Scoping study into climate change and climate variability

Peter Deuter
QLD Department of Primary Industries and Fisheries

Project Number: VG05051

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Know-how for Horticulture™

Final Report

HAL Project Number :- VG05051 (31/5/06)

Project Title :- Scoping Study - Climate Change and Climate Variability - Risks and Opportunities for Horticulture

Author Name :- Peter Deuter

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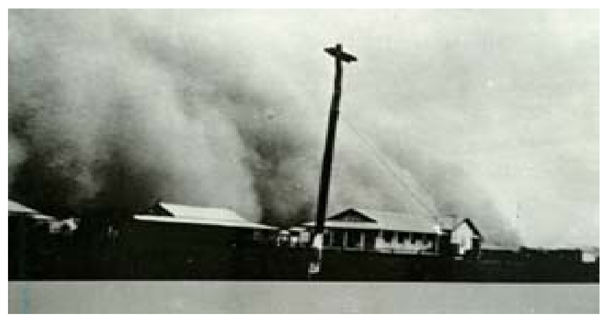

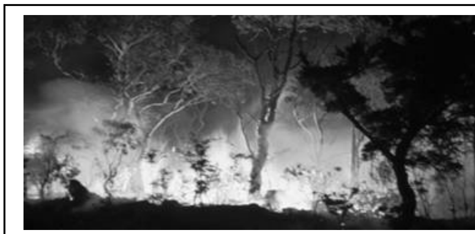

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Date :- 31/5/06

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Media Summary

Key components of the project

The **terms of Reference** for this Scoping Study are as follows :-

1. Climate Change

- Document historical changes in the Australian climate to date.
- Present climate change scenarios for a number of important horticultural regions in Australia, for time periods up to 2030, based on best available science.
- Determine and document how these projected changes in climate could affect horticultural industries in future decades.
- Document potential adaptation mechanisms, that horticultural industries and growers might use to cope with these potential changes.
- Document the key research challenges for the next five years, that must be addressed to equip the horticulture demand chain to adapt to a changing climate.

2. Climate Variability

- Consult widely with climate scientists on tools that the vegetable (and the wider horticultural industry) might be able to use to its advantage in better managing climate variability.
- Scan the literature on tools which the vegetable (and the wider horticultural industry) could use to its advantage in better managing climate variability.
- Assess these tools for their ability to deliver information to growers and the horticultural industry to be able to better manage climate variability.
- Identify the shortcomings of these tools (for their application in horticulture), and in so doing determine potential modifications for them to be more useful in horticulture.
- Identify the types of tools that might be more useful in horticulture in better managing climate variability.

This scoping study includes a list of management tools currently available to agriculture for managing climate change and climate variability, on which horticultural industries might capitalise.

Industry significance of the project

Australia has one of the most variable climates in the world, with large extremes of rainfall and temperature. Climate change as a consequence of global warming will add to the difficulties which horticultural industries have in coping with an already variable climate. Australian's agricultural (including horticultural) industries, businesses and communities have historically been subject to greatly fluctuating incomes due to seasonal climate variation. They incur significant costs associated with drought, frosts, heat waves, storms and floods.

Horticultural industries are already dealing with increased threats from imported products; the need to become even more efficient; and changing social, economic and institutional pressures. Industry and individual growers will need to develop adaptive strategies to manage adverse environmental conditions, in addition to developing and implementing improved production/management practices to increase efficiency and productivity and meet supply chain needs.

Key outcomes

Climate Change.
Australian annual mean **temperatures have increased by 0.82^{o}C since 1910**, with rapid increases since 1950 (Smith, 2004). Night-time temperatures have increased faster (0.11^{o}C/decade) than daytime temperatures (0.06^{o}C/decade), together with increasing frequency of hot days (35^{o}C or more) of 0.08 days per year and a decreasing trend in cold nights (5^{o}C or less) of 0.16 nights per year.

A mean **warming of 0.4 to 2.0^{o}C** is anticipated over most of Australia **by the year 2030** (relative to 1990), and 1 to 6^{o}C by 2070 (CSIRO, 2001). Mean temperature change is likely to be greatest inland and least on the coast. Most warming is expected to occur in spring and summer, and least in winter.

Most of the anticipated climate changes point towards the need for a very high standard of crop management in order to respond to the challenges that expected changes pose. Industry and farm managers will need to **distinguish between 'old climate expectations' and 'new climate realities**' in determining and implementing new adaptation strategies or options.

For horticultural industries to successfully adapt to increasing temperatures and changing rainfall patterns, there will be a need to develop both pre-emptive and reactive adaptation strategies or options.

Climate Variability.
Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.

The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced.

There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons. It is expected, although this has not been extensively tested, that other forecast systems would be needed to be able to provide this requirement for horticulture for rainfall forecasts.

A lead-time of up to 4 months would be very useful for many horticultural industries. The usefulness of the 3 month season forecasts embodied in most current forecast systems is significantly reduced by the need for most horticultural industries to have a season forecast of one month or less.

There are numerous web sites that provide information that can be useful to producers, industries, consultants and advisors in making more informed decisions. These information sources aim to provide a better understanding of climate variability, and how this variability affects specific industries. None of these are specific to Australian horticultural industries.

Conclusions and recommendations for practical application to industry.

There appear to be many potentially significant impacts of climate change on horticultural industries, some of which may be positive, some negative. ***It will be essential to reducing the impact of climate change, that a clearer understanding of what these impacts are, and that management strategies be identified and implemented to either offset the negative impacts, or to take advantage of positive responses***.

- For horticultural industries to successfully adapt to increasing temperatures and subsequent climate changes, there will be a need to develop both pre-emptive and reactive adaptation strategies or options. Horticultural industries are already dealing with increased threats from imported products, the need to become even more efficient, and changing social, economic and institutional pressures. Industry will need to develop these adaptive strategies to manage adverse environmental conditions in addition to developing and implementing improved production practices to increase efficiency and productivity.

- Temperature is the main factor determining location and timing of horticultural production in Australia. Increased temperatures may require changes in cultivars, timing of planting and harvesting. Increasing temperatures may also result in some current production areas becoming marginal, especially in the early and/or late periods of the production season.

- Some regions which are currently marginal for production, may offer some production advantages.

Recommendations for future R&D

Key challenges for horticulture :-

1. **Assess the Impact of Climate Change** – this might include :-

    - Identifying current "at risk" production sites (regions) and/or industries.
    - Documenting the effects of climate change for major overseas production regions, especially in those countries that are major competitors to Australian production; including identifying any additional export opportunities for Australian growers.
    - Determine climate change impacts on water reliability/availability.
    - Improving the reliability of climate change modelling outputs (scenarios).
    - Calculating expected shifts in crop maturity times for different regions.

2. **Understand How Crops Respond to Climate Change & Climate Variability** – including :-

    - Identifying those agronomic and physiological factors affecting crop performance.
    - Determining the sensitivities of these factors in a variable and changing climate.
    - Developing a better understanding, and ability to take advantage of, CO_2 fertilization and its effects on yield.

3. **Develop Climate Change Adaptation Strategies**, in response to 1. and 2. above – some examples might be :-

- Identifying management options – i.e. adaptation strategies.
- Identifying alternative districts that may be suitable for production.
- Monitoring climate changes in existing production areas.
- Reviewing irrigation research.
- Developing strategies to improve property management.

4. **Better Understand Climate Variability**

- Developing a better understanding of current climate variability and how it might be managed more effectively.
- Assessing the requirements of horticultural industries for seasonal temperature (and rainfall) forecasting information.
- Developing a better understanding of the lead-time and season requirements of horticultural industries, including the climate science understanding that would be embodied in a forecasting tool.

Tools used in managing climate variability, have in the main been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. None of these tools have been designed specifically with any horticultural industry or application in mind. Currently the limitation of these tools in their application to horticultural production is the lack of climate science that addresses the lead-time and season requirements of horticultural industries. Given a sound forecast system that meets the requirements of the industry, the appropriate tools can be produced.

A lead-time of up to 4 months would be very useful for many horticultural industries. The usefulness of the 3 month season forecasts which is embodied in most current forecast systems, is significantly reduced by the need for most horticultural industries to have a season forecast of one month or less.

There are numerous web sites that provide information that can be useful to producers, industries, consultants and advisors in making more informed decisions. These information sources aim to provide a better understanding of climate variability, and how this variability affects specific industries. None of these are specific to Australian horticultural industries.

The steps in addressing climate change in horticulture in Australia should commence with identifying those industries and/or specific locations which are most at risk from climate change, followed by the development of adaptation strategies for those industries and regions at risk. At the same time, climate variability (particularly temperature) will continue to challenge managers of horticultural supply and demand chains (production and marketing). Forecasting tools need to be developed, with the requirements of horticultural industries and managers specifically in mind.

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Technical Summary

Nature of the problem

Australia has one of the most variable climates in the world, with large extremes of rainfall and temperature. Climate change as a consequence of global warming will add to the difficulties which horticultural industries have in coping with an already variable climate. Australian's agricultural (including horticultural) industries, businesses and communities have historically been subject to greatly fluctuating incomes due to seasonal climate variation. They incur significant costs associated with drought, frosts, heat waves, storms and floods.
Horticultural industries are already dealing with increased threats from imported products; the need to become even more efficient; and changing social, economic and institutional pressures. Industry and individual growers will need to develop adaptive strategies to manage adverse environmental conditions, in addition to developing and implementing improved production practices to increase efficiency and productivity.

The Australian horticultural industry will be affected by climate change through :-

- Changes in frost frequency
- Damage from extreme events
- Increased, or changing pest and disease incidence
- Changes in time to harvest
- Changes in the suitability of cultivars
- Downgrading product quality
- Pollination difficulties for some crops
- Increased risk of spread and proliferation of soil borne diseases
- Increased irrigation demand
- Increased atmospheric CO_2 concentrations will benefit productivity of most horticultural crops, although the extent of this benefit is unknown.

Tools used in managing climate variability, have in the main been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. None of these tools have been designed specifically with any horticultural industry or application in mind.
Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.

The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced.

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Brief description of the science undertaken

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This scoping study includes a list of management tools currently available to agriculture for managing climate change and climate variability, on which horticultural industries might capitalise.
The role of software tools is to embody the science, rather than to drive it. Currently the limitation on the use of these tools in their application to horticultural production is the lack of climate science understanding that addresses the lead-time and season requirements of the industry. Given a sound forecast system that meets the requirements of the industry, the appropriate tools can be produced.

Major research findings and industry outcomes

Climate Change

Australian annual mean **temperatures have increased by 0.82^{o}C since 1910**, with rapid increases since 1950 (Smith, 2004). Night-time temperatures have increased faster (0.11^{o}C/decade) than daytime temperatures (0.06^{o}C/decade), together with increasing frequency of hot days (35^{o}C or more) of 0.08 days per year and a decreasing trend in cold nights (5^{o}C or less) of 0.16 nights per year.

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Recommendations to industry, research peers and HAL

There appear to be many potentially significant impacts of climate change on horticultural industries, some of which may be positive, some negative. ***It will be essential to reducing the impact of climate change, that a clearer understanding of what these impacts are, and that management strategies be identified and implemented to either offset the negative impacts, or to take advantage of positive responses***.
Climate change as a consequence of global warming, will add to the difficulties which horticulture industries already have in coping with a very variable climate.

- In order for horticultural industries to successfully adapt to increasing temperatures and subsequent climate changes, there will be a need to develop both pre-emptive and reactive adaptation strategies or options. Horticultural industries are already dealing with increased threats from imported products, the need to become even more efficient and changing social, economic and institutional pressures. Industry will need to develop these adaptive strategies to manage adverse environmental conditions in addition to developing and implementing improved production practices to increase efficiency and productivity.

- Temperature is the main factor determining location and timing of horticultural production in Australia. Increased temperatures may require changes in cultivars, and timing of planting and harvesting. Increasing temperatures may also result in some current production areas becoming marginal, especially in the early and/or late periods of the production season.

- Some regions which are currently marginal for production, may offer some production advantages.

The following are some **R&D challenges for horticulture** to consider (short to medium term) :-

1. **Assess the Impact of Climate Change** – by :-

    - Identifying current "at risk" Australian production sites (regions) and/or industries.
    - Documenting climate change impacts on overseas competitors; and identifying any additional export opportunities for Australian producers.
    - Calculating expected shifts in crop maturity times for different regions.
    - Determine climate change impacts on water reliability/availability.
    - Improving the reliability of climate change modelling outputs.

