Queensland Government

'Climate Change - Risks and Opportunities for the Custard Apple Industry'

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A paper presented at the National Australian Custard Apple Conference 2011. "Quality and Quantity – Finding and Understanding the Balance". 14th - 16th July, Sunshine Coast, Queensland, Australia.

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SUMMARY

Climate affects the custard apple industry in a range of ways through impacts on growth, disease risk, fruit set and industry location.

Climates in Australia are influenced by surrounding oceans, and are very variable from year to year. However, amidst this variability there are significant trends, with Australian annual mean temperatures increasing since 1910, and particularly since 1950, with night-time temperatures increasing faster (0.11°C/decade) than daytime temperatures (0.06°C/decade). These temperature increases and other climate changes are expected to continue as a result of greenhouse gas emissions, with ongoing impacts on the custard apple industry.

Five sites were chosen to assess possible future climate changes : Mareeba, Yeppoon, Bundaberg, Nambour and Lismore, these sites representing the extent of the majority of custard apple production in eastern Australia. A fifth site (Coffs Harbour) was selected as it is south of the current production regions.

A mean warming of 0.8 to 1.2°C is anticipated over most of these sites by the year 2030, relative to 1990.

This paper assesses the potential effects of climate change on custard apple production, and suggests strategies for adaptation.

KEY WORDS: custard apple, climate change scenarios, climate variability, adaptation strategies, greenhouse gasses, climate model simulations, climate change impacts, management options, seasonal climate forecasting

INTRODUCTION

The custard apple industry is affected in a range of ways by climate since it affects growth, disease risk, fruit set and industry location (see Table 1). 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.

There is increasing evidence that human activities are already changing the global and Australian climate, and that more change seems likely. Consequently, historical conditions may become increasingly less pertinent as a guide to risk management or industry adjustment. This paper assesses the evidence for climate change, drawing particularly on the IPCC Fourth Assessment Report (IPCC 2007, 2002, 2001, Solomon et al., 2007), and explores the potential impacts and implications of such changes for the custard apple industry in Australia.

AUSTRALIAN CUSTARD APPLE INDUSTRY

Custard apples are grown in sub-tropical regions in eastern Australia from the Atherton Tableland to northern NSW. The tropics tend to be too hot and more southerly regions are too cool. Some production occurs in WA north of Perth.

The main growing regions are Atherton Tableland, Yeppoon, Bundaberg, Nambour, Glasshouse Mountains and the Lismore-Alstonville Region of Nthn NSW.

Flowering and fruit set occur from October to January in Qld and December to March in northern NSW, with harvesting following from February to July and April to October respectively.

Table 1 - Seasonal Availability Chart - Australian Custard Apple Production.

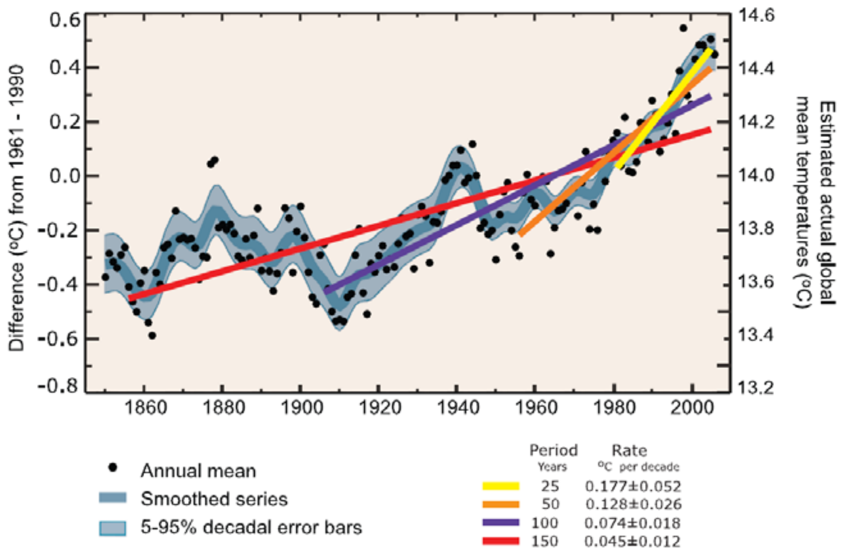
Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Queensland		---	---	---	---	---						
			***	***	***							
Central Queensland		---	---	---	---							
			***	***	***							
South East Queensland			---	---	---	---	---					
				***	***	***						
Northern NSW				---	---	---	---	---	---	---		
						***	***	***	***			
Legend:	---	**Season Length**					***	**Season Peak**				

Source – www.custardapple.com.au

WHAT IS CHANGING, AND BY HOW MUCH?

