exceeds the amount of water actually available to be evaporated in most parts of the State. Evaporation is highest in the hot, dry and windy interior and least in the cool and moist south and eastern regions of the State.

The combined impact of seasonal distribution of rainfall, evaporation, temperature and frost is reflected on the land use pattern and length of growing season for crop production. About one third of eastern New South Wales has suitable climatic conditions for crop growing throughout the year. The length of the growing season shortens gradually towards the north-west primarily due to decreasing rainfall. The north-west corner of the State is unsuitable for crop production because of harsh climatic conditions.

Only about 7% of the State is under crops, 6% under sown pastures and 17% under native pastures. Much of the remaining is grazing land having native shrubs. In the coastal and tablelands regions, agricultural land is used for intensive grazing of sheep and cattle. These regions have about half of the sown pastures of the State. Western slopes and plains have three quarters of the State's cropping area and nearly half each of sown and native pastures. In the upper and lower far western plains, most of the land is rough grazing or sparse woodland, useable as extensive and seasonal grazing but unfit for crop production.

Large areas of New South Wales have moderately fertile soils and are characterised by low cost pastures and dryland cropping. These factors give the State a competitive advantage in a variety of food and fibre products. New South Wales represents 10% of the area of the country, but the gross value of its livestock and crop production represents 26% of Australia's gross agricultural production. It produces 30% of the meat, 41% of the wheat, 99% of the rice and 71% of the cotton of Australia.

NSW Agriculture is committed to helping NSW food and fibre industries and rural communities to be economically viable and environmentally sustainable. Improved climate risk management is its major goal. It is developing, demonstrating and promoting best practice systems for soil, water, land resource management and vegetation management in the light of high variability of rainfall. The Department is undertaking risk analysis studies and developing strategies for managing drought, natural disasters and seasonal climate variability. It is promoting improved use of seasonal forecast information, relevant climate and weather data, and decision support tools.

Climate workshops for the growers are run to train them in interpreting and using the climate data, forecast information and decision support tools in risk management at their properties.

QUEENSLAND

The difference that occurs in climate across an area the size of Queensland is considerable. Low rainfall and hot summers in the inland west, a monsoon season in the north, and warm temperate conditions along the coastal strip contrast with low minimum temperatures that can be experienced inland and about the southern ranges.

The climate of the coastal strip is influenced by the warm waters of the Coral and Tasman Seas, which in general keep the region free from extremes of temperature and provide moisture for rainfall. The annual median rainfall along the coastal strip is generally within the range of 1,000 to 1,600 mm., increasing to over 3,200 mm. along parts of the North Queensland coast near Innisfail.

The mountains of the Great Divide in Queensland attain a maximum height of 1,622 m at Mt. Bartle Frere near Innisfail, and there are several peaks in excess of 1,000 m, mainly in the north and again in the far south-east. Along sections of the Great Divide, the elevation abruptly increases away from the coastal plain, and then west of the divide it gradually descends onto the western plains.

On the western side of the Great Divide, the rainfall drops quickly to an annual median of about 700 mm, and then gradually decreases further. At the same time, average maximum temperatures gradually increase with increasing distance from the coast. Further to the west the land slowly flattens out to the dry inland plains, marked by cold nights. It is in the west where the hottest temperatures in the State most commonly occur during summer, and where the annual median rainfall drops below 200 mm.

The way in which the climate changes across the State is reflected by marked changes in vegetation, which ranges from the tropical rainforests of the coastal zone of North Queensland to the cooler forests of the southern highlands, through the pastoral belt of areas such as the Darling Downs to the dry saltpans of the western inland.

Tropical Cyclones are a natural hazard from about November through to May in coastal regions. They bring with them devastating winds, heavy rain and the threat of coastal inundation from tidal surges. Whilst tropical cyclones are a threat to coastal communities, they are a major source of rain for the dry inland regions. Settlement to the west of the Great Dividing Range was made difficult by a lack of a reliable water supply. Settlement onto the open plains that flourished during years of good rainfall floundered during drought periods.

The beef cattle industry is the dominant land use in Queensland, with intensive stocking in the high rainfall tropics and extensive grazing in the arid grasslands of the south-west. Sheep are grazed on native grasslands in the semi-arid central and south-west of the State. Cereal and other crops are grown in combination with sheep and cattle in the south of the State, particularly in the Darling Downs. Sugarcane and tropical horticulture dominate much of the east coast.

NORTHERN TERRITORY

The climate differs from that of southern Australia, and varies greatly between the Territory's northern and southern extremities. Four-fifths of the Territory lies north of the Tropic of Capricorn. The strip within about 150 km of the coast is mainly flat or undulating country up to about 200 m elevation, with extensive coastal swamps or wetlands in some parts. The interior of the 'Top End' is dominated by the rocky Arnhem Land plateau. To its south-west lie the rugged hills of the southern Katherine region, while in the east the land rises generally more gently through the hilly country of the southern Roper–McArthur district to the grassy plains of the Barkly Tableland. These systems of hills divide the coastal river drainage systems from the broad but shallow inland basin, where streams are usually dry for most of the year. South again the land rises very gradually; western areas are dominated by sandy desert. Toward central Australia, the land rises more steeply into a higher plateau and rocky ranges, where a number of peaks exceed 1,500 m elevation. The plateau declines steeply toward the sand dunes of the Simpson Desert in the south-east whilst the Lake Amadeus trough separates it from the lower ranges of the far south-west.

Two major atmospheric pressure systems affect the Territory: the subtropical ridge of high pressure cells (highs or anticyclones), and a broad tropical low pressure region called the monsoon trough. The subtropical highs move in a west to east direction: across southern Australia in winter, and further south in summer, usually separated by low pressure troughs or cold fronts. The highs provide the driving force behind the south-east trade winds that dominate the Territory's weather in the winter months.

The monsoon trough is a broad area of low atmospheric pressure running east–west through the tropics in the summer months. During the summer it lies for lengthy periods over north Australia, and is the source of much rainfall. Tropical cyclones can develop off the coast in the wet season, usually forming within an active monsoon trough. Heavy rain and high winds, sometimes of destructive strength, can be experienced along the coast within several hundred kilometres of the centre of a cyclone.

Northern and, to a lesser extent, central parts of the Territory experience two distinct seasons: the 'wet' (October to April) and the 'dry' (May to September). The change between seasons is usually gradual, with transition months of October and November (often called the 'build-up') at the start of the wet, and April at its end. In central parts the contrast between wet and dry is not generally as marked as in the north.

The Alice Springs district is dry for much of the year, and has an erratic rainfall pattern, with a slight summer maximum. While zero rainfall can be experienced in all calendar months, significant totals are also possible in all months, but are more likely in summer. Winters (June to August) are cool and summers (December to February) hot; the terms 'spring' and 'autumn' are not usually applied to the transition seasons in between.

In the southern and central parts, weather is more variable from October to April than in the north. Sometimes decaying tropical cyclones or the monsoon trough move well south into the central regions, bringing widespread rain and thunderstorms. In general, though, east to south-easterly winds and fine conditions predominate. Temperatures can be scorching, and dust devils, whirling dust pillars raised by columns of rising hot air, are frequently seen. During October to November wildfires are fairly common—usually ignited by lightning from dry, gusty thunderstorms.

From May to September the prevailing south-easterlies bring predominantly fine conditions throughout the Territory. Rainfall in the north is low to non-existent in most areas, although light showers are common about the north-east coast and occasionally develop elsewhere over the northern Top End. Wildfires are widespread in the north during this season, particularly in later months, fuelled by the abundant wet season growth that has been dried by the prevailing south-easterlies.

Cold fronts between subtropical high cells frequently move across the Alice Springs district, particularly in the winter months, when they may also occasionally reach the Top End. Winds before a front tend to be warm to hot and, in summer, humid. The front's passage may be marked by thunderstorms or, if rainfall has been very low for a prolonged period, a wall of dust. The cool south-easterlies that follow the front generally clear the sky of cloud and are often very dry. Large areas of cloud, known as 'northwest cloud bands' occasionally blow across Australia from the tropical Indian Ocean. These can bring widespread rain, and sometimes storms, to southern parts, especially if a cold front moves into the area and enhances the cloud band.

Research and development

Seasonal forecasting

The major organisations undertaking research and development into seasonal forecasting are the Bureau of Meteorology Research Centre (BMRC) within the Bureau of Meteorology (BoM), CSIRO Atmospheric Research (DAR) supported by CSIRO Marine Research, and the CSIRO Antarctic Research. Other organisations include the Queensland Department of Primary Industries (QDPI) through its climatologist at Toowoomba, and a number of private forecasters who provide services to individual clients. Details on the latter will be provided in the section on services.

The Bureau of Meteorology has been developing methods for seasonal climate predictions since the early 1900s (Nicholls 1997). The Bureau's National Climate Centre began preparing and testing monthly Seasonal Climate Outlooks in 1988, and issuing them publicly in 1989. These have been based primarily on statistical forecasts, although BMRC is also working with CSIRO in the development and use of General Circulation Models (GCM's). The latter include both atmospheric models and ocean–atmosphere models.

The Climate Modelling Program within CSIRO Atmospheric Research seeks a better understanding of climate and its variations in order to assess the way in which climate is likely to change in future due to the enhanced greenhouse effect and to natural climatic variability, and to predict climate variability up to 12 months ahead.

By building upon results from global climate models and limited-area models, the Climate Impact Group produces assessments of the likely impact of climatic change. The Group's scenarios have provided the basis for assessment studies performed by various groups throughout Australia and overseas and have played an important part in the policy-making process.

The Program makes a major contribution to the CSIRO Climate Change Research Program; and to the Climate Variability and Impacts Program, which encompasses a range of research activities examining climatic fluctuations and climatic extremes.

CSIRO Marine Research (CMR) has been developing an ocean observing network to support research on predictability of climate since 1983. Part of the network was transferred to the Bureau of Meteorology in 1996 to establish an operational framework and secure funding for the future. CMR maintains a portion of the network for research on climate processes.

CMR and BMRC established the Joint Australian Facility for Ocean Observing Systems in 1997 to carry out research on the design of ocean observing systems. CMR has been developing an ocean model since 1995 and validating it with observations from areas known to have an impact on Australian climate. The modelling project is partially supported by CVAP. The model is used as the ocean component of climate prediction systems being developed at DAR and BMRC.

The Queensland Centre for Climate Applications (QCCA), a new initiative of the Queensland Government, will enhance current climate applications research, development and extension being undertaken by the Department of Primary Industries and the Department of Natural Resources. QCCA is based in Toowoomba with a major node at the Indooroopilly Resource Sciences Centre and regional staff throughout the State.

QCCA will seek to improve both the long-term economic viability of Queensland's rural industries, and the sustainability of the natural resource base by developing knowledge and skills to combine climatic, agricultural and resource information that assists industry and policy makers to make better decisions. A primary goal of this initiative is to improve both *on-farm and off-farm* methods of 'best practice' for managing the impacts of climate variability and change. Major scientific and technical breakthroughs in agro-climatology have occurred in recent years to assist managers cope with the impacts of climatic variability.

QCCA will provide a range of practical benefits to Queensland by helping primary producers to better manage fluctuations in climate and thus to improve profits, sustainable economic development, and self reliance in managing drought. It will also significantly

- assist Landcare objectives, the management of water, land and vegetation resources, and initiatives in Property Management Planning (PMP);
- strengthen research, development and collaborative links with national and international climate agencies so that landholders are kept at the forefront of advances in climatology, seasonal forecasting, and knowledge of climate change;
- assist the Queensland Government to objectively assess drought situations and policy, reduce the cost of drought subsidies, and gain Federal drought funding assistance; and
- build on existing products and services such as the Australian RAINMAN, WHEATMAN and GRAZEON

software, the *Long Paddock* Internet site, phone and fax SOI hotlines, the book *Will It Rain?*, and the *Managing for Climate* PMP workshops.

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Most research to date into the value and use of seasonal forecasting has been undertaken by the Queensland Department of Primary Industries (QDPI), in collaboration with CSIRO Tropical Agriculture, particularly with respect to crops and crop management, and by the National Rangelands Program of the CSIRO Wildlife and Ecology, with some input from the Bureau of Resource Sciences and the Institute of Animal Science in Victoria.

A new project called 'Oceans to Farms' is being initiated by CSIRO Tropical Agriculture, in collaboration with the CSIRO Atmospheric Research, the Bureau of Meteorology Research Centre, the National Climate Centre of the Bureau of Meteorology, State Departments and the Queensland Centre for Climate Applications (QCCA), to identify what information on ocean climate is potentially useful in the management of agricultural systems. This project aims to evaluate forecasts based on ocean data (such as Sea Surface Temperatures) and intermediate-complexity coupled ocean–atmosphere models. New forecasts must be developed and evaluated in conjunction with industry needs, and because these needs vary by industry and location a collaborative approach is necessary. The value of these new forecasts will be tested for the grains, extensive grazing and sugar industries across Australia. The forecasts will be assessed using agricultural models that simulate production under a range of management strategies in a way that allows forecasts to be compared with no-forecasts. The output from the models will be used to assess economic impacts and to develop simple rules of thumb for adoption by industry.

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STATISTICAL FORECASTS

The Climate Group within the Bureau of Meteorology Research Centre aims to document, explain and simulate the causes of major fluctuations and changes of the Australian climate, develop methods to monitor and predict climate variations, and investigate the impacts of climate variations on Australia. A significant proportion of its work has been targeted at developing and testing statistical forecasts.

Since 1989, the Bureau of Meteorology has been issuing seasonal outlooks for the next three months, based primarily on the Southern Oscillation Index (SOI) (Nicholls 1997). This is based on the long-term trend in the differences in atmospheric pressure between Darwin and Tahiti. The SOI has proved to be a reasonably reliable indicator over much of eastern Australia, with respect to spring and summer rainfall (McBride and Nicholls 1983). There is also a significant signal in the south-west of Western Australia associated with Indian Ocean influences. A new statistical forecast system, which uses global and regional patterns of sea surface temperatures (SSTs) as predictors, has been developed. The system generally shows more skill than the SOI-based operational system, and allows a lead time of two to three weeks. It has been in use operationally since late 1998. Both the SST-based scheme and the previous SOI-based scheme use discriminant analysis techniques to construct the forecast.

The phase of the SOI is also being used to produce seasonal outlooks (Stone and Auliciems 1992; Stone *et al.* 1996a), the information being made available by the Queensland Department of Primary Industries to farmers and their advisers in north-eastern Australia. Five phases are used—falling, negative, neutral, rising and positive.

Summer rains over much of northern Australia are primarily associated with the onset of the monsoon season. The incidence of tropical cyclones crossing the Queensland coast is 15 times higher during a La Niña compared with an El Niño event (Hastings 1990). The SOI therefore provides a means of forecasting Australian seasonal tropical cyclonic activity (Nicholls 1992).

Droughts, including El Niño events, are typically associated with relatively cloud-free skies. It is therefore not surprising that the incidence of early and late frosts is elevated during El Niño events and has been related to the SOI (Stone *et al.* 1996b).

Other promising indicators of ENSO events include:

- Sea surface level anomalies, as measured by the National Tidal Facility in Adelaide (Mitchell 1994). Sea level varies diurnally with the tides under predominantly lunar influence, but mean sea level varies with prevailing anomalies in windspeed and direction, water temperature, and in the long-term with the size of the arctic and antarctic ice packs. Positive anomalies in sea level have been detected in the north-west between Port Hedland and Darwin in the spring of years that precede years of low winter rainfall in southern Australia (Allan *et al.* 1990, Figure 2 of Mitchell 1994). These are probably related to the north-westerly jet stream that frequently blows from the Indian Ocean to bring rains to southern and south-eastern Australia. Sea level anomalies up to a year ahead of ENSO events have also been detected in the eastern sector of the Great Australian Bight (Figure 2 of Mitchell 1994). Similar anomalies documented in the 1996 issues of the Climate Diagnostics Bulletin preceded the 1997 ENSO event (Mitchell, pers. comm.). The National Tidal Facility web site is http://www.ntf.flinders.edu.au.

- Circumpolar currents in the Antarctic region. The Antarctic CRC Polar Atmosphere Program is concerned with the study of Antarctic Weather Systems and with the role of the Antarctic in the Global Climate System. The program combines observational activities with analysis and numerical modelling of weather and climate. Observational programs make use of satellites, drifting buoys, land-based weather stations and research cruises. The modelling programs aim to describe the linkages and feedbacks between the atmosphere, ocean, sea ice and Antarctic ice cap, creating an understanding of the overall system. Changing the circulation of the oceans—particularly of the deep oceans—results in a change of climate. Bearing in mind that the characteristics and circulation of perhaps 50 to 60% of the sub-surface waters of the oceans are determined by what happens at the air–sea interface of the Southern Ocean surrounding Antarctica, the Antarctic 'sources' of deep water are in turn major controls on climate. Special emphasis has been on observing changes in the circumpolar currents, as these may be able to provide long lead times in the detection of El Niño and other global climatic events.

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Specific research projects currently (or recently) being undertaken in this area include:

- Development of improved climate forecasting systems (1993–1997)—Dr N. Nicholls, BMRC + States (LWRRDC)
- Improved climate prediction during El Niño events—Dr W.J. Wright, BoM (LWRRDC)
- SILO—Agrometeorological information systems—Mr A. Beswick, QDNR (LWRRDC)

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GENERAL CIRCULATION MODELS (GCMS)

Lead times in terms of years rather than months are needed to attain significant financial benefits in many pastoral systems. There is therefore a robust case for further research to extend seasonal forecasts to time periods that are annual and beyond.

GCMs of the global climate have been shown to offer more promise in extending forecasts from 3 to 12 months than the SOI, particularly in terms of forecasting changes in SSTs in the central and eastern tropical Pacific (Kleeman *et al.* 1995). This longer lead time would certainly be more useful to livestock producers. The GCMs have yet to be properly tested for rainfall prediction, although their SST predictions can be used statistically to estimate changes in the SOI and rainfall with reasonable success.

The Bureau of Meteorology has been using a coupled ocean–atmosphere model to predict El Niño since 1994. The model has a highly simplified vertical structure and representation of SST. BMRC and CSIRO, with support from the Climate Variability in Agriculture R&D Program (CVAP), are developing a much more realistic model, considered the most promising approach to accurate predictions with extended lead times.

The climate group at The University of Melbourne (School of Earth Sciences) is using their GCM to understand the variability of rainfall over Australia, particularly the mechanisms producing droughts and floods. Investigations have addressed the impact of oceanic conditions (eg. Simmonds 1990; Simmonds and Rocha 1991).

The studies of Simmonds and Lynch (1992), Simmonds (1993) and Simmonds and Hope (1998a) are designed to quantify with models the influence of surface conditions (and particularly soil moisture content). An on-going series of model experiments is being conducted to explore the influence of changes in large-scale circulation on Australian rainfall (Simmonds *et al.* 1992a, b).

Specific research projects currently (or recently) being undertaken in this area include:

- Atlas of near-global ENSO and climate variability since 1871—Dr Rob Allan, CSIRO Division of Atmospheric Research (LWRRDC)
- Development and testing of climate models for seasonal prediction for Australia—Dr Gary Meyers, CSIRO Marine Research (LWRRDC)
- Extended seasonal climate predictions using a dynamical climate model—Dr Gary Meyers, CSIRO Marine Research and Dr Neville Smith, Bureau of Meteorology Research Centre (LWRRDC)
- From oceans to farms: integrated management of climate variability—Dr Andrew Ash, CSIRO Tropical Agriculture (LWRRDC)
- Global Seasonal Climate Forecasts for Australian Environmental Outlooks—Mr R.A. Young, QDNR (DISR, Department of Industry, Science and Resources; Industry, Science and Technology Program—ISTP)
- Air–sea exchange processes—Mr F. Bradley, CSIRO Land and Water

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SEASONAL FORECASTS BASED ON SYNOPTIC SCALE STUDY OF THE UPPER ATMOSPHERE

Forecasting Drought from Teleconnections

Strong relationships have been developed between both global (Southern Oscillation Index) and local (geopotential height) phenomena in one season and the occurrence of low precipitation in any of the next four seasons. The relations explain more than 50% of the variance in the precipitation for regions of up to 700,000 km^2 and more than 35% of the variance for up to 1.3m km^2 in eastern Australia. The strong relationships occurred when precipitation was regressed against one of the variables in years that were selected on the basis of the magnitude of a third, so called partitioning, variable. The relations are shown to be able to provide forecasts of precipitation in all seasons of the year. Statistical tests show that the strong forecasting relations could not occur by chance.

Forecasting drought in southern Australia

A long- and medium-range rainfall and crop yield forecasting model has been developed by Holton (1996, 1997) using mean sea level pressure differences and 500 hpa geopotential height differences between stations over the general northern Australian and Indian/Pacific Ocean area. These pressure and height stations are located in areas found by Drosdowsky and Williams (1991) to correlate highly with the SOI in the current and preceding year. The pressure and height difference are therefore a measure of the current and preceding years' strength of the ENSO phenomenon over a much wider area than that calculated by the SOI.

Specific research projects currently (or recently) being undertaken in this area include:

Seasonal rainfall and winter crop yield forecasting for southern Australia. Mr J.P. Egan, South Australian Research and Development Institute, PIRSA; Mr I Holton, Bureau of Meteorology, Adelaide Regional Office; Dr W.J. Grace, Bureau of Meteorology Research Centre, Melbourne (LWRRDC).

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CLIMATE ANALYSIS, INTERPRETATION AND MONITORING

The University of Melbourne climate group is performing a wide variety of climate analyses aimed at understanding Australia rainfall variability. Records covering most of this century are being used to, for example, quantify the persistence of rainfall deviations, both when the effect of the SOI is both included and excluded (Simmonds and Hope 1997, 1998b).

Atmospheric water vapour budget studies using high quality meteorological analyses are now being undertaken to dissect the transport patterns responsible for extreme rainfall seasons. This approach is being successfully applied to studying analogous rainfall variations over China (Simmonds and Bi 1997; Simmonds *et al.* 1998).

Cyclonic weather systems are known to be an important component in rainfall totals, particularly in southern Australia. The Melbourne University group has developed a sophisticated automatic algorithm for tracking cyclones from model output or observed analyses (Murray and Simmonds 1991; Simmonds and Murray 1998; Simmonds *et al.* 1998). Considerable progress is being made in terms of relating the inter-annual and inter-decadal variation of cyclone numbers to the south of Australia to similar variations of southern Australian rainfall. This is being done with the automatic scheme, as well as with manual techniques (Leighton 1997; Leighton *et al.* 1997).