2. **Understand How Crops Respond to Climate Change & Climate Variability** – by :-

    - Identifying those agronomic and physiological factors affecting crop performance.
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    - Developing a better understanding, and ability to take advantage of, CO_2 fertilization and its effects on yield.

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    - Identifying alternative districts that may be suitable for production.
    - Monitoring climate changes in existing production areas.

- ❖ Reviewing irrigation research.
- ❖ Developing strategies to improve property (enterprise) management.

4. Better Understand Climate Variability

- ❖ Developing a better understanding of current climate variability and how it might be managed more effectively.
- ❖ Assessing the requirements of horticultural industries for seasonal temperature (and rainfall) forecasting information.
- ❖ Developing a better understanding of the lead-time and season requirements of horticultural industries, including the climate science understanding that would be embodied in a forecasting tool.

There are many tools for managing climate variability designed for a number of agricultural industries. No tools have been specifically designed for horticulture in Australia. The majority of these tools are associated with rainfall variability and very few provide information on how to manage variability in temperature. Temperature is the major factor in determining where horticulture crops can be grown successfully, and then how well these crops perform under varying seasonal conditions.

The requirements of horticultural industries for **seasonal temperature (and rainfall) forecasting information**, needs to be assessed.

e.g. Lettuce – in the Australian environment, temperature varies considerably from season to season in most districts, and cultivar selection and planting times cannot always be satisfactorily matched with the temperature conditions that significantly influence quality during the head filling stage, which is up to 3 months after transplanting, depending on season and location. To be able to make much better decisions on cultivar selection, planting dates and marketing plans, growers need information on the temperature regime for the growing period up to harvest (a forecast with 3-4 months lead-time). This is due to the need for growers to plan production and order lettuce seedlings well in advance of planting. This information is currently not available.

Contribution to new technology and any future work suggested.

There appear to be many potentially significant impacts of climate change on horticultural industries, some of which may be positive, some negative. ***It will be essential to reducing the impact of climate change, that a clearer understanding of what these impacts are, and that management strategies be identified and implemented to either offset the negative impacts, or to take advantage of positive responses***.

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The steps in addressing climate change in horticulture in Australia should commence with identifying those industries and/or specific locations which are most at risk from climate change, followed by the development of adaptation strategies for those industries and regions at risk. At the same time, climate variability (particularly temperature) will continue to challenge managers of horticultural supply and demand chains (production and marketing). Forecasting tools need to be developed, with the requirements of horticultural industries and managers specifically in mind.

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Introduction

Australia has one of the most variable climates in the world, with large extremes of rainfall and temperature. Climate change as a consequence of global warming will add to the difficulties which horticultural industries have in coping with an already variable climate. Australia's agricultural (including horticultural) industries, businesses and communities have historically been subject to greatly fluctuating incomes due to seasonal climate variation. They incur significant costs associated with drought, frosts, heat waves, storms and floods.
Horticultural industries are already dealing with increased threats from imported products; the need to become even more efficient; and changing social, economic and institutional pressures. Industry and individual growers will need to develop adaptive strategies to manage adverse environmental conditions, in addition to developing and implementing improved production practices to increase efficiency and productivity.

With an improvement in our understanding of climate change and variability, it will be possible for industries and individuals to develop a capacity to change practices, change locations or even change enterprises to deal with change that is occurring, and the evidence is that these changes will continue to occur.

Australian horticultural industries will be affected by climate change through :-

- Changes in frost frequency
- Damage from extreme events
- Increased pest and disease incidence
- Changes in time to harvest
- Changes in the suitability of cultivars
- Downgrading product quality
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Review of Literature

Climate affects Australian horticultural industries in a range of ways through impacts on industry location, plant growth, pest and disease risk and product quality (Howden, et al., 2003). Amongst many other considerations, management and infrastructure decisions attempt to account for these climate effects and risks. Such decisions will usually use the historical climate as a guide to future conditions, as there are no scientifically validated or published tools available which have been designed specifically with the requirements of horticultural industries in mind.

There is increasing evidence that human activities are already changing the global climate, and that more change seems likely. Consequently, historical conditions may become increasingly less pertinent as a guide to industry activities or industry adjustment. This Scoping Study Project assesses the evidence for climate change, drawing particularly on the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (IPCC 2001a,b, 2002), and explores the potential impacts and implications of such changes for horticultural industries in Australia.

Rainfall

Since 1900, Australian annual average rainfall shows a moderate increase (7.9mm/decade), but it is dominated by high year-to-year variability (Smith, 2004). While north-eastern Australia has become wetter since 1950, much of eastern and southern Australia has become drier. This is due to a weakening or southward shift of the frontal systems that bring most rain to these regions (Marshall, 2003). Rainfall intensity in eastern Australia has increased from 1910 to 1998, but has decreased in the far southwest of Australia (Haylock and Nicholls, 2000) over this same time period. Over New South Wales, extreme daily rainfall intensity and frequency has decreased from 1950 to 2003 (Hennessy *et al*., 2004b).

The frequency of tropical cyclones in the Australian region has decreased since 1967 (Hennessy, 2004c), along with an increase in cyclone intensity, possibly as a result of a shift in areas of formation. Explosively developing cyclones, including east coast lows off the New South Wales coast, have increased between 1979 and 1999 (Lim and Simmonds, 2002).

There appear to be many potentially significant impacts of climate change on horticultural industries, some of which may be positive, some negative. It will be essential in reducing the impact of climate change, that a clearer understanding of what these impacts are, and that management strategies be identified and implemented to either offset the negative impacts, or to take advantage of positive responses. Previous assessments of climate change adaptations have been made for other industries (e.g. Howden et al., 2003). One of the general conclusions from these analyses is that the best defence against future climate change is to continue to develop the capacity and knowledge to manage our response to current climate variability more effectively.

Temperature

Australian annual mean temperatures have increased by 0.82^{o}C since 1910, with rapid increases, particularly since 1950 (Smith, 2004), with night-time temperatures increasing faster (0.11^{o}C/decade) than daytime temperatures (0.06^{o}C/decade). Night-time (minimum) temperatures have particularly risen sharply in the northeast of Australia. There are also trends from 1957 to 2003 of increasing frequency in hot days (35^{o}C or more) of 0.08 days per year and a decreasing trend in cold nights (5^{o}C or less) of 0.16 nights per year (Hennessy *et al*., 2004a).

A mean warming of 0.4 to 2.0^{o}C is anticipated over most of Australia by the year 2030, relative to 1990, and 1 to 6^{o}C by 2070 (CSIRO, 2001). Climate change is occurring and there are two options; ignore it in the hope that it will go away and accept the consequences; or develop strategies to manage climate change.

In 2001, the Victorian government embarked on a pilot project, which aimed at determining the potential for growing certain commodities (including cool climate grapes) across Gippsland, and the likely shift in that potential as climate change occurs in the region. This project has demonstrated that climate change will impact different agricultural activities in different ways over time and in different regions.

> "Some areas will become more suitable for certain activities while others will become less suitable. Further work will consider more detailed analysis of the outputs to assist the development of appropriate long-term responses, as well as the application of the methodology in other regions of Victoria." (Anon, 2001).

The Southern Oscillation

The Southern Oscillation is a see-saw of air pressure between the eastern equatorial Pacific and the Australian-Indonesian region. When the atmospheric pressure is high over one region, it is usually low over the other. This oscillation of air pressure between these two regions affects the weather in many parts of the world, but the effects vary between countries and at different times of the year (Partridge, 2001).

The Southern Oscillation is the most important influence on the year to year variability of our weather in Australia. The Southern Oscillation explains about 40% of the variation in eastern Australian rainfall (high rainfall variability is a normal feature of weather patterns in eastern Australia).

The Southern Oscillation Index (SOI).

The strength of the Southern Oscillation is measured by the difference in air pressure between the eastern equatorial Pacific and the Australian-Indonesian region. A mathematical formula is applied to the anomalous air pressure differences between Darwin and Tahiti, and the result is referred to as the Southern Oscillation Index (SOI). The SOI usually ranges from -30 to +30.

The SOI does not have the same influence on all parts of Australia. Its strongest influence is on eastern Australia. When the SOI is strongly positive, the trade winds blow across the Pacific picking up moisture. This often results in above average rainfall in eastern Australia. When the SOI is strongly negative, trade winds are weak and rainfall can be below average. This is often referred to as an *El Niño*. The acronym ENSO (El Niño Southern Oscillation) is often used to describe this situation; that is the combination of El Niño and Southern Oscillation (Partridge, 2001).

The relationship between the SOI and rainfall is strongest in winter, spring and summer in Eastern Australia, although a strong trend in the SOI in autumn often settles into a pattern for the remainder of the year.

Sea Surface Temperatures (SST) and the SOI.

The Coral Sea (western Pacific) temperatures can cool by 1^{o}C during an El Niño event, which can have a large impact on our rainfall. In contrast, SST's in the eastern Pacific may rise by 2-5^{o}C to 26-29^{o}C during an El Niño phase. Under a positive SOI, strong trade winds help push warm water in the equatorial Pacific region towards Australia, promoting more rainfall. Under a negative SOI, these trade winds are weakened, the sea surface off eastern Australia cools, reducing the potential for rainfall (Partridge, 2001).

Climate Prediction.

Advice on the status and development of ENSO has been provided from a number of sources in Australia since 1989, initially from the National Climate Centre (Anon, 2001, pp 63-65).
The Bureau of Meteorology produces three monthly outlook information (for a 3 month season) for each state and nationally, and is updated regularly. e.g. the most recent national update [http://www.bom.gov.au/climate/ahead/] is for the **National Seasonal Rainfall Outlook: probabilities for May to July 2006**, issued 21st April 2006. A corresponding outlook is issued for temperature.

“The *rainfall* outlooks perform best in eastern and northern Australia between July and January, but are less useful in autumn and in the west of the continent. The skill at predicting seasonal *maximum temperature* peaks in early winter and drops off marginally during the second half of the year. The lowest point in skill occurs in early autumn. The skill at predicting seasonal *minimum temperature* peaks in late autumn and again in mid-spring. There are also two distinct periods when the skill is lowest - namely late summer and mid-winter.”

“These rainfall and temperature outlooks are based on SST patterns in the Pacific and Indian Oceans, and they relate to a three month period or season. The Bureau's seasonal outlooks are general statements about the probability or risk of wetter or drier than average weather over a three-month period. The outlooks are based on the statistics of chance (the odds) taken from Australian rainfall/temperatures and sea surface temperature records for the tropical Pacific and Indian Oceans. They are not, however, categorical predictions about future rainfall, and they are not about rainfall within individual months of the three-month outlook period. ***The temperature outlooks are for the average maximum and minimum temperatures for the entire three-month outlook period. Information about whether individual days or weeks may be unusually hot or cold, is unavailable.”*** (http://www.bom.gov.au/climate/ahead/rain_ahead.shtml)

Seasonal rainfall forecasts are also provided by the Department of Primary Industries, Queensland (DPI&F) http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/
The "Outlook" is based on the Southern Oscillation Index (SOI). Sea-Surface Temperature (SST) patterns in the Pacific Ocean are also important in driving climate variability and are useful guides to potential climate patterns in Australia (and other parts of the world too).

DPI&F provides rainfall probability information using its "SOI Phase System" and the current "Outlook Message" gives commentary on the seasonal outlook. These seasonal climate forecasts provide outlooks for a three month season with a zero lead-time.

A lead-time of up to 4 months would be very useful for many horticultural industries. The usefulness of the 3 month season forecasts embodied in most current forecast systems is significantly reduced by the need for most horticultural industries to have a seasonal forecast of one month or less. Currently the limitation on the use of these tools in horticultural production, is the lack of climate science understanding that addresses the lead-time and season requirements of the industry.

Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.

There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons. It is expected, although this has not been extensively tested, that other forecast systems would be needed to be able to provide this requirement for horticulture for rainfall forecasts.

Climate Applications.

Climate Applications (or tools) are used to improve decision making and planning in agriculture. There are many applications for managing climate variability designed for a number of agricultural industries. None of these have been specifically designed for horticulture in Australia, and nor do they have the lead-times which would be necessary for these tools to have useful application in horticulture. The majority of these tools are associated with rainfall variability, and very few provide information on how to manage variability in temperature. Temperature is the major factor in determining where horticultural crops can be grown successfully, and then how well these crops perform under varying seasonal conditions. Limited development of experimental tools specific to horticulture, has been undertaken by DPI&F, Queensland.