Recent changes

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). The concentration of these atmospheric constituents has consequences for the absorption of solar radiation by the atmosphere, and thus global and regional climates. In the case of the main 'greenhouse gases', notably carbon dioxide (CO_2) and its effect on temperature (Fig 1), methane (CH_4) and nitrous oxide (N_2O), the direction, magnitude and longevity of this effect is well-established; and the increased concentrations of these gases results in a net warming of the globe (IPCC, 2007, 2000, Solomon et al., 2007). In the case of the minor or more transient gases (such as the tropospheric ozone-precursors), the effect is known to be warming, but the degree, duration and distribution of the warming around the planet is less certain. Nevertheless, independent evidence from observations of the climate of the past century and a half, strongly implies that the total global radiant energy (gases and particulates) is having a warming effect on the world.

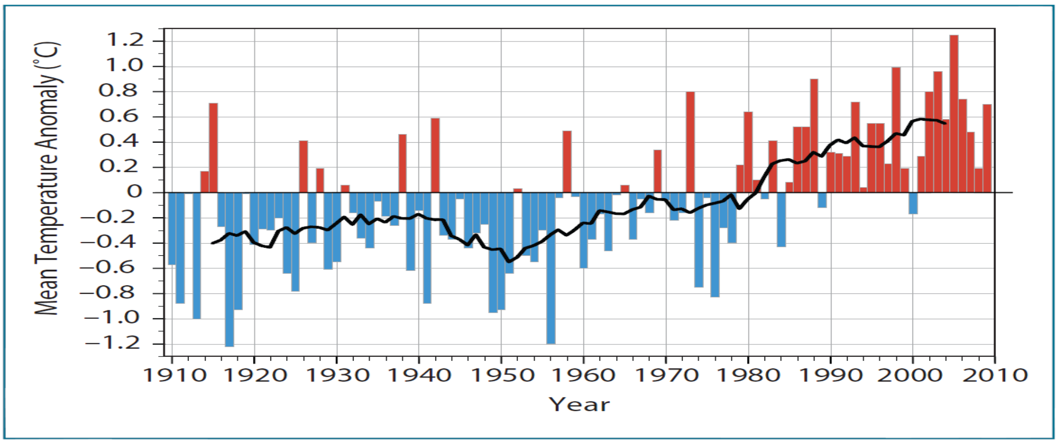


Annual global mean temperatures (black dots) with linear fits to the data. The left hand axis shows temperature anomalies relative to the 1961 to 1990 average and the right hand axis shows estimated actual temperatures, both in °C. Linear trends are shown for the last 25 (yellow), 50 (orange), 100 (purple) and 150 years (red). The smooth blue curve shows decadal variations with the decadal 90% error range shown as a pale blue band about that line. The total temperature increase from the period 1850 to 1899 to the period 2001 to 2005 is 0.76°C ± 0.19°C.

Fig 1. *Changes in annual global mean temperature (Solomon et al., 2007)*

"The global average surface temperature has increased, especially since about 1950. The updated 100-year trend (1906–2005) of 0.74°C ± 0.18°C is larger than the 100-year warming trend at the time of the TAR (1901–2000) of 0.6°C ± 0.2°C due to additional warm years. The total temperature increase from 1850-1899 to 2001-2005 is 0.76°C ± 0.19°C. The rate of warming averaged over the last 50 years (0.13°C ± 0.03°C per decade) is nearly twice that for the last 100 years". (Solomon et al., 2007). About three-quarters of the change observed since 1850 is attributed to human actions (IPCC, 2007).

Australian annual mean temperatures have increased by 0.82°C since 1910, with rapid increases, particularly since 1950 (Smith, 2004), with night-time temperatures increasing faster (0.11°C/decade) than daytime temperatures (0.06°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°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 (Hennessy *et al*., 2004a).



Time-series (1910–2009) of Queensland's annual mean surface temperature anomalies.

Fig 2. *Annual Temperature Changes in Queensland – (1910-2009)*
Source :- Climate Change in Queensland - What the Science is Telling Us - http://www.climatechange.qld.gov.au/pdf/climate-change-in-queensland-2010.pdf

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. This is due to a weakening or southward shift of the frontal systems that bring most rain to these regions (Marshall, 2003) and generally wetter conditions during the 1950's. 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.

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

The general nature of the changes described above also include changes in regions where the custard apple industry is strongly represented.

Five sites were chosen to assess possible future climate changes – Mareeba, Yeppoon, Bundaberg, Nambour and Lismore, these sites representing the extent of the majority of custard apple production in eastern Australia. A fifth site (Coffs Harbour) was selected as it is south of the current production regions.

Fig 3. *Five sites (plus one) assessed for climate change impacts.*

Table 2 - Historical temperature changes (1957 to 2005) with temperature trends expressed in degrees Celsius per 100 years, for six eastern Australian locations.