Antarctica clearly plays a role in the weather and climate of southern Australia. The ice and the distribution of rain-bearing cyclonic systems to the south of Australia appear to be linked in subtle ways, and the climate group at the University of Melbourne have explored these links, using both models and analysis of observed data (Simmonds and Wu 1993a, 1993b; Watkins and Simmonds 1995; Godfred-Spenning and Simmonds 1996; Simmonds 1996)

Cold outbreaks significantly affect land-based activities, particularly grazing. The Antarctic connection of a significant number of these has been established (Perrin and Simmonds 1995a, 1995b). The Southern Oscillation is known to be a significant influence on rainfall over Australia, and the Oscillation appears to influence, and be influenced by, the extent of sea ice around the Antarctic continent (Simmonds and Jacka, 1995).

The ocean plays a crucial role in the climate system because ocean currents and subsurface thermal structure vary slowly over months to years, in contrast to the daily fluctuations of weather in the atmosphere. When the slow ocean processes influence sea surface temperature and the interface to the atmosphere, the climate system develops a degree of predictability associated with the slow time scale of the ocean.

CSIRO Marine Research has a number of projects focused on understanding ocean processes from an observational perspective. Variability of heat exchange between the ocean and the atmosphere has been identified as a crucial process in the Australian region (Godfrey *et al.*1998). Also, the transfer of heat from the Pacific to the Indian Ocean by the Indonesian throughflow is an important regional process (Meyers 1996).

Variation of deep ocean thermal structure associated with known patterns of sea surface temperature in the Indian Ocean have been identified (Meyers 1998). As our understanding of processes develops, the insights are used to validate and improve the CMR ocean model (Schiller *et al.* 1998a; Schiller *et al.*1998b).

New ways of determining the quantity and spatial and temporal distribution of rainfall are being investigated. This includes making use of cloud-top temperatures (Bryceson 1994), radar monitoring and neural networks.

Specific research projects currently (or recently) being undertaken in this area include Spatial distribution of rainfall and storm movement (using remote sensing) Mr J. Elliott, Bureau of Meteorology

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VALUE OF SEASONAL FORECASTS

The value of a seasonal outlook depends on the skill or accuracy of the forecast, and its marginal value relative to other readily available sources of information to the manager of a particular production system. If the information is ignored, or it does not lead to changed decisions, it has no economic impact or value (Freebairn 1996). If the forecast is inaccurate then the information is likely to have negative value in the current season.

Benefits from accurate forecasts in one year can be more than totally offset by an incorrect forecast in another year. Other sources of information such as available feed or soil moisture, or the fact that a farm is stocked well below capacity, may render a forecast of limited value. Flock or herd structure, and the number or timing of decisions on a farm, may also mean that a lead time of only three months is of limited value. Likewise it should be kept in mind that mean annual rainfall, inter- and intra-year variability in rainfall, climatic systems, the reliability of different indices for seasonal forecasting, and major agricultural systems all vary dramatically across Australia. The reliability of seasonal outlooks also varies with time of year. From a national viewpoint one also needs to take into account the adoption rate by farmers, and whether there are net benefits to the economy (Crellin 1988).

The benefits of improved seasonal forecasts vary between industries and across Australia. Soils and vegetation in pastoral areas exposed to high climate variability can benefit through de-stocking in advance of drought so as to avoid overgrazing, stock losses and accelerated erosion. Crop producers can assess whether or not to sow or fertilise a crop if the chance of a harvest is significantly diminished. Demands for irrigation water can be better estimated.

Cropping and irrigation

The value of seasonal forecasts to crop producers can be significant, but it varies with management and initial conditions, as well as with cropping systems and location (eg. Hammer *et al.* 1996; Marshall *et al.* 1996). The forecasts can influence decisions on when and what area to sow, and whether to irrigate and/or fertilise a crop.

Monitoring the SOI can aid in the forecasts of wheat yields in Australia, near the date of sowing and well before harvest (Rimmington and Nicholls 1993). They also observed a negative correlation with the SOI in the year before sowing, due in part to the tendency for years of positive SOI (wet years) to follow years of negative SOI (dry years) and *vice versa*.

Clewett *et al.* (1991) used a crop model and 60 years of historical climate records to study grain sorghum production from a shallow storage irrigation scheme in Queensland. They aimed to determine the optimum design of a shallow farm dam and optimise irrigation scheduling. They showed that spring values of the SOI are linked to subsequent and large changes in the probability distributions of rainfall, run-off, water storage, crop production and gross margins. Growing crops in seasons with a strongly negative SOI before planting were unprofitable, compared with seasons with a strongly positive SOI before planting. SOI data can therefore be used to adjust the management strategy according to the level of climatic risk.

In the northern part of the Australian grain belt, significant increases in profit (up to 20%) and/or reduction in risk (up to 35%) can be achieved with wheat crops based on a seasonal forecast available at planting time (Hammer *et al.* 1996). This can be achieved through tactical adjustment of nitrogen fertiliser application or cultivar maturity with significant financial benefits (Marshall *et al.* 1996).

Opportunistic crops are those that are not sown every year, only when moisture conditions are adequate. For example, if soils in north-western Victoria have adequate moisture in October, then a sunflower crop can be sown with a high probability of a good harvest (Jessop 1977). In a similar way, seasonal forecasts can be used to determine whether a particular cereal, oilseed or legume crop should be sown, based in particular on the probability of a favourable harvest. There seems scope to do this in Queensland with sorghum crops (Nicholls 1986; Hammer *et al.* 1996).

The El Niño–Southern Oscillation (ENSO) has a dominant effect on climate in a number of the world's large-scale irrigation areas. Dudley and Hearn (1993) modified existing models to examine irrigation options for cotton growers in the highly variable, summer rainfall environment of the Namoi Valley of northern New South Wales. They showed that expected returns were markedly reduced if the SOI was negative at planting time. However, they concluded that little could be done in the way of operational management decisions to reduce the harmful effects of a dry SOI event, or enhance the beneficial effects of a wet SOI event, given the current water allocation scheme. They suggested that if irrigators knew the current SOI before the commencement of each cotton season, more profitable timing of investment in plant and equipment might result. These benefits might be extended to suppliers of farm inputs and to processors.

Rangelands

A large part of the rangelands in the eastern half of Australia is particularly sensitive to the climatic events of El Niño, with consequences for stocking rate and land degradation. A policy of reducing stocking rate on the basis of El Niño forecasts can significantly reduce environmental degradation in adverse seasons (McKeon and White 1992).

Stafford Smith *et al.* (1996) evaluated SOI forecasts as a means of managing property stocking rates in the Charters Towers region of northern Queensland. Forecasting strategies appeared to have little benefit given today's skills with the SOI, but improved skill has considerable potential both to improve economic returns and to help protect the resource. Sensitivity studies showed that the system being studied was particularly sensitive to assumptions about buying and selling decisions, and long-term impacts on vegetation condition.

Stafford Smith (1996) concluded that:

- forecasting with the current skill and currently suggested tactics based on SOI values has modest long-term *economic* benefits for grazing enterprises at present, at least in the Dalrymple Shire in Queensland;
- forecasting with the current skill and tactics based on SOI values can provide some benefits in terms of long-term resource protection;
- forecasting with possible future skill based on new climate modelling approaches has considerable potential for economic and environmental benefits in the future, and there may also be better tactics for using the current SOI skill;
- getting stocking rate strategies right will have more immediate and bigger economic and environmental benefits.

In summary, the financial benefits of seasonal forecasts may not be easily realised based on existing skill levels, lead times and decision points (Stafford Smith *et al.* 1999).

Clewett and Drosdowsky (1996) found that winter SOI values were useful in terms of reducing the risks of lost animal production, overgrazing, land degradation, and costs associated with supplementary feeding. However, they noted that many primary producers make important management decisions during autumn when climate forecasting has low skill. They therefore concluded that future climate research needs to target this 'predictability gap'.

In the more remote areas of northern Australia, cattle graze extensively on sub-tropical grasslands. Management inputs are kept to a minimum, stock being handled only at the time of the annual muster, usually in summer, so that seasonal forecasts are of limited use.

Temperate grasslands

Preliminary studies using models of grassland systems have shown that even high skill levels appear to offer low financial benefits in the medium term, despite increased animal welfare and protection for soils and vegetation (Bowman *et al.* 1995).

Morley (1994a, 1994b) concludes, after examining rainfall data for Bendigo, Holbrook and Goondiwindi, that most variations in rainfall are essentially random. He asserts that having information on the SOI for the months June to August adds little accuracy to predicting how much to feed stock in late summer–autumn in southern Australia, compared with information on August and September rainfall, the amount of pasture dry matter in December, and the pasture dry matter in other months.

Bowman *et al.* (1995) examined the value of seasonal outlooks to wool producers in northern and western Victoria assuming forecast accuracies for the next 12 months of 60, 80 and 100%. They concluded that the financial benefits for wool producers of reliable seasonal outlooks in southern Australia are probably substantially less than generally anticipated, although there could be significant benefits in protection of the natural resource base, and in reducing livestock deaths. The more accurate the seasonal forecasts, the better was the long-term financial performance of the farm.

These preliminary studies in the grasslands and rangelands of Australia show that the financial benefits of seasonal outlooks to managers of grazing livestock may not be easily realised. This appears to be a consequence of a) inadequate climate forecasting skills over much of the continent, including insufficient lead times, and b) few decision points and limited flexibility with grazing livestock systems, requiring longer lead times in which to prepare for adverse events. Such studies highlight the need for further research to determine whether and how the management and timing of decisions of many grassland systems should be modified to take advantage of forecast information.

Specific research projects currently (or recently) being undertaken in this area include:

- Grazier-based profitable and sustainable strategies for managing climate variability—Dr Mark Stafford Smith, CSIRO Division of Wildlife & Ecology (LWRRDC)
- The application of climate forecasts to crop management in northern Australia—Dr Peter Carberry, APSRU
- Evaluating the role of seasonal climate forecasting in tactical management of cropping systems in north-east Australia—Dr Roger Stone, APSRU

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USE OF SEASONAL FORECASTS

The National Farmers Federation, in its publication 'New Horizons', endorses the view of many farmers that improved seasonal forecasting is a high research priority to assist them in managing their properties. This has also been highlighted in surveys undertaken in Queensland (Stone and Marcussen 1994) and Western Australia (Elliott and Foster 1994) within Phase I of the NCVP (Nicholls *et al.*1995). Managers of water and other climate-sensitive sectors of the economy also claim that they would like to see significant advances in skill levels and lead times in seasonal forecasting (Anon 1997).

Farmer awareness and use of seasonal forecasts since they began in 1989 have been highest in Queensland for a number of reasons. These include:

- the high incidence of drought in north-eastern Australia in the 1990s;
- the higher correlation between the spring SOI and summer rainfall over much of Queensland compared with other areas of Australia;
- the greater research and extension effort by QDPI into incorporating the SOI into farmer decision making;
- the employment of a climatologist (Dr Roger Stone) by QDPI;
- the publication of an explanatory booklet (Partridge 1994);

- the development and release of decision aids including the Australian RAINMAN software; and
- information on the SOI being made available through the media, infofax, and through the World Wide Web (http://www.dpi.qld.gov.au/longpdk), and training workshops for farmers and their advisers.

In March 1998, QCCA surveyed pastoralists throughout Australia on their use and perceived value of seasonal forecasts and related government services (C. Paull, personal communication). Although the data are still being analysed, it is clear that many graziers do use the forecasts to aid their stocking and stock trading decision, even though the reliability of forecasts remains an issue in many areas. This is particularly the case in southern and Western Australia where SOI-based forecasts have less skill.

Farmers in Queensland have certainly reacted to adverse SOI information by sending cattle to market thereby reducing stocking rates on their properties. However, those with say high debt have often decided to gamble on say sowing a crop, despite an adverse forecast, when they are already threatened with foreclosure of their properties.

A survey of grain growers in northern New South Wales in 1998 (P. Hayman and S. Huda, personal communication) has shown that farmers have used four day weather forecasts to plan their sowing and spraying operations. They have also used frost risk information to switch crops and crop cultivars, and they have used the seasonal rainfall outlook to increase their nitrogen application rates and the area sown to crop.

In January 1997, the Queensland University of Technology, with assistance and support from the Queensland Department of Primary Industries, surveyed primary producers in south-east Queensland (Hastings and O'Sullivan 1998). Most of these were cattle producers with some dairy farmers, croppers and others in agricultural production. The aim was to gauge producer opinions of the impact of seasonal climate patterns and seasonal forecasting.

Results indicate that:

- producers still rely to a large extent on their own intuition and experience (66%) to determine future weather patterns;
- El Niño–Southern Oscillation-based forecasting were known to 96% of respondents, but 48% of those who indicated that SOI-based information had been of some importance in their decision-making did not believe its use was 'reasonably successful';
- climatic information was used to aid decisions in cropping, livestock buying and selling, setting stocking rates and supplementary feeding;
- the rural media is considered to be a creditable and useful source of seasonal climate forecasts/ information (67%). Fax and internet climatic information services had been used by less than one-third of respondents;
- probability statements were favoured for presenting forecasts (74%). 66% accepted that probability-based forecasts cannot be judged later as having been either 'right' or 'wrong';
- 44% of respondents agreed (with 27% neutral) that SOI and probability-based forecasting places undue responsibility on 'users' to interpret the information;
- 75% indicated that provided their information is useful, they were not concerned whether a forecast source uses strictly scientific methods, or non-scientific/other methods; and
- 60% indicated "it is better to respond to seasonal climate variability as it unfolds, rather than try to anticipate risks and hedge according to a forecast/ personal outlook".

Two other surveys on the needs and use of climate information were conducted in New South Wales in 1997 and 1998. The first survey on 'Rural needs and climate variability' was conducted by the University of Newcastle. 'Feedback from graziers and farmers on seasonal forecasting information' was also obtained by NSW Agriculture under the *Aussie GRASS* project. Combined and generalised, the two surveys reveal the following information:

Variability of climate is well known by the farmers in NSW but it is often poorly understood. Research has shown, on average, that many producers do not comprehend the explanations and predictions given to them by the meteorologists. Almost 70% of the respondents think that the priority in weather forecasting is for city people. However, the Bureau of Meteorology's daily forecasts are seen as the most useful day-to-day source of weather information, followed by media sources. The Bureau of Meteorology is also seen as the most reliable supplier of long-term climate information by a majority of producers. About 40% of the respondents regard Bureau of Meteorology forecasts as either unreliable, or they are unsure of their reliability.

The seasonal forecast is the most popular climatic information product, being used by a majority of farmers. Also popular are rainfall maps (62%), and maps of drought-declared areas (43%).

About 60% of producers plan for climate variability on a seasonal basis, whereas 16% plan only on a day to day basis. For over 80% of the farmers the big picture information is slightly to moderately important in planning risk management or decision-making

About 80% of the respondents indicated that accurate information on the seasonal outlook of rainfall, the SOI and El Niño would be useful to them so as to make better management decisions.

90% of the farmers prefer two or more ways for accessing the seasonal climate outlook. The top preference is to use the fax, followed by rural newspapers, internet and radio. Very low preference has so far been shown for computer packages and daily newspapers.

80% of the farmers have one or more problems in using the big picture information. While some find it difficult to access or interpret, a majority indicated that they have no confidence in the accuracy of the information. Only 20% of the farmers find no problem in its use.

There is a tendency for respondents on large properties to use climate predictions to a greater extent. The age of the respondents significantly affects the sources of climate information the respondents draw upon. There is a clear tendency that older farmers are less likely to draw upon a broad range of sources of climate information.

It was concluded that producers are vitally interested in climate information and predictions of important weather parameters like rainfall and frost. There is a large need for relevant and user-friendly information about climate in rural NSW. The surveys suggest that there is scope to improve official forecasts to build more confidence, and also to establish a better understanding of official forecasts.

Specific research projects currently (or recently) being undertaken in this area include:

- Evaluating the role of seasonal climate forecasting in tactical management of cropping systems in north-east Australia—Dr Roger Stone, QDPI (LWRRDC)
- Northern wheatbelt climate study—Mr P. Hayman, NSW Agriculture, Tamworth, and Dr S. Huda, University of Western Sydney (GRDC)
- Seasonal climate variability and crop yield forecasting—Mr A. Hafi, ABARE (LWRRDC)
- Seasonal rainfall and winter crop yield forecasting for southern Australia—Mr J.P. Egan, South Australian Research and Development Institute; Mr I. Holton, Bureau of Meteorology, Adelaide Regional Office; Dr W.J. Grace, Bureau of Meteorology Research Centre
- Climate risk options for managing frost risk in the eastern wheatbelt—Dr D.G. Abrecht, Agriculture Western Australia
- From oceans to farms: integrated management of climate variability—Dr A. Ash, CSIRO Tropical Agriculture (LWRRDC)
- Insurance-based risk management for drought—Mr B. Mayers, Agricultural Risk Management P/L (LWRRDC)
- Farmers training needs for managing climate risk—Mr P. Wylie, Macro Agricultural Consultants (LWRRDC)
- Climate and fisheries on the S.E. Australian Continental Shelf and Slope—Dr T. Koslow, CSIRO Division of Fisheries. (LWRRDC)
- R&D opportunities for using seasonal climate forecasts in the Australian water industry—Prof. Tom McMahon, University of Melbourne. (LWRRDC)
- Seasonal streamflow forecasts to improve management of water resources—Mr N. Clarkson, QDPI (LWRRDC)

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Vegetation monitoring and assessment

The major organisations currently undertaking research and development in this area include the CSIRO Earth Observation Centre, in collaboration with CSIRO Land and Water Resources, the Environmental Resources Information Network (ERIN) within the Commonwealth Department of the Environment, the Queensland Department of Natural Resources, and the Western Australian Departments of Agriculture (AgWA) and Land Administration (DOLA).

REMOTE SENSING

Vegetation cover is important as an indicator of available fodder and to protect the soil resource from erosion. Cover can be estimated using remote sensing, field measurements, pasture and crop models and farm survey data.

Remote sensing has been used to assist in assessing the severity of drought across Australia, current satellite imagery being compared with that in previous years. It has also helped in determining the spatial extent of exceptional droughts (McVicar and Jupp 1998a). Another valuable use is in aiding the validation of temporal (including temporal/spatial) agronomic models, as are being incorporated into the National Drought Alert System known as *Aussie GRASS* (Australian Grassland and Rangeland Assessment by Spatial Simulation) (Brook and Carter 1994).

The most commonly used measure of vegetative condition has been the Normalised Difference Vegetation Index (NDVI) based on the reflection of red and near infrared (NIR) light. Chlorophyll pigments in leaves absorb red light, and changes in leaf structure can influence NIR reflectance. Foliage presence, as measured for example through the Leaf Area Index (LAI), is generally related to vegetative condition. Thermal data, transformed to the Normalised Difference Temperature Index (NDTI), are also of value in assessing vegetative cover and drought monitoring (Bierwirth and McVicar 1998)

The Advanced Very High Radiometric Resolution (AVHRR) sensor on the polar orbiting NOAA (U.S. National Oceanographic and Atmospheric Administration) satellites are probably the main tool for vegetation monitoring. Other platforms include the polar-orbiting U.S. Landsat and

French SPOT satellites and the Japanese Geostationary Meteorological (GMS) satellite located above the equator at 140°E. The NOAA and Landsat satellites orbit at about 700 km altitude, whereas the GMS satellite is at an altitude of some 36,000 km, providing views of cloud cover across Australasia.

As a service to the agricultural and environmental sectors, the CSIRO Marine Research produce a composite NDVI image of the whole of Australia every two weeks using data obtained from the Australian Centre for Remote Sensing (ACRES). A two-week compositing period is used in order to minimise the cloud cover in the data. The composite images have a resolution of 1 km. They are made available to customers about 10 days after the end of the two-week period. Historical data are also available going back to 1991.

Bureau of Meteorology

AVHRR data are recorded and archived daily within the Bureau of Meteorology Research Centre (BMRC). A compositing pathway has been established using these data. To highlight changes in the monthly maximum value composite NDVI between sequential months, the Maximum Value Composite Differential (MVCD) has been developed (Tuddenham *et al.* 1994, Tuddenham and Le Marshall, 1996). The MVCD is based on the difference between two images recorded at say two-monthly intervals, with a log stretch to enhance the subtle difference in the NDVI signal that has occurred over that time. The changes may involve either a browning or greening of the vegetation cover during the two month period. This can be useful to identify whether a season is atypical in terms of the timing of either seedling emergence or herbage drying off.

CSIRO Earth Observation Centre, Canberra

The CSIRO Earth Observation Centre (EOC) is the science program within the CSIRO Office of Space Science and Applications (COSSA). Dr David Jupp is the Head of COSSA and the Science Leader of the EOC.

The EOC brings a level of collaborative and coordinated underpinning for generic Earth Observation science in CSIRO. Supported research activities are driven by a wide range of applications in Australia and internationally and are being actively undertaken by a distributed group of about 50 scientists spread through CSIRO and its collaborators.

The EOC focuses on four primary areas: applications support, measurement models, data systems and sensor systems.

EOC Tasks are the basic management units, and can take the form of:

- Working Groups—explorations of issues and Earth Observation science problems by groups from the EOC Divisions and other contributing groups;
- Science Projects—teams of scientists from the EOC Divisions and other groups coming together to resolve issues. Science Projects are outcome-oriented and collaborative; and
- Implementation Teams—Working Groups and/or Science Projects can lead to specific outcomes which may need implementing (eg. as software, manuals, official standards) or technology transfer.

CSIRO's Access to the Research Aircraft Facilities program is a part of the EOC.

For more information, visit the EOC Web Site: http://www.eoc.csiro.au

Use of thermal data in drought monitoring:

In Australia, daytime thermal data are used to monitor regional environmental conditions relevant to the Drought Exceptional Circumstances (DEC) decision making process. McVicar *et al.* (1992) and Jupp *et al.* (1998) jointly developed the Normalised Difference Temperature Index (NDTI), to remove seasonal trends from the analysis of daytime land surface temperatures derived from the AVHRR sensor. The NDTI has the form:

$$NDTI = \frac{T_\infty - T_s}{T_\infty - T_0}$$

where:

T_∞ is a modelled surface temperature if there is an infinite surface resistance, that is, ET is zero;

T_s is the surface temperature observed from the AVHRR sensor; and

T_0 is a modelled surface temperature if there is zero surface resistance; hence ET equals ET_p (potential evapotranspiration).

T_∞ and T_0 can be thought of as the physically-limited upper and lower temperatures respectively, for given meteorological conditions and surface resistances. They define an envelope within which meaningful AVHRR surface temperatures must fall. If T_s is close to the T_0 value it is an indication of conditions being 'wet'. Whereas if T_s is close to the T_∞ value, dryness is indicated.

T_∞ and T_0 are calculated through the inversion of a resistance energy balance model. The parameters which are required at the time of satellite overpass are meteorological and vegetation-related parameters.