A number of the tools described in this report include Whopper Cropper, Rainman and Seasonal Crop Outlook (Anon, 2001, pp 60-62).

Over the last 20 years there has been much research and development devoted to an increasing understanding of climate variability, and finding mechanisms and applications to better manage this variability (Hammer, et. al., 2000).

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Materials & Methods

The **terms of reference** for this Scoping Study are as follows :-

1. Climate Change

- Document historical changes in the Australian climate to date.
- Present climate change scenarios for a number of important horticultural regions in Australia, for time periods up to 2030, based on best available science.
- Determine and document how these projected changes in climate could affect horticultural industries in future decades.
- Document potential adaptation mechanisms, that horticultural industries and growers might use to cope with these potential changes.
- Document the key research challenges for the next five years, that must be addressed to equip the horticulture demand chain to adapt to a changing climate.

2. Climate Variability

- Consult widely with climate scientists on tools that the vegetable (and the wider horticultural industry) might be able to use to its advantage in better managing climate variability.
- Scan the literature on tools which the vegetable (and the wider horticultural industry) could use to its advantage in better managing climate variability.
- Assess these tools for their ability to deliver information to growers and horticultural industry to be able to better manage climate variability.
- Identify the shortcomings of these tools (for their application in horticulture), and in so doing determine potential modifications for them to be more useful in horticulture.
- Identify the types of tools that might be more useful in horticulture in better managing climate variability.

This scoping study includes a list of management tools currently available to agriculture for managing climate change and climate variability on which horticultural industries might capitalise. The role of software tools is to embody the science, rather than to drive it. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced.

The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons. It is expected, although this has not been extensively tested, that other forecast systems would be needed to be able to provide this requirement for horticulture for rainfall forecasts.

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Results

1. CLIMATE CHANGE - Risks and Opportunities for Horticulture

WHAT IS CHANGING, AND BY HOW MUCH?

It is certain that the atmospheric concentration of various gases and particulates has changed over the past century, and there is much evidence that they are now higher than at any time in the past 420,000 years (Petit et al., 2000).

Australian annual mean temperatures have increased by 0.82^{o}C since 1910, with rapid increases since 1950 (Smith, 2004). Night-time temperatures have increased faster (0.11^{o}C/decade) than daytime temperatures (0.06^{o}C/decade), together with increasing frequency of hot days (35^{o}C or more) of 0.08 days per year and a decreasing trend in cold nights (5^{o}C or less) of 0.16 nights per year.

Table 1. Historical temperature changes (1957 to 2005) with temperature trends expressed in degrees Celsius per 100 years, calculated using linear regression, for eleven locations in Australia.

Site	Annual mean temperature change	Annual dewpoint temperature change	Winter minimum change	Summer maximum change
Mareeba	+ 2.52	+ 1.34	+ 5.3	+ 0.9
Bundaberg	+ 1.70	+ 1.75	+ 2.2	+ 1.0
Nambour	+ 3.26	+ 1.72	+ 6.1	+ 1.1
Gatton	+ 1.97	+ 1.32	+ 1.5	+ 2.9
Toowoomba	+ 1.46	+ 0.64	+ 2.7	+ 1.3
Coffs Harbour	+ 1.93	+ 0.14	+ 3.4	+ 0.9
Mildura	+ 0.49	- 0.77	- 0.1	+ 1.6
Hay	+ 0.4	+ 1.0	- 0.3	+ 2.0
Bairnsdale	+ 0.4	+ 0.3	- 1.7	+ 5.4
Forthside	+ 1.7	+ 0.9	+ 3.0	- 0.8
Manjimup	+ 1.14	+ 1.82	+ 1.4	+ 0.9

Table 2. Changes in a) the **numbers of frosts**, b) the **timing of the first** and c) **last frosts** and d) the **length of the frost period** at 8 locations (over the past 50 years).

Site	**a) Change in the number of frosts**	**b) Change in the timing of the first frost (days)**	**c) Change in the timing of the last frost (days)**	**d) Change in the length of the frost period (days)**
Nambour	- 14	+ 39	- 43	- 81
Gatton	- 9	+ 12	- 19	- 31
Toowoomba	- 15	+ 26	- 14	- 40
Coffs Harbour	- 6	+ 27	- 16	- 43
Hay	+ 2	- 12	+ 14	+ 30
Bairnsdale	+ 9	- 11	+ 25	+ 43
Forthside	- 25	+ 29	- 13	- 32
Manjimup	- 4	+ 15	- 43	- 58

Since 1900, annual Australian-average rainfall shows a moderate increase (7.9mm/decade), but it is dominated by high year-to-year variability (Smith, 2004). While north-eastern Australia has become wetter since 1950, much of eastern and southern Australia has become drier.

The frequency of tropical cyclones in the Australian region has decreased since 1967 (Hennessy et al, 2004), along with an increase in cyclone intensity.

There are strong trends of increased mean annual temperature across selected growing regions. About 60 to 80% of the warming arises from increases in night-time temperatures and 55 to 70% of the warming is from temperature increases in the May-October period. At a number of sites including Forthside in northern Tasmania, a significant decrease in the number of frosts has occurred, together with an increase in the frost free period.

The rate of rise for minimum temperatures has been greater than for maximum temperatures.

Table 3. Historical changes in a) **evaporation** (mm) and b) heat stress frequency (**days per year with maximum temperature greater than 35^{o}C**) and radiation (MJ/m^2) for ten sites in Australia (1957 to 2005).

Site	**a) Daily evaporation change (mm)**	**b) Change in heat stress frequency (days per year above 35^{o}C)**
Mareeba	+ 0.28	+ 0.5
Bundaberg	+ 0.16	+ 0.65
Nambour	+ 0.44	+ 1.4
Gatton	+ 0.55	+ 7.2
Toowoomba	+ 0.46	- 0.16
Coffs Harbour	+ 0.62	+ 0.36
Mildura	+ 0.32	+ 3.94
Hay	0*	+ 1.9
Bairnsdale	+ 0.1	+ 4.3
Forthside	+0.1	0*

* - no change measured

PROJECTIONS OF FUTURE CHANGE

A selection of climate models, driven by a range of scenarios of human development, technology and environmental governance, project the global mean temperature to rise a further 2 to 5.8^{o}C during the 21st Century (IPCC, 2000). The projected warming is not evenly distributed around the globe; continental areas warm more than the ocean and coastal areas, and the poles warm faster than equatorial areas.

A mean warming of 0.4 to 2.0^{o}C is anticipated over most of Australia by the year 2030, relative to 1990, and 1^{o}C to 6^{o}C by 2070 (CSIRO, 2001). Mean temperature change is likely to be greatest inland and least on the coast. Most warming is expected to occur in spring and summer, and least in winter.

Table 4. Historical mean temperature increases (^{o}C) for eight locations compared with **future temperature change**.

Site	Historical temperature increases (^{o}C/100 yrs)	Future temperature increases (^{o}C)	
		2030	2070
Mareeba	+ 2.52	0.3 to 1.7	1 to 6
Bundaberg	+ 1.70	0.3 to 1.7	1 to 6
Nambour	+ 3.26	0.3 to 1.7	1 to 6
Gatton	+ 1.97	0.3 to 1.7	1 to 6
Toowoomba	+ 1.46	0.3 to 1.7	1 to 6
Coffs Harbour	+ 1.93	0.2 to 1.6	0.7 to 4.8
Mildura	+ 0.49	0.2 to 1.8	0.7 to 5.5
Manjimup	+ 1.14	0.2 to 1.6	0.8 to 5.2

A ***mean warming*** of 0.4 to 2.0^{o}C is anticipated over most of Australia by the year 2030, relative to 1990, and 1 to 6^{o}C by 2070 (CSIRO, 2001). Mean temperature change is likely to be greatest inland and least on the coast. Most warming is expected to occur in spring and summer, and least in winter.
There is no strong indication whether the ***diurnal temperature range*** is likely to change. In contrast, the current trend towards lower ***frost risk*** is likely to continue in all frost-affected sites. However, whilst there is an expectation of a 10 to 50% increase in ***days over 35^{o}C*** by 2030, the occurrence of hot spells is more likely to increase in frequency in inland growing areas (e.g. Mildura) and to a lesser extent on the coast.

A tendency for less ***rainfall*** is expected in the south-west of WA (-20 to +5% by 2030 and -60 to +10% by 2070). In much of eastern Australia, projected ranges are uncertain (e.g. -10 to +10% by 2030 and -35 to +35% by 2070). Recent analyses indicate that Queensland coastal rainfall may on balance decline but that this may vary with season.

When broken down by seasons, across Australia :-

- Spring rainfall tends towards decreases, ranging from zero to -20% by 2030 and zero to -60% by 2070
- Autumn shows a tendency for decreases with changes from +7% to -13% by 2030 and +20% to -40% by 2070
- Summer ($\pm$7% by 2030 and $\pm$20% by 2070)
- Winter ($\pm$13% by 2030 and $\pm$40% by 2070) showing no particular directional changes (Cai et al., 2003).

There is uncertainty as to the likely change in the frequency and strength of ***El Niño (ENSO) events***. Even in the absence of increases in El Niño events, projected changes in atmospheric moisture balance (rainfall minus potential evaporation) will lead to drier conditions over eastern and southern Australia, with a greater likelihood of droughts. These more frequent droughts are likely to be accompanied by higher temperatures, which will compound the problem. This, combined with expectations of increased evaporation, suggest increased irrigation demands.

Rainfall intensity is expected to generally increase with warmer temperatures, as the air can hold more moisture (about 6 to 8% per ^{o}C) enabling more intense precipitation.
Rainfall across southern Australia is anticipated to decline, particularly from autumn to spring with some inland and eastern coastal areas becoming wetter in summer (CSIRO, 2001) but this summer rainfall will be less useful than rainfall in other seasons, due to potentially higher summer evaporation rates, whilst rainfall in northern Australia may increase in some locations and seasons.
In southern Australia, river flows are anticipated to drop, placing additional stress on catchments that are already over-allocated. At the same time, there will be increasing water demand due to warmer temperatures.

HOW WILL CLIMATE CHANGE AFFECT AUSTRALIAN HORTICULTURAL INDUSTRIES?

The following are potential impacts on horticulture identified by the Australian Greenhouse Office (http://www.greenhouse.gov.au/impacts/agriculture.html) and http://www.greenhouse.gov.au/science/guide/pubs/chapter4.pdf

- Changes in frost frequency
- Damage from extreme events (hail, heat stress)
- Increased pest and disease incidence
- Changes in time to harvest for some crops and locations
- Changes in the suitability of cultivars for current and future production locations
- Reduced availability of irrigation water in some locations and some seasons
- Greater seasonal variability
- Negative impacts on soils and crops due to extreme events such as extreme rainfall events and flooding.

Additionally, climate change will affect industries through :-

- Greater potential for downgrading product quality e.g. sunburn
- Pollination failures if heat stress days occur during flowering
- Increased risk of spread and proliferation of soil borne diseases as a result of more intense rainfall events (coupled with warmer temperatures).
- Increased irrigation demand especially during dry periods
- Increased atmospheric CO_2 concentrations will benefit productivity of most horticultural crops, although the extent of this benefit is unknown.
- Increased incidence of disorders such as tip burn and blossom end rot.
- Increased incidence of pests and diseases and the range of some pests may be extended.

HOW CAN AUSTRALIAN HORTICULTURE INDUSTRIES ADAPT TO CLIMATE CHANGE?

There appear to be many potentially significant impacts of climate change on horticultural industries, some of which may be positive, some negative. ***It will be essential to reducing the impact of climate change, that a clearer understanding of what these impacts are, and that management strategies be identified and implemented to either offset the negative impacts, or to take advantage of positive responses***. Previous assessments of such adaptations have been made for other industries (e.g. Howden et al. 2003). One of the general conclusions from these analyses is that the best defence against future climate change is to continue to develop the capacity and knowledge to manage our response to current climate variability more effectively. Climate change is occurring and there are two options; ignore it in the hope that it will go away and accept the consequences; or develop strategies to manage climate change.

Most of the anticipated climate changes point towards the need for a very high standard of crop management in order to respond to the challenges that expected changes pose. Industry and farm managers will need to distinguish between 'old climate expectations' and 'new climate realities' in determining and implementing new adaptation strategies or options.