Site	Annual mean temperature change	Winter minima change	Summer maxima change
Mareeba	2.52	5.3	0.9
Bundaberg	1.70	2.2	1.0
Yeppoon	0.79	1.2	-0.01
Nambour	3.26	6.1	1.1
Lismore	0.47	0.36	0.2
Coffs Harbour	1.93	3.4	0.9

Temperature affects custard apples in many ways, including influencing timing and reliability of flowering, fruit growth, ripening and fruit quality. Custard apple fruit are susceptible to skin discolouration and splitting when prolonged temperatures below about 13°C are experienced during the later stages of fruit development (DPI&F, 1998).

Temperatures of 25°C to 28°C during flowering (October to February) are favourable for good fruit set. At temperatures above 28°C, custard apples produce more growth and fewer flowers, and drying of flower parts increases (Sanewski,1988).

Temperatures above 32^{o}C are more conducive to vegetative flushing and increased competition between fruitlets and vegetative growth, resulting in reduced fruit set (George and Nissen,1987)

There are strong trends of increased mean annual temperature across the five sites (Table 2), ranging from 0.47^{o}C per century (Lismore) to 3.26^{o}C per century (Nambour). About 60 to 80% of the warming arises from change in night-time temperatures and 55 to 70% of the warming is from temperature increases in the May-October period.

Custard Apples are sensitive to ***frosts***, which can kill or severely damage both young and bearing trees. Temperatures at or about 4^{o}C can affect fruit quality through splitting and discolouration (Sanewski,1988).

In frost-affected custard apple-growing regions in Australia, there have been significant decreases in the number of frosts (Table 3), the date of last frost, the length of the frost period and the date of the first frost (i.e. the first frost is slightly later - see Nambour example in Fig. 4) over the past five decades. These changes are largely explained by the general increases in minimum temperatures experienced at these sites.

If minimum temperatures increase as projected, and providing rainfall doesn't decrease too markedly, then the historical trends towards lowered risk of frost are likely to continue.

Table 3 - Changes in the numbers of frosts, the timing of the first and last frosts and the length of the frost period in frost affected sites (over the past 100 years), for six eastern Australian locations.

Site	Change in the number of frosts	Change in the timing of the first frost	Change in the timing of the last frost	Change in the length of the frost period
Nambour	-14	39	-43	-81
Lismore	-1.7	17	15	-2
Coffs Harbour	-6	27	-16	-43

Note: Mareeba, Yeppoon and Bundaberg are generally not frost-affected.

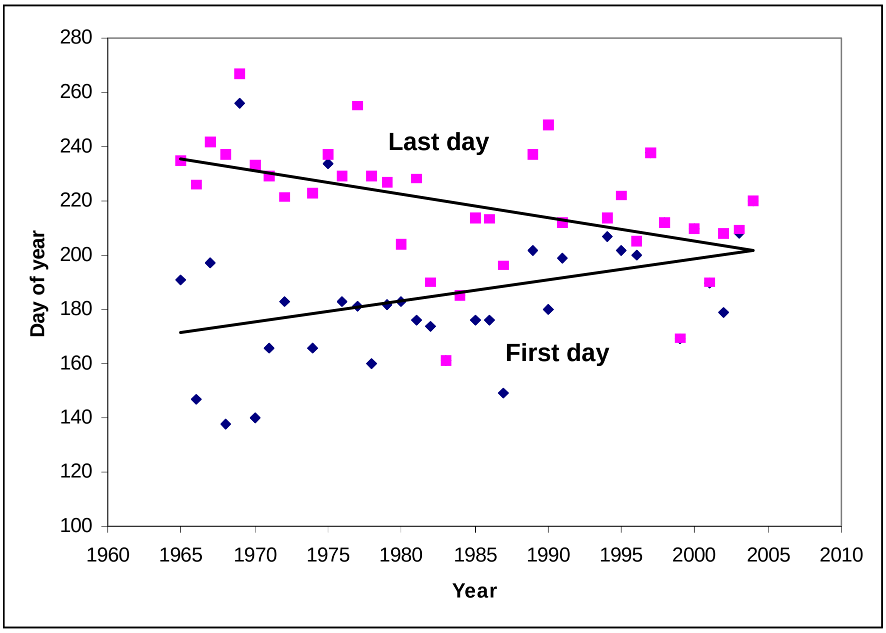


***Fig 4 -** Trends in frost incidence for Nambour.*

Relative humidity

A relative humidity of 70% to 80% is best for fruit set and the development of good fruit shape (Sanewski,1988). Poor fruit set in southeast Queensland is often as a result of relative humidity below 30% (George and Nissen, 1988.)

Optimum conditions are :-

- Temperature - 25^{o}+/-5^{o}C
- Relative Humidity – 75-90% (George, 2011)

Periods of ***heat stress*** (for example - days with temperatures above 35^{o}C) especially if accompanied by low humidity will adversely affect fruit set. Fruit can also be burnt by high radiation loads. Generally across the five sites, there are trends towards increasing numbers of heat stress days (Table 4).

