Climate change and its implications for cotton production

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Human activities are increasing the atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O; IPCC 2007a). These greenhouse gases affect the radiative balance of the earth, keeping it warmer than it would otherwise be. There is strong evidence that these changes in atmospheric composition are affecting the climate at both global and continental levels (IPCC 2007a). Global temperatures have increased by $0.76^{o}C$ since 1850 and the rate of warming since 1950 is twice that of the last 100 years. Most of this observed increase since the mid-20th century is very likely due to increasing anthropogenic greenhouse gas concentrations. Moreover, discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns (IPCC 2007a). Additionally, many studies show that physical systems and biological systems are already responding to the temperature changes (e.g. decreases in ice extent and changes in growing seasons and animal behaviours; IPCC 2007b).

Experience in the cotton industry in Australia demonstrates significant sensitivity to climate factors in terms of yield and yield variability, quality, water availability, pest and weed issues, input costs and natural resource management. Consequently if the climate changes, there are likely to be systemic changes in cotton production systems. This paper will outline the climate changes that are already occurring in Australia, projections of future changes that may be of significance to the cotton industry and the likely impacts of these. This paper does not address the issue of how to sustainably reduce greenhouse gas emissions from the cotton industry as this topic is dealt with by another paper at this conference (Keogh 2008).

Climate and atmospheric changes

The main climate variables projected to change over the forthcoming decades that are likely to be important in terms of their impact on cotton production systems are maximum and minimum temperatures and rainfall. We will summarise briefly here the changes in these climate factors that have been observed over the past decades and the anticipated changes over forthcoming decades, drawing on the recent IPCC Fourth Assessment Report (Hennessy *et al.* 2007). We will also address atmospheric CO_2 concentrations.

Historical climate and other changes

Australia has been getting warmer. Since 1910, the average maximum (day-time) temperature has risen by $0.7^{o}C$ and the minimum (night-time) temperature by $1.1^{o}C$, with much of this change occurring since 1950 (Alexander *et al.* 2006). There is increasing evidence of a human ‘fingerprint’ in recent temperature trends with increases very likely to have been in response to continued growth in atmospheric greenhouse gas concentrations arising from human activity (e.g. Karoly and Braganza 2005). Additionally, droughts have become hotter since about 1973 because temperatures are higher for a given rainfall level (Nicholls 2004).

As well as changes in average temperatures, there have been changes in temperature extremes. From 1957 to 2004, averaged across Australia there has been an increase in hot days ($35^{o}C$ or more) of 0.10

days/year, an increase in hot nights (20°C or more) of 0.18 nights/year, a decrease in cold days (15°C or less) of 0.14 days/year and a decrease in cold nights (5°C or less) of 0.15 nights/year (Alexander *et al.* 2006).

Rainfall has also changed, with these changes differing between regions. Since 1950, summer monsoon rainfall has increased in the north-western region of Australia while southern and eastern Australia have become drier (Smith 2004). Increased rainfall in the northwest during the period 1910 to 2006 may be in response to anthropogenic factors including increased aerosol pollution in Asia and changes in cyclone activity in response to warming in the Pacific and Indian oceans (Nicholls 2006). Rainfall decreases in the south and southwest are likely due to a combination of increased atmospheric greenhouse gas concentrations, natural climate variability and land use change (IOCI 2002). There have been limited studies to date attributing the causes of decreased rainfall in the east where cotton is grown although similar drivers of change are likely involved (Syktus *et al.* 2005).

Extreme rainfall events have also changed in some regions with heavy rainfall increasing in north-western and central Australia and over the western tablelands of New South Wales (NSW), but decreasing in the southeast, southwest and central east-coast (Hennessy *et al.* 2007).

Over the past decade, the rate of global change has been occurring at or above the highest scenarios generated by the IPCC less than 10 years ago. Greenhouse gas emissions, atmospheric carbon dioxide concentrations, global temperature rise and global sea level rise are all at or exceeding the ‘worst-case’ scenarios of the IPCC (Rahmstorf *et al*. 2007).