In order for horticultural industries to successfully adapt to increasing temperatures and subsequent climate changes, there will be a need to develop both pre-emptive and reactive adaptation strategies or options. Horticultural industries are already dealing with increased threats from imported product, the need to become even more efficient as well as changing social, economic and institutional pressures. Industry will need to develop these adaptive strategies to manage adverse environmental conditions in addition to developing and implementing improved production practices to increase efficiency and productivity.
Temperature is the main factor determining location and timing of horticultural production in Australia. Increased temperatures may require changes in cultivars, and timing of planting and harvesting. Increasing temperatures may also result in some current production areas becoming marginal, especially in the early and/or late periods of the production season. Some regions, which are currently marginal for production, may offer some production advantages.

Some **management options for adaptation** are as follows :-

- Closer monitoring and more responsive management of diseases and insect pests and predators. Better control mechanisms will be required.
- For many perennial crops, plan for earlier harvest times and address associated marketing issues including market access and timing.
- Increased irrigation requirements, requiring increased water storage capacity, more accurate moisture monitoring systems and more efficient irrigation systems.
- Relocation of production systems to more favourable districts.
- Changing cultivars or developing new more suitable cultivars
- Improved forecasting of seasonal conditions (medium and long term forecasts).
- Developing strategies to hedge production risks and manage climate variability e.g. – specific cultivars or protected cropping for high value crops.

The following may be useful **steps in developing adaptation strategies** and options :-

- How vulnerable are crops and regions to climate change?
- What are the climate change impacts for the most vulnerable crops and regions?

- Where are the knowledge gaps preventing adaptation to climate change?
- What are the potential adaptation strategies for crops and regions?
- What are the costs and benefits of these adaptation strategies?
- How acceptable are these strategies and what are the capabilities of industries and individual growers to implement these strategies?
- What are the barriers to adoption?

WHAT ARE THE KEY RESEARCH CHALLENGES FOR THE NEXT FIVE YEARS?

We are in the early stages of assessing the impacts and consequences of climate change in horticulture in Australia. Growers are already managing production within a very variable climate. The best defence in managing the impacts of climate change in any system is to improve on the management for current climate variability. The following are challenges for growers, industry and scientists to address as climates continue to change :-

Some options for improved management under a changing climate :-

1. **Assess the Impact of Climate Change** – this might include :-

    - ❖ **Identify current "at risk" production sites,** as the climate continues to change. What is the change in frequency of hot days above specific threshold temperatures, e.g. 30°C; together with a possible reduction in water supply for irrigation?

    - ❖ **Document climate change scenarios for all major horticultural regions in Australia,** based on best available science; including an understanding of the impact of these likely changes on industries.

    - ❖ **Document climate change scenarios for major overseas production regions,** especially in those countries that are major competitors to Australian production; including identifying any additional export opportunities for Australian growers.

    - ❖ **Calculate expected shifts in crop maturity times for different growing areas** for use in marketing plans, in conjunction with monitoring climate changes in existing production areas, as the climate changes.

    - ❖ **Determine climate change impacts on water reliability/availability.**

    - ❖ **Improve the reliability of climate change modelling outputs**, to reduce the variation within future scenarios. Are the current climate change scenarios appropriate for horticultural industries to respond to?

2. **Understand How Crops Respond to Climate Change** – including :-

    - ❖ Identify those **agronomic and physiological factors affecting crop performance**, that can be influenced easily by growers, to account for climate change as it is happening e.g. cultivar choice, irrigation technologies, planting times, etc.

    - ❖ Determine the **sensitivities of these factors in a changing climate** - how sensitive are particular cultivars to increasing temperatures (the sensitivity to increasing frequency of hot days – or decreasing frequency of cold nights on crop growth and development, and product quality; and why can some cultivars tolerate more variability)?

- ❖ Develop a better understanding, and ability to take advantage of, **CO_2 fertilization** and its effects on yield – this is one potential advantage of climate change and increasing CO_2 in the atmosphere, but we do not know the extent of this potential advantage to the large range of crops in horticulture.

3. **Develop Adaptation Strategies** in response to 1. and 2. above – some examples might be :-

- ❖ Identify **management options** that growers and industry can use to manage climate variability and to be able to adapt to a changing climate – i.e. **adaptation strategies** for industries and individual growers, addressing economic, environmental and social impacts.

- ❖ **Identify alternative districts that may be suitable for production,** as the climate continues to change – these are areas which are currently not suitable e.g. eastern Darling Downs could become warmer in the winter, and as a result become a more important vegetable producing region, whilst the Lockyer Valley could become less important as its current winter production window shrinks as winters become shorter and warmer.

- ❖ Continue to **monitor climate changes in existing production areas** (including overseas competitors) – Tables 1-4 demonstrate that climate change will not be the same in all horticultural growing regions.

- ❖ **If expansion of horticultural industries were to occur**, as well as developing a market for the increased production, it will be important to ensure that climate factors have an appropriate weighting in the decision. i.e., this should be part of the land/environment suitability studies.

- ❖ **Review irrigation research** in Australia and undertake any necessary research to fill any gaps in knowledge regarding efficient water use under a changing climate, including an understanding of the barriers to adoption of improved irrigation methods and strategies to overcome them.

- ❖ Develop strategies to **improve property management** and land management to better cope with extreme events and reduce the potential impact.

4. **Better Understand Climate Variability**

- ❖ **Better understand current climate variability** and how it might be managed more effectively, including the use of forecasting tools, information packages or prediction systems such as Australian Rainman, and the use of seasonal climate forecasting.

- ❖ Assess the **requirements of horticultural industries for seasonal temperature** (and rainfall) forecasting information.

- A better understanding of the limitations on the use of forecasting tools, such as the **lead-time and season requirements of the horticultural industries**, including the climate science understanding that would be embodied in a forecasting tool.

The steps in addressing climate change in horticulture in Australia should commence with identifying those industries and specific locations which are most at risk for climate change, followed by the development of adaptation strategies for those industries and regions at risk. At the same time, climate variability (particularly temperature) will continue to challenge managers of horticulture supply and demand chains (production and marketing). Forecasting tools need to be developed with horticulture specifically in mind.

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2. CLIMATE VARIABILITY

Tools for Managing Climate Variability (Climate Applications)

Each of the tools listed and summarised below has in the main, been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. None of these tools have been designed specifically with any horticultural industry or application in mind. The role of tools is to embody the science, rather than to drive it.

Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.

The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced.

There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons. It is expected, although this has not been extensively tested, that other forecast systems would be needed to be able to provide this requirement for horticulture for rainfall forecasts.

A lead-time of up to 4 months would be very useful for many horticultural industries. The usefulness of the 3 month season forecasts embodied in most current forecast systems is significantly reduced by the need for most horticultural industries to have a season forecast of one month or less.

This section briefly describes each tool, its purpose and where it is being used. In the context of this scoping study, a "Tool for Managing Climate Variability" is defined as any information package (hard copy, CD or web based), or software package (CD or web based), that can be used to improve risk management decision making. This list cannot be considered as being exhaustive.

A more detailed assessment of a small selection of these tools is found in the Appendices of this report.

a) Web Based Tools

1. **Rainfall to Pasture Growth Outlook Tool -** http://www.mla.com.au/TopicHierarchy/InformationCentre/FeedAndPastures/Pasturemanagement/Rainfall+to+Pasture+Growth+Outlook+tool.htm

Developed with leading beef and sheep producers, the Rainfall to Pasture Growth Outlook Tool shows actual rainfall and indices of soil moisture and pasture growth for the past 9 months and an outlook for the next 3 months for over 3300 locations across southern Australia.
How the tool can help
Designed specifically to fit the Meat and Livestock Australia, 'More Beef from Pastures'

package, the Rainfall to Pasture Growth Outlook tool takes the guess work out of making a number of very important decisions :-

- What classes of stock should I have on the property at different times of year?
- When should I be calving?
- When should I wean?
- What age should I aim to sell at?
- What pastures could I have?
- How risky is spending money on pasture improvement?

Because the tool covers such a diverse range of soil and pasture types across southern Australia, it provides an index of potential pasture growth, not a prediction of actual growth. The pasture growth index should be interpreted in light of local knowledge as to species, soil type, fertiliser history and aspect.
This tool has limited application in horticulture, but a similar tool which answers appropriate questions for managers of horticultural enterprises would be useful.

2. AgClimate - http://www.agclimate.org/

AgClimate provides new tools to help peanut, tomato, potato, pastures and livestock producers in south-eastern USA, understand and plan for climatic conditions. It is an interactive web site with climate, agriculture, and forestry information that allows users to assess management options under forecast climate conditions.

AgClimate has very limited use in horticulture in Australia, but it could be used as the basis for a similar tool if developed specifically for selected locations in Australia.

The following is an example output for one element of AgClimate for the Baker County in Florida :-

3. Cotton Logic - http://www.mv.pi.csiro.au/CottonLOGIC/index.shtml

The latest management tool that will help with cotton farming decisions, in particular for insect pests and nutrition, has been developed by a team of researchers at CSIRO Plant Industry.

CottonLOGIC is a decision support tool for the Australian Cotton Industry, developed by CSIRO Plant Industry and is distributed for free to Cotton growers and Consultants by the Australian Cotton Cooperative Research Centre.
It will run on Windows 3.x, Windows 95, 98, 2000 and NT operating systems.
Information on insect pressures, crop inputs, pesticide applications, field operations and much more can be stored and easily accessed. This information can then be used to make decisions to improve cotton crop production and sustainability.

It incorporates ;

- EntomoLOGIC- Pest management decision support system
- NutriLOGIC - Analyses soil and petiole nitrate tests and gives Nitrogen recommendations to maximise yield.
- Support for Rotation and Refuge crops
- User-Definable INGARD Thresholds
- Weather Data Entry for Operations
- Forecast Temperature Data Entry for more accurate Heliothis pressure prediction
- A comprehensive range of cotton pest and beneficial insect pictures

This tool has little application for horticultural managers but it could be used as the basis for a similar tool if developed specifically for selected locations in Australia.

4. Yield Prophet® - http://www.yieldprophet.com.au/yp/wflogin.aspx

Yield Prophet is an on-line crop production model designed to provide grain growers with real-time information about the crop during growth.

To assist in management decisions, growers enter inputs at any time during the season to generate reports of projected yield outcomes showing the impact of crop type and variety, sowing time, nitrogen fertiliser and irrigation.

Yield Prophet ® is a subscriber only service, however, visitors may browse with restricted access.

Yield Prophet ® does not generate recommendations or advice. Yield Prophet® uses the computer simulation model APSIM (see APSRU – p 36.) together with paddock specific soil, crop and climate data to generate information about the likely outcomes of farming decisions. APSIM does not take into account weed competition, pest/disease pressure, pesticide damage, farmer error, or extreme events (such as extreme weather, flood and fire). For more information about APSIM please look at www.apsim.info

If appropriate tools for managing climate variability were available, the delivery mechanism used by Yield Prophet could have many advantages.

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b) Web Based Sources of Information for Managing Climate Variability

There are numerous web sites that provide information that can be useful to producers, industries, consultants and advisors in making more informed decisions. These information sources aim to provide a better understanding of climate variability, and how this variability affects specific industries. None of these have been designed specifically for Australian horticultural industries.

- **Climatology for the peanut Industry -**

Part I http://www2.dpi.qld.gov.au/climate/9428.html
Part II http://www2.dpi.qld.gov.au/climate/9144.html

This information is regularly updated for the peanut industry, and includes climate forecasts, and discussions on what this might mean for managers of peanut enterprises.

- **LongPaddock –** http://www.longpaddock.qld.gov.au/

The Long Paddock website is provided by the Queensland Government. It supplies decision-support information services to help clients in all states of Australia to better manage climatic risks. It contains detailed information on the current climate situation including Sea Surface Temperatures (SST), value of the Southern Oscillation Index (SOI), recent rainfall events, seasonal outlooks, drought maps and pasture growth forecasts. The information is aimed at grazing and grain industries in the main, although much of the information has application, and can be useful to managers of horticultural enterprises.

- **Queensland DPI&F Climate Information -** http://www2.dpi.qld.gov.au/climate/

The Queensland Department of Primary Industries & Fisheries (DPI&F) climate web site containing the 'Current Climate Note' and other updates including the latest on the SOI, rainfall probabilities for Queensland and Australia, includes information on sea surface temperatures, regional crop outlooks and information on services, workshops and products.

DPI&F is actively pursuing ways to best manage climate variability, and be prepared and be able to take advantage of climate change. The crops and primary industries which are being targeted by this information are in the main, broad-acre grain and grazing industries.
Much of the information has application in horticulture, but requires interpretation for the specific needs of growers, regions and industries.