Fruit set is also enhanced by high diurnal temperature ranges (the difference between daytime maxima and night-time minima); this too has been decreasing in most of the six sites (Table 4). A low diurnal temperature range decreases the chances of male and female flower parts being open at the same time to achieve pollination.

Irrigation demand is strongly affected by evaporation rates. High quality, long-term and consistent measurements of evaporation are rare. We have used the Penman-Monteith equation (FAO) to estimate potential evaporation based on more commonly measured atmospheric variables. However, wind-run is not varied and where this has changed, we will not have represented this in our estimates which show increases in potential evaporation across all sites, except Lismore (Table 4). This is likely to have resulted in progressively higher irrigation requirements over time, assuming that all other factors (e.g. technology, pricing, availability) were not changed.

Table 4 - Historical changes in evaporation (mm), diurnal temperature range (^{o}C), heat stress frequency (days per year with maximum temperature greater than 35^{o}C) for six eastern Australian locations (1957 to 2005), with trends expressed as a change per 100 years.

Site	Daily evaporation change	Change in diurnal temperature range	Change in heat stress frequency
Mareeba	0.28	-3.1	1.05
Yeppoon	0.89	-2.44	5.03
Bundaberg	0.16	-0.25	1.29
Nambour	0.44	-2.76	2.79
Lismore	0	0.22	0.22
Coffs Harbour	0.62	-1.04	0.72

Table 5 - How climate affects critical stages in custard apple production.

Climatic factor	Impact on custard apple growth and development
Storm damage (incl. cyclones)	Fruit loss, tree and infrastructure damage
Frost	Frosts kill or severely damage both young and bearing trees
Very low humidity at flowering	Desiccation of pollen and fruitset failure
Heat stress	Desiccation of pollen and fruitset failure
Higher maximum and minimum temperatures	Earlier maturity under higher temperature conditions
Diurnal temperature variation	The greater the diurnal temperature range the greater the chances for male and female flower parts being open at the same time, and therefore achieving pollination and fruit set
Wet conditions for 24 hours or longer	Pollen becomes too moist, it breaks down and leads to fruitset failure
Hot sites and hot windy conditions	Higher evaporation rates and thus greater need for irrigation and mulch
Combination of suitable soils and climate	Industry location

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 5.8ºC during the 21st Century (IPCC, 2000). This is a large range, with about half of the variation in projected temperatures being due to uncertainties in the climate models, and the other half due to uncertainties regarding greenhouse gas emissions which are closely tied to social, economic and technological aspects of our future. 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. When translated to Australia, there are anticipated to be substantial increases in temperature over and above those already experienced.

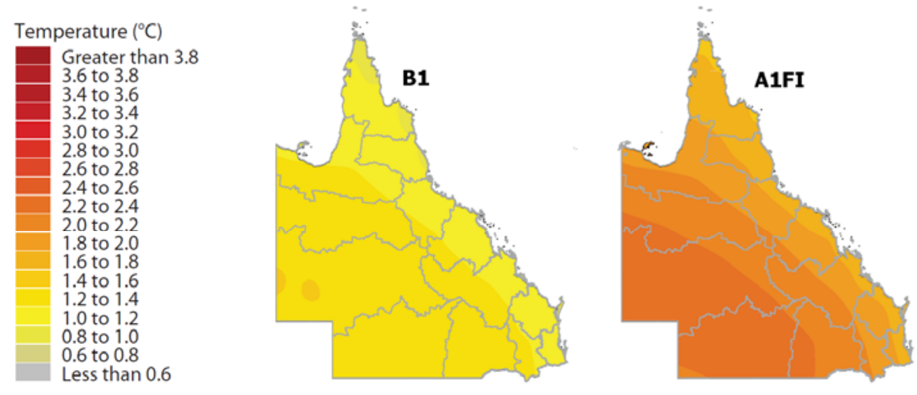
For the five custard apple growing sites assessed, expected changes by 2030 vary from 0.8 to 1.3^{o}C. The changes up to 2030 are consistent with the existing trends in mean temperature.

Table 6 - Historical mean temperature increases (^{o}C) for eight eastern Australian locations compared with A1F1 Scenario of temperature increase from the 1990 baseline period.

Site	Temperature increase (^{o}C/100 yrs)	A1F1 Scenario - 2030 (^{o}C)
Mareeba	2.5	0.8
Yeppoon	1.5	0.9
Bundaberg	1.7	1.0
Nambour	3.2	1.0
Lismore	2.1	1.2
Coffs Harbour	1.9	1.2

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 across Australia, the occurrence of hot spells is more likely to increase in frequency in inland areas and to a lesser extent on the coast.