Meteorological data which are required includes air temperature, solar radiation, relative humidity (or some other measure of vapor pressure) and wind speed. However, many meteorological stations only record daily air temperature extremes and rainfall. McVicar and Jupp (1998) have tested and extended strategies to determine air temperature, solar radiation and relative humidity at the time of the satellite overpass. Wind speed can be obtained from daily wind run data, if available, or long-term climate surfaces.

Vegetation parameters, mainly Leaf Area Index (LAI) (m^2 leaf per m^2 ground), are obtained from reflective data. For four dates in 1995, in cereal cropping and pasture environments in Victoria, relationships were developed between 1 m^2 *in situ* LAI measurements and the planetary-corrected albedo LANDSAT TM simple ratio (McVicar *et al.* 1996b). These relationships were then used to scale the TM simple ratio to provide estimates of LAI at a 30 m^2 cell size for the entire TM scene centred on the township of Elmore, approximately 45 kms north west of Bendigo. These data were then related to AVHRR simple ratio with a resampled cell size of 1 km^2 (McVicar *et al.* 1996a). Hence 1 m^2 measurements of LAI were scaled to 1 km^2 estimates of LAI by using TM data as the intermediate scalar. For wooded sites within the Murray–Darling Basin, 30 m^2 field sites were established and LAI measured, which was subsequently related to AVHRR vegetation indices (McVicar *et al.* 1996d). This enables AVHRR reflective data to be scaled to estimates of LAI for cropping and pastures (McVicar *et al.* 1996a) and wooded vegetation (McVicar *et al.* 1996d). Hence the NDTI is calculated at the points, which are sometimes separated by distances of 500 km, where meteorological data are recorded to support the calculation. AVHRR-derived NDVI and T_s are used as covariates to interpolate the NDTI away from the ground meteorological stations using a spline interpolation algorithm called ANU_SPLIN (Hutchinson 1995). This results in NDTI images. This has been done for 10 years of AVHRR data focusing on the Murray–Darling Basin, South-east Australia.

The thermal data used in the NDTI calculations are affected by a few environmental parameters. The controlling parameter of the NDTI is the partitioning of the available energy into the latent and sensible heat fluxes; this partitioning is determined by the available moisture to be transferred to the atmosphere via ET. The amount of energy partitioned into the sensible heat flux is one determinant of the observed surface temperature. Consequently the NDTI is more sensitive to changes in resource availability than the NDVI, which integrates the response of the environment to the resource. The NDTI has a greater ability to map the availability of water. This provides a measure of stress when plants are not yet responding to a reduction in chlorophyll content, thereby reducing the NDVI. More important is the ability of the NDTI to map moisture availability that will be influenced by rainfall which falls between meteorological stations. The NDVI will not be able to map these events with the same temporal resolution due to the time lag between rainfall and plant response.

The aim of producing the NDTI is to allow insight into the regional water balance. This is achieved by ET being common to both water balance and energy balance model formulations. In water balance models ET is defined in terms of volume of water, usually measured as millilitres per day. In energy balance models ET is defined in terms of energy, measured in watts per unit area. Independent of any remote sensing input a water balance model, based on the analysis of meteorological data, can be calculated. Outputs from water balance models include estimates of soil moisture and the moisture availability. The water balance derived moisture availability can be used to determine the amount of net available energy (AE) at the Earth's surface utilised by the latent heat flux. The remaining AE is partitioned toward the sensible heat fluxes. The sensible heat flux can then be physically inverted to provide a modelled surface temperature based on the water balance moisture availability, denoted, $T_{s\ WB}$. This can be compared with the AVHRR-derived surface temperature, denoted $T_{s\ AVHRR}$.

The residual between the two parameters $T_{s\ AVHRR}$ and $T_{s\ WB}$ is minimised using a global optimisation technique called simulated annealing, which alters some water balance operating characteristics (McVicar *et al.* 1996c). This allows daytime thermal observations to be linked to the water balance model by bringing the two temperatures into agreement over the 10 years of data. The residual, expressed as

$$\sum (T_{s-AVHRR} - T_{s-WB})^2$$

is minimised.

Department of Land Administration, WA

There are two groups producing a continental Normalised Difference Vegetation Index. CSIRO in Hobart is using data from the Australian Centre for Remote Sensing (ACRES), Alice Springs, and the Western Australian Department of Land Administration (DOLA) is using data from Perth, Darwin and Melbourne. Given that the long-term commitment of ACRES to supplying such data may be in doubt, then the DOLA approach could be more robust. Furthermore, DOLA was able to use NOAA-9 to obtain continental data during the very severe drought of 1994 when NOAA data were unavailable via ACRES.

There are currently two operational satellites, NOAA-12 in the morning and evening, and NOAA-14 in the afternoon and midnight. There are also two other earlier NOAA satellites still orbiting in standby mode.

DOLA undertook a project for several years to monitor vegetation condition using time series analysis of the NDVI obtained from the AVHRR sensor (Smith 1994). This has been applied to the extensive rangelands of WA (Cridland *et al.* 1994). Stocking density and when to muster are important issues, exacerbated by the size of individual paddocks. Pastoralists only want to muster livestock once a year. Having an indication of the available feed can assist in the decision of when to muster.

Cridland *et al.* (1994) analysed the four years of NDVI data, by plotting the NDVI signal as a time series. The height, in NDVI units, from a varying baseline to the maximum peak within the growing season, is calculated. This green 'flush' is the response of the landscape to rainfall. The baseline was varied to take account of the influence of perennial cover on the NDVI signal. The baseline is defined as the minimum from the previous year.

The vegetation response or 'flush' recorded as the maximum for a particular year is then considered relative to the absolute maximum 'flush' within the four (or more) years of data. As well as indicating where and when grazing condition is poor, both images may be used to highlight opportunities to increase stocking densities due to an increase in available feed. This can help place individual years within an historical context.

There is a need to establish a drought monitoring system based on NOAA data, using a consistent baseline, time series and agreed products. There needs to be a client in the Federal government. There also needs to be a dual system using both water balance modelling and remotely sensed data. Both techniques throw up anomalous data, so there is a need for cross-checking.

Probably the ideal system is where CSIRO produce the software and a consistent long-term NDVI dataset free of orbital and sensor drift, with atmospheric correction and BRDF (Bi-directional Reflectance Distribution Function). BoM is the major collector and source of NOAA data, but DOLA and CSIRO Hobart are the major users, and the major source of processed NOAA data, including the NDVI. There is a need to coordinate the activities of these groups. ERIN should become a receiver of the DOLA NDVI information.

DOLA is also engaged in monitoring bushfire activity in northern Australia, at a continental scale on behalf of ERIN, and at a finer resolution for the Bushfire Services of Western Australia and the Bushfire Council of the Northern Territory. Fire without follow-up rain can be ecologically devastating, so fire control and hotspot monitoring are very relevant to managing for climate variability, this being particularly important in the savanna country of Northern Australia.

Landsat Thematic Mapper (TM) and occasionally Spot data are used for monitoring land surface and cover, and productivity or yield. Information on the area of crop sown and cereal yield forecasts is provided on request to the Australian Wheat Board (commercial-in-confidence).

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Environmental Resources Information Network

The Environmental Resources Information Network (ERIN) has, over a number of years, used a number of techniques to analyse changes in AVHRR derived NDVI images. Recently all AVHRR data held by ERIN have been recalibrated using the method proposed by Roderick *et al.* (1996). There are a number of analytical tools that have been used to interpret the NDVI data.

Firstly mapping the divergence of NDVI relative to the long term mean has been done at 2-monthly intervals. Having such a fine temporal resolution is important for putting data into an historical context as it allows changes due to vegetation phenology, inherent seasonal changes in solar radiation and air temperature to be normalised. This is similar to the MVCI proposed above, and is important for determining the divergence from 'normal' conditions for the particular month rather than using yearly extremes. Secondly, the analytical approach of the 'flush' which has been applied to WA and follows the idea of determining the flush of NDVI at a pixel level on an annual basis and will be applied to the entire Australian continent.

Queensland Department of Natural Resources

Satellite-based information on vegetative cover is an important layer within a GIS devoted to monitoring seasonal changes in vegetation, land clearing and the extent and severity of drought (Brook and Carter 1994; Carter *et al.* 1996). Considerable emphasis has been devoted to field validation of NDVI data and model output with respect to pasture biomass and tree cover (Wood *et al.* 1996).

1. Monthly NOAA NDVI satellite data are presented as decile (relative) greenness maps in the same manner as rainfall is often reported. This and other information is disseminated in the QDNR/QDPI monthly newsletter 'A summary of seasonal conditions in Queensland'.

2. A new NOAA receiver has been installed for fire mapping. CAPS software will be used for post-acquisition processing. Maps of fire scars will be used to 'reset' grass biomass in spatial models and to investigate fire frequency in grazed lands. Combining data on area burnt with model biomass and nitrogen content will allow calculation of greenhouse gas emissions.

3. Calibration and validation of spatial models: NDVI and thermal data provide a high resolution (spatial and temporal) data set that can be matched to a synthetic NDVI produced by biological models. For project QPI20, NDVI data were compared to the model's synthetic NDVI signal in order to independently validate the model, both spatially and temporally. In the current *Aussie GRASS* project, the NDVI imagery is being used to spatially fine tune some of the pasture growth parameters. NDVI data are also being used with a genetic algorithm to investigate optimisation of model parameters such as transpiration use efficiency (Carter *et al.*, in press).

4. Tree and land use and soil attribute mapping:

   Long-term mean NDVI data have been used to map tree density and cropping areas on a national basis. Tree density is an input to spatial models and cropping areas are used to modify stock densities (Carter *et al.* 1996). Long-term mean NDVI and thermal data have been used as an input into soil organic carbon mapping in Queensland (McKeon *et al.* 1998).

5. Research is in progress to translate mean NDVI and air temperature data into tree biomass data for Australia.

6. In Queensland the State Landuse and Trees Study (SLATS) is mapping tree density, tree clearing rates and some land use with Landsat TM imagery for the entire State. Images for 1988, 1991, 1995 and 1997 have been acquired and are being processed. In the future some historic data will be acquired to map historic clearing and regrowth.

Data from this project will upgrade existing NOAA-based tree maps used in spatial models. The data are also being investigated for mapping land degradation.

Agriculture Western Australia (AgWA)

NOAA imagery from DOLA is being used to monitor vegetation greenness in Western Australia, following on from the earlier work of Smith (1994) and Cridland *et al.* (1994). AgWA is using Intergraph which uses a more generic grid analysis (GRID) package than used by Cridland. Monitoring of the rangelands is continuing, thus providing another layer of data to enhance and validate *Aussie GRASS* in Western Australia (G. Beeston, personal communication). This is an integral part of the rangelands component of the recently established National Land and Water Audit. Alec Holm of AgWA is primarily responsible for this work; he is currently undertaking PhD studies at the University of Western Australia. GRASP is being tested further north by Ian Watson at the Northam Office of AgWA, in collaboration with Greg McKeon and Wayne Hall of QDPI/QDNR.

Remote sensing information is now incorporated into the Pastoral Lease inspection reports that are undertaken every five years in Western Australia. Agribusiness (eg. Heytesbury Pastoral Company) is now also interested in pasture monitoring, including the use of the *Aussie GRASS* model for estimating spatial and temporal changes in vegetation cover.

New South Wales Agriculture

NSW Agriculture uses NOAA satellite data to produce 'vegetation greenness' maps of NSW, on a monthly basis. The maps are based on the application of an NDVI ratio across the data. The data have the NDVI ratio calculated prior to NSW Agriculture receiving it from the CSIRO Division of Marine Research. Data used are taken from a series of up to 14 days, to make a composite. The NDVI index has been routinely derived and archived from NOAA satellite data since 1986, and serves as a good basis for monitoring vegetation trends over this period. The index is a valuable agricultural tool for monitoring green vegetation extent and vigour. NSW Agriculture developed a simple change image that better highlights areas of increasing or decreasing vegetation vigour.

Both vegetation greenness and vegetation greenness change maps are produced monthly by the Resource Information Unit, NSW Agriculture. End users include NSW Agriculture field staff, Stock and Station Agents, Bee Keepers, Bush fire Brigades, Grain buyers, Soil Conservationists and other Government Departments.

The maps are available via the Internet at www.agric.nsw.gov.au/climate/green and www.agric.nsw.gov.au/climate/change. Hard copy maps are available for either the whole State or for particular areas or time periods if required. Additional vector overlays are available to assist with location of features.

Specific research projects currently (or recently) being undertaken in this area include

- Drought monitoring of the Australian continent by satellite—Dr Richard Smith, Department of Land Administration, Western Australia (LWRRDC and RIRDC)
- Use by managers in rangeland environments of near real-time satellite measures of seasonal vegetation response—Dr S. Cridland, ERIN
- Developing a sustainable satellite fire monitoring program for rural northern Australia—Mr Jeremy Russell-Smith, Bushfires Council of the Northern Territory
- Development of a national drought alert strategic information system—Mr John Carter, QDNR

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AGRONOMIC MODELLING—GRASSLANDS

Biophysical models of agricultural systems are an effective means of determining the responsiveness of soil moisture, plants and livestock to changing climatic conditions, and for determining the effectiveness of the rainfall (White 1997). Since such models should also be realistically responsive to changes in management, the effects of both management and climate can be studied simultaneously. For example, Fouché *et al.* (1985) used a model to show how the frequency and duration of droughts on the South African veldt increased with stocking rate.

The more variable the climate, the more valuable models are as adjuncts to field experimentation. This is in part because a field experiment of say only three years in duration is likely to be an unrepresentative sample of the long-term behaviour of a farming system.

Agronomic models are probably the best tools for determining the severity of drought and the effectiveness of rainfall. They are also invaluable for estimating the productivity, environmental and financial consequences of different management strategies when applied to farming systems exposed to a variable climate. Vegetative cover is a major constraint to wind and water erosion, although soil type and topography are also important. The outputs of agronomic models are therefore important in assessing the agronomic and environmental condition of an area exposed to drought.

Agronomic models are usually specific to particular agroecosystems and vegetation types, and include:

GRASP—tropical and subtropical rangelands (McKeon *et al.* 1990);

GRASSGRO—temperate grasslands (Moore *et al.* 1997); available from Horizon Software;

DYNAMOF—temperate grasslands, Victoria (Bowman *et al.* 1989, 1993), based on BREW (White *et al.* 1983);

ARIDGROW—arid lands of central Australia (Hobbs *et al.* 1994);

Forage flow model (arid lands) (Pickup 1995, 1996);

SEESAW—sub-arid lands, western New South Wales (Ludwig and Marsden 1995a, b; Ludwig *et al.* 1994);

SAVANNA-AU (Coughenour 1993; Ludwig and Tongway 1997)

WAVES—hydrological/Leaf Area Index Model (Dawes and Short 1993);

IMAGES—(Hacker *et al.* 1991; Yan and Wang 1996)

Several of these models are being compared within the *Aussie GRASS* project in terms of their ability to simulate specific pasture communities. GRASP is the model currently used for all communities in Australia. IMAGES (Hacker *et al.* 1991; Yan and Wang 1996) has recently been rewritten by Emma Raaff, in collaboration with David Stephens; improvements include the replacement of implicit variables with explicit variables. GRASP and IMAGES are being tested by Ian Watson at the Northam Office of AgWA, in collaboration with Greg McKeon of QDNR. ARIDGROW is being compared with GRASP simulations for central Australia. Comparisons between the GRASP and GRASSGRO models in the high rainfall temperate zone of New South Wales are planned.

With the emphasis on managing risk, there is therefore a need to encourage farmers to use appropriate Decision Support Systems (DSS) to determine the likely consequences of different management strategies, and the associated risks. In many instances this will be done indirectly through a participatory dialogue with advisers who are familiar with the value and use of such tools. In this way farmers will become better informed about the variability in the environment in which they operate, and better able to make appropriate decisions to improve the productivity, sustainability and financial viability of the farming systems which they manage.

There are a number of DSS for analysing climate data, as well as a range of models and DSS to improve the management of the land. Increased use of these DSS will need a high level of field testing, extensive consultation with users as to their decision requirements, adequate software support, and careful monitoring of their adoption and use.

Models and other DSS have an important role in identifying those management strategies that are financially viable and exposed to minimum physical and financial risk, particularly in areas exposed to a variable climate. However, they are only of value if they are embedded in a broader vision, of acknowledging that DSS are not an end in themselves, but are a very useful, possibly essential tool, in achieving improved management and self-reliance.

Specific research projects currently (or recently) being undertaken in this area include:

- Pasture and forage systems (GRAZPLAN)—Dr John Donnelly, CSIRO Plant Industry (AWRAPO, Australian Wool Research and Promotion Organisation; Australia and Pacific Science Foundation; MLA, Meat and Livestock Australia; Australian Pastoral Research Trust; LWRRDC)
- Strategies to cope with climatic variability in the perennial pasture zone of south-eastern Australia—Mr Stephen Clark, Pastoral and Veterinary Research Institute, Hamilton, Vic. (LWRRDC)
- Grazier-based profitable and sustainable strategies for managing climatic variability (DroughtPlan)—Dr Mark Stafford Smith, CSIRO Wildlife & Ecology (LWRRDC, MRC)
- Estimating safe carrying capacities for grazing properties—Dr Peter Johnston, QDPI (NHT, QDPI, QDNR)
- Rangeland capability assessment in western Queensland—Mr David Cobon, QDPI

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AGRONOMIC MODELLING—CROPS

A number of cereal, oilseed and legume crop models have now been developed in Australia, most of these being integrated into the Agricultural Production Systems Simulator (APSIM, McCown *et al.* 1996) being developed by the Agricultural Production Systems Research Unit (APSRU) at Toowoomba in Queensland. APSRU is a joint facility of the Queensland Department of Primary Industries and CSIRO Tropical Agriculture.

Crop models have already been shown to be of value in comparing the likely consequences of different management strategies when applied within a variable climate. These include choice of crop or cultivar, time of sowing, fertiliser input, and use of irrigation water. The value of seasonal forecasts has also been investigated. As highlighted in the following section, they can also be used in cropping areas in assessing and ranking the severity of individual droughts.

At the regional level, Stephens (1995) linked his STIN yield forecasting model with an Oracle database of meteorological data and ABS shire (county) level yield data. With this system, crop yields and soil moisture at sowing were able to be forecast in real-time (Stephens *et al.* 1994; Stephens 1997). Predicted yields can be plotted as colour maps (for publication on the Web or in farming journals) as a *per cent* change from the five-year means, or as a ranked percentile in comparison to all other years of historical data. The model calculates a water balance, and estimates Crop Water Use Efficiency and increases in yield attributable to technology (after the effect of climate has been removed), as well as the variability in yields and trends in climate as they relate to crop production.

Climate Risk and Yield Information Service

The timing and amount of early season rainfall has been identified as the most important climatic factor influencing farm management decisions. The ability to maximise profits in better seasons and minimise losses in the poorer seasons by adjusting crop area and inputs on the basis of early season information on rainfall and yields leads to increased long-term profitability.

During 1996 a trial involving farmers and advisers from South Australia and Western Australia determined the usefulness of relevant, timely information on yield and climatic risk in making decisions before and after sowing. Information was generated by two computer programs, Tact and Pycal, using farmers' own rainfall data which was faxed weekly to the relevant State Departments. The results were returned by fax within 24 hours.

In 1997 the trial was extended to encompass a larger area of the Eyre Peninsula of South Australia, and the eastern wheatbelt of Western Australia. The processes involved were automated to involve 150 participants for the 1997 season and the trial was run as a joint project between Primary Industries and Resources South Australia, Agriculture Western Australia and the Kondinin Group.

Specific research projects currently (or recently) being undertaken in this area include:

- Decision support for climatic risk management in dryland crop production—Mr Jim Egan, South Australian Research and Development Institute, PIRSA (LWRRDC, GRDC and RIRDC).
- Seasonal rainfall and winter crop yield forecasting for southern Australia—Mr Jim Egan, South Australian Research and Development Institute, PIRSA (LWRRDC, GRDC and RIRDC).
- Assessing and Forecasting Variability in Wheat Production in Western Australia—Dr David Stephens, Agricultural Western Australia
- The application of climate forecasts to crop management in northern Australia—Dr Peter Carberry, CSIRO/APSRU
- Evaluating the role of seasonal climate forecasting in tactical management of cropping systems in north-east Australia—Dr Roger Stone, QDPI/APSRU (LWRRDC)
- Seasonal climate variability and crop yield forecasting—Mr Ahmed Hafi, ABARE (LWRRDC)
- Effects of Improved Climate Forecasting on Competitiveness in the International Grain Market—Dr Graeme Hammer, QDPI/APSRU

- Improving management of seasonal conditions for low rainfall crop production—Mr Jim Egan, South Australian Research and Development Institute, PIRSA (GRDC)
- Developing and promoting systems for managing climatic and spatial risks in dryland crop production—Dr Doug Abrecht, Agriculture Western Australia (GRDC)
- Assessing and managing seasonal risks and opportunities in crop production—Dr Doug Abrecht, Agriculture Western Australia (GRDC)
- Climate risk options for managing frost risk in the eastern wheatbelt—Dr Doug Abrecht, Agriculture Western Australia (GRDC)
- Modelling cropping systems to ensure greater water use and water use efficiency—Dr Ian Fillery, CSIRO Plant Industry, Centre for Mediterranean Agricultural Research, Floreat Park, WA (GRDC)
- Application of a crop model to examine the efficiency and sustainability of wheat farming in Western Australia—Dr Ian Fillery, CSIRO Plant Industry, Centre for Mediterranean Agricultural Research, Floreat Park, WA (GRDC)
- Managing the risks associated with early sowing of lupins—Dr Doug Abrecht, Agriculture Western Australia (GRDC)
- Improved potential yield estimates for farmers and advisers—Dr David Tennant, Agriculture Western Australia (GRDC)
- Analysis of Cropping Systems in Northern NSW using Simulation Models—Dr H. Marcellos, APSRU (GRDC)
- FARMSCAPE—Farmer–adviser–researcher monitoring, simulation, and communication for best dryland cropping practice—Dr Bob McCown, CSIRO/APSRU (GRDC)
- Developing database and knowledge-based resources for commercial advisers using the cropping systems simulator APSIM—Dr Zvi Hochman, CSIRO/APSRU (GRDC)
- Whopper Cropper—a data base and graphics interface to connect crop management advisors with the simulation capacity of APSIM—Dr Graeme Hammer, QCCA/APSRU (GRDC)
- Better management of climate variability within the agribusiness service sector—Dr Peter Carberry, CSIRO/APSRU

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DROUGHT ASSESSMENT AND THE IDENTIFICATION OF EXCEPTIONAL DROUGHTS

Models have been used by the Bureau of Resource Sciences (BRS) and collaborating organisations to assess the effectiveness of rainfall and to improve the objective estimation of Drought Exceptional Circumstances (DEC) (White and O'Meagher 1995; O'Meagher *et al.* 1999). Rainfall and other climate data collected for approximately 100 years have been input into models of farming systems in order to characterise and rank past droughts, and determine appropriate indicators and criteria for estimating the severity and extent of future droughts.