The following includes some of the information available from this site :-

Climate outlook summary including El Niño Watch — January to March 2006
Current climate note - http://www2.dpi.qld.gov.au/climate/ — Detailed outlook for three months – updated each month
Rainfall probability maps Queensland, Australia, the world — for three months – updated each month
Seasonal crop outlook — Sorghum –updated each month during the season
Seasonal crop outlook — Wheat – updated each month during the season
Climatology for peanut growers

Using climate forecasts — Some key points
The Season Ahead — A quarterly newsletter for western Queensland.

- **Managing Climate Variability R&D Program**

http://www.managingclimate.gov.au/information_resources.asp?section=21#reports

Four of the latest issues of the Climag magazine can be downloaded from the above web site.

Also available are case studies of farmers who have used climate applications to better manage their enterprises. It is called the Masters of the Climate , where farmers from across Australia have documented how they have applied new climate forecasting tools and information. This booklet is filled with their insights. All of these case studies are from managers of broad-acre or grazing enterprises.

A particularly interesting aspect of this is the "Science Behind the Case Studies" document which is available at -
http://www.lwa.gov.au/downloads/publications_pdf/PK050943_Science.pdf

A small selection of Climate Variability in Agriculture Program (CVAP) Projects funded over the past 10 years :-

- Advanced Climate Forecasting: helping industry make better decisions more often (JCU20) (November 2004 - February 2006) Dr (Yvette) Everingham, James Cook University Townsville Qld
- Horses for courses: using the best tools for managing climatic risk (MIG1) (July 2004 - April 2007) (Cameron) Weeks, Mingenew-Irwin Group
- Increasing success of tree establishment by using seasonal climate forecasts (CSE20) (October 2004 - May 2007) Dr (Mark) Howden, CSIRO Sustainable Ecosystems
- Managing climate risk for livestock producers (KON5) (July 2003 - January 2004)
- Managing natural resource issues in a variable and changing climate (CSE24) (October 2004 - Dec 2006) Dr (Mark) Howden, CSIRO Sustainable Ecosystems
- Seasonal climate forecasts to improve dairy farmers' feedbase management (DAN20) (June 2004 - May 2007) Ms (Katrina) Sinclair, NSW Department of Primary Industries Orange NSW
- Better management of climate variability within the agribusiness service sector (CTC18) (October 1998 - December 2000) Dr PS (Peter) Carberry, CSC Australia Pty Ltd
- Dairy El Nino risk management study (DRD3) (July 1997 - December1997) Mr G (Greg) Hayes, VCG Australia Pty Ltd Albury NSW
- Decision support for climatic risk management in dryland crop production (DAS12) (July 1993 - December 1995) Mr J (Jim) Egan, Primary Industries and Resources South Australia Port Lincoln SA
- Development of improved seasonal climate forecast systems (BOM1) (April 1993 - December 1997) Dr N (Neville) Nicholls, Australian Bureau of Meteorology Melbourne Vic
- Evaluating the role of seasonal climate forecasting in tactical management of cropping systems in north-east Australia (QPI38) (July 1996 - December 1999) Dr RC (Roger) Stone, Department of Primary Industries Queensland Brisbane Qld

- Grazier-based profitable and sustainable strategies for managing climatic variability (CWE8) (October 1993 - September 1995) Dr M (Mark) Stafford-Smith, CSIRO Sustainable Ecosystems Alice Springs NT
- Seasonal climate information and farmers' risk assessment and decision-making (UQL20) (January 1999 - August 2001) Dr L (Lenard) Dalgleish, University of Queensland Brisbane Qld

- **NSW Department of Primary Industries -** http://www.agric.nsw.gov.au/reader/nr-climate

The NSW Department of Primary Industries web site contains information on climate variability, SOI, drought, ElNino, and how to use seasonal rainfall outlook information. None of this information is specifically targeted towards horticulture, although much of this information is useful for managing climate variability by managers of horticultural enterprises.

- **Climate and weather information sources -** http://www2.dpi.qld.gov.au/climate/9193.html

This is a specific listing of 20 climate and weather related web sites in Australia and overseas. They provide detailed information on the seasonal outlook, much of which is useful for horticulture, although not specifically designed for this purpose.

- **Bureau of Meteorology (BOM) –** http://www.bom.gov.au/climate/

The term climate is used in the broadest sense. It spans the past (yesterday's temperature, statistics over a long period) through to the future (outlooks based on slowly changing patterns like El Niño) and information about climate change, much of which is very useful for managers of horticultural enterprises. See Appendix 2. for further information.

- **National Oceanic and Atmospheric Administration (NOAA) -** http://www.noaa.gov/

A US-based site containing the National Oceanic and Atmospheric Administration (NOAA) services and data. It includes information on current weather watches and warnings, hurricanes, tornadoes, tides and currents, buoys, nautical and aeronautical charts, real-time satellite imagery, environmental, geostationary and polar satellites, El Niño & La Niña, global warming, drought, climate prediction, archived weather data, paleoclimatology and current research on air quality, atmospheric processes and climate and human interactions.
A very useful site for gaining a good understanding of climate variability issues.

- **The Climate Prediction Centre (CPC) -** http://www.cpc.ncep.noaa.gov/

The Climate Prediction Centre (CPC) in the United States has a very useful internet site for monitoring conditions (eg westerly wind bursts, Kelvin wave activity, sea surface and sub-surface temperatures etc) in the Pacific. The ENSO Diagnostics Discussion in the Climate Highlights section is highly recommended for those interested in progress of El Niño/La Niña state.

- **Madden Julian Oscillation (MJO) –** http://www.apsru.gov.au/mjo/ or http://www.bom.gov.au/climate/tropnote/tropnote.shtml

The MJO is a band of low air pressure originating off the east coast of central Africa travelling eastward across the Indian Ocean and northern Australia roughly every 30 to 60 days. Research has shown the MJO to be a useful indicator of the timing of potential rainfall events (but not amounts). Knowledge of the position of the MJO can be useful for improving tactical decision making by managers of horticultural enterprises.
See Appendix 5. for more detail.

- **Southern Oscillation Index (SOI) –** http://www.bom.gov.au/climate/glossary/soi.shtml or http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/SouthernOscillationIndex/index.html or http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/RainfallProbability/index.html

The Southern Oscillation Index (SOI) is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. The SOI is a prediction system which is used in a number of forecasting tools (e.g. Rainman StreamFlow).
See Appendix 1. for more detail.

- **Sea Surface Temperatures (SST) -** http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/SeaSurfaceTemperature/index.html

Sea-Surface Temperature patterns in the Pacific Ocean and Indian Oceans are important in driving climate variability and are useful guides to potential climate patterns in Australia (and other parts of the world). SST's are used by the Bureau of Meteorology in developing rainfall and temperature outlooks.
See Appendix 2. for more detail.

- **Summer crop outlook - Farm level**

Evaluating long-term potential yields in response to different input quantities can help manage risk and plan input quantities for the coming year for Sorghum and Wheat.

Considerable insights can be gained from using these simple computer tools. They are a great resource of information and add to experience and other knowledge sources for sorghum and wheat growers. Knowing soil water, even roughly can assist planning of input quantities and planted areas.

Seasonal crop outlook—Sorghum January 06 -
http://www2.dpi.qld.gov.au/fieldcrops/14206.html

- **Land Water & Wool - Improved seasonal forecasting for wool producers in western Queensland Pastoral Zone**
  - http://www2.dpi.qld.gov.au/climate/14793.html

The purpose of this site is to provide climate information including seasonal forecasts for western Queensland primary producers. The products and climatic descriptions are customised specifically for pastoral management systems located in western Queensland. Maps show the main towns and shire boundaries. The seasonal forecasts are issued for rainfall and pasture growth including a measure of their skill. Skill indicates the confidence that the forecast probabilities will represent the actual outcome. The climate information includes educational material and simple explanations of other websites that help interpret climatic conditions in western Queensland (e.g. sea surface temperatures, Madden Julian Oscillation, westerly winds). The educational material helps with understanding of a range of climatic terms including probabilities, medians and skill.

- **Agricultural Production Systems Research Unit (APSRU) -** http://www.apsru.gov.au/apsru/

The Agricultural Production Systems Research Unit (APSRU) is an unincorporated joint venture between the state of Queensland through its Department of Primary Industries and Fisheries and Department of Natural Resources and Mines, CSIRO through its Divisions of Sustainable Ecosystems and Land & Water, and The University of Queensland.

APSRU has developed a number of products including APSIM (Agricultural Production Systems sIMulator). APSIM was developed to simulate biophysical processes in farming systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk. APSIM is structured around plant, soil and management modules. These modules include a diverse range of crops, pastures and trees, and soil processes including water balance, N and P transformations, soil pH, erosion and a full range of management controls. APSIM resulted from a need for tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factor while addressing the long-term resource management issues.
The systems approach used by APSRU is of great value to horticultural cropping systems. Models for horticultural crops which can be used by APSIM, would be required to be able to realize on this value.
Whopper Cropper uses APSIM outputs to develop a range of scenarios for broad-acre cropping (See Appendix 3. for more detail).

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c) CD Based Tools

- **Rainman StreamFlow version 4. -** http://www.dpi.qld.gov.au/rainman/

Rainman StreamFlow is a forecasting tool, which contains records for Australia, including historical monthly and daily rainfall for 3800 locations; monthly and daily streamflow for nearly 400 locations; and world-wide, monthly rainfall records for some 9500 locations.

Rainman StreamFlow can analyse these records for individual locations for seasonal, monthly and daily rainfall patterns; forecast seasonal rainfall based on the Southern Oscillation Index (SOI) or Sea Surface Temperatures (SST); group locations for spatial analysis; import monthly and daily rainfall and streamflow data; and print results as tables and graphs or maps - http://www2.dpi.qld.gov.au/rainman/13234.html

The standard seasonal forecast is for 3 months with a zero lead-time.

The Rainman StreamFlow software is available from the Department of Primary Industries and Fisheries, Queensland.

Standard and Educational ($125); Professional ($450); for a single licence only. Upgrades from a previous version cost $25 (including GST and P&P).

Monthly rainfall and predictor data, and maps, can be updated automatically over the Internet for no charge. Data is usually available after about the tenth day of the following month.

See Appendix 1. for more detail.

- **Whopper Cropper -**

The information in Whopper Cropper enables grain and cotton crop management advisers and producers to make better crop management decisions, using cropping systems modelling and seasonal climate forecasting. Whopper Cropper combines seasonal climate forecasting with cropping systems modelling to predict the production risk that growers face in the coming cropping season. This helps producers to choose the best management options for the coming season. Whopper Cropper is the result of interaction between researchers and crop management advisers developing this modelling technology and making it widely available.

A "Whopper Cropper" for horticulture would require the same crop modelling input as has been developed for the range of broad-acre crops included in Agricultural Production Systems sIMulator (APSIM).
There exists in APSIM the generic 'PLANT' module. This has recently been parameterised to develop a Broccoli module. Similarly a 'Sweet corn' module is available. With similar parameterisation from experimental trials other horticultural crops could be modelled.

WhopperCropper is distributed by Nutrient Management Systems (phone 0407 692251).

See Appendix 3. for more detail.

d) Hard Copy Tools

- **"Will it Rain? The effect of the Southern Oscillation and El Nino on Australia."**

Will It Rain? is a book for farmers, graziers, students and anyone else interested in the weather and seasonal forecasting. Will it Rain? was written as a companion to the Rainman StreamFlow CD and software to explain the weather systems associated with the Southern Oscillation and El Nino - terms which appear frequently in the media. It is available from DPI&F Book Sales for $24.05. http://dpishop.dpi.qld.gov.au/bookweb/details.cgi?ITEMNO=9780734501394

The book describes : -

- what causes the weather over Australia
- the Southern Oscillation and how it influences seasonal weather
- how the Southern Oscillation affects crop and pasture growth
- how farm managers can use the Southern Oscillation Index to reduce risk from the weather
- present seasonal forecasting information and future developments.
- the third edition contains a new Chapter 6 about new indicators that have potential for more accurate and longer-term seasonal forecasting.

e) Potential Tools

- **Land Suitability Analysis - Spatial Analysis Modelling**

In 2001, the Victorian Government embarked on a pilot project, which aimed to determine the potential for growing certain commodities (including cool climate grapes) across Gippsland, and the likely shift in that potential as climate change occurs in the region. This project has demonstrated that climate change will impact different agricultural activities in different ways over time and in different regions.