Best estimate (50th percentile) of projected change in annual temperature (°C), by 2050 for low (B1) and high (A1FI) emissions scenarios

Fig 5. *Changes in temperature for two contrasting scenarios for **2030**.*

Emission scenarios
The A1F1 Scenario describes a future world where very rapid economic growth occurs together with a world population which peaks about 2050 and then declines, with a fossil-fuel intense energy system
The B1 Scenario describes a world which is significantly different – much less emphasis on materialism and the introduction of clean technologies. - https://wiki.csiro.au/confluence/display/ozclim/Science

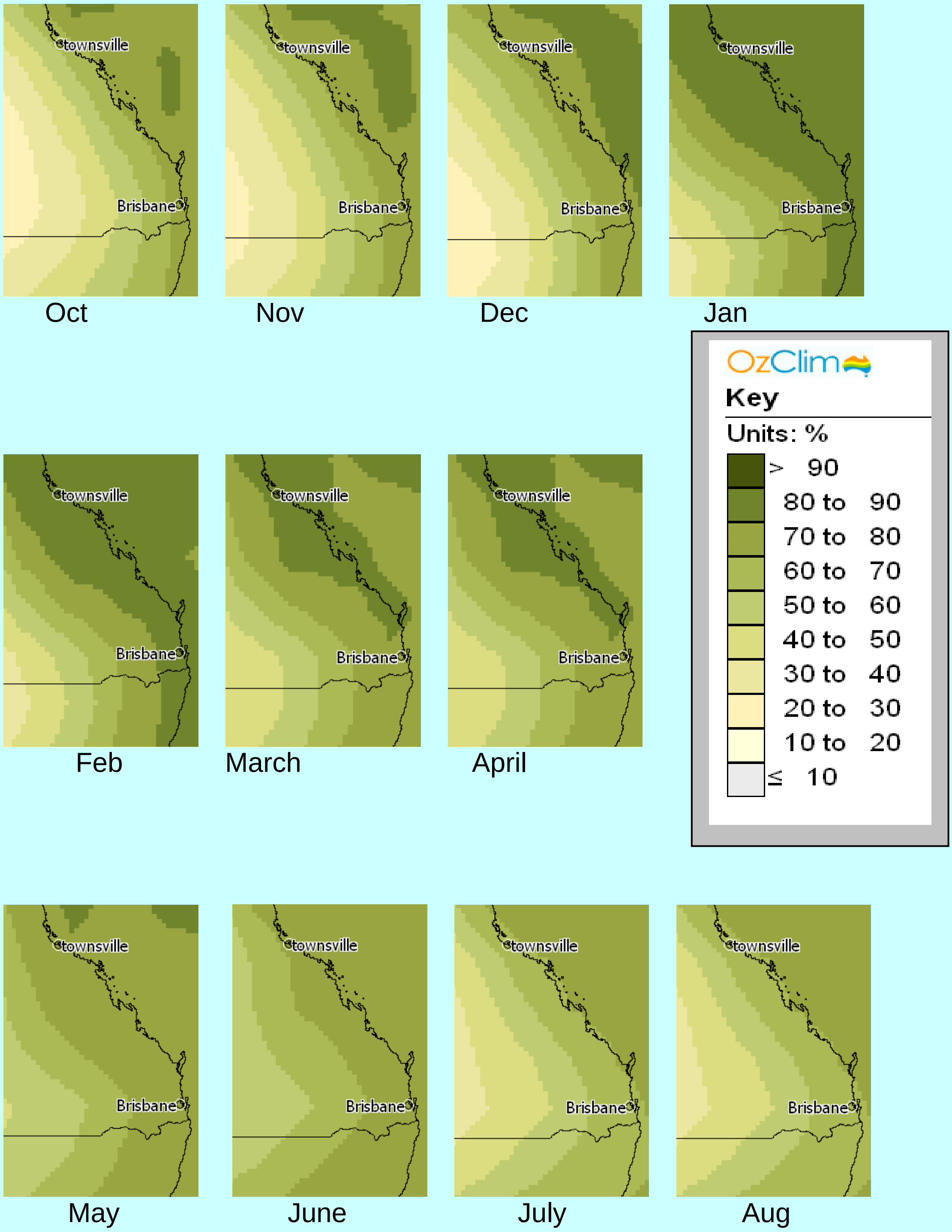
Annual humidity tends to decrease over Australia, with largest decreases in the south and west, and little change along the east coast.

Small decreases in relative humidity are projected over most of Australia. The range of change in annual humidity by 2030 is around -2% to +0.5% with the best estimate being a 1% decline.

Table 7 - Relative Humidity decrease (%) for six eastern Australian locations - A1F1 Scenario Seasonal Relative Humidity decrease from the 1990 baseline period.