Future projections of change

A selection of global climate models, driven by a range of scenarios of human development, technology and environmental governance, project that average Australian temperatures will increase by 0.1 to 1.3°C by the year 2020, relative to 1990, 0.3 to 3.4°C by 2050 and 0.4 to 6.7°C by 2080. This translates to 1 to 32 more days/year over 35°C by 2020 and 3 to 84 more by 2050, with 1 to 16 fewer days/year below 0°C by 2020 and 2 to 32 fewer by 2050. A tendency for decreased annual rainfall is likely over most of southern and sub-tropical Australia, with a tendency for increases in Tasmania and the ‘Top End’ of the Northern Territory (Hennessy *et al.* 2007). In the cotton growing regions, whilst there is a significant range in rainfall changes (from -20% to +20% by 2030 depending on season and location), there are likely to be drier conditions in winter, spring and autumn with a relatively small probability of increased rainfall (Table 1: CSIRO 2007). By contrast in summer there is approximately an even chance of rainfall decrease or increase (Table 1). On an annual basis the rainfall changes range from -20% to +5%, again with a higher probability of decreases than increases and the magnitude of decreases (up to 20% lower) greater than for increases (up to 5% higher).

Increases in extreme daily rainfall are also likely. For example, the intensity of the 1-in-20 year daily-rainfall event is likely to increase by up to 10% in parts of South Australia by the year 2030, 5 to 70% by the year 2050 in Victoria, up to 25% in northern Queensland by 2050 and up to 30% by the year 2040 in south-east Queensland (Hennessy *et al*. 2007).

Table 1. Ranges in projected changes in rainfall across the cotton growing regions of eastern Australia for 2030. Changes are expressed as proportional change in the 10th, 50th (median) and 90th percentiles. For example, the 10th percentile values are the reductions in rainfall that are exceeded in all but 10% of the scenarios of change. The rainfall changes below reflect both the uncertainty due to the emissions scenarios as well as uncertainty from variation in projected climate changes from global climate models (CSIRO 2007).

	10th percentile	50th percentile	90th percentile
Winter	-10 to -20	-2 to -10	+2 to +5
Spring	-10 to -20	-5 to-10	+2 to +5
Summer	-5 to -20	-2 to +2	+5 to +20
Autumn	-10 to -20	-5 to +2	+5 to +10
Annual	-5 to -20	-2 to -5	+2 to +5

Potential evaporation (or evaporative demand) is likely to increase with climate change (CSIRO 2007) and this combined with anticipated reductions in rainfall suggest up to 20% more droughts over most of Australia by 2030 (Mpelasoka *et al.* 2007). The effects of climate change on drought frequency are likely to be modulated by phases of the ENSO and IPO in the future as they have been in the past (IPCC 2007a).

The frequency of severe tropical cyclones (Categories 3, 4 and 5) on the east Australian coast is projected to increase by 22% for the mid-range greenhouse gas emission scenarios from 2000-2050, with a 200 km southward shift in the cyclone genesis region, leading to greater exposure in southeast Queensland and northeast NSW (Abbs *et al*. 2007) with an inference that the large-scale floods that are associated with such events increasing.

Carbon dioxide concentrations are projected to increase from the current 384ppm to between 550ppm and about 1000ppm depending on the scenarios for greenhouse gas emissions (IPCC 2007a). Emissions trajectories are currently towards the high end of this scenario range.