Studies to date include using:

- a model of a Merino ewe flock grazing an annual ryegrass and subterranean clover pasture near Heathcote in northern Victoria (White *et al.* 1998);
- a model of an annual grass and subterranean clover pasture grazed by either Merino wethers or breeding ewes at Wellington in the central tablelands of New South Wales (Donnelly *et al.* 1998);
- a rangeland model at Charleville (south-west mulga country, sheep) and Charters Towers (northern speargrass, cattle) in Queensland (Stafford Smith and McKeon 1998);
- a Stress Index model to estimate long-term wheat yields and soil moisture accumulation at 16 representative sites across the Australian wheat belt (Stephens 1998);
- an Agricultural Production Systems Simulator (APSIM, McCown *et al.* 1996) to assess the severity of drought on wheat-fallow, sorghum-fallow and wheat-sorghum (opportunity cropping) production systems at a range of sites throughout north-eastern Australia (Keating and Meinke 1998); and
- a composite measure of the financial situation of farm families and generated regional estimates using ABARE survey data (Ockerby *et al.* 1996). They proposed that the estimates could be used in conjunction with rainfall and other seasonal data to generate benchmarks of one in 25 year economic events.

Associated with the above studies was a review of the role and values of remote sensing in determining the existence and spatial limits to exceptional droughts (McVicar and Jupp 1998).

A workshop at the conclusion of these studies (White and Bordas 1997) concluded that rainfall, soil moisture, grassland and crop production (or an index thereof, which may be derived from a model or remote sensing), liveweight gain, supplementary feed requirements, net farm income or a measure of financial stress are all useful indicators of DEC. Of these, the three most reliable indicators of rainfall deficit and effectiveness are simulated grassland and crop production, and the estimated requirements of livestock for supplementary feed, based on appropriate management regimes. The feasibility of taking account of significant long-term climate shifts was also demonstrated. An income-based approach to determining exceptional circumstances due to climatic and other events has been advocated by Thompson and Powell (1998), despite concerns as to the practicality of such an approach, and the extent to which it would limit structural adjustment and the capacity for rural industries to become more efficient (O'Meagher *et al.* 1998).

Drought monitoring in New South Wales

A study on the evaluation of the meteorological indices used in drought monitoring in various parts of the world was carried out by the NSW Agriculture in 1997 (Harpal Mavi, pers.comm.). The objective of the study was to identify and develop improved criteria for drought assessment and mitigation in NSW. Main findings and recommendations emerging from the study are summarised as follows.

Analysis of rainfall is the primary basis of identification of drought but there are a number of pitfalls if drought is assessed solely on rainfall criteria or indices. Rainfall measurements may vary considerably over relatively small distances. Rainfall occurring at one time of the year can be carried over using fallow to provide moisture at other times of the year, making irrelevant the average monthly rainfall values. Failure of rain at the optimum time may downgrade the otherwise average rainfall conditions in terms of production potential. Average rainfall conditions mask the influence of rainfall intensity and the duration of rainfall spells on the actual performance of crops and pastures.

Soil water balance and agronomic simulation models perform better than the rainfall indicators in the assessment of agricultural droughts. However, like rainfall indicators, they too have limitations. If wrong information about plant characteristics or soil parameters is used in running a simulation then these can greatly influence the output of the model. Some of the models may tend to amplify minor events, and at other times suppress major events are presented in a suppressed form. These differing and far from reality results can create a confusing situation.

The study led to the conclusion that drought measurement is a difficult and complex task. No single measure, a rainfall index, a water balance model, an agronomic model or field surveys, can identify, effectively and objectively, the true extent and severity of a drought. Adopting a single measure for assessing drought is unrealistic and may not stand the test of time and the court of law. The Commonwealth Government recognised this in basing its decisions on Drought Exceptional Circumstances on six criteria, as well as visits by the Rural Adjustment Scheme Advisory Council, to affected areas. A combination of measures, including rainfall analysis, and soil moisture balance indices supported by field surveys—is proposed by NSW Agriculture to be the most realistic approach to assess the extent and intensity of drought.

Based on the monitoring criteria, an early warning system should be developed to appraise the community as well as State and Federal governments of the true nature of the situation and to counteract exaggerations and panic. A climatic information service developed and operated on an inter-disciplinary basis providing products tailored to planning requirements will be a great aid in the drought mitigation actions. A contingency drought mitigation plan should be prepared and activated as soon as the early warning system begins to send signals of the impending drought.

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Exceptional Circumstances

BRS is currently working to enhance government responsiveness to Exceptional Circumstances (usually drought) by improving its capacity to deliver evidence-based assessments to AFFA (Agriculture, Fisheries and Forestry Australia, formerly DPIE, the Department of Primary Industries & Energy) and the Minister. This is being done through researching new approaches to the analysis of climate variability and its impacts on agriculture, and developing an integrated Toolset that will integrate scientific evidence from a range of sources so as to provide customised delivery of assessments of Exceptional Circumstance applications (G. Laughlin, personal communication).

Although the EC declaration procedures are currently under review, they are still likely to be invoked according to the following criteria:

- a rare event with a severe impact on producers; with prolonged effects upon production and farm income;
- of sufficient scale to warrant government involvement; and
- impacts should be beyond the capacity of normal, responsible risk management and likely to cause unwarranted, undesirable and unnecessary structural change.

Current research by BRS and its collaborators is therefore being devoted to developing qualitative and quantitative descriptions of:

- different attributes of climate variability (short, medium and long term variations in the rainfall of major growing seasons) as causes of events; and
- the impacts on agricultural production and sustainability, such as through:
  - combinations of enhanced AVHRR reflectances and brightness temperatures that are well correlated with useful measures of biomass production such as laser-based vegetation profiling;
  - the outputs from pasture simulations and pasture experiments; and
  - the principles of good risk management at regional scales.

Trends in the incidence of Drought Exceptional Circumstances in New South Wales

This study was undertaken by Harpal Mavi (pers. comm.) in order to assess, understand and highlight:

1. trends and frequency of drought exceptional circumstances events in NSW
2. seasonal comparison in the trends and frequency of drought exceptional circumstances.
3. adequacy of the statistical technique to assess a severe and rare drought event.

Rainfall records were collected for 62 well distributed stations for which long term uninterrupted records are available. These stations represent all the rainfall regimes and major agro-ecological regions of NSW.

The Excel® macros written to analyse rainfall records for the assessment of Drought Exceptional Circumstances (DEC) according to one of the Federal Government criteria were used to statistically analyse the historical rainfall records. For each of the stations, DEC events were counted for each decade for comparison. Eleven year running averages and averages for: i) the entire period of record, ii) the period up to 1900, iii) the period 1901 to 1950 and iv) the period 1951 to 1997 were worked out and plotted along with the actual rainfall to compare changes and trends in rainfall. The number of years with rainfall below the 20th and above the 80th percentiles were counted and compared. DEC events identified on the basis of different time series data at selected stations were compared to assess the sensitivity of the technique to identify a rare and severe drought event.

Preliminary results of the analysis of the last 100 years data show no consistency in the incidence of Drought Exceptional Circumstances. Three-quarters of the Drought Exceptional Circumstances events of the last 100 years occurred in the first half of the century. The decade 1935–1944 was the worst with 26% of the total events. Substantially higher rainfall in the second half of the century, compared to the first half, has contributed toward the lesser number of the drought events in this period. There is a need to examine the current statistical method to assess a rare and severe event in the light of an increasing trend in rainfall due to the greenhouse effect.

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Specific research projects currently (or recently) being undertaken in this area include:

- Objective criteria for exceptional circumstances declarations: improving scientific and economic inputs to decision making—Dr David White, Bureau of Resource Sciences (now with ASIT Consulting)
- Enhanced framework for analysing climate variability and its impacts for policy purposes—Dr Greg Laughlin, Bureau of Rural Sciences

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ALERT SYSTEMS—NATIONAL, REGIONAL, ON-FARM

Aussie GRASS

Aussie GRASS (Australian Grassland and Rangeland Assessment by Spatial Simulation), a spatial modelling framework for assessing the condition of Australia's grazing lands, has been developed by the Queensland Departments of Natural Resources and Primary Industries (Hall *et al.* 1997). This integrated climate data, natural resources data, remote sensing, historical agronomic research and simulation model to provide useful and objective assessment of drought conditions. The system has been operational in Queensland, using a pasture growth model (GRASP, Littleboy and McKeon 1997) to generate estimates of vegetative cover and condition on a monthly basis across the State of Queensland. The framework proved invaluable to the Rural Adjustment Scheme Advisory Council (RASAC) and the Commonwealth Government in their regular assessments of the severity and extent of drought across Queensland (White 1997).

The second stage of the project (*Aussie GRASS*) involves the national collaboration of State and Territory agencies and CSIRO Divisions, including an analysis of available regional models of plant growth, issues of extension, satellite data and biophysical data sets. For example, Agriculture Western Australia is to provide enhanced underlying datasets for that State that are then incorporated into the *Aussie GRASS* GIS to enable spatial and temporal changes in vegetative cover to be better simulated. As mentioned in the section 'Agronomic modelling—grasslands' (page 27), the GRASP model is being compared with IMAGES, ARIDGROW and SEESAW for grasslands in central and southern Australia, and with GRASSGRO for higher rainfall temperate pastures, to assess which model is the most appropriate for different areas. This is largely influenced by the relative proportion of C_3 and C_4 plants in different environments. Collaborators include Ian Watson, Greg Beeston, Matt Boland and Andrew Craig (W.A.), Roger Tynan and Russell Flavel (S.A.), Ron Hacker, Rob Richards, Judy Bean, Daryl Green, Allan McGuffiche, Graeme Tupper, John Crichton and Harpal Mavi (NSW), Rod Dyer (NT) and Col Paull (QDPI).

The national *Aussie GRASS* model currently produces products on a monthly timestep that are available to collaborators via a password-protected web site. Most of these products are yet to be fully calibrated and validated, except for Queensland. Calibration and validation will be conducted using field data collected using 'spider mapping' techniques. Further details are available at http://www.dnr.qld.gov.au/longpdk/agrass/proj.html

A series of training workshops is currently underway throughout Australia to educate researchers and extension officers about the project and available products. The workshops also provide an ideal forum for further product development.

STIN

When the regional wheat yield forecasting model (STIN) of Stephens (1995) is run with a constant technology assumption for all years of rainfall data, accumulated negative deviations in crop yields may be used to form a Drought Exceptional Circumstance Index (DECI) (Stephens 1998) which should help governments assess which areas in the cropping zone were experiencing drought exceptional circumstances and would therefore qualify for financial assistance from the Commonwealth Government.

An Automated Weather Station Network has also been set up in Western Australia to provide necessary data to underpin research into spatial and temporal crop and grassland modelling in that State (Ian Foster, personal communication). These approximately 20 AWSs are not in the BoM network, being deliberately set at a different height, with a different format and hourly measurements. They were originally installed for wind erosion research, but are now being used in the climate modelling program. http://www.agric.wa.gov.au/climate

Soil water balance modelling based on WATBAL (Fitzpatrick and Nix 1969), with estimates at 5-day intervals (pentads) gives good estimates of duration of growth in the rangelands for areas where rainfall data are available. The usefulness of rainfall terciles to aid decision making in the cropping areas is also under investigation. Maps are also being produced for each month on the frequency of waterlogging for different soil types.

SLUIS

SLUIS, the Sustainable Land Use Information System, was developed for the Commonwealth Government as a system to provide integrated scientific information relating to the effects of climate variability on land surface processes (Lyons *et al.* 1997; Shao *et al.* 1997; Munro *et al.* 1998). Primary information sources include soils, vegetation, topography, and weather conditions. Outputs are primarily focused on integrating atmospheric and land surface hydrology. Its development has been a collaborative project of the Bureau of Resource Sciences; the Centre for Advanced Numerical Computation in Engineering and Science, University of New South Wales; and the School of Mathematics of the University of New South Wales.

It works by integrating the outputs of a numerical weather prediction model with a land surface hydrological model. Soil moisture is estimated at a range of depths, along with surface run-off, taking into account soil temperature, wind speed and direction, radiation and humidity.

SLUIS has been constructed in such a way that it is capable of being coupled to Global Climate Models, providing effective downscaling to improve resolution in time and for regional and continental areas. It should therefore provide valuable information for analysing and predicting the impacts of climate variability and change.

Specific research projects currently (or recently) being undertaken in this area include:

- Development of a national drought alert strategic information system—Mr Ken Brook, QCCA (LWRRDC)
- Australian grassland and rangeland assessment by spatial simulation: *Aussie GRASS*—Dr Wayne Hall, QDNR (LWRRDC)
- Sustainable Land Use Information System (SLUIS)—Br Bob Munro, Bureau of Rural Sciences

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Managing within a variable climate

Increased self-reliance by rural producers requires the ability to manage both crop and livestock enterprises exposed to a variable climate and to minimise the impact of drought. It also requires the ability to more effectively manage risk: production risk, environmental risk, financial risk and market risk (White 1997). Improved seasonal outlooks are but one approach to assisting farmers to become more self-reliant. Ways of offsetting the risks associated with climate variability in order to create opportunities require a systems approach (Hammer and Nicholls 1996).

MANAGING CLIMATE VARIABILITY PER SE—*GRASSLANDS*

Variability in climate implies variability in the feed supply, and hence in the short-term carrying capacity of the sward. Managers usually respond to this by varying the number of livestock grazing their properties. Thus if recent rainfall and current paddock feed is well below average then decisions may be made to sell off classes of stock, usually starting with the oldest and least productive animals. Stock may also be put on agistment by transferring them temporarily to other properties that are experiencing a more favourable season. In areas where transport costs are high relative to the value of surplus stock, then livestock may be shot or even left to starve, although the latter may not be an option where animal welfare legislation is in place.

The majority of traded livestock are bought in good seasons and sold in adverse seasons, and this variation in supply and demand is reflected in their price. Determining the long-term optimal stocking rate, and when and which animals to buy and sell are therefore critical decisions affecting the overall profitability of the farm.

Fodder may be conserved in the form of hay, straw or grain. This can pose a problem in that the higher the stocking rate the greater the need for stored fodder, but the lower the capacity to grow surplus grass to provide hay or straw. Feed wheat can be the cheapest source of energy in a drought, although oaten grain has a higher fibre content so that livestock are less prone to acidosis.

Of course, the cheapest means of fodder conservation is often on the animal's back, so if livestock are in good condition prior to a drought then they should need less fodder reserves to keep them alive. However, higher liveweight is associated with higher maintenance requirements, so a prudent manager will be feeding supplements at a rate that causes them to lose weight to a level that is more appropriate for enduring a drought. If animals are too light in weight then there is a risk of substantial losses associated with malnutrition, disease or inclement weather. Weighing of livestock, and feeding on the basis of nutrient requirements (eg. use GrazFeed software; Freer *et al.* 1997), are therefore appropriate tactics during drought.

Specific research projects currently (or recently) being undertaken in this area include:

- Pasture and forage systems (GRAZPLAN)—Dr John Donnelly, CSIRO Plant Industry (AWRAPO; Australia and Pacific Science Foundation; MLA; Australian Pastoral Research Trust; LWRRDC)

- Strategies to cope with climatic variability in the perennial pasture zone of south-eastern Australia—Mr Stephen Clark, Pastoral and Veterinary Research Institute, Hamilton, Vic. (LWRRDC)
- Grazier-based profitable and sustainable strategies for managing climatic variability (DroughtPlan)—Dr Mark Stafford Smith, CSIRO Wildlife & Ecology (LWRRDC, MRC)
- Estimating safe carrying capacities for grazing properties—Dr Peter Johnston, QDPI (NHT, QDPI, QDNR)
- Rangeland capability assessment in western Queensland—Mr David Cobon, QDPI
- Systems overview of the northern Australian beef industry for optimal management of resources, Mr David Mayer, QDPI
- Improved understanding of the population dynamics of perennial plants important for sustainable sheep grazing and for rangeland monitoring—Dr Ian Watson, Agriculture Western Australia
- Strategies for maximising the persistence of perennial grasses through drought—Dr Jim Scott, University of New England (LWRRDC, MRC)
- Exploiting drought opportunities: control of total grazing pressure of grasslands—Dr Ron Hacker, New South Wales Agriculture (LWRRDC, IWS)
- Management strategies to maximise opportunities for sustainable economic gain in chenopod shrublands—Mr D. Atkins, Agriculture Western Australia (AWRAPO)
- Reclaiming and sustaining productivity of Queensland bluegrass downs—Mr H. Bishop, QDPI
- Improved pasture management and beef production through *parthenium* weed control—Mr H. Chamberlain, QDPI
- Silage systems for beef production and drought feeding for northern Australia—Mr Ken Rich, Agresult, Buderim Qld (MRC, Pioneer Hi-Bred Australia)
- Enhancing profits from poplar box country by tactical pasture management—Dr R. Silcock, QDPI
- Evaluation of the impact of climate change on northern Australian grazing industries—Dr Greg McKeon, QDNR
- Regeneration of drought-affected pastures—Mr G. Lambert, QDPI
- Coping with rainfall variability in tropical savannas—Dr Peter O'Reagain, QDPI
- Optimising phosphorus use in Victoria—Mr Cameron Gourley, DNRE, Vic.

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MANAGING CLIMATE VARIABILITY PER SE—CROPS

Establishing a crop is an expensive operation, yet significant financial returns to cropping are obtained in only about 30% of seasons over much of Australia. Aids to estimating the likelihood of a successful crop are therefore in demand. There is therefore considerable interest in having reliable seasonal forecasts, in determining the most appropriate cultivars and sowing dates for different locations and seasons, in controlling weeds and other impediments to growth and yield, in determining appropriate fertiliser and pesticide applications, in monitoring soil moisture and, where a physical and financially viable option, in irrigating the crop. The number of crops in a pasture-livestock rotation, and the mix of cereal, legume and oilseed crops, can affect soil structure and nutrient status, crop health, grain yield and the financial viability of the farming system.

Specific research projects currently (or recently) being undertaken in this area include:

- Decision support for climatic risk management in dryland crop production—Mr Jim Egan, South Australian Research and Development Institute, PIRSA (LWRRDC, GRDC and RIRDC).
- Seasonal rainfall and winter crop yield forecasting for southern Australia—Mr Jim Egan, South Australian Research and Development Institute, PIRSA (LWRRDC, GRDC and RIRDC).
- Assessing and Forecasting Variability in Wheat Production in Western Australia—Dr David Stephens, Agricultural Western Australia
- The application of climate forecasts to crop management in northern Australia—Dr Peter Carberry, CSIRO/APSRU
- Evaluating the role of seasonal climate forecasting in tactical management of cropping systems in north-east Australia—Dr Roger Stone, QDPI/APSRU (LWRRDC)
- Seasonal climate forecasting to improve industry competitiveness—Dr Russell Muchow, CSIRO Tropical Agriculture (LWRRDC)
- Improving management of seasonal conditions for low rainfall crop production—Mr Jim Egan, South Australian Research and Development Institute, PIRSA (GRDC)
- Developing and promoting systems for managing climatic and spatial risks in dryland crop production—Dr Doug Abrecht, Agriculture Western Australia (GRDC)
- Assessing and managing seasonal risks and opportunities in crop production—Dr Doug Abrecht, Agriculture Western Australia (GRDC)
- Climate risk options for managing frost risk in the eastern wheatbelt—Dr Doug Abrecht, Agriculture Western Australia (GRDC)
- Modelling cropping systems to ensure greater water use and water use efficiency—Dr Ian Fillery, CSIRO Plant Industry, Centre for Mediterranean Agricultural Research, Floreat Park, WA (GRDC)
- Application of a crop model to examine the efficiency and sustainability of wheat farming in Western Australia—Dr Ian Fillery, CSIRO Plant Industry, Centre for Mediterranean Agricultural Research, Floreat Park, WA (GRDC)
- Managing the risks associated with early sowing of lupins—Dr Doug Abrecht, Agriculture Western Australia (GRDC)
- Improved potential yield estimates for farmers and advisers—Dr David Tennant, Agriculture Western Australia (GRDC)
- Analysis of Cropping Systems in Northern NSW using Simulation Models—Dr H. Marcellos, APSRU (GRDC)
- FARMSCAPE—Farmer–adviser–researcher monitoring, simulation, and communication for best dryland cropping practice—Dr Bob McCown, CSIRO/APSRU (GRDC)
- Developing database and knowledge-based resources for commercial advisers using the cropping systems simulator APSIM—Dr Zvi Hochman, CSIRO/APSRU (GRDC)
- Whopper Cropper—a data base and graphics interface to connect crop management advisors with the simulation capacity of APSIM—Dr Graeme Hammer, QCCA/APSRU (GRDC)
- Better management of climate variability within the agribusiness service sector—Dr Peter Carberry, CSIRO/APSRU

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DECISION SUPPORT SYSTEMS

Models and other Decision Support Systems (DSS) have an important role in identifying those management strategies that are financially viable and exposed to minimum physical and financial risk, particularly in areas exposed to a variable climate. Many computerised DSS have a mathematical model at their core. This enables them to simulate the biological relationships and feedbacks between the major components of biological systems. They therefore often contain the information that is most relevant to management about the behaviour of a production system. DSS based on these models are able to mimic the dynamic nature of these biological systems in response to alternative management strategies, technological inputs, and continually varying environmental conditions.

It is nevertheless important to appreciate that DSS are only of value if they are embedded in a broader vision, of acknowledging that DSS are not an end in themselves, but are a very useful, possibly essential tool, in achieving improved management and self-reliance.

There are a number of DSS for analysing climate data, as well as a range of models and DSS to improve the management of the land (Bywater 1990; Stuth and Stafford Smith 1993; White *et al.* 1993). Increased use of these DSS will need a high level of field testing, extensive consultation with users as to their decision requirements, adequate software support, and careful monitoring of their adoption and use.

DSS have applications in other areas of relevance to managing the land within a variable climate. These include land use decisions (choice of enterprise and integration of enterprises at property, catchment and regional scales), management of agricultural and horticultural crops, including diagnosis of crop pests and diseases and integrated pest management (IPM), livestock health and management, managing stream flow, and controlling irrigation systems to increase water use efficiency.

Climate

Australian RAINMAN allows users to determine the probability of rainfall of a given amount in any period of interest, based on the climatic records for different locations over the past 80 or more years. An important feature is the ability to adjust these probabilities according to the Southern Oscillation Index or Sea Surface Temperatures (Clewett and Drosdowsky 1996).