Site	RH (%) **decrease** (Summer)	RH (%) **decrease** (Autumn)	RH (%) **decrease** (Winter)	RH (%) **decrease** (Spring)
Mareeba	0.6	0.7	0.4	0.3
Yeppoon	0.9	0.7	0.7	0.6
Bundaberg	0.9	0.6	0.8	0.8
Nambour	0.8	1.0	1.0	0.8
Lismore	1.1	1.6	1.5	1.3
Coffs Harbour	1.2	1.8	2.1	1.8

Relative Humidity Projections for 2030



Projected Monthly Relative Humidity (%) in eastern AUSTRALIA for the year 2030 - October to September. Model: CSIRO-Mk3.5. Emission Scenario: SRES marker scenario A1FI, Global Warming Rate: moderate

Source : http://www.csiro.au/ozclim/home.do

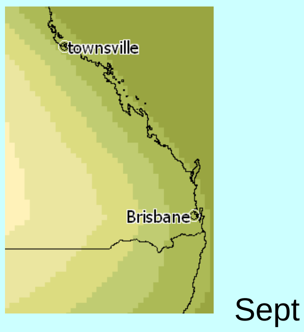


Fig 6. *Changes in Monthly Relative Humidity for **2030**.*

A tendency for less ***rainfall*** is expected in the south-west of WA (-20 to +5% by 2030, -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.

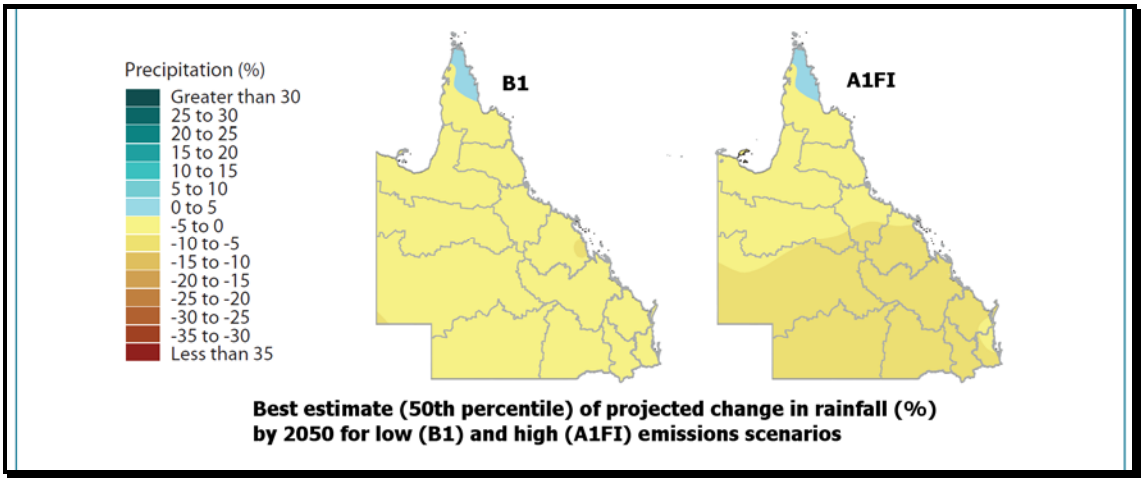


Fig 7. *Changes in rainfall for two contrasting scenarios for **2030**.*

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 Nino 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. If rainfall intensity does increase, this may increase soil erosion risk and also may increase the frequency of waterlogging.

Scenarios of rainfall intensity (e.g. Hennessy, 2004b) indicate considerable geographical diversity in possible responses, with a tendency for a decrease in rainfall extremes along the east coast in autumn and winter, although most models project an increase in the intensity of extreme rainfall in spring and summer on the north-east coast.

When broken down by ***seasons***, 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 (±7% by 2030 and ±20% by 2070) and winter (±13% by 2030 and ±40% by 2070) showing no particular directional changes (Cai et al. 2003).