This expert modelling technique allows for an assessment of impact on a wide range of commodities beyond the historic focus of standard cropping and pasture models. It contains the methodology for linking the hierarchical analysis method for land suitability with scenario modelling. It could also be applied to horticulture, overlaying the production requirements of various crops (and varieties of crops), with climate changes.

In the development and practice of **Land Suitability Analysis, DNRE Victoria**, approximately 20 commodity models across fruits, vegetables, cropping, flowers and plantations have been created that are directly transferable for potential climate change impact.

Climate change will impact different agricultural/horticultural activities in diverse ways over time and space. Some areas will become more suitable for certain activities while others will become less suitable.

- **PlantGro**
  http://www.topoclimate.com/plantgro.htm

PlantGro (TM) is a software package that can be **used to predict the growth and development of plants** under different environmental conditions. It can also predict the activity of insects and plant diseases. The program input is the data contained in plant, soils and climate files. By changing climate files to represent future climate change scenarios, plant growth and development can be predicted.

PlantGro is available from :-
Topoclimate Services Pty Ltd
P.O.Box 47,
Coffs Harbour NSW 2450
Australia

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Discussion

This Scoping Study set out to document climate change and climate variability issues in horticulture and identify tools which can be used in horticulture, especially in the vegetable industry, to better manage climate variability and change.

Climate Change

There is ample evidence available to support the view that climate change has occurred over the past 100 years in Australia. Australian annual mean temperatures have increased by 0.82°C since 1910, with rapid increases since 1950 (Smith, 2004). Night-time temperatures have increased faster (0.11°C/decade) than daytime temperatures (0.06°C/decade), together with increasing frequency of hot days (35°C or more) of 0.08 days per year and a decreasing trend in cold nights (5°C or less) of 0.16 nights per year.

Similarly, future climate change modelling outputs which have produced scenarios, based on a range of parameters, including the increasing levels of greenhouse gasses (especially carbon dioxide), demonstrate a very high probability of ongoing climate change in Australia.

Climate change as a consequence of global warming, will add to the difficulties which horticultural industries already have in coping with an extremely variable climate. A mean warming of 0.4 to 2.0°C is anticipated over most of Australia by the year 2030 (relative to 1990), and 1 to 6°C by 2070 (CSIRO, 2001). Mean temperature change is likely to be greatest inland and least on the coast. Most warming is expected to occur in spring and summer, and least in winter. These changes will have different effects on a range of horticultural crops grown in the diverse environments and different seasons across Australia.

Most of the anticipated climate changes point towards the need for a very high standard of crop management in order to respond to the challenges that expected changes pose. Industry and farm managers will need to distinguish between 'old climate expectations' and 'new climate realities' in determining and implementing new adaptation strategies or options.

In order for horticultural industries to successfully adapt to increasing temperatures and changing rainfall patterns, there will be a need to develop both pre-emptive and reactive adaptation strategies or options.

Climate Variability.

There are a large number of "tools" available to agricultural managers for managing climate variability, but none of these are particularly suitable for use by managers in horticulture.

Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.

The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced.

There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons. It is expected, although this has not been extensively tested, that other forecast systems would be needed to be able to provide this requirement for horticulture for rainfall forecasts.

A lead-time of up to 4 months would be very useful for many horticultural industries. The usefulness of the 3 month season forecasts embodied in most current forecast systems is significantly reduced by the need for most horticultural industries to have a season forecast of one month or less.

Conversely, there are numerous sources of information, especially web based information sources, that can be useful to horticultural producers, industries, consultants and advisors in making more informed decisions. Although these information sources are not specifically designed with horticulture in mind, they do aim to provide a better understanding of climate variability, and how this variability affects specific industries.

Because there are no specific tools or information sources which have been designed to address climate change and variability issues specific to horticulture, the following challenges will require addressing by horticultural industries in the short to medium term :-

1. Assess the impact of climate change
2. Understand how crops respond to climate change
3. Develop adaptation strategies, in response to 1. and 2. above
4. Better understand climate variability and develop tools with specific application to horticultural industries.

The steps in addressing climate change in horticulture in Australia should commence with identifying those industries and specific locations which are most at risk for climate change, followed by the development of adaptation strategies for those industries and regions at risk. At the same time, climate variability (particularly temperature) will continue to challenge managers of horticulture supply and demand chains (production and marketing). Forecasting tools need to be developed with horticulture specifically in mind.

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Technology Transfer

The purpose of this Scoping Study has been to document climate change and climate variability issues for consideration by the Vegetable Industry Advisory Committee, who have commissioned this Scoping Study.

A Milestone Report was presented to Horticulture Australia Ltd and the Vegetable IAC in February 2006, and this Final Report completes the work program of this Scoping Study (VG05051).

As part of this Scoping Study activity, two conference papers were prepared and presented by Peter Deuter to specific audiences :-

a) Howden, M., Newett, S. and **Deuter, P.** (2005). Climate Change - Risks and Opportunities for the Avocado Industry. Joint New Zealand and Australian avocado conference, Tauranga, NZ, 20-22nd September 2005.
b) **Deuter, P.**, Howden, M., and Webb, L. (2006). Climate Change - Risks and Opportunities for the Vegetable Industry. Australian Vegetable Industry Conference, Brisbane, 10-12th May 2006.

The proceedings of both these conferences have been distributed to attendees on CD. The presentations and the papers are also available from Peter Deuter peter.deuter@dpi.qld.gov.au

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Recommendations

The purpose of this Scoping Study has been to document climate change and climate variability issues for consideration by the Vegetable Industry Advisory Committee, who have commissioned this Scoping Study.

Climate change as a consequence of global warming, will add to the difficulties which horticulture industries already have in coping with a very variable climate.

The following are some **R&D challenges for horticulture** to consider in the short to medium term, to address the risks and opportunities of current and future climate change, as well as the difficulties which managers have in making informed decisions in a very variable climate.

Each one these <u>four main challenges</u> can be addressed through R&D and further harnessing the knowledge and skills of scientists, growers, consultants, and other managers in the horticulture supply and demand chain :-

1. **Assess the Impact of Climate Change** – by :-

    - ❖ Identifying current "at risk" Australian production sites (regions).
    - ❖ Documenting climate change impacts on overseas competitors; and identifying any additional export opportunities for Australian producers.
    - ❖ Calculating expected shifts in crop maturity times for different regions.
    - ❖ Determine climate change impacts on water reliability/availability.
    - ❖ Improving the reliability of climate change modelling outputs.

2. **Understand How Crops Respond to Climate Change** – by :-

    - ❖ Identifying those agronomic and physiological factors affecting crop performance.
    - ❖ Determining the sensitivities of these factors in a changing climate.
    - ❖ Developing a better understanding, and ability to take advantage of, CO_2 fertilization and its effects on yield.

3. **Develop Adaptation Strategies**, in response to 1. and 2. above – by :-

    - ❖ Identifying management options – i.e. adaptation strategies.
    - ❖ Identifying alternative districts that may be suitable for production.
    - ❖ Monitoring climate changes in existing production areas.
    - ❖ Reviewing irrigation research.
    - ❖ Developing strategies to improve property (enterprise) management.

4. **Better Understand Climate Variability**

    - ❖ Developing a better understanding of current climate variability, how it affects horticulture, and how growers might manage it more effectively.
    - ❖ Assess the requirements of horticultural industries for seasonal temperature (and rainfall) forecasting information.
    - ❖ Address the lead-time and season requirements of the horticultural industries, including the climate science understanding that would be embodied in a forecasting tool.

There are many tools for managing climate variability designed for a number of agricultural industries. **No tools for managing climate variability have been specifically designed for horticulture in Australia.** The majority of these tools are associated with rainfall variability, and very few provide information on how to manage variability in temperature. Temperature is the major factor in determining where horticultural crops can be grown successfully, and then how well these crops perform under varying seasonal conditions.

e.g. Lettuce - the Australian environment (particularly temperature) varies considerably from season to season in all lettuce growing districts, and cultivar selection and planting times cannot always be satisfactorily matched with the temperature conditions that significantly influence product quality during the head filling stage, which is up to 3 months after transplanting, depending on season and location. To be able to make much better decisions on cultivar selection, planting dates and marketing plans, growers need information on the temperature regime for the head development and maturity period up to harvest (a forecast for a 2-3 week period, with a lead-time of 3-4 months). This information is currently not available.

Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.

The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced.

The steps in addressing climate change in horticulture in Australia should commence with identifying those industries and specific locations which are most at risk from climate change, followed by the development of adaptation strategies for those industries and regions at risk. At the same time, climate variability (particularly temperature) will continue to challenge managers of horticultural supply and demand chains (production and marketing). Forecasting tools need to be developed, with horticulture specifically in mind.

With an improvement in our understanding of climate change and variability, it will be possible for industries and individuals to develop a capacity to change practices, change locations or even change enterprises to deal with changes in climate that are occurring, and the evidence is that this will continue to occur. These responses to climate change could include change in current land use over large areas, through to changing varieties or changing some management practices.

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Appendix 1. – Rainman StreamFlow Version 4

Rainman StreamFlow is a forecasting tool which contains records for Australia, including historical monthly and daily rainfall for 3800 locations; monthly and daily streamflow for nearly 400 locations; and world-wide, monthly rainfall records for some 9500 locations.
Rainman StreamFlow can analyse these records for individual locations for seasonal, monthly and daily rainfall patterns and forecast seasonal rainfall based on the Southern Oscillation Index (SOI) or Sea Surface Temperatures (SST). It can group locations for spatial analysis, import monthly and daily rainfall and streamflow data, and print results as tables and graphs or maps - http://www2.dpi.qld.gov.au/rainman/13234.html

The standard forecasts for which Rainman Streamflow has been designed, are for a 3 month season, and a zero lead-time which are appropriate for the grain and grazing industries for which this tool has been designed.
The combination of long season (3 months) and short lead-time (zero) is a significant constraint to the use of this tool in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons. It is expected, although this has not been extensively tested, that other forecast systems would be needed to be able to provide this requirement for horticulture for rainfall forecasts.

The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

Some examples of Rainman Streamflow outputs :-

Analyses as tables

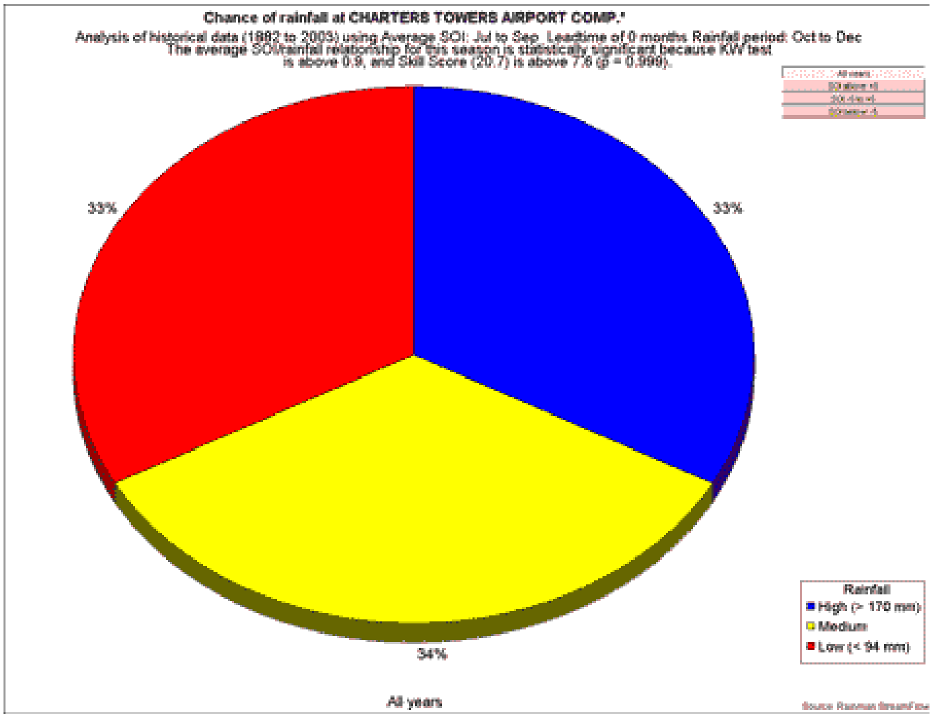
a) - 'What chance do I have of getting 120 mm of rainfall between August and October at Charters Towers, Queensland?