MetAccess allows users to summarise and analyse long-term daily recordings of weather events in a great variety of ways and to display the results in graphical or tabular form (Donnelly *et al.* 1997). A particularly useful feature is its facility for calculating an estimate of the long-term probability of the occurrence of specified weather events or patterns at any locality for which weather records are available. The software makes use of daily meteorological records, including rainfall, maximum and minimum temperatures, evaporation rate and frost occurrence.

Cropping systems

TACT is a tactical wheat sowing decision aid developed by Abrecht and Robinson (1996), initially for the eastern wheatbelt of WA. It incorporates a CERES-based wheat simulation model, a daily rainfall database, average monthly values of other climate data, and sorting and simple economic analysis routines. Outputs from the TACT program include probabilities for wheat yield and profitability under various management regimes, and a suite of rainfall probability statistics, for selected locations. It has been adapted for use in low rainfall cropping districts of SA by inclusion of local rainfall and climate data and modification of soil type options. Validation and modification of TACT for these districts is continuing.

PYCAL (Potential Yield Calculator) is a computer program developed by David and Shaun Tennant of Agriculture WA to monitor current seasonal rainfall against the historic record (rainfall deciles), and to estimate stored soil water and potential yield for a range of cereal, pulse and oilseed crops. Potential yield calculations are based on the growing season rainfall (April to October)/yield relationships developed by French and Schultz (1984). With local modifications and addition of local rainfall decile tables, PYCAL is applicable right across the southern Australian wheatbelt.

SOWHAT is an Excel® spreadsheet template developed by Balston and Egan (in press) as a decision support tool for farmers in areas of South Australia receiving less than 350 mm average annual rainfall. It builds on the work of Huda *et al* (1994) which demonstrated the potential to identify years with a high probability of above average wheat yields (opportunity years) and those with a low probability of good yields (high risk years) in the low rainfall upper Eyre Peninsula on the basis of total rainfall received between 1 April and 15 June, and use this information to develop sowing strategy 'rules of thumb'. SOWHAT enables farmers to use their own farm records to develop their own 'rules of thumb' relating early season rainfall to farm wheat yields. Analysis of a number of farmer data sets from low rainfall districts across SA using SOWHAT has confirmed the importance of early season rainfall in achieving high yields and the value of adjusting crop sowing programs on this basis.

The value of climatic risk information generated by TACT and PYCAL has been tested in farmer decision support trials in various low rainfall districts of WA and SA during the crop sowing periods (April to July) of 1996 to 1998, using a 'fax-back' method to exchange rainfall data and yield and rainfall probability information on a weekly basis. The success of these trials stimulated the development of the Climate Risk and Yield Information Service (CRYIS) by the Kondinin Group, in collaboration with Agriculture WA and PIRSA, and its testing as a pilot commercial service in the eastern wheatbelt of WA and on the upper Eyre Peninsula in SA during 1997 and 1998. The automated data handling, processing and faxing systems developed for CRYIS also offer potential for delivery of other climate, market or technical information direct to farmers on a regular basis.

HOWOFTEN? manipulates rainfall records so that questions like the following may be answered:

How often do I get a planting rain in May? What is the chance of rain at harvest?

How long must I fallow to fill the soil profile? Does the SOI have any influence?

It is therefore useful for identifying when planning opportunities occur, when flooding rains are most likely, if sufficient rainfall has fallen to fill a soil profile, and whether more rain really did fall in the 1950s. Produced by APSRU (QDPI, and CSIRO), Toowoomba and the Queensland Department of Natural Resources, it is available from the QDPI Client Information Centres at Dalby and Toowoomba.

HOWWET? uses farm rainfall records to calculate how much fallow rainfall is actually stored in the soil. The accumulation of mineralised nitrogen is also estimated through the fallow. A better knowledge of soil water and nitrogen status may be useful when deciding how long to fallow, selecting crop type and plant density, choosing pre-crop irrigation requirements and estimating expected yields.

Daily rainfall totals are entered by the user. Weekly evaporation potential and some simple soil properties are retrieved from the program's own database. Calculations also track how stubble cover improves infiltration and reduces soil erosion. Nitrogen estimates are based on relationships between soil moisture, temperature and the amount of organic nitrogen in the soil. Produced by APSRU (QDPI, and CSIRO), Toowoomba and the Queensland Department of Natural Resources, it may be purchased from the Client Information Centre, Department of Primary Industries, PO Box 102, Toowoomba Qld 4350.

APSIM (Agricultural Production Systems sIMulator) has been developed by CSIRO and the Queensland Department of Primary Industries to assist the search for better farming strategies and the development of aids to better production decision making under risk (McCown *et al.* 1996). Changes in the status of soil state variables are simulated continuously in response to weather and management. Crops come and go, each finding the soil in a particular state and leaving it in an altered state. A large number of crop models have now been integrated into the APSIM framework

Temperate grasslands

The *GrazPlan* project of CSIRO Plant Industry (Donnelly *et al.* 1997) is targeting a range of environments differing in soil types and pasture species. Abiotic inputs required for the soil moisture budget and pasture growth models are maximum and minimum air temperature, precipitation, pan evaporation and daylength. Daily radiation is included where available; otherwise it is predicted from latitude, day of year and rainfall. Annual species, perennial grasses and perennial herbs are represented differently in the model on the basis of their morphology and ecology. The rate of net primary production is modelled as a maximum sward growth rate (dependent on the amount of light intercepted), scaled by the lesser of two factors governing the ability of plants in the sward to convert light into biomass. In annual swards, seeds pass from an unripe pool to which assimilate is directed, through a period of innate dormancy, to a pool of seeds in enforced dormancy.

For example, the *GRASSGRO* DSS of Moore *et al.* (1997) contains a library of information on pasture species such as *Phalaris* and subterranean clover (*Trifolium subterraneum*), including their responsiveness to soil moisture on different soil types, the onset of the reproductive and dormant stages in relation to daylength and their potential for growth in relation to temperature. Biomass is divided into four classes: live, senescing, standing dead and litter. Shoot material is further classified into five digestibility classes, ranging from 75–85% digestible to 35–45% digestible material. This provides inputs to another module that simulates diet selection by sheep and cattle and their subsequent productivity; this module also stands alone as the *GrazFeed* model for pasture assessment (Freer *et al.* 1997).

SheepO is a multi-paddock DSS designed to determine the likely outcome in terms of production and financial performance of a wide range of management decisions for sheep flocks in the winter rainfall areas of southern Australia (Whelan *et al.* 1987; Ransom 1992). The program uses pasture growth rates for individual years as the basis of its calculations. First developed in Victoria, its development has continued within New South Wales Agriculture (McPhee 1993).

Tropical grasslands

FEEDMAN is an easy-to-use computer program to help beef producers compare feeding options for growing cattle in terms of forage utilisation, animal performance, market options and economics (Rickert *et al.* 1996, Rickert 1998). It was designed for the 'endowed' zone of northern Australia, the region with relatively fertile soils and effective rainfall in both the warm and cool seasons.

After describing a farm in terms of paddocks, that may contain a range of soil types and forages, monthly forage growth and sustainable stocking rates are calculated in response to monthly rainfall, soil nitrogen status and tree density. Monthly rainfall can be entered directly or be selected from historical records. Also, growing cattle (steers and heifers of different breeds and age) can be allocated to each paddock and FEEDMAN estimates animal liveweight and market options for each mob. An economic assessment of a farm follows. Results appear on the screen and in printed reports. Thus, FEEDMAN evaluates a wide range of management options chosen by the user. Since the reliability of FEEDMAN depends on accurate inputs, key inputs can be changed by the user to reflect local conditions.

Farm descriptions can be stored and recalled for further use or modification. Extensive help notes provide directions and explanations for each component of FEEDMAN.

Rangelands

RANGEPACK (Stafford Smith and Foran 1989) is a strategy assessment tool that follows a herd or flock through successive years to evaluate the lagged effects of climatic fluctuations on herd numbers, allowing the user to follow the gradual implementation of a new strategy. The outcome of the biological and marketing strategies of a property can therefore be followed through good and bad years and linked to economic returns. It has been used to identify optimal drought management strategies for cattle and sheep pastoral properties, respectively (Foran and Stafford Smith 1991; Stafford Smith and Foran 1992).

Crop-livestock integration

Simulation models of agricultural systems are usually specific to one enterprise. However, many farms have more than one enterprise, mixed wheat and sheep farms being common in parts of Australia. Whole-farm models such as MIDAS are in fact mathematical programs that are useful for optimising land use to maximise profit, particularly if different soil types are involved (Morrison *et al.* 1986). Their reliability is greatest if seasonal variability is minimal and an average season is assumed.

Mathematical programs present difficulties in adequately representing the often non-linear nature of biological processes and the marked variation between seasons, particularly as these carryover into subsequent years. Considerable effort has therefore had to be put into *MIDAS* to make it biologically realistic. A more recent version, *MUDAS* (Kingwell *et al.* 1992; Kingwell and Schilizzi 1994; Schilizzi and Kingwell 1999), caters for 11 different types of seasons. Needless to say there is considerable interest by agricultural systems analysts in its performance. For sequences of seasons, use of other models is appropriate.

Mathematical programs have also been used to identify alternative, more profitable pasture-crop rotations in the wheat-sheep zones of Victoria (Oram 1985), New South Wales (Johnston and Matuska 1985) and South Australia (Hansen and Krause 1989).

In theory, rather than linear programming, various versions of non-linear programming could be used, particularly quadratic programming or, more generally, convex programming (but not non-convex as with logistic curves). It is probably more appropriate to deal with non-linear relationships, such as nitrogen-yield relationships, outside the linear program, and then insert the optimal nitrogen input level as a datum into the whole-farm model (S. Schilizzi, personal communication).

Ideally a number of pasture-livestock and crop models could be run simultaneously to predict changes in the productivity and profitability of multi-enterprise farming systems over a range of seasons, and with different combinations of management strategies. The anticipated integration of the GrazPlan and APSIM models should help bring this about (McCown *et al.* 1996). This would enable mathematical programs such as MIDAS to be used more effectively to optimise the land use, taking into account the variability in the climate.

Specific research projects currently (or recently) being undertaken in this area include:

- Decision support for climatic risk management in dryland crop production. Mr J.P. Egan, South Australian Research and Development Institute, PIRSA (LWRRDC, GRDC and RIRDC).
- Improving management of seasonal conditions for low rainfall crop production. Mr J.P. Egan, South Australian Research and Development Institute, PIRSA (GRDC).
- Further development and application of Australian RAINMAN to improve management of climate variability—Dr J. Clewett, QDPI (LWRRDC, RIRDC)
- Using climatic data for agricultural decision making—Dr D.G. Abrecht, Agriculture Western Australia
- FEEDMAN—a pasture and crop decision support system—Dr K. Rickert, University of Queensland (AMRC; Australian Meat Research Committee)
- Pasture and forage systems (GRAZPLAN)—Dr John Donnelly, CSIRO Plant Industry (AWRAPO; Australia and Pacific Science Foundation; MLA, Meat and Livestock Australia; Australian Pastoral Research Trust; LWRRDC)
- Grazier-based profitable and sustainable strategies for managing climatic variability (DroughtPlan)—Dr Mark Stafford Smith, CSIRO Wildlife and Ecology (LWRRDC, MRC; Meat Research Corporation)

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IMPROVING CLIMATE-BASED MEDIA SERVICES

Climate is now better monitored than ever through technologies ranging from satellites to automated weather stations and electronic fieldbooks. Telecommunication services enable the Bureau of Meteorology to quickly acquire information from numerous sources across Australia and around the globe, to process the vast amounts of data through high powered computers, and make the final products (forecasts, tables, maps, video sequences) available to the media and private citizens through fax services and the World Wide Web. As the community becomes more computer-literate, and tools (models and decision support services) are developed that can make use of current and historical data, the demand for such services increases rapidly.

The Bureau of Meteorology is planning to offer a web-based search facility that will allow users to find out what data are available in the Bureau's climate database. This will be linked to the main Bureau site: http://www.bom.gov.au/ and will enable users to submit data requests over the Internet for quotation of costs.

SILO is a web-based information system bringing agriculturally relevant meteorological information and derived products to rural Australia. Already it offers a wide range of agro-meteorological information and comment, with the first collaborative products, developed by QDNR and BoM in conjunction with CSIRO and QDPI, approaching completion. For basic data the Bureau of Meteorology can offer:

- gridded (interpolated) data sites covering Australia at 0.25 degree resolution every day;
- observations from their network of observers across Australia, either by the web or ftp;
- meteogram output from the weather prediction program. This raw data, as used by meteorologists, might be used in research or development of short-term (1–5 days) forecasts, perhaps to assist irrigation scheduling, tactical pesticide application, or run-off containment.

QDNR has developed two additional data sets based on the BoM's basic data, and can offer:

- the data drill, providing a continuous climate data set derived from interpolations. It is available across Australia every 5 km daily since 1957, or since the 1890s for rainfall data only;
- the patched point data set combines observed data with the data drill to give a continuous daily dataset at all Australian RAINMAN stations.

Some of these datasets are available automatically now, either free on the web, or by subscription. Subscription information is available at http://www.bom.gov.au/silo/Subscriptions.html

QCCA is also developing systems to manage an Internet-based information technology service for rural and other clients on climate and related matters. This will be a user pays service, but subsidised by differential pricing for Queensland, Australian (other than Queensland) and overseas clients. Currently about 40% of the internet accesses seeking information from QCCA are from the USA.

QCCA is also producing a multi-media CD-ROM for distribution to client groups. It is now starting to provide media and expertise to foster training in and use of climate forecasting throughout Australia and the world.

Specific research projects currently (or recently) being undertaken in this area include SILO—Agrometeorological information systems—Mr A. Beswick, QNR (LWRRDC).

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Drought mitigation

Droughts are an integral part of a highly variable climate, as exists over much of Australia. They therefore cannot be eliminated. However, preparing for drought can greatly reduce its impact of drought. Fortunately, the recognition of the Commonwealth, State and Territory governments of the need for a National Drought Policy, ratified in 1992, has been accompanied by a proliferation of aids to assist farmers to become more self-reliant.

The first step in planning for drought is to budget for both non-drought and drought occurrences in the year ahead. More precise planning can be done using decision support systems that take account of the wide range of seasons that can be anticipated in any one environment, and relate these closely to the demands of a particular management system. In this way the production and financial consequences of a whole range of strategic and tactical can be determined, along with the associated requirements for fodder and financial reserves to survive below-average seasons.

Seasonal forecasts are one tool that can assist the planning process, though their usefulness varies greatly with location and farming system. It is important to include four possible outcomes in the planning process. There are drought years that are forecast, and those that are not forecast due to inaccurate forecasts. Then there are non-drought years that are forecast, and those that are not forecast. The opportunity costs of the latter can be very high, in that stocking rates could be reduced, or crops not sown, when a drought year had been incorrectly forecast to occur. Farm income can then be well down, despite the occurrence of a relatively good season.

For livestock producers, knowing when and what stock to buy and sell, and how much of what supplement to feed, can make a very large difference to the financial impact of a drought. A trading strategy in which stock are sold at relatively low cost when pastures dry off, and bought in when rains occur and stock prices rise, can lead to significant financial losses. Choice of an appropriate long-term stocking rate, assessment of available feed and rainfall probabilities at critical times of the year (usually pre-summer and pre-winter), which stock to sell when paddock feed is limiting, and an appropriate level of supplementary feed and financial reserves, are all important.

Livestock that are fed to maintain too much weight can be very expensive to retain, whereas those that are too light in weight can be very prone to losses associated with cold, wet and windy weather. Wheat is often the cheapest supplement in terms of energy relative to cost, although it should be introduced gradually over time to the diet to avoid losses through acidosis. Roughage should also be fed to ruminants in late pregnancy or early lactation. The GrazFeed software developed by CSIRO Plant Industry, and distributed through Horizon Software, can assist greatly in determining appropriate rations. New South Wales Agriculture has estimated savings of $7.5 million to graziers in southern NSW farmers through careful rationing in feeding supplements during a severe dry spell in the 1992 drought as a consequence of using this software (Donnelly 1998).

Irrigation is often touted as a means of drought proofing farms, but this is seldom the case in countries where the prices for farm products are not subsidised, and where water is realistically priced. However, irrigation can enable diversification, and allow a range of profitable crops to be produced.

Dryland farmers are well-advised to include drought-tolerant species in their swards.

Specific research projects currently (or recently) being undertaken in this area include:

- Strategies for maximising the persistence of perennial grasses through drought—Dr Jim Scott, University of New England (LWRRDC, MRC)
- Pasture and forage systems (GRAZPLAN)—Dr John Donnelly, CSIRO Plant Industry (AWRAPO; Australia and Pacific Science Foundation; MLA; Australian Pastoral Research Trust; LWRRDC)
- Grazier-based profitable and sustainable strategies for managing climatic variability (DroughtPlan)—Dr Mark Stafford Smith, CSIRO Wildlife and Ecology (LWRRDC, MRC)
- Decision support for climatic risk management in dryland crop production. Mr J.P. Egan, South Australian Research and Development Institute, PIRSA (LWRRDC, GRDC and RIRDC).

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Climate change

Australia's climate is changing. Changes have occurred in the past and will continue to do so in the future. Therefore, adaptation to change is unavoidable, as are the consequent changes in land use and land management. This adaptation is an essential component of sustainable agriculture. If climate change is accelerated by human activities, then adaptation will almost certainly have to be rapid, with increased risks of human suffering and environmental degradation. However, if we devise appropriate proactive strategies to adapt to climate and other environmental changes as or before they occur, then their impact will be lessened.

Global climate models are being developed within CSIRO Atmospheric Research (DAR) to model the enhanced greenhouse effect. While it is important to estimate the likely magnitude of climate change, it is also important to know what is likely to happen as climate changes. This creates a demand amongst both researchers and policy makers for estimates of regional climate changes to provide information on the possible impacts.

LIKELY IMPACTS OF CLIMATE CHANGE

Climate change impacts must be evaluated, a task that requires integration of research. The main objectives of DAR's Climate Impact Group are therefore:

- to provide the best available specific regional estimates of climate change likely to be experienced in Australia, quantifying and reducing the uncertainties as far as possible, and identifying possible impact areas;
- to provide scenario output data in the most appropriate form for use in impact studies, and to

collaborate as far as possible with local or specialised groups and experts in the evaluation of such impacts.

To address the above objectives, the Climate Impact Group must critically assess all possible sources of information on future climate change. This includes historical and palaeoclimatic data, but concentrates on GCMs and limited area models. Particular attention is being paid to obtaining information at finer spatial scales, down to the small catchment scales of tens of kilometres. This requires the preferential use of higher resolution GCM results, nested limited-area models, and spatial interpolation techniques. Sensitivity studies using stand-alone limited-area models are being performed on particular synoptic events that currently are too small to be modelled in detail in GCMs.

Collaborative studies are being undertaken on a range of possible impact areas, including agricultural, hydrological and coastal impacts. Recent initiatives include the development of new climate change scenarios for Australia, and the development of OzClim, a climate scenario and impacts package for use on personal computers.

The Queensland Departments of Natural Resources and Primary Industries have been particularly active in studying adaptation to climate change. McKeon *et al.* (1993) suggest that adoption of new practices will require confidence that climate change can be separated from the naturally high year-to-year variability in rainfall that characterises these systems:

- the motivation to change based on the perceived risk and opportunities of climate change;
- development of new technologies and demonstration of their benefits;
- protection against establishment failure of new practices during less favourable climate periods; and
- alteration of transport and market infrastructure to support altered production.

They further propose that recently improved seasonal forecasting skill, based on increased understanding of the El Niño–Southern Oscillation and/or the use of general circulation models in real time, can be used to adapt grassland management to climate change. By linking management decisions with respect to say stocking rate, pasture burning, forage cropping, animal supplementation and herd management to forecasts of above- or below-average rainfall, management would 'drift' in the right direction thereby adapting to a new, if uncertain, climate regime.

Given the highly variable nature of our climate, it is difficult to ascertain just what changes are likely to take place over the next 50 years. For example, the exceptionally dry period in the early 1990s over much of eastern Australia was preceded by above-average rainfall years, particularly in the 1970s. However, if one goes further back into the climate records, especially pre-European as indicated from river and lake sediments, coral cores and tree rings, one can find ample evidence of much more horrendous droughts.

There is some evidence that daily maximum, mean and minimum temperatures are increasing, but not in a uniform manner across Australia. Average minimum May temperatures have increased by 0.7°C a decade over the past 40 years in Queensland's pastoral and cropping zone, which has significance for agriculture particularly in terms of anticipated increased growth of tropical grasses (McKeon *et al.* 1998).

The most probable scenario for climate change across Australia is for more extreme events in terms of droughts and flooding rains, the latter being accompanied by an increased frequency and intensity of cyclones crossing the Queensland coast. A southerly shift in our weather systems is also anticipated, the monsoonal rains and warmer weather that typifies our tropics and sub-tropics extending further south. This would be expected to be accompanied by southerly migration of tropical pests and diseases.

Specific research projects currently (or recently) being undertaken in this area include:

- CLIMARC—Computerising the Australian Climate Archives—Mr Nick Clarkson, QCCA (LWRRDC)
- A Century's perspective on climate variability and impacts on agriculture—Dr Bill Wright, BoM (LWRRDC)
- Adapting to climate change on the Eyre Peninsula, South Australia, 1900–1990—Dr Les Heathcote, Flinders University
- Learning from history: preventing future land and pasture degradation under climate change—Dr Greg McKeon, QDNR

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GREENHOUSE GAS EMISSIONS

Components of agricultural systems act as sources and sinks of greenhouse gases, notably methane, nitrous oxide and carbon dioxide. Ruminant livestock, for example, belch up significant quantities of methane gas, whereas forest plantations can be significant carbon sinks. Many reliable agronomic models can, with only minor modification, be adapted to estimate the effects of changes in management on agricultural systems. Systems analysis approaches based around such models can therefore be used to estimate the consequences of changing management strategies on levels of emissions (Boag *et al.* 1994). Thus increasing stocking rates lead to higher levels of emissions. Specific examples include Howden and O'Leary (1995) for cropping systems, and Howden *et al.* (1993, 1994, 1996) for ruminant livestock systems. In general, it would appear that management practices that help limit greenhouse gas emissions from the agricultural sector are also more likely to be considered sustainable in terms of land management.

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Climate and animal disease

The effect of climate on an animal disease varies considerably depending on the disease, and on the management and husbandry systems used. Here we briefly describe various types of interaction between climate and disease through a number of examples, using work from a number of recent studies in Australia.