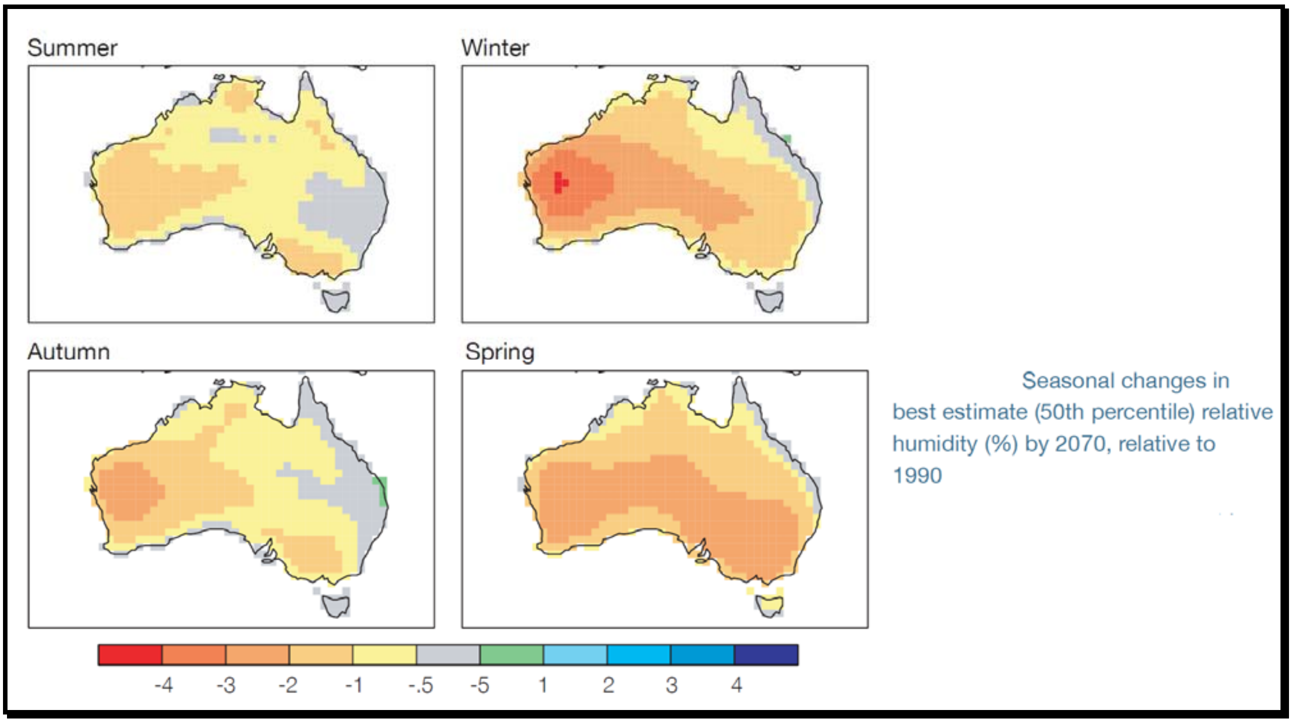


Fig 8. *Changes in seasonal relative humidity for **2070***

Australian ***tropical cyclone*** frequency and regions of occurrence show little change under enhanced greenhouse conditions, but there is a 56% increase in the number of ***storms*** with wind speeds exceeding 30 ms^{-1} (108 km per hr) and an increase in the number of storms south of latitude 30°S (Walsh *et al*., 2004). However, the confidence in these projections is only moderate due to issues with representation of ENSO in the models.

Climate change may bring slightly higher extreme ***wind speeds*** to parts of southern Australia, especially in spring and summer, but lower wind speeds on the north coast of NSW and the Queensland coast, with exceptions under cyclonic conditions.

HOW WILL CLIMATE CHANGE AFFECT THE AUSTRALIAN CUSTARD APPLE INDUSTRY?

Climate change could feasibly affect the custard apple industry in many ways. Potential effects of the climate changes outlined above are briefly documented, based on current understanding of custard apple agronomy and physiology.

Table 8 - Climate change impacts on custard apple growth and development.

Change	Issues	Potential impacts on custard apple growth and development
Temp. related	Less diurnal temperature range	Reduced chances of overlap between open stages of male and female flower parts. Therefore less potential for pollination and fruitset.
	Hotter summer temperatures	Pollination failures if heat stress days occur during flowering.
	Significantly warmer temperatures in general	A shift in the growing regions - away from the hotter producing areas to new areas currently regarded as being marginally too cool.
	Time to reach maturity	Warmer temperatures suggest that fruit will set and reach maturity earlier in the season, shifting the harvest times for different areas.
	Insect activity	Insect activity is closely related to temperature, so a rise in temperature suggests more active insect populations (both pests and predators).
	Increasing number of heat stress days	Pollination failures if heat stress days occur during flowering.
Moisture related	Greater moisture extremes - more frequent excessively wet and dry periods.	Increased irrigation demand during dry spells, and potential water-logging under high intensity rainfall events.

Heat stress

Generally, the frequency of heat stress days is likely to increase only marginally if temperature increases by 2030 are at the lower end of the projection range (B1 Scenario), but increase by two to five-fold if temperature increases are at the upper end of the range (A1F1 Scenario). The increase in heat stress frequency with temperature is essentially exponential. If temperature increases proceed as indicated in the climate change scenarios, heat stress days would be commonplace during flowering at all of the five sites, by 2030.

So, where there is an increase in the number of heat stress days during flowering, reduced fruit set will also most likely occur, especially if accompanied by low humidity.

Pollination and Humidity

During the flowering, pollination and fruit set phases in custard apple, stigmas loose their receptivity to pollen before pollen is released, a process called dichogamy. The result is a low level of natural pollination and subsequent fruit set when these female and male stages within each flower do not properly coincide (George et al., 1988).

Stigmas may remain receptive for longer under high humidity conditions, providing opportunities for higher levels of pollination and fruit set. High temperature and low humidity has the opposite effect. Relative humidity below 75% has a negative impact on fruit set by affecting stigma receptivity (George, 2011).