Climate change impacts

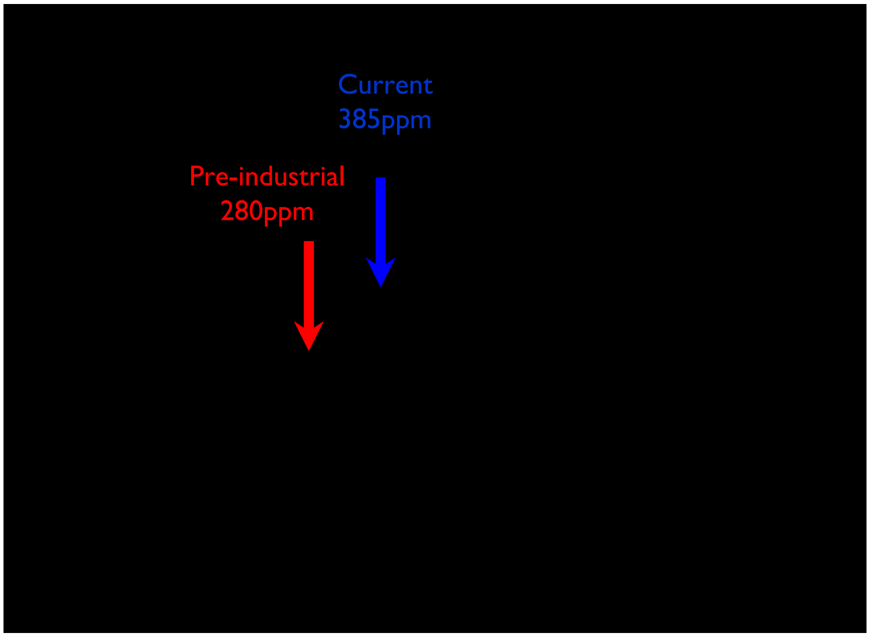
Changes in climate and atmospheric conditions as outlined above are highly likely to impact on the cotton industry through direct impacts on productivity and quality, through changes in water resource availability and via changes in pest and disease pressures. Aspects of the expected impacts are described briefly below. A companion paper in this conference (Bange and Constable 2008) describes some of the management adaptations that could be used to manage the risks associated with such impacts and to take advantage of possible opportunities.

Carbon dioxide

Atmospheric carbon dioxide (CO_2) concentrations are well known to be a limiting factor for the growth of plants like cotton that have the C_3 photosynthetic pathway. Increasing CO_2 concentrations tend to increase photosynthetic rates and increased radiation use efficiency (Fig 1), leading to increased plant growth. Elevated CO_2 also reduces transpiration by reducing stomatal conductance, increasing water use efficiency (i.e. amount of cotton per unit water used).

Studies of the effects of CO_2 on cotton have consistently shown high levels of growth response. For example, in Free-Air Carbon-dioxide Experiments (FACE) which had CO_2 concentrations increased to 550ppm, biomass was increased by 37% and lint yield by 43% (Mauney *et al*. 1994). The increase in biomass and yield was attributed to increased early leaf area, more profuse flowering and a longer period of fruit retention. In other experiments, doubling of CO_2 has increased cotton biomass by 35%, whole boll yields by 40% and lint yields by 60% (Reddy *et al*. 2000).

Figure 1 The relationship between radiation use efficiency and atmospheric CO2 concentration with pre-industrial and current CO2 concentrations indicated (after Reddy *et al*. 2000).

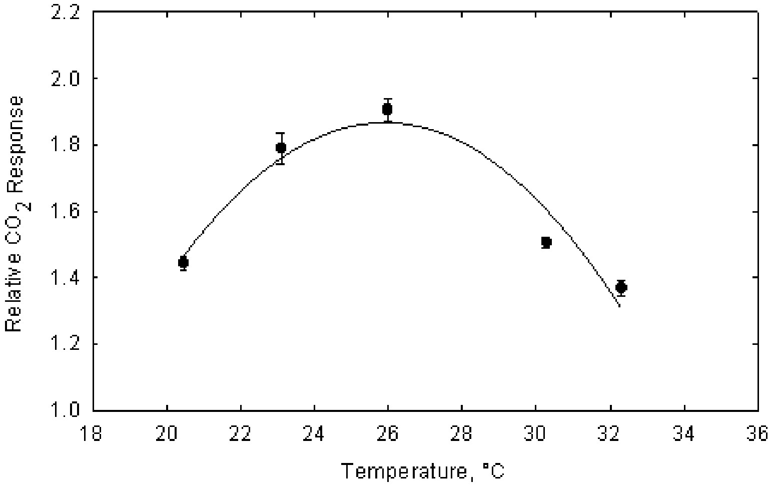


Elevated atmospheric concentrations of CO_2 also tend to reduce transpiration per unit leaf area. In many crop species, this is largely balanced out by increased leaf area per plant, resulting in total crop water use being approximately the same under low and high CO_2. In contrast, Samarakoon and Gifford (1996) found that cotton had approximately a 15% reduction in transpiration per unit leaf area under doubled CO_2: only half that for other species. However, the effects of CO2 on growth and leaf area were relatively larger. This resulted in water use per plant being 45-50% *higher* for cotton under high CO_2 when compared with other crops. This resulted in the soil drying faster under high CO_2 than under low CO_2. This result contrasts with that