For some diseases, climate factors may determine the pattern of the disease through direct effects on the distribution of the agent. Screw-worm fly (SWF) is a case in which the disease is the pest itself. Although SWF is not found in Australia, it is considered a serious threat to Australia's livestock industries, and studies have been undertaken to determine the areas at risk if it were introduced, and optimal control strategies.

Climate may modulate the persistence and expression of a disease. Anthrax, which can affect a wide variety of domestic and wild animals, and humans, is an example of this type of interaction.

More complex interactions between climate and disease can occur if there are multiple hosts and vectors involved. Arboviral diseases such as bluetongue and Akabane in animals, and Japanese encephalitis and Ross River virus in man, fall into this category.

For other diseases, spread may usually be determined primarily by local conditions, but under certain circumstances, climatic factors can play a significant role. Foot-and-mouth disease (FMD) is an example of such a disease. Although it is spread mainly by close contact between susceptible animals and infected animals, suitable weather conditions can in some situations lead to long distance spread of airborne virus. FMD is considered one of the most serious diseases of livestock and because of its potential to cause major disruptions to Australia's trade in livestock and livestock products has been the subject of intensive study.

Because of the complexity in the interaction between climate and disease, multi-disciplinary approaches involving skills in epidemiology, modelling, meteorology and geographic information systems are often required to understand and study the processes involved. Some recent examples of modelling studies undertaken in Australia are described below.

SCREW WORM FLY

Screw-worm flies (SWF) are obligate parasites of warm-blooded animals, including humans. Adult SWF lay their eggs on the edges of wounds and the larvae burrow into the underlying tissues to feed on blood. Parasitism of animal tissues by SWF larvae (myiasis) causes serious production losses. Although female SWF may range for up to 25–50 km in search of wounded animals in which to lay eggs, they do not actively migrate. SWF prefer moist well-shaded areas and are unlikely to survive in completely open country, particularly if subjected to intense heat and low humidity. The optimal temperature range for the fly is 20–30°C. Flies will not move at temperatures below 10°C, and in the range 10–16°C they are very sluggish and probably will not mate (DPIE 1996).

Simple climate-matching models, such as Climex or Bioclim, can indicate both sporadic and potential endemic areas in which the pest could survive over winter (Sutherst and Maywald 1985). Mayer *et al.* (1994) reported on a more comprehensive assessment of potential SWF abundance and spread using a hybrid simulation technique incorporating deterministic simulation models and a geographic information system (GIS). This work has formed the basis of a bioeconomic decision-making tool developed by the Queensland Department of Primary Industry to assist with the management of a SWF incursion.

ANTHRAX

Anthrax is caused by a spore-forming bacterium. It is endemic in many countries of the world, particularly in tropical and sub-tropical areas, but the disease is usually only seen in well-defined endemic areas where environmental conditions appear particularly favourable for the survival of the spores. Anthrax spores are very resistant to inactivation and can persist in soil for many years, particularly in warm climates and in soils with a neutral to alkaline pH and that contain organic matter. Environmental factors that contribute to the risk of disease include soil type and weather conditions. To some extent, the soil type might be considered a 'static' variable. Outbreaks tend to be associated with periods of hot, dry and humid weather—conditions that enable anthrax spores to germinate and generate higher numbers of spores in favourable niches that could infect susceptible animals. Drought is another factor—stock ingest more soil while grazing, and this can increase the chance that spores are ingested.

A review of the 1997 anthrax outbreak in Victoria highlighted the importance of weather conditions as a predisposing factor for the outbreak (Galvin 1997).

BLUETONGUE

Bluetongue is an insect-spread disease of ruminants characterised by inflammation, congestion, swelling and haemorrhages. The disease is variable in severity. Sheep are generally the worst affected, with cattle having milder disease. For Australia, where bluetongue infection without clinical disease is recognised, it is an important issue in the export of cattle and sheep. Hence, there has been considerable interest in describing the relationship between presence of the virus and climatic factors. Statistical models, using a variety of techniques have been developed (eg. Wright *et al.* 1993, Ward 1994, Ward and Thurmond 1995).

More recently, Ward and Carpenter (1996a, 1996b) have used simulation modelling to investigate infection of Australian cattle herds with bluetongue viruses.

In 1997, the Australian Quarantine and Inspection Service (AQIS), commissioned a study into the feasibility of developing a forecasting system for bluetongue transmission based on existing data, with a view to better management of the arboviral risks in the live cattle export trade. Following a positive report by the consultants, AQIS sought tenders for the development of a computerised area forecasting system that would permit regionalisation for bluetongue in Australia that is dynamic, taking into account the variability of climatic conditions which control the distribution of bluetongue virus vectors. Ausvet Animal Health Services subsequently assembled a multidisciplinary team that includes experts from the private sector, from the NSW Department of Agriculture, Commonwealth Bureau of Resource Sciences, Northern Territory Department of Primary Industries and Fisheries, Queensland Department of Primary Industry and Agriculture Western Australia to undertake this project which is due to be completed in 2000.

JAPANESE ENCEPHALITIS

Japanese encephalitis (JE) is a mosquito-borne disease that occurs over much of Asia. Humans, horses and pigs are at risk of clinical disease, with pigs being very important amplifying hosts. For other species—cattle, sheep, goats and some wild species—infection is rarely clinically apparent. Water birds (herons and egrets) are the main reservoir and amplifying hosts for the virus. Their migration also has the potential to spread the disease considerable distances. A number of different mosquitoes can act as the vector to spread the virus, both between birds and also to and between other hosts (DPIE, 1996).

In 1995, JE reached the northern tip of Australia. Mosquitoes capable of spreading the disease exist throughout Australia, although it is not known how efficient the species of mosquito in Australia will be as vectors. Assessing the risk of the disease spreading to different parts of Australia, and the seasonal changes in potential levels of disease is complex. Such assessment needs to take into account the interactions between populations of the various hosts and vectors. To a large extent, the environmental component is concerned with estimating the population dynamics of the vector and requires information about temperature, humidity, rainfall, and surface water. The Bureau of Resource Sciences (BRS) has undertaken an assessment of potential spread of JE in Australia using a GIS approach.

BRS is also working with the National Centre for Epidemiology and Population Health, ANU using modelling and GIS to study another important arboviral disease in Australia, Ross River fever.

FOOT-AND-MOUTH DISEASE

FMD is one of the most contagious of animal diseases affecting cloven-hoofed animals. It spreads rapidly through a farm and to adjoining farms by close animal-to-animal contact. Animals are infected by ingesting or, especially for ruminants, by inhaling the virus. Australia is free of FMD and maintains strict quarantine controls on animals and products from infected countries. Contingency plans (DPIE, 1996) are in place to eradicate the disease should it be introduced.

The BRS has developed a sophisticated FMD simulation model. This has been used to assist disease planners by predicting the potential size, duration and impact of FMD outbreaks under Australian conditions (Garner 1993, Garner and Lack 1995a), and to evaluate various control strategies (Garner and Lack 1995b, Garner *et al.* 1997).

The major method of spread of FMD is by the movement of infected animals or contaminated products or equipment. However, under the right conditions—a concentrated source of the virus, high humidity, stable atmospheric conditions and presence of susceptible livestock downwind—long distance spread by wind can occur. Although it is thought that most wind-borne spread over land travels less than 10 km, there is good evidence that spread of FMD has occasionally occurred over distances of 60 km over land, and 250 km over water (Hugh-Jones and Wright 1970; Gloster *et al.* 1982). Studies in New Zealand indicate that meteorological conditions favourable to wind-borne spread occur there. Sanson *et al.* (1991) describe a computerised disease recording and information system (EpiMAN) developed at Massey University for use in an exotic disease emergency. The system incorporates a database management system, a GIS, a simulation model for FMD, a virus plume model, and expert system elements. The system is being adapted and tested for use in Europe.

Recognising the importance for animal health authorities to have an indication of the potential for windborne spread of FMD under Australian conditions, in 1994 the Meat Research Corporation commissioned a study on this issue. Weather records and livestock distribution data were used to identify areas at risk. Aerosol virus production and extent of spread that could be expected from typical Australian livestock enterprises was modelled. The study involved the use of viral production models, plume models, deposition models and geographic information systems to integrate and analyse the available data (Garner and Cannon 1995).

Projects, contacts and institutions

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Services

The principal information base for describing the climate of Australia, its variability and its long-term trends is provided by the Bureau of Meteorology which has national responsibility for meteorological (including climate) monitoring (Anon 1997). It operates the official national climate observing infrastructure and the National Climate Centre (NCC), the latter being the custodian of Australia's historical climate record. The NCC has responsibility for collecting and maintaining data relevant to Australia's climatological data archive, and for establishing appropriate quality control, data storage and access systems. The historical records held by the Bureau provide an essential basis for the study of the climate of Australia and the globe, and for assessing climate variability and climate change in the region. There are approximately 65 gigabytes of climatological data stored in the Australian Data Archive for Meteorology (ADAM), the on-line archive. On-line access to archive data is possible through SILO (Special Information for Land Owners; http://www.bom.gov.au/silo), a joint initiative of the Bureau of Meteorology, the Queensland Department of Primary Industries and the Queensland Department of Natural Resources, developed with funding from LWRRDC and RIRDC. This provides real and historical rainfall, temperature, humidity and drought analyses, along with agricultural information. Both public interest information, and tailored information available via subscription, may be accessed from this site.

A number of other organisations, including the National Tidal Facility and a number of State agricultural, forestry and water resource agencies, also operate observations networks which make an important contribution to the national climate record. The Bureau promotes the application of climate data and provides data to users both through advertised data services, such as publications and polling fax systems, on-line through the World Wide Web at http://www.bom.gov.au/ and http://www.bom.gov.au/silo, and on request. Climate data are also available through the Long Paddock site of the Queensland Department of Natural Resources http://www.dnr.qld.gov.au/longpdk.

Monthly rainfall data for about 4,500 locations around Australia are available with the Australian RAINMAN package, distributed by QDPI and BoM. Rainfall probabilities may be calculated from recent values of the Southern Oscillation Index or Sea Surface Temperatures in the Indian Ocean. Historical daily climate data may be analysed using MetAccess software, developed by CSIRO Plant Industry and distributed through Horizon Software.

Short-term weather and longer-term climate forecasts are made available through the media, including newspapers, radio, television and the World Wide Web. The former include the daily and 3–5 day rainfall and temperature forecasts that are released every few hours, along with specialist forecasts concerning inclement weather that threatens horticultural and agricultural crops, and the survival of livestock (especially new-born lambs and calves and shorn sheep). This includes cold, wet and windy weather, frost occurrences, or warm humid conditions that favour fungal spores which could infect plants or livestock.

Promotion of climate data applications at field days, agricultural shows, and through the media and farmers' groups and organisations, is actively undertaken by the Bureau of Meteorology and State agricultural and primary industry agencies. One of the most popular climate educational kits has been the video and work manual *Farming a Sunburnt Country*. The kit is designed to build an awareness of the value of using historical weather records, decision support systems and climate prediction tools in managing on-farm decisions, such as crop planting and stock numbers.

State agricultural agencies continue to promote the use of climate information through workshops conducted under the Property Management Planning Program, particularly in Queensland and New South Wales. These are aimed at increasing the ability of farmers to manage climatic opportunities and risks, and thus be more self-reliant despite the high variability of the climate and product prices. This is consistent with the aims of the National Drought Policy, which highlights the need for farmers to be able to plan for and manage these risks and the physical and financial components of their farming businesses.

The Queensland Centre for Climate Applications also provides a climate forecasting and advisory service to farmers through its climatologist, Dr Roger Stone, based at Toowoomba. Climate information is available via a telephone answering service (SOI Phone Hotline: (07) 3896 9602), by infofax (SOI Fax Hotline: 1902 935 300; Farmfax (07) 3222 2996) and via The Long Paddock site on the World Wide Web, http://www.dnr.qld.gov.au/longpdk

New South Wales Agriculture is also establishing a climate information service for farmers (Harpal Mavi, pers. comm.). Only the Regional Reviews are accessible on the web site at this stage at http://www.agric.nsw.gov.au

Agriculture Western Australia makes near-real-time predictions of crop yields for the major producing shires (counties in South Australia) across the Australian wheatbelt. These are made available to the public on about the second Friday of each month throughout the growing season (July to December). These may be accessed on the web at http://www.agric.wa.gov.au/ climate. These maps are also published in the *Profarmer* magazine distributed by the Kondinin Group and will appear in the District Reports section of *Australian Grain*. A colour map of plant available soil moisture around sowing time (31 May) across Western Australia is also produced in early June and then placed on the web.

Agricultural forecasts, warnings and services (Bureau of Meteorology)

Summary weather forecasts are issued four times a day for each State and Territory for about the next 24 hours. Warnings of forecast hazardous weather, including tropical cyclones, conditions favourable for the generation and rapid spread of bushfires; gales (wind speed greater than 63 km/h), severe thunderstorms (including damaging wind gusts, large hail, very heavy rain or tornadoes), and floods are also provided. This information is disseminated via the media, including radio, television and newspapers, and via the internet (http://www.bom.gov.au), dial-up telephone services (Weathercall; phone: 0055 33551), and Infofax—a Telstra-polled fax information service providing weather reports and forecasts, weather charts and satellite images (phone: 019 725 001). A range of hardcopy and on-line subscription services are also available, more information being available from Bureau offices. In addition, there are specific agricultural forecasts, warnings and forecasts available in each State and Territory:

WESTERN AUSTRALIA

Warnings for sheep farmers:

- a warning of cold, wet and windy conditions when newly shorn sheep or newly born lambs will be at risk;
- based on results from field experiments relating chill factor to wind speed, rainfall and temperature values;
- issued year round.

Frost risk forecasts:

- a frost indicator (eg. scattered, widespread);
- issued year round for the Geraldton area;
- issued from April to May to the end of the year for the south-west district.

Contact: Regional Director, Western Australia, Bureau of Meteorology, P.O. Box 1370, West Perth, WA 6872.
Tel: (08) 9263 2222

SOUTH AUSTRALIA

Warnings for sheep farmers:

- a warning of cold, wet and windy conditions when newly shorn sheep or newly born lambs will be at risk;
- based on results from field experiments relating chill factor to wind speed, rainfall and temperature values;
- issued year round.

Frost risk forecasts:

- for Riverland, Murray Bridge, Salisbury, Two Wells, Virginia and the Barossa Valley;
- issued from mid-May to mid-November.

Downy Mildew service:

- operates on an *ad hoc* basis at the appropriate time, through consultation between the Department of Agriculture and the Bureau of Meteorology;
- seeks to inform viticulturalists whether rain and humidity over a three- to four-day period are critical to the development of infection.

Forecasts for fruit drying:

- specific advice for fruit growers is broadcast over the Country Hour program of the ABC;
- operates during the summer months.

Warnings for barley growers:

- warnings of prolonged periods of hot, dry, strong winds for the Yorke and Eyre Peninsulas;
- issued during November and December.

Contact: Regional Director, South Australia, Bureau of Meteorology, GPO Box 421, Norwood, SA 5067.
Tel: (08) 8366 2600

VICTORIA

Warnings for farmers and graziers:

- a warning of unseasonable wet and windy conditions when vulnerable stock will be at risk;
- based on results from field experiments relating chill factor to wind speed, rainfall and temperature values;
- issued September to April inclusive.

Frost risk forecasts:

- overnight minimum air temperatures of minus 2°C or lower over a significant areas are expected (June to mid-August);
- overnight minimum air temperatures of 0°C or lower over a significant area expected (remainder of the year).

Warnings of weather conducive to the spread of plant disease are issued to fruit growers:

- Brown Rot warnings (January to March)

Forecasts for fruit drying:

- specific forecasts and advices for the Sunraysia district for the fruit drying period;
- recorded information service which includes up-to-date radar information;
- issued February to mid-April.

Contact: Regional Director, Victoria, Bureau of Meteorology, GPO Box 1636M, Melbourne, Vic. 3001. Tel: (03) 9669 4000

TASMANIA

Warnings for sheep farmers:

- a warning of cold, wet and windy conditions when newly born lambs and newly shorn sheep will be at risk;
- based on results from field experiments relating chill factor to wind speed, rainfall and temperature values;
- issued throughout the year.

Evaporation data for irrigation and water loss applications:

- Class A pan evaporation data for eight locations are published daily in the three main newspapers, weekly in the *Tasmanian Country*, and broadcast daily.

Contact: Regional Director, Tasmania, Bureau of Meteorology, GPO Box 727G, Hobart, Tas 7001. Tel: (03) 6221 2000

NEW SOUTH WALES

Warnings for sheep farmers:

- a warning of cold, wet and windy conditions when newly born lambs and newly shorn sheep will be at risk;
- based on results from field experiments relating chill factor to wind speed, rainfall and temperature values;
- issued year round.

Forecasts for cane firing:

- wind forecasts are prepared daily for the Tweed, Richmond and Clarence Valleys;
- issued June to December inclusive.

Contact: Regional Director, New South Wales, Bureau of Meteorology, GPO A737, Sydney South, NSW 2000. Tel: (02) 9296 1555

QUEENSLAND

Forecasts for cane firing:

- wind forecasts are provided for cane-firing for the following areas: Babinda, Ayr, Cairns–Mossman, Mackay–Proserpine, Bundaberg–Childers, Moreton;
- issued mid-June to December.

Warnings for sheep farmers:

- a warning of cold, wet and windy conditions when newly born lambs or newly shorn sheep will be at risk;
- based on results from field experiments relating chill factor to wind speed, rainfall and temperature values;
- issued as necessary.

Contact: Regional Director, Queensland, Bureau of Meteorology, GPO Box 413, Brisbane, Qld 4001. Tel: (07) 3239 8700

NORTHERN TERRITORY

Frost risk forecasts:

- a frost risk is appended to the Alice Springs forecast issued from May to September inclusive.

Contact: Regional Director, Northern Territory, Bureau of Meteorology, GPO Box 735, Darwin, NT 0801. Tel: (08) 8920 3800

NATIONAL CLIMATE CENTRE

Seasonal Climate Outlook

The Seasonal Climate Outlook gives seasonal (three-month) rainfall risk assessments, outlining the probability of the rainfall total for the subsequent three months being in the lowest one-third of historical falls, the middle one-third, or the upper one-third. The Seasonal Climate Outlook (SCO) is available in two forms:

- a two-page media release, usually issued in the second week of the month, faxed to media and other organisations, available on WeatherByFax (1902 935 251, 60c per minute) and on the web at http://www.bom.gov.au/climate/ahead/rain_ahead.shtml
- a 22-page booklet, available in printed form and in electronic form (PDF format) via the web at http://www.bom.gov.au/silo/products/SClimate.html

  The SCO contains the rainfall risk assessment for Australia, in map form, tabular form for the Bureau of Meteorology rainfall districts and towns around the country, official Troup SOI value for the most recent month, SOI analogues and information concerning rainfall outcomes for the analogue years, stratified climatological rainfall probabilities based on recent values of the SOI, southern and northern wet season reports, recent rainfall descriptions and maps, recent sea surface temperature anomalies, and a six-month NINO3 prediction. Current cost is $130 per year for print form or electronic form, $200 per year for both forms.

Contact: Mr. Grant Beard, Climate Analysis Section, National Climate Centre, Bureau of Meteorology, GPO Box 1289K, Melbourne VIC 3001, Tel: (03) 9669 4527, Fax: (03) 9669 4678.

Climate Monitoring Bulletin

Technical publication reporting monthly on the recent climate of Australia and the Southern Hemisphere. Contains recent climate indices, global analyses and anomalies of atmospheric and oceanic variables, descriptions and maps of recent Australian rainfall and temperature patterns, ozone reports, and reports from the National Tidal Facility. Available by subscription, and published by the National Climate Centre, Bureau of Meteorology.

Contact: Mr. Grant Beard, Climate Analysis Section, National Climate Centre, Bureau of Meteorology, GPO Box 1289K, Melbourne VIC 3001, Tel: (03) 9669 4527; Fax: (03) 9669 4678.

Rainfall reports

One and three month rainfall percentiles and isohyet analyses for Australia. This is available on WeatherByFax (1902 935 262, five pages, 60c per minute), or on the web at

http://www.bom.gov.au/climate/current/rainfall_1month.shtml,
http://www.bom.gov.au/climate/current/rainfall_3month.shtml,
http://www.bom.gov.au/climate/rainmaps/montha.shtml,
http://www.bom.gov.au/climate/rainmaps/montha3a.shtml,
http://www.bom.gov.au/climate/rainmaps/monthda.shtml,
http://www.bom.gov.au/climate/rainmaps/monthd3a.shtml

This information is also contained in the Seasonal Climate Outlook booklet (see above). Rainfall totals for selected sites around Australia are also included in the WeatherByFax version.

WeatherByFax (1902 935 261, four pages, 60c per minute). This contains a description of recent rainfall, map, and totals for selected totals around Australia.

Private forecasting services

Australia has a number of private forecasters including the following.

AGRICULTURAL WEATHER SERVICES

Agricultural Weather Services (A Division of WeatherNews Pty Ltd), Suite 4, 25 Prospect Street, Box Hill, Vic, 3128.

Mr Rob Cowle (Manager): Tel: (03) 9899 3140; Fax: (03) 9899 3141; rob@wni.co.jp

Mr Sylvio Desvaux (Climatologist): Tel: (08) 9387 7955; Fax: (08) 9387 6686; sylvio@perth.wni.com

Agricultural Weather Services (AWS) has been preparing seasonal weather outlooks since 1984. Initially the information was prepared for the offshore petroleum industry and for the broad-acre farming areas of Western Australia, but has since been expanded to cover the whole of Australia and adjacent waters. Services are offered to clients involved in the agricultural, pastoral, mining, construction and leisure industries in all parts of Australia.

AWS's services offered by subscription include:

- Seasonal outlooks for the following 12 months with monthly rainfall range—issued quarterly in February, May, August and November.
- Indications of the probability of normal, below or above normal rainfall for the next three months, issued each month.
- Lists of anticipated rain-dates for the next two months.
- Short-term forecasts by telephone for particular farming operations are available.
- Outlooks for the Tropical Cyclone season of tropical cyclone and wet season activity and distribution—issued annually in October.
- Monitoring during the tropical cyclone season.
- Forecasts relating to individual tropical cyclones.

In the preparation of the outlooks of both seasonal rainfall and tropical activity AWS uses statistical analogue techniques supported by consideration of current dynamic features of the atmosphere/ocean system. The techniques are applications derived from the work of many published authors and internal research by AWS. The correlations of the SOI, Tahiti and Darwin atmospheric pressure with those of previous years are of fundamental consideration as are the sea surface temperature distributions over the Southern Hemisphere in particular. Selected years are ranked according to their corresponding values and trends. The distributions and trends of the relevant parameters in the analogue years are used as 'first guess' weighted predictors of their distributions in the forthcoming seasons. These outputs are modified accordingly to incorporate the current atmospheric dynamics such the frequency and intensity of tropical cloud bands, southern cold fronts and the long wave pattern in the mid-troposphere.

As well as supplying the information to subscribers by post, fax and electronically, AWS operates for general use an Infofax sevice covering a wide range of forecast and data products. Telephone discussions with the duty forecaster on the shorter term weather trends are available on 1902 210 221. AWS has a website which may be accessed at http://weather.foxtel.com.au

HEAVENLY GREEN

Mr David Florian, Tel: (03) 9716 2458;
Fax: (03) 9718 1577

The service provided by Heavenly Green is based on the assumptions that the sun's movements influence temperatures on Earth, and that Mercury controls wind patterns. The incidence of fog, rain, snow and hail is attributed to the moon, which also influences temperature.

HOLTON WEATHER FORECASTING PTY LTD

Mr Ian Holton, PO Box 728, Nairne SA 5252;
Tel: (08) 8388 6700; Fax: (08) 8388 6788;
holton7@senet.com.au

Holton Weather Forecasting provides weather services for crop growers, graziers, horticulturalists, irrigators and the general agricultural industry in the south-east Australian agricultural area, including South Australia, Victoria (except Gippsland), southern and central New South Wales, and northern Tasmania.

Holton long-range weather forecasts have been scientifically proven over an independent 15 year period to forecast rainfall for the growing season with a correlation of 0.7 to 0.9 (on a scale of 0 to 1) over almost all the cropping regions of south-eastern Australia (Holton 1998). Shorter range 10-day weather forecasts have proven to be of high value for farming decisions. In 1997, they predicted the significant August, September and October rains approximately one week before each event. In 1998 the 10-day forecasts have again performed at a high accuracy, predicting the two 'season-break' rainfalls approximately ten days before each one occurred. Based on past experience, the 10-day forecasts could be expected to continue to perform around the 80% accuracy level in the future.

Holton weather forecasts are based on upper level wind patterns, surface pressure observations, and computer rainfall models, all of which use input data from the northern and western areas of Australia and from the Indian Ocean.

The Holton Weather Package comprises (1) long-range growing season rainfall forecasts, (2) weekly 10 day weather forecasts, and, (3) telephone access. This package is designed to give total weather support to your farm or horticultural business. The long-range rainfall forecast for the coming growing season is first issued in early November, the year prior to the growing season, to enable farmers to make long-term decisions well in advance. It is then updated in early March, April, May, June, etc through to December to help you with agricultural decisions throughout the growing season. The 10-day weather forecasts are faxed, e-mailed or posted to clients each Friday from March to December, enabling them to plan their farm activities for the following week The telephone service is available on most week days during specified hours.

References

Holton, I. (1996). Seasonal and yearly prediction of rainfall and crop yields in Australia. *Proceedings of the Second Australian Conference on Agricultural Meteorology*, 1–4 October 1996, The University of Queensland, pp. 127–129.

Holton, I. (in press). Prediction of growing season rainfall and crop yields in southern Australia. *Australian Meteorology Magazine*.

Holton, I. and Egan, J.P. (1997). Developing better forecasts for seasonal rainfall and crop yields in southern Australia. In *Proceedings of Farming Systems Developments 1997 Workshop*, Adelaide, March 1997, pp. 189–191.

LAMOND WEATHER SERVICES

Mr M.H. (Mal) Lamond, Principal, Lamond Weather Services, 6/117 Broadway, Nedlands W.A. 6009.
Tel: (08) 9386 2645; Fax: (08) 9386 2646;
lamond@iinet.net.au

Austweather Pty Ltd was the predecessor of Lamond Weather, and was the first (1983) private weather service in Australia to offer seasonal outlooks based on ENSO concepts. In 1992 Austweather became Lamond Weather Services and continues to provide seasonal, year-long and short-term forecasts to clients throughout Australia and south-east Asia.

Lamond Weather provides seasonal and year long outlooks with lead times of 15 months. Assessment of these outlooks has shown significant scientific skill (Smith 1994). It also provides special climatological information for individual farmers, pastoralists, horticulturalists and other primary producers, as well as clients in mining and other industries. Almost a third of clients are in each of Western Australia, South Australia and Victoria, with a few in Queensland and New South Wales.

At around September/October a comprehensive outlook is produced for the following year. For each of the Bureau of Meteorology Rainfall Districts, forecasts are provided for the ensuing four quarters, the timing of the autumn break, growing season rainfall and annual rainfall. This outlook is accompanied by a description of the basis of the forecast, and the most appropriate analogue year. There are monthly updates to this forecast, keeping the end-date constant.

The forecasts are based on an assessment of global and Southern Hemisphere circulations and ocean anomalies. Contact is maintained with national and overseas meteorological authorities which make routine assessments of changes in global weather developments, including the Southern Oscillation–El Niño events, and the periodic shifts in the blocking patterns that affect the motion of long atmospheric wave patterns around the southern hemisphere. Recent developments include extension of the service to forecasting the value of the Southern Oscillation Index over the next three to four months.

Reference

Smith, I. (1994). Assessments of categorical rainfall predictions. *Australian Meteorology Magazine* **43**, 143–151.

LEON MORANDY

Mr Leon Morandy, 53 Kinsellas Road, Mango Hill Qld 4509; Tel: (07) 3203 1856; Fax: (07) 3203 1856

Annual forecasts for Queensland and northern New South Wales are distributed late in the year to farmers, gardeners and other clients. Weekly updates are also provided to clients, and to the media. These forecasts are based on predicted tidal heights.

WEATHERWATCH (AUST.) RURAL SERVICES

Mr Don White, WeatherWatch (Aust), PO Box 37, Frenchs Forest, NSW 2086; Tel: (02) 9451 7102; Fax: (02) 9975 1608; Mobile: 0417 248 705; donwhite@ozemail.com.au

1. *The WeatherWatch Subscription Service* has been developed to meet the specific requirements of primary producers who could gain commercially from short, medium or long term weather outlooks and assessments. These are geared especially to their individual needs, and specifically referring to their region of interest and to the meteorological variables that are important to their particular operation. A feature of the service is the emphasis on individual contact between the clients and the forecasters, which provides the flexibility of satisfying weather queries on the spot, when variations in temperature, rainfall, wind etc could be of critical economic importance to their operations. By arrangement, a special watch can be kept of developments that could cause problems to clients, so that they can be advised as early as possible of sudden or unexpected changes.

   The main feature of the service is the provision of monthly and seasonal assessments sent to clients around the 2nd week of each month. They include analysis of the likely weather developments in the coming six weeks, mindful of the clients' special needs, as well as a broader assessment of the way the following two to nine months are shaping up. Probability forecasts allow clients to make a final judgement.

   The WeatherWatch Subscription Service is joined for a period of 12 months. In addition, clients automatically become members of the WeatherWatch Verbal Service and can receive a short term (up to five days) outlook for their area at any time they require. They can also seek a more detailed discussion with the Service's duty forecasters about the way the weather is shaping up in their region and the signs to look out for. Joint Membership is available so that up to three neighbours can join the one service, thereby sharing the cost. All will receive full benefits of membership and their own monthly reports. The WeatherWatch Subscription Service (Rural) is also available to larger groups. Any number of individuals can join this service if they are in a meteorologically uniform area, subject to certain conditions:

2. *The WeatherWatch Verbal Service* has been developed to meet the specific requirements of primary producers who require occasional weather information for specific purposes at various times throughout the year. This requirement can often be satisfied by a discussion with a forecaster on the way the weather is shaping up and by an opportunity to ask specific questions related to the clients' individual requirements.

   The WeatherWatch Verbal Service is joined for an annual fee after which a client will be sent a membership number and information on how to use the service. This service provides:

   - short term forecasts for a client's area—up to 4–5 days ahead, including probability assessments;
   - assessments on how the weather patterns are shaping up;
   - general services.

WeatherWatch (Aust.) also offers an extensive range of short and long term weather forecasts and assessments, as well as information services.

WORLDWEATHER ENTERPRISES

Mr Haydon Walker, Worldweather Enterprises, Crohamhurst Observatory, P.O. Box 110, Roma Street, Brisbane, Qld 4003. Tel: (07) 3895 8060;
Fax: (07) 3891 7414; Mobile: 017 846 890
haydonwalker@ozemail.com.au

The present system of forecasting is based on the major planetary revolutions around the sun and these range from 11 to 165 years in length. The planetary cycles are only utilised when the major planets are in close proximity to the 18th hour R.A. (Right Ascension) or 2701 heliocentric longitude.

Assuming one were utilising a planetary cycle of 84 years in length, it would be imperative that the sunspot activity of 84 years ago would be the same as at the present time. This rarely occurs, so one must modify or intensify the amount of rainfall in any particular month according to whether the sunspot activity is above or below that of the previous cyclical period.

The late Indigo Jones and Lennox Walker considered that the positions of the planets in relation to the sun caused a waxing or waning of the sunspot cycle. Normally when any of the major planets are in the vicinity of the 18th hour R.A., Australia experiences dry or drought years. In years of high sunspot activity Australia experiences wet or flood years. Conversely, in years of low sunspot activity Australia experiences dry or drought years.

Until a means for forecasting sunspot activity is devised, Mr Walker believes that we must continue to utilise the planetary theory as a guide to sunspot activity.

Detailed yearly forecasts may be prepared for business firms for the various States and these reports would be broken into months, giving the anticipated rainfall in the various Divisions and Metropolitan area, whether light, moderate or heavy and above or below normal. The anticipated rainfall distribution dates as based on the metropolitan areas are also included.

Monthly forecasts may be prepared for the various States and forwarded on about the 25th of each month. These reports would give the anticipated rainfall in the various Divisions and Metropolitan area together with the anticipated rainfall distribution dates and an extensive line of temperature extremes as based on the Metropolitan area.

Yearly forecasts may be prepared for a particular area and these reports would give the anticipated rainfall each month, whether light, moderate or heavy and above or below normal. Special reports and exclusive service forecasts may be prepared to suit specific requirements.

State agro-climatic services

In addition to the above, the extension and advisory services of the various State Departments of Agriculture and Primary Industries provide advice, backed up by ongoing scientific research, to assist producers manage their properties and farm businesses whilst exposed to a variable climate and various forms of risk. There are also a number of private agricultural, environmental and natural resource management consultants who are skilled in advising on how to cope with year to year variability in climate, production and product prices. Many of these are registered with the Australian Association of Agricultural Consultants (AAAC), a section of the Australian Institute of Agricultural Science and Technology.

NSW AGRICULTURE

NSW Agriculture is providing climate services for the producers throughout the State. The services are in the process of further expansion and strengthening. Two types of service have been trialled by the Department for 18 months—a seasonal rainfall outlook and a weekly agronomical advisory. Seasonal rainfall maps and outlook for the next three months are important components of the *Regional Review*, a monthly update of seasonal conditions and outlook for agriculture in New South Wales. Farmers and other users can look at climate information on the Department's external web site in the Regional Review, accessible at http://www.agric.nsw.gov.au/climate/rr/current/

Rainfall maps

Each month the Resource Information Unit downloads rainfall maps for the ongoing season from the Bureau of Meteorology web site and converts these to a more readable format. Coloured maps are used in the written version of the report and on the Department's web site, and black and white versions are faxed to department offices and other interested parties.

Rainfall Outlook

A monthly rainfall outlook for the next three months is prepared on the basis of data, maps, and information obtained from various national and international sources. These include global maps of sea surface temperature, wind and temperature anomalies, El Niño outlook, and various GCM outputs available on various web sites. A regular flow of data pertaining to daily, 30 and 90 day averages of SOI is maintained to keep a track of status and trends in the SOI and to interpret these in terms of their likely impact on rainfall in the State. The Bureau of Meteorology prepares an outlook of rainfall for Australia on the basis of sea surface temperatures; QDPI also bases its outlooks on the phases of the SOI. Several United States climate agencies also prepare rainfall outlooks for various regions of the world, including Australia. Information from this wide spectrum of sources is extracted, integrated and interpreted and an outlook for rainfall in NSW is prepared.

Weekly Agronomy Advisory

Weekly services to producers have been provided on a trial basis in collaboration with the Special Services Unit of the Bureau of Meteorology. Agronomy comments/ advisory was a component of the *Farmweather* fax service for the north central grain belt of NSW known as the 'Stock and Grain' region. District Agronomists of the region were provided a weather forecast information for the region by the Bureau of Meteorology through fax. In turn, District Agronomists faxed back agronomy comments and advice for the farmers, which they prepared taking account of the forecast information that they had received from the Bureau. The Special Services Unit of BoM attached the agronomy advisory with weather forecast information for the region and faxed to the clients. This service is currently under review.

Contact: Dr Harpal Mavi; Tel: (02) 6391 3637;
Fax: (02) 6369 3767; harpal.mavi@agric.nsw.gov.au

QUEENSLAND DEPARTMENTS OF PRIMARY INDUSTRIES AND NATURAL RESOURCES

The Queensland Centre for Climate Applications (QCCA), based at Toowoomba and Indooroopilly, has a major extension component backed up by climate applications research and development and extension being undertaken by the Department of Primary Industries and the Department of Natural Resources.

The service includes provision of climatological advice by its own climatologist, Dr Roger Stone. This is distributed through the media, extension officers, the *Managing for Climate* PMP workshops, phone and fax hotlines and the Long Paddock World Wide Web site at http://www.dnr.qld.gov.au/longpdk

A range of software for assisting managers cope with a variable climate, including Australian RAINMAN, WHEATMAN and GRAZEON, have been produced. Publications include the book *Will It Rain?* Current work includes building on existing products and services such as the *Long Paddock* Internet site, and the phone and fax SOI hotlines.

Contacts and Institutions

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Dr Harpal S. Mavi, Agroclimatologist, Agricultural Resource Management, New South Wales Agriculture, Locked Bag 21, Orange NSW 2800.
Tel: (02) 6391 3637; Fax: (02) 6391 3767; harpal.mavi@agric.nsw.gov.au

Dr Roger Stone, Queensland Department of Primary Industries, PO Box 102, Toowoomba, Qld 4350.
Tel: (07) 4688 1293; Mobile: 0412 559 408;
Fax: (07) 4688 1193; stoner@dpi.qld.gov.au

Ms Mary Voice, Superintendent, National Climate Centre, GPO Box 1289K, Melbourne Vic. 3001.
Tel: (03) 9669 4086; Fax: (03) 9669 4515;
M.Voice@bom.gov.au

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Anon (1997a). Climate activities in Australia 1997. Bureau of Meteorology, Melbourne, 173 pp.

Crowder, R.B. (1995). The wonders of the weather. Bureau of Meteorology, Australian Government Publishing Service, Canberra, 270 pp.

Paull, C.J. and Peacock, A. (1998). Australian climate/ weather services and use of the information. Queensland Department of Primary Industries, GPO Box 46, Brisbane Qld 4001

Peacock, I.J. (1994). Will it Rain? The effects of the Southern Oscillation and El Niño on Australia. Queensland Department of Primary Industries, Information Series QI94015, 2nd edition.

Specialist media services

WEATHER 21

Weather 21 is a 24-hour television station that provides Austar pay TV subscribers with weather forecast, current weather conditions, and radar and satellite images showing 21 weather patterns. The channel uses data downloaded by computer from the Bureau of Meteorology, as well as weather predictions produced by the Bureau and the station's three meteorologists. Weather 21 is a joint venture between Austar Entertainment and Cox Inall Communications. The station also provides daily details of commodity prices, currency fluctuations and Australian Stock Exchange indices.

Education

Access to information

KONDININ GROUP: INFORMATION FOR AGRICULTURE

The Kondinin Group strives to be the premier provider of independent and credible information to improve agriculture. The Group has more than 20,000 members of which 40% are in New South Wales, 20% are in Western Australia, 16% are in Victoria, 13% are in South Australia, and 7% are in Queensland (Eyres 1998). It is rapidly establishing itself as a one-stop shop for agricultural information, making use of its magazine *Farming Ahead* (which incorporates CSIRO's *Rural Research*), and FarmLine—which is a user pays 1800 Infofax service, e-commerce and on-line facilities. An Inquiry Management System (IMS) keeps track of inquiries, farmers and other clients paying for access to information. Each inquiry is key worded and indexed using the AGDEX classification to allow FarmLine operators to search on previous inquiries thereby improving the efficiency and cost-effectiveness of the service. FarmLine has recently secured funding through RIRDC to make FarmLine available on the Internet. This will make the task of retrieving information even easier for customers.

The Kondinin Group has a key role in information dissemination in the *Climate Risk and Yield Information Service* (CRYIS) as part of the *Managing Climate Variability Project*, in collaboration with Agriculture Western Australia and Primary Industries and Resources South Australia (see 'Climate Risk and Yield Information Service' on page 30).

References

Eyres, A. (1998). Making the most of Kondinin Group's FarmLine Information Service. *Proceedings of the 1998 National Conference of the Australasian Association of Agricultural Consultants*, 24–25 September 1998, Macquarie University, pp.67–70.

Contacts

Mr Tony Eyres, Information Services Manager, Kondinin Group, 177 Great Eastern Highway, Belmont WA 6104, Tel: (08) 9478 3343; Fax: (08) 9479 7509; tony@kondinin.com.au ; http://www.kondinin.com.au

Mr Gary McKenzie, Research and Development Manager, Tel: (08) 9478 3343; Fax: (08) 9479 7509; gary@kondinin.com.au

Farmer training

CLIMATE WORKSHOPS

Climate Training Workshops for Producers in NSW

A Climate Project under the Drought Regional Initiative Program in NSW commenced in April 1997 with its major objective of running climate training workshops for producers. During the first one and a half years of the project, 126 training workshops have been held in various regions of the State involving about 2000 participants, mainly NSW producers. The aim of the workshops is to train the growers i) to interpret the synoptic charts, cloud pictures and rainfall probability analysis, ii) to examine the outlook for the current season in the light of risks it poses and opportunities it offers, iii) to discuss management options and decisions for now and as the season unfolds, and iv) have an opportunity to raise issues that tie in climate and drought.

Climate application modules for use in training workshops have been developed in consultation with the Bureau of Meteorology. The modules provide information about basic weather systems and the advances that are occurring in weather forecasting, interpretation of different weather systems as they affect various agricultural systems in the State, and practical examples of how seasonal climate information can be used by the producers and other users.

Evaluation of the climate participants indicates that producers find the training very useful and that there is a significant need for further workshops. For further information contact Mr Paul Carberry, Climate Workshop Coordinator, New South Wales Agriculture, PO Box 116, Coonabarabran, NSW 2357; Tel: (02) 6842 1377; Fax: (02) 6842 2190; paul.carberry@agric.nsw.gov.au

A New South Wales Agriculture Climatology Advisory Unit is being established at the Tamworth Crop Improvement Centre to help the farming community better understand and manage the effect of climate on agricultural production. This Statewide service will work closely with experts in Queensland and other parts of Australia plus other NSW Agriculture research and extension staff.

Climate Training Workshops for Producers in Queensland

QCCA provides workshops for producers covering basic climate science, weather and seasonal climate forecasting. Advanced climate application workshops for industry are being developed and tested. Workshops are also being conducted to assess the benefits and value of seasonal forecasts in the grazing and water industries, as part of the DroughtPlan and Streamflow projects (refer Compendium on 'Climate variability and drought research in relation to Australian agriculture'). These workshops are based on the PMP formula, and are targeted to specific group needs to increase their level of drought-preparedness, self-reliance and long-term viability. For further information contact Mr Colin Paull, Queensland Centre for Climate Applications, 80 Meiers Road, Indooroopilly, Qld 4068; Tel: (07) 3896 9587; Fax: (07) 3896 9843; Colin.Paull@dnr.qld.gov.au

PUBLICATIONS, INCLUDING VIDEOS, FOR FARMERS

Property Management Planning plays a major part in the efficient use of the land. Whole property management involves planning for all aspects of the entire property—land, vegetation, livestock and finances. It must be backed up with suitable information and guidelines on the management of each aspect.

QDPI have therefore published a series of Graziers' Guides (Ian Partridge of QCCA, Toowoomba) including *Managing southern speargrass, Managing northern speargrass, Managing mitchell grass, Managing mulga grasslands*, and *Managing native pastures*. More are in preparation. These guides focus on the management of the native pasture resource with particular attention to the avoidance of overgrazing. Strategies involving the use of seasonal forecasts for assessing stocking rates in the coming season, or for decisions on whether to burn grasslands in the spring, are discussed.

The Bureau of Meteorology produced a video (as part of a climate kit, including a workbook) entitled *Farming a sunburnt country*. The video and kit was commissioned by DPIE (now AFFA) and introduced the concept of El Niño and decision making based on Australian climate patterns and seasonal forecasts. QDPI, in collaboration with the Bureau of Meteorology, also produced a booklet entitled *Will it rain?* by Ian Partridge which describes features of the Australia climate and El Niño—rainfall relationships; it is distributed with the Australian RAINMAN software package, or purchased separately.

The South Australian Film Corporation, in collaboration with PISA, has produced a video entitled *Making plans, an effective way to plan your property's future*. This was aimed at encouraging producer involvement in PMP.

Tertiary education courses

All faculties of agricultural science include elements of agricultural climatology, managing within a variable climate, and risk management within some of the subjects that they teach. In this survey we attempted to identify those areas where explicit attention was given to such topics.

COLLEGES OF TECHNICAL AND FURTHER EDUCATION (TAFE)

Murrumbidgee College of Agriculture, Yanco, NSW 2703

Murrumbidgee College of Agriculture offers a Certificate in Agriculture and a Certificate in Rural Business Management. In Certificate III in Agriculture, agricultural climatology is a part of the module on Plant Systems. In the Certificate in Rural Business Management, agricultural climatology is one of the sections of the module on Crop Production.

Contact: The Principal: Tel: (02) 6951 2699;
Fax: (02) 6951 2600; mca@agric.nsw.gov.au

NSW Western Institute of TAFE

NSW Western Institute of TAFE offers an Associate Diploma in Rural Business Management. This diploma has one module on Agricultural Climatology which is used as a learning guide by the students. The contents of the module give introductory information on climate resource, map reading, how microclimate is modified to suit agriculture, and impact of extreme weather on agriculture.

Contact: Keith McDonald, Western Institute of TAFE, Orange, Tel: (02) 6363 7662

C B Alexander Agricultural College (Tocal), Patterson, NSW

The C B Alexander Agricultural College (Tocal) offers a Certificate in Landcare course. One of the units of this course is 'Climate and your farm'. It has four components, including:

- World Weather—How it affects Australia
- Using Climate Information in Farm Planning
- Using Climate Information for Farm Management
- Using Weather Forecasts on the farms

Contact: Tel: 1800 025 520; Fax: (02) 4938 5549

Emerald Agricultural College, Emerald, Qld 4720

Emerald Agricultural College offers a one year Certificate IV Course in Agricultural Practices and a Diploma in Applied Science in Agricultural Practices. Climatology is a core subject in both these courses. The contents of the climatology course have been designed to provide students with a knowledge of climate formation.