Male and female stages overlap for longer in custard apple varieties which have a naturally high fruit set capability.

HOW CAN THE INDUSTRY ADAPT?

There appear to be many potentially significant impacts of climate changes on the custard apple industry, some of which may be positive, some negative. There is a need to identify management strategies to either offset 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 current climate variability more effectively.

Most of the anticipated climate changes point towards the need for a very high standard of orchard management in order to respond to the challenges that expected changes pose. Some of the expected changes may even see a need to consider a shift in orchard location (e.g. Schulze and Kunz, 1995). There is also a need to adapt marketing plans to accommodate anticipated changes in harvest times. Therefore the following potential management implications for growers and the industry may need to be considered.

Table 9. Potential implications for custard apple orchard management as a result of anticipated climate change.

Issue	Potential management implications
Warmer night temperatures	Areas previously considered too cool may now have potential as custard apple production sites.
Higher summer temperatures	Increased irrigation requirements, increased water storage capacity, more accurate moisture monitoring systems and more efficient irrigation systems. Re-locate to cooler micro-climates or more southerly locations.
Earlier maturity times	Plan for earlier harvest times and address associated marketing issues.
Waterlogged soils	Even greater attention required for the control of this disease:- Better drainage, eg. higher row mounding.
Insect activity	Closer monitoring and more responsive management of insect pests and predators. Better control mechanisms
Increasing number of heat stress days	Efficient and effective irrigation scheduling and application system. Select sites with greater water holding capacity in the root zone, eg. deeper loams. Greater use of mulch.
Increase in number of cyclones and storm events	Consider re-location of orchards to areas less prone to cyclones and other extreme weather events such as hail. Re-visit the use of windbreaks to reduce damage to trees and fruit. Canopy management systems implemented, not only to improve productivity and fruit quality but also to keep tree size smaller to reduce structural damage in storms.
Increase in frequency of droughts	Installation of adequate water harvesting and storage structures to capitalise on high rainfall events when they do occur. Greater need for the selection, installation and maintenance of effective moisture monitoring and irrigation scheduling systems. Installation and maintenance of more efficient and effective irrigation systems capable of adequately watering the whole orchard using less water and with a quicker turn-around. Effective use of under-tree mulching to reduce temperature in root zone, help maintain soil organic matter levels in the face of increased soil temperatures and reduce unnecessary evaporation. Allow for possible increases in irrigation demand and also consider risks to supply reliability.
Frost and cold weather during flowering	If frost risk declines, plantings could occur in locations currently unsuitable.

In order for adaptation to climate change to be successful there will be a need to incorporate both pre-emptive and reactive adaptation strategies. These will need to occur in conjunction with already changing social, economic and institutional pressures. With this in mind, adaptation measures aimed at reducing the negative impacts of climate change will have to reflect and enhance current 'best-practices' designed to cope with adverse conditions. Whilst a range of technological and managerial options may exist as indicated in Table 9, the adoption of these new practices will require:

1. Confidence that climate changes several years or decades into the future can be effectively predicted against a naturally high year-to-year variability in temperature and rainfall that characterises these systems;
2. The motivation to change to avoid risks or use opportunities,
3. Development of new technologies, and demonstration of their benefits; and
4. Protection against establishment failure of new practices during less favourable climate periods (McKeon *et al*., 1993).

Adaptation strategies that incorporate the above considerations are more likely to be of value, as they will be more readily incorporated into existing on-farm management strategies.

WHAT ARE THE KEY RESEARCH CHALLENGES FOR THE FUTURE?

We are in the early stages of assessing the impacts and consequences of climate change in horticulture in Australia. Growers are already managing horticultural 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 of current climate variability. The following are challenges for growers, industry and scientists to address as climates continue to change :-

- Understand current climate variability and how it might be managed more effectively including the use of seasonal climate forecasting
- Continue to monitor climate changes in existing production areas
- Identify those agronomic and physiological factors affecting custard apple performance, which can be influenced easily by growers, to account for climate change as it is happening
- Determine the sensitivities of these factors in a changing climate
- Identify management options which growers and industry can use to manage climate variability and to be able to adapt to a changing climate
- Identify current "at risk" production sites, and new areas that may be suitable for production, following climate change
- If expansion of the custard apple industry is to occur, it will be important to ensure that future climate factors have an appropriate weighting in the decision

- Improving the reliability of climate change modelling outputs, to reduce the variation within future scenarios
- Keep abreast of developments in irrigation monitoring systems and more efficient irrigation systems, including overhead evaporative cooling irrigation
- Review irrigation research in Australia and undertake any necessary research to fill any gaps in knowledge regarding efficient water use in custard apple production
- Calculate expected shifts in crop maturity times for different growing areas for use in marketing plans
- Better understand and take advantage of CO_2 fertilization, and its effects on yield

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