Chance of rainfall at CHARTERS TOWERS AIRPORT COMP.*
Analysis of historical data (1882 to 2003) using average SOI: Jul to Sep Leadtime of 0 months
The average SOI/rainfall relationship for this season is statistically significant because KW test is above 0.9, and Skill Score (20.7) is above 7.6 (p = 0.999). Chance result or real skill ? Help

Rainfall period: Oct to Dec	SOI below -5	SOI -5 to +5	SOI above +5	All years
% yrs with at least 356 mm	0	6	13	6
210 mm	8	26	48	26
160 mm	11	41	68	39
120 mm	31	54	81	54
100 mm	47	67	84	65
80 mm	58	78	94	76
36 mm	86	100	97	95
% yrs above median 128 mm	19	50	81	49
KS/KW probability tests	KS=0.999	KS=0.04	KS=0.999	KW=0.999
Significance level	***	Not significant	***	
Years in historical record	36	54	31	121
Highest recorded (mm)	250	562	532	562
Lowest recorded (mm)	7	36	34	7
Median rainfall (mm)	95	130	190	128
Average rainfall (mm)	100	158	209	154

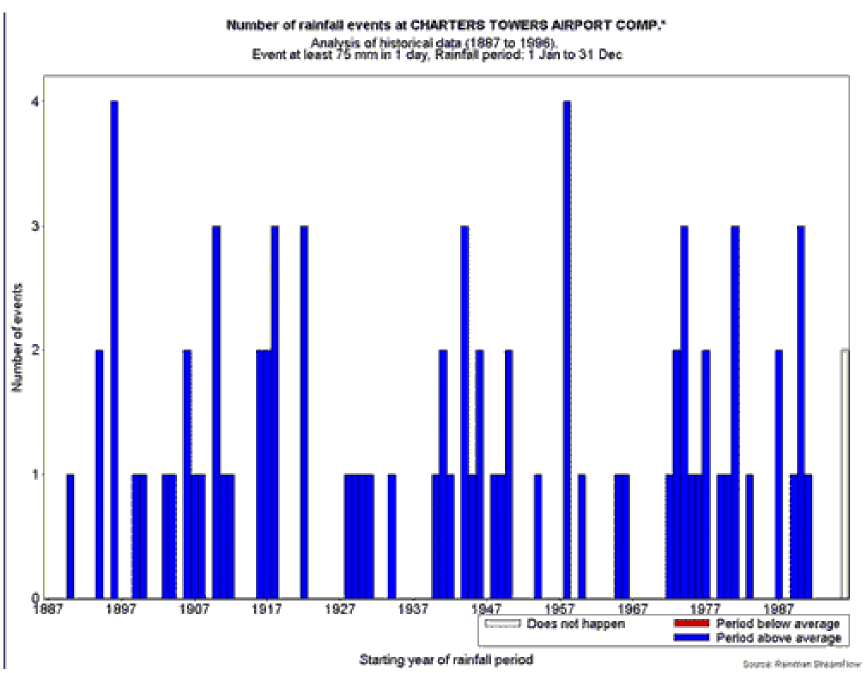
Analyses as pie charts

b) - ***'How does the SOI affect my chances of rainfall in the spring?'***



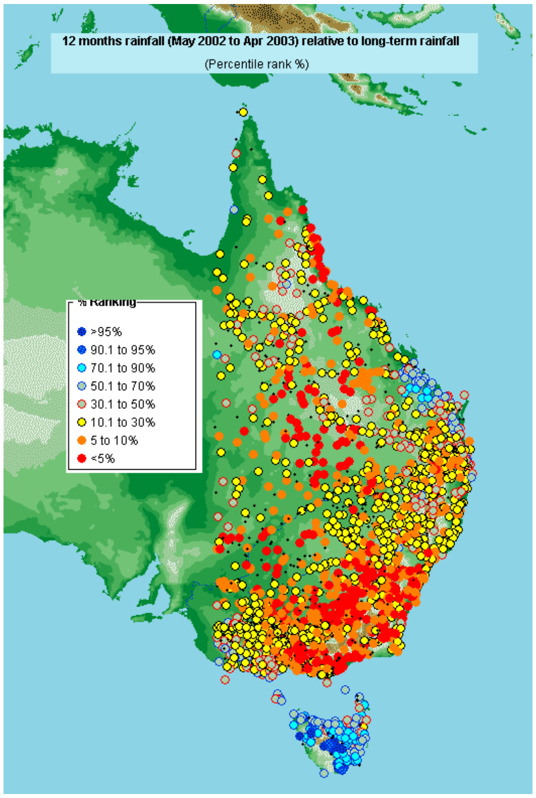
Analyses as bar graphs

c) - ***'How often have we had 75 mm of rain in 1 day?***
Have these extreme rainfall events become more frequent in recent years?'



Analyses as maps

d) - *'How dry were the 12 months up to April 2003 relative to the long-term average?'*



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Appendix 2. – Bureau of Meteorology – Seasonal Temperature Outlook.

Advice on the status and development of ENSO has been provided from a number of sources in Australia since 1989, initially from the National Climate Centre (Anon, 2001, pp 63-65).

The Bureau of Meteorology (BOM) produces three-monthly outlook information for each state, and nationally, and is updated regularly. e.g. the most recent National Seasonal Rainfall Outlook is available at :- [http://www.bom.gov.au/climate/ahead/] **A corresponding outlook is issued for temperature.**

"The *rainfall* outlooks perform best in eastern and northern Australia between July and January, but are less useful in autumn and in the west of the continent. The skill at predicting seasonal *maximum temperature* peaks in early winter and drops off marginally during the second half of the year. The lowest point in skill occurs in early autumn. The skill at predicting seasonal *minimum temperature* peaks in late autumn and again in mid-spring. There are also two distinct periods when the skill is lowest - namely late summer and mid-winter." (http://www.bom.gov.au/climate/ahead/rain_ahead.shtml)

These rainfall and temperature outlooks are based on Sea Surface Temperature (SST) patterns in the Pacific and Indian Oceans, and they relate to a three month season, and a zero lead-time.

The combination of long season (3 months) and short lead-time (zero), is a significant constraint to the use of this tool in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons. It is expected, although this has not been extensively tested, that other forecast systems would be needed to be able to provide this requirement for horticulture for rainfall forecasts.

There are many tools for managing climate variability, designed for a number of agricultural industries. No tools have been specifically designed for horticulture in Australia. The majority of these tools are associated with rainfall variability, and very few provide information on how to manage variability in temperature. Temperature is the major factor in determining where horticulture crops can be grown successfully, and then how well these crops perform under varying seasonal conditions.

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Appendix 3. – Whopper Cropper

The following is an (updated) summary of the a paper by Rohan Nelson and Howard Cox, titled – **"Whopper Cropper: a *discussion support system* for managing climate risk in Australia's northern cropping systems"**, available at :-
http://www.bom.gov.au/climate/cli2000/rNelson.html

Whopper Cropper was developed in response to a demand by extension professionals for access to the broad-acre cropping systems modelling capability of the APSIM model (McCown *et al*. 1996) and to seasonal climate forecasting using the SOI phase forecasting system of Stone *et al*. (1996).

To create the Whopper Cropper database, a team of researchers from the Agricultural Production Systems Research Unit (APSRU) have used the APSIM model to simulate a variety of broad-acre crops with different starting soil conditions and management options, for 16 regions between Gunnedah in Central New South Wales and Clermont in Central Queensland.

These simulations provide information on the impact of climate risk on broad acre crop yields for crop management alternatives beyond the experience of individual farmers, using historical climate records to obtain a long term perspective. Whopper Cropper's graphical user interface is designed to support workshops that enable farmers to explore management strategies at the beginning of each cropping season.

A "Whopper Cropper" for horticulture would require the same crop modelling input as has been developed for the range of broad-acre crops included in APSIM. There exists in APSIM the generic 'PLANT' module. This has recently been parameterised to develop a Broccoli module. Similarly a 'Sweet corn' module is available. With similar parameterisation from experimental trials other horticultural crops could be modelled.

Managing climate risk in cropping systems

Crop management decisions can be supported using decision support systems such as Whopper Cropper, that simulate the effects of management and climate variability on crop yields.

Providing data such as rainfall to managers increases the information surrounding complex management decisions, but may not help managers focus on the outcomes that are important to them. Consequently, Whopper Cropper is designed to provide distributions of crop yields that enable the likely impact of management options to be rapidly evaluated.

It was developed using an iterative development process that involved extension professionals and the target user group. Through this feedback process, Whopper Cropper developed into a software tool that extension professionals could use interactively in discussion with farmers about management options. An evolving recognition of the effectiveness of Whopper Cropper in this role has led the development team to refer to it as a *discussion* support system.

What is Whopper Cropper?

Whopper Cropper (Nelson *et al*. 1999) is a database of pre-run APSIM simulations with an easy-to-use graphical interface facilitating time series, probability and diagnostic analyses. To create the Whopper Cropper database, a team of researchers from the Agricultural Production Systems Research Unit (APSRU) have used the APSIM model to simulate a variety of broad-acre crops with different starting soil conditions and management options, for 26 regions between Dubbo in Central New South Wales and Clermont in Central Queensland. Whopper Cropper's graphical user interface can be used to view probability distributions of crop yields by SOI phase to discuss the best management options for the coming season. Future versions of Whopper

Cropper ncludes a facility to simulate distributions of gross margins, to combine distributions of yield and price for each crop management option.

A new WhopperCropper project has built on the success of the prvious project. The capability is now being distributed through all states except Tasmania. The training, distribution and support process is conducted through a private commercial delivery partner that has access to up to 800 advisors and consultants. This improves adoption and allows increased time for R&D. Support to state agency staff and educational institutions is provided by the project staff.

Case studies using Whopper Cropper

Whopper Cropper has been designed to support workshops in which farmers can explore crop management options for the coming season.

Some examples of the use of Whopper Cropper are :-

a) What is the range of yields expected for my district?

Yield outcomes are very variable in Central Queensland (Figure 1). The mean sorghum yield associated with a positive SOI phase for September/October is 1000 kg/ha greater than that for a negative SOI. Whopper Cropper provides insight into the management options that may be varied to improve the reliability of crop production. Growers can explore management strategies by varying area sown, forward selling, N fertiliser input, irrigation planning, plant density and other crop choices.

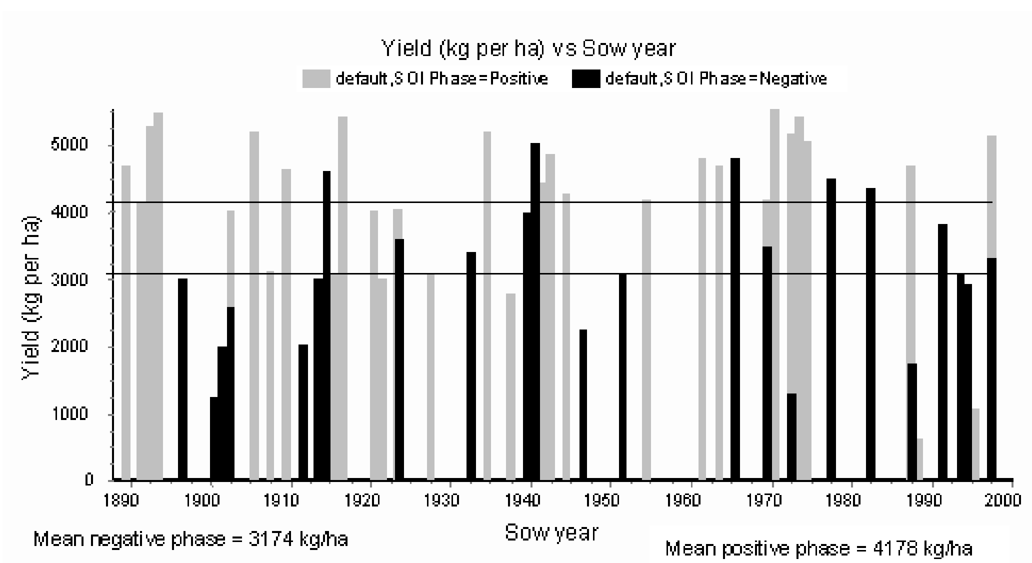

Figure 1 Comparison of grain yields of sorghum sown in November at Biloela with negative and positive SOI phases for September/October (170mm PAWC 67% full medium maturity, 7 plants/m^2, 50 kgN/ha)

b) What is the optimum sowing time? – For sorghum, should I sow early (September – November) or wait to the more conventional time of December – January?