Contact: Tel: (07) 4982 8777; Fax: (07) 4982 8710

Longreach Pastoral College, Longreach, Qld 4730

Longreach Pastoral College offers a Certificate in Pastoral Production and a Diploma in Applied Science (Pastoral Production). Climatology is a core subject in both Certificate and Diploma courses. The contents of the climatology module are designed to assist the students in gaining knowledge of climatic patterns.

Contact: The Principal; Tel: (07) 4658 4699; Fax: (07) 4658 1956

Burdekin Agricultural College, Clare, Qld 4807

Burdekin Agricultural College offers a Diploma of Applied Science. Climatology is a core subject in this Diploma course. The contents of the course provide information on climatic formation and patterns.

Contact: Richard Wilson, Associate Director Student Services; Tel: (07) 4782 7188; Fax: (07) 4782 7291; dirbac@bigpond.com.au

UNIVERSITIES

The University of Western Australia

'Risky Business': learning about decision making in uncertain and risky situations.

'Risky Business' is a simulation game and professional training workshop developed by the Centre for Legumes in Mediterranean Agriculture (CLIMA) and the Faculty of Agriculture at the University of Western Australia. It is designed to enable professionals to gain a greater understanding of the principles and processes of decision making under risky and uncertain conditions from a client's point of view.

The workshop provides a fun and relaxed atmosphere for interactive and motivational learning about decision making and adoption of new innovations. Players are presented with background material, and play a simulation game, which provides hands-on learning about a business manager's decision-making processes under risky and uncertain conditions.

The idea of the game is to manage a small business over 10 years (or seasons) and try to make money. In this simulation, the business is a farming venture. However, the principles learned are transferable to any other type of business where potentially high risk decisions are made regularly. This simulation game not only actively involves the participants, but takes the learning a step further by providing them with an opportunity to be in charge of events and have full authority and responsibility for their business. It is the decisions made by players during the game that provides them with a better understanding of how clients make real decisions about their businesses.

During the game, players select and manage their business enterprises in a climate of uncertain yields and prices, and decide whether or not to adopt a new innovation. Players are provided with instant feedback about the results of their decisions at the end of each season, and have the opportunity to interact with other players. This helps make the game an effective learning tool. As the game progresses, players must also consider the mid- to long-term repercussions of the choices they make. The winner of the game is the player who, at the end of the period, has the greatest net worth.

There are now several working versions of the 'Risky Business' workshop, including:

- Horticulture—irrigated vegetable growing
- Mixed enterprise dryland farm with the option to invest in an innovation
- Mixed enterprise dryland farm facing salinity problems—addresses issues involved with decisions on tree planting
- Mixed enterprise dryland farm with the option of participating in price risk management using instruments like contracts and futures

Past participants in workshops have come from institutions such as banks, trading companies, universities and government agencies such as RAFCOR, Agriculture, and Commerce and Trade. The players have included biological scientists, quality managers, policy economists, librarians, district leaders, bankers and systems analysts. The game is used successfully as a teaching tool in the undergraduate degree courses for Agriculture, Natural Resource Management and Horticulture. Participants agree that the workshops were fun, worthwhile and improved their knowledge about the difficulties of decision making under conditions of risk and uncertainty.

Contact: Dr Steven Schilizzi, Department of Agriculture and Resource Economics, University of Western Australia, Nedlands, W.A. 6907; Tel: (08) 9380 2105; Fax: (08) 9380 1098; schilizz@cyllene.uwa.edu.au

The Flinders University of South Australia, Adelaide, SA

The School of Earth Sciences at Flinders University offers courses in meteorology at undergraduate and postgraduate level.

Undergraduate: The Discipline offers a combined undergraduate program in meteorology and oceanography. After passing first year science, candidates for the B.Sc degree follow a two year program which is equally divided between meteorology, oceanography and classical mathematical physics.

On the atmospheric side, the program involves both physical and dynamical meteorology, with emphasis on thermodynamics, radiative transfer, aviation meteorology, micrometeorology and physical climatology. Comprehensive laboratory sessions focus on numerical modelling of atmospheric phenomena using computer facilities.

Postgraduate: Programs leading to the B.Sc. Honours, M.Sc. and Ph.D in meteorology are offered. The latter two degree programs are by research. There is a strong emphasis on interdisciplinary collaboration through projects with agricultural and biological sciences.

FIAMS (the Flinders Institute for Atmospheric and Marine Science) is a multidisciplinary institute in the School of Earth Sciences. The research projects of the Institute involve graduate students of the School of Earth Sciences. Current research programs of the institute are:

- Airborne measurements of atmospheric and chemical parameters from micro-scale turbulence to macro-scale convection systems.
- Pollution studies based on airborne measurement applications.
- Climate variability studies based on the analysis of long time series.
- Instrument development for airborne platforms.
- Studies related to air–sea interaction.
- Analysis of water mass distribution and ageing and their role in climate change.
- Analysis of sea surface temperature for waters south of Australia based on satellite imagery.

Contact: D.D. Baldocchi; Baldocchi@atdd.noaa.gov ; http://ara.es.flinders.edu.au/FIAMS/general.html

The University of Adelaide, Roseworthy Campus

Undergraduate students in their final year at The University of Adelaide, Roseworthy Campus are using GRASSGRO (Moore *et al.* 1998) in association with pasture cuts in the field. This enables them to view their observations of current pasture growth in an historical context.

Use is also being made of APSFront, the user-friendly Windows front-end of APSIM from the Agricultural Production Systems Research Unit (APSRU) at Toowoomba. This allows staff and students to simulate the management and production of a wide range of crops, including wheat, sorghum, cotton, chickpea, mungbeans and peanuts. Further information on APSFront and APSIM may be obtained at http://www.apsru.gov.au and http://www.farmscape.tag.csiro.au

During 1994 to 1998 Dr Bellotti supervised a GRDC project UA325 soil processes under grazed pastures: their impact on crop production. In this project GRASSGRO was linked to NWheat within the APSIM framework in order to simulate the effects of grazed pastures on subsequent growth and development of wheat.

Dr Bill Bellotti, Department of Agronomy & Farming Systems, Roseworthy, S.A. 5371. Tel: (08) 8303 7728; Fax: (08) 8303 7929; wbellott@roseworthy.adelaide.edu.au

The University of Melbourne, School of Earth Sciences, Parkville, Victoria 3052

The School of Earth Sciences of the University of Melbourne offers programs in Atmospheric Sciences. At the undergraduate level, Atmospheric Sciences as a major discipline. Masters and Ph.D. degrees are awarded in Atmospheric Sciences. The fields of research at the postgraduate level include meteorology, climatology and oceanography.

The research projects currently being undertaken by the postgraduate students include:

- Sea ice and its effect upon weather and climate in high southern latitudes.
- Severe gales in southern Victoria.
- A study of the mechanism of atmospheric carbon dioxide transport.
- Air–sea interaction and low frequency climate variability.
- Varieties of synoptic climatology across the Australian region and relationships with significant weather related phenomena.
- Assessment of urban heat island bias in Australian climate record.
- Climate variability caused by south polar air-ice interactions.
- Vertical structure of gases over south east Australia.
- South-east Australia mesoscale convective weather systems.

Contact: Associate Professor Ian Simmonds; Tel: (03) 9344 7216; Fax: (03) 9344 7761; ihs@met.unimelb.edu.au ; http://www.met.unimelb.edu.au/postgrad/postgrad.html

Monash University, Melbourne,Vic 3806

The Monash University offers a program in Atmospheric Science related topics through either a postgraduate course in the Department of Mathematics or a postgraduate course in the Department of Geography and Environmental Science.

A Graduate course leading to a M.Sc in Meteorology is offered through the Centre for Dynamical Meteorology and Oceanography at Monash University and involves a research thesis comprising 67% and course work worth 33%. This degree course aims to provide a strong theoretical background in the fundamentals of meteorology and their practical applications.

Courses for majoring in Atmospheric Science and for postgraduate degree in Meteorology.

Undergraduate: Introduction to Atmospheric Sciences, Climate of the Earth Boundary Layer, Numerical Methods, Air Pollution Meteorology and Modelling, Dynamical Meteorology, The Australian Atmospheric Environment, Climate Change and Variability.

Postgraduate: Advanced Dynamically Meteorology, Waves in Fluids, Numerical Weather Analysis and Prediction, Cloud Physics and Convention, Radiative Transfer and Remote Sensing, Synoptic Meteorology Laboratory, Climate Variability.

Current research projects:

- Greenhouse climate change detection.
- Variability of the Southern Hemisphere circulation, particularly associated with the El Niño-Southern Oscillation.
- Wind field modelling.
- Atmospheric dispersion modelling.
- Extra-tropical cyclogenesis.
- Tropical cyclone genesis.
- Southern Ocean cloud experiment II.
- Structure and dynamics of sub-tropical cold fronts.

Contact: Professor David Karoly; Tel: (03) 9905 9669; Fax: (03) 9905 9689; http://www.monash.edu.au

Australian National University, Canberra, ACT 0200

The School of Resource Management and Environmental Science within the Australian National University includes the Departments of Geography, Human Ecology and Forestry. The School offers training in climatology at both undergraduate and postgraduate levels.

Undergraduate : Earth Systems, Processes in Physical Geography 2, Climatology.

Postgraduate: Post graduate degrees in Geography and postgraduate degrees in Resource and Environmental Studies are by research. The fields of research in which facilities are available are global climate modelling, digital elevation modelling, ecoclimatology and natural hazards.

Current and recent research projects:

- Construction of a data base of geomorphic evidence for past climate change across northern Australia.
- Investigation of geomorphic features sensitive to climate variation.
- Multi-decadal climatic variability and change, with emphasis on both diagnostic analysis and Global Climate Model applications.
- An Atlas of El Nino Southern Oscillation variability over the last 120 years.

Contact: R.J. Wasson; Tel: (02) 6249 2706; Fax: (02) 6249 3770; enquiries@geography.anu.edu.au

The Centre for Resource and Environmental Studies (CRES)

The Centre for Resource and Environmental Studies (CRES) is a small, independent centre within the Institute of Advanced Studies (IAS) of the Australian National University. Its role is to undertake research and postgraduate training in resource and postgraduate training in resource and environmental issues of national and global significance. The principal challenge is to develop concepts, theories, frameworks, models and methods that transcend the bounds of traditional disciplinary approaches, but build on sound disciplinary foundations. Interdisciplinary and transdisciplinary research that seeks to balance production and conservation within a framework of sustainability has been a central focus for CRES since its establishment in 1973.

Relevant research has included the development of climate and topographic surfaces with linkages to hydrological models. There has been considerable work on drought and flood monitoring and policy, land salinisation, greenhouse issues and forestry ecology. There is now increasing emphasis on ecological economics, landscape processes and water resources research.

References

Ghassemi, F., Jakeman, A.J. and Nix, H.A. (1995). *Salinisation of land and water resources: human causes, extent and case studies*. University of New South Wales Press Ltd, Sydney, 526 pp.

Hutchinson, M.F., Nix, H.A. and McMahon, J.P. (1992). Climate constraints on cropping systems. In *Field Crop Ecosystems*, edited by C.J. Pearson, Chapter 3, pp. 37–58, Elsevier Science, Amsterdam.

Jakeman, A.J., Beck, M.B. and McAleer, M.J. (editors) (1993). Modelling change in environmental systems, John Wiley and Sons, Chichester, 584 pp.

Smith, D.I. (1998). *Water in Australia: resources and management*. Oxford University Press, Melbourne, 384 pp.

Contact: Valda Semets, Executive Officer,
Tel: (02) 6249 3176; Fax: (02) 6249 0757;
Valda.Semets@anu.edu.au

The University of New South Wales, Sydney NSW 2052

The Department of Geography and Department of Civil Engineering has limited programs in climatology.

Australian Climate and Vegetation is an undergraduate course offered in the Geography Department.

Postgraduate research facilities in drought and crop yield forecasting are available in the Civil and Environmental Engineering Department.

Recent publication:

Opoku-Ankomah,Y., and Cordery, I., 1993. Temporal variation of relations between NSW Rainfall and Southern Oscillation. *International Journal of Climatology* **13**, 51–64.

Contact Associate Professor Ian Cordery, School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW, 2052. Tel: (02) 9385 5024;
Fax: (02) 9385 6139; I.Cordery@unsw.edu.au;
http://www.unsw.edu.au

Macquarie University, NSW 2109

Located in the School of Earth Sciences of the Macquarie University, the Physical Geography area offers undergraduate teaching, postgraduate teaching and postgraduate research in Atmospheric Science. In research, the Physical Geography area is also linked to Climatic Impacts Centre and Natural Hazards Research Centre of the Macquarie University. At the undergraduate level it offers a strong core program in Atmospheric Science as a major for B.Sc. in Science. At postgraduate, it offers a Postgraduate Diploma, Masters and Doctorate in Atmospheric Science.

Undergraduate: Planet Earth, Global Environmental Crisis, Climatic Impacts, Atmospheric Environment, Global Climates, Biometeorology, Applied Meteorology.

Postgraduate: Advanced Meteorology, Applied Meteorology, Climate Modelling, Boundary Layer Processes, Hydrology, Natural Hazards.

Major areas of research thrust: natural hazards, climatic impacts on environment and society, air pollution, climate modelling, boundary layer studies, applied meteorology.

Current projects (Natural Hazards Research Centre):

- Climatological analysis of NHRC hail data set for Sydney.
- Evaluation of hail risk in cotton growing areas of New South Wales.
- Data base on fatalities from tropical cyclones.
- Rainfall and run off relationships.
- Climate and hail losses in winter cereal crops in NSW.

Current projects (Climatic Impacts Centre):

- Economic and social benefits of Bureau of Meteorology's services.
- Climate impacts assessment methods.
- Regional (NSW) flooding, agricultural and other impacts.
- Land surface model development.
- Planetary boundary layer research
- The generation and maximum intensity of tropical cyclones.

Contacts:

Physical Geography: Ms Karyn Knowles;
Tel: (02) 9850 8426 Fax: (02) 9850 8420;
physgeog@mq.edu.au ;
http://physgeog.es.mq.edu.au/physgeog/

Climatic Impacts Centre: Tel: (02) 9850 8398;
Fax: (02) 9850 9671; marg@cic.mq.edu.au

Natural Hazards Research Centre: Tel: (02) 9850 9683;
Fax: (02) 9850 9394; NHRC@ocs1.ocs.mq.edu.au

University of Western Sydney, Hawkesbury, Richmond, NSW 2753

The University of Western Sydney, Hawkesbury Campus, has Masters and Ph.D. degree programs in Applied Science (Agricultural and Rural Development) with one major field of either Agricultural Education, Farming Systems, Extension and Rural Development or Marketing and Rural Commerce).

Agroclimatology is one of the subjects for a Masters degree in this program. The major field of research at the postgraduate level in the discipline of agroclimatology is the development and application of decision support systems so as to minimise agroclimatic risks in farming.

Research projects currently being undertaken by the Ph.D. Students include:

- Decision support for climate risk management in dry land crop production

- Decision support for improved climatic risk/ opportunity management in dry land cropping systems.

Contact: Dr. Samsul Huda; Tel: (02) 4570 1390; Fax: (02) 4570 1750; s.huda@uws.edu.au ; http://www.hawkesbury.uws.edu.au

The University of Newcastle, Newcastle, NSW

The Department of Geography and Environmental Science of the University of Newcastle offers undergraduate and postgraduate degree programs in Physical Geography with climatology as a major field. The courses offered are:

Undergraduate: Introduction to Physical Geography, Biogeography and Climatology, Advanced Climatology.

Postgraduate: Natural Hazards.

The postgraduate research fields are synoptic climatology, air pollution, acid rains and fog, climate change, grapevine phenology, studies of vineyard evaporation and water balance.

Recent publications:

Bridgeman, H.A., Maddock, M.N., and Geering D,J. 1997. Cattle egret migration, satellite telemetry and weather in south-eastern Australia, *Corella* **21**, 69–76.

Bridgeman, H.A., Maddock, M.N., and Geering D,J. (in press). Assessing the relationships between cattle egret migration and meteorology in south-west Pacific, a review. *International Journal of Biometeorology*.

Contact: A/Professor Howard A Bridgeman; Tel: (02) 4921 5093; Fax: (02) 4921 5877; gghab@cc.newcastle.edu.au; http://www.newcastle.edu.au/department/gg/

University of New England, Armidale, NSW 2351

The Department of Geography and Planning at the University of New England offers both Masters and Ph.D. programs in Geography with Climatology as a major field.

Undergraduate courses are offered covering the atmospheric system, biogeography, natural hazards, topics in climatology, applied climatology, and special topics in physical geography.

Postgraduate: Masters and Ph.D. in Geography with Climatology as major field. The fields of research at the postgraduate level include meteorology, climatology and natural hazards (Southern Hemisphere climatology, severe local storms, tropical rainfall).

Contact: Associate Professor J.E. Hobbs; Tel: (02) 6773 2903

The Division of Agronomy and Soil Science (Pasture Agronomy Group)

The Division of Agronomy and Soil Science (Pasture Agronomy Group) offers research facilities in agroclimatology. The field of research at the postgraduate level is on the persistence of grasses through drought.

Recently completed postgraduate research includes:

- Adaptation of cocksfoot to drought conditions.
- Persistence of perennial grasses through drought.

Contact: Dr. Jim Scott; Tel: (02) 6773 2594; Fax: (02) 6773 3238; jscott@metz.une.edu.au

Southern Cross University, Lismore, NSW 2480

Southern Cross University offers a Bachelor of Applied Science degree. One of the elective subjects for this degree is Hydrology and Climatology.

Contact: Tel: (02) 6620 3000; Fax: (02) 6622 1300; http://www.scu.edu.au

The University of Queensland, Brisbane, Qld

The University of Queensland offers training in climatology in the Department of Geographical Sciences and Planning. The subjects offered are

Undergraduate:

- Physical Geography—Applied Climatology, human impact and natural hazards.
- Climatology—Physical and applied climatology.

Postgraduate: Climatology Project—Studies within specialised field of applied climatology.

Current postgraduate research:

- Cell resolution for modelling rainfall run off in watersheds.
- Spatial and Temporal Evolution of Drought in Queensland and northern New South Wales.
- Effectiveness management of Tropical Cyclone Hazards.
- Patterns of Sea Surface Temperatures and Australian Rainfall Anomalies in Years of Extreme Rainfall.
- Remote Sensing of Precipitation Generation Mechanism along Wet Tropical Coast of North East Queensland.

Contact: Dr. Andris Auliciems; Tel: (07) 3336 5353; A.Auliciems@mailbox.uq.edu.au; http:// www.geosp.uq.edu.au

Agricultural Systems Teaching in the University of Queensland, Gatton College

Teaching in Agricultural Systems commenced at the University of Queensland in the early 1980's. From the outset there was a strong emphasis on managing variability in dryland farming systems, namely prices and climate, and to this end, models were useful tools for teaching and understanding the interactions in complex systems. Commonly, systems are characterised by the level of productivity, reliability and sustainability. Students are encouraged to consider temporal trends in these characters. Undergraduate subjects range from those that focus on model development to applied subjects that use a specific model to teach management principles. Australian RAINMAN is used extensively to teach students an appreciation of climate variability. Since BEEFUP analyses beef production in Queensland over a range of locations, seasons and price trends, it is used to illustrate spatial and temporal variations and the benefits of simulation experiments. These concepts are further developed by using PERFECT, a model which estimates productivity, reliability and sustainability of management options in dryland cropping systems. Other packages such as RANGEPACK, CAMDAIRY, STOCKUP, FEEDUP and Watershed, are commonly used to teach management principles within discipline based subjects.

Some students move from an introduction to model development into an honours project or a postgraduate project on model development. Experience has shown that a good introduction to model development is achieved through building relatively simple soil water balance and plant growth models on a spread sheet. Whilst a spreadsheet limits the size of the model to simulations of one year, with each line representing a daily time step, this limitation is offset by the ease of manipulating equations and the convenient visual presentation of output.

Contact: Dr Ken Rickert, School of Natural and Rural Systems Management, University of Queensland, Gatton College, Qld 4345; Tel: (07) 5460 1113;
Fax: (07) 5460 1324; krickert@uqg.uq.edu.au ;
http://www.nrsm.uq.edu.au

James Cook University of North Queensland, Townsville, Qld—Department of Electrical and Computing Engineering

The Department of Electrical and Computing Engineering at James Cook University of North Queensland has two research projects in the field of satellite meteorology:

Satellite Transmission Rain Attenuation Project. The aim of the project is to address the shortfall of satellite propagation data in tropical regions. Results gathered from this project will be used for the design of future satellite systems for many years to come.

JCUMetSat GMS Weather Pictures Receiving Project. The aim of this project is to receive, colour enhance and interpret and create archives of the cloud pictures from the GMS satellite which is operated by the Japan Meteorological agency. The coloured enhanced pictures are put on web site to be used by general public. The pictures at the web site are the latest cloud picture of the globe, cloud picture of Australia, pictures of special interest such as cyclones, typhoons and other interesting weather phenonema. The Australian cloud pictures are also shown as a movie. The internet address to access satellite pictures from JCU is

http://www.ece.jcu.edu.au/JCUMetSat/web/metsat.html

Contact: Prof. J.C. Kikkert; Tel: (07) 4781 4259; Fax: (07) 4725 1348; keith.kikkert@jcu.edu.au

Centre for Disaster Studies, James Cook University, Cairns, Qld 4870

The Centre for Disaster Studies lies within James Cook University and is situated at Cairns. It is positioned for research of disaster cyclones (hurricanes, typhoons), tornadoes, floods, drought, bushfires, and landslides,

Opportunities exist for post graduate and professional course work study and research through this Centre with the wide range of disciplines listed at James Cook University.

Special training for Disaster Response personnel, incorporating the holistic theme of the Centre.

Current Research Projects:

- Community Vulnerability to Cyclone and Storm Surge.
- Physical Natural Hazards—Palaeocatastrophic Wave Impacts and Long Term Palaeoflood records.
- Impacts of Tropical Cyclones on the Great Barrier Reef including an Atlas of Cyclones affecting the reef from1969 to 1996.
- Psychological Preparedness for Natural Disasters—Implications for Public Education and Warning messages.
- Wind Tunnel Experimentation.

Contact: Ms Linda Berry, Tel: (07) 4042 1215;
Fax: (07) 4042 1214; Linda.Berry@jcu.edu.au ; http://www.tesag.jcu.edu.au/cds/cdsweb.htm

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