If the SOI remains near zero (Spring 2000) through September and October there is little difference in the potential outcome from a November or a January sowing time (Figure 2). However, if the SOI became positive, November sowing opportunities offer an advantage in terms of expected yield. This last occurred in spring 1998 when several local growers took advantage of the opportunity. However, if the SOI became negative, as it was in spring 1997, the January sowing time appears slightly more favourable.

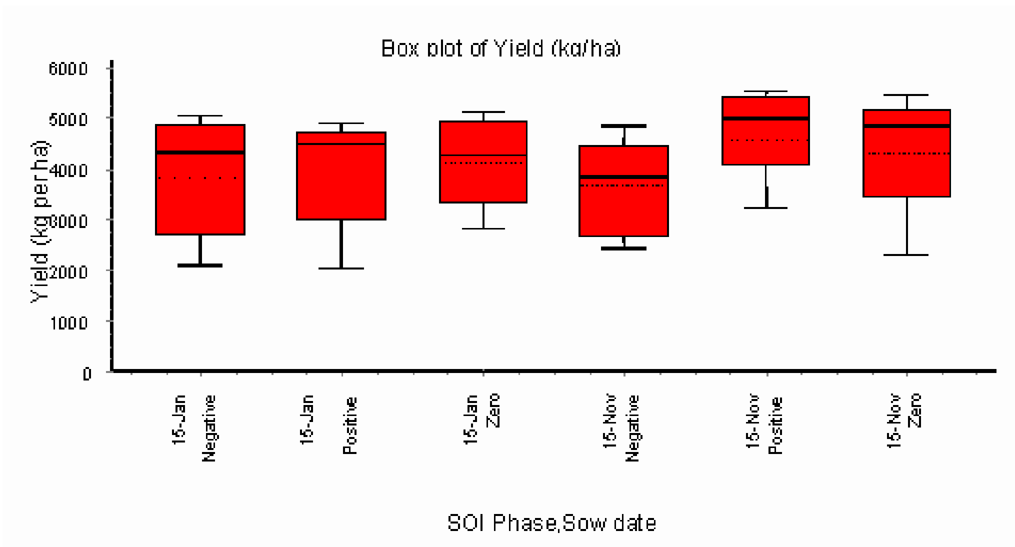

Figure 2: Modelled yield distributions of sorghum sown in November or January with three SOI phases for September and October (170mm PAWC, 67% full, medium maturity, 7 plants/m^2)

Conclusion

Whopper Cropper was developed in response to a growing demand from extension professionals for access to cropping systems modelling and seasonal climate forecasting to enhance the management of cropping systems. The development and extension of Whopper Cropper is an incremental step in the evolution of decision/discussion support systems in Australian Agriculture, focusing on management outcomes rather than farming system inputs. Whopper Cropper enables users to easily manipulate and view a wide range of crop management options, and evaluate likely outcomes given current seasonal climate forecasting information. It has proved to be an effective *discussion* support system for enhancing the management of climate risk in cropping systems. Delivery has been focussed on professional advisors and is being successfully conducted through a commercial delivery partner.

A "Whopper Cropper" for horticulture would require the same crop modelling input as has been developed for the range of broad-acre crops included in APSIM. There exists in APSIM the generic 'PLANT' module. This has recently been parameterised to develop a Broccoli module. Similarly a 'Sweet corn' module is available. With similar parameterisation from experimental trials other horticultural crops could be modelled.

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Appendix 4. – "Will it Rain? The effect of the Southern Oscillation and El Nino on Australia."

Will It Rain? is a book for farmers, graziers, students and anyone else interested in the weather and seasonal forecasting. Will it Rain? was written as a companion to the Rainman StreamFlow CD and software to explain the weather systems associated with the Southern Oscillation and El Nino - terms which appear frequently in the media. It is available from DPI&F Book Sales for $24.05. http://dpishop.dpi.qld.gov.au/bookweb/details.cgi?ITEMNO=9780734501394

The book describes : -

- what causes the weather over Australia
- the Southern Oscillation and how it influences seasonal weather
- how the Southern Oscillation affects crop and pasture growth
- how farm managers can use the Southern Oscillation Index to reduce risk from the weather
- present seasonal forecasting information and future developments.
- this third edition contains a new Chapter 6 about new indicators that have potential for more accurate and longer-term seasonal forecasting.

The Southern Oscillation

The Southern Oscillation is the most important influence on the year to year variability of our weather in Australia. The Southern Oscillation which is a see-saw of air pressure between the eastern equatorial Pacific and the Australian-Indonesian Region, explains about 40% of the variation in eastern Australian rainfall (high rainfall variability is a normal feature of weather patterns in eastern Australia).

When the atmospheric pressure is high over one region, it is usually low over the other. This oscillation of air pressure between these two regions affects the weather in many parts of the world, but the effects vary between countries and at different times of the year.

The Southern Oscillation Index (SOI).

The strength of the Southern Oscillation is measured by the difference in air pressure between the eastern Pacific and Australia. A mathematical formula is applied to the air pressure differences between Darwin and Tahiti, and is referred to as the Southern Oscillation Index (SOI). The SOI usually ranges from -30 to +30.

The SOI doesn't have the same influence on all parts of Australia. Its strongest influence is on eastern Australia. When the SOI is strongly positive, the trade winds blow across the Pacific picking up moisture. This often results in above average rainfall in eastern Australia. When the SOI is strongly negative, trade winds are weak and rainfall can be below average. This is often referred to as an *El Niño*. The acronym ENSO (El Niño Southern Oscillation) is often used to describe this situation; that is the combination of El Niño and Southern Oscillation.

The relationship between the SOI and rainfall is strongest in winter, spring and summer in Eastern Australia, although a strong trend in SOI in autumn often settles into a pattern for the remainder of the year.

During the autumn, the skill levels associated with predicting future rainfall outlook, are often reduced. This is known as the ‘predictability barrier’.

Sea Surface Temperatures (SST’s), the SOI and Rainfall.

Coral Sea (western Pacific) temperatures can cool by 1^{o}C during an El Niño event, which can have a large impact on our rainfall. In contrast, SST’s in the eastern Pacific may rise by 2-5^{o}C to 26-29^{o}C during an El Niño phase. Under a positive SOI, strong trade winds help push warm water in the equatorial Pacific region towards Australia, promoting more rainfall. Under a negative SOI, these trade winds are weakened, the sea surface off eastern Australia cools, reducing the potential for rainfall.

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Appendix 5. – Madden Julian Oscillation (MJO) –

http://www.apsru.gov.au/mjo/ or http://www.bom.gov.au/climate/tropnote/tropnote.shtml

The MJO (sometimes referred to as the '40 day wave') is a band of low air pressure originating off the east coast of central Africa between latitudes 10^{o}N and 10^{o}S, travelling eastward across the Indian Ocean and northern Australia roughly every 30 to 60 days.

Research has shown the MJO to be a useful indicator of the timing of potential rainfall events (but not amounts). It is a useful tool for managers of agricultural and horticultural businesses.

A brief, non-technical description of the MJO is provided by the Bureau of Meteorology (BOM) at - http://www.bom.gov.au/silo/products/iso.shtml

The MJO has the most influence in winter when it may strengthen an upper-level trough.

The accuracy of weather forecasts are significantly reduced for periods exceeding 4 or 5 days, and are generally not available for periods over 10 days. Climate forecasts on the other hand are generally not feasible for periods of less than 3 months. The result is what might be termed a weather-climate gap. The MJO, as a band of low air pressure travelling eastward across the Indian Ocean and northern Australia roughly every 30 to 60 days has the potential to provide information to managers to fill this gap.

Information on, and the passage of, the MJO can be followed at :-
http://www.apsru.gov.au/mjo/index.asp

There are 8 phases of the MJO that correspond with the location of convection (rainfall) in the tropics – phase 1. corresponds with the east coast of equatorial Africa, Phase 4 with eastern Australia, and Phase 8 with the central Pacific (see Fig 3).

Research has shown that the location of the MJO, or phase, is linked with patterns in Australia's rainfall. This validates anecdotal evidence about the effect of the MJO recognised by many in the rural sector.

Using the maps for each of the 8 phases (see Fig 4 - for Phase 4 – winter), and the current location of the MJO (see Fig 3 - for 21st May 2006), managers can determine the potential for increased rainfall at a location in Australia.

Fig 3. - A graphical representation of the positioning (up to 21st May 2006) of the MJO - http://www.apsru.gov.au/mjo/index.asp

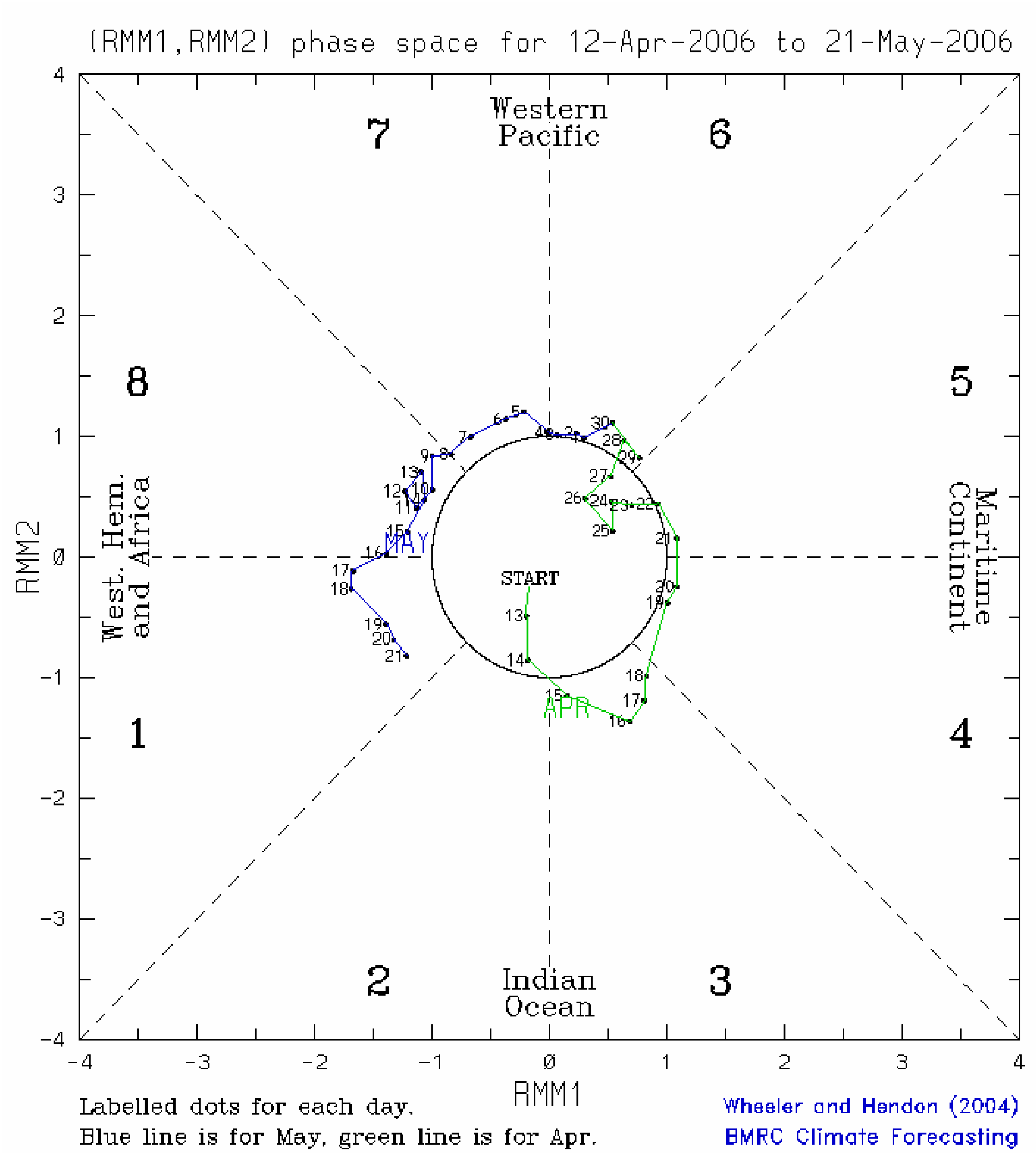

Fig 4. – MJO - Winter Phase 4 – demonstrating rainfall enhancement (closed squares) and rainfall suppression (open circles) - for eastern Australia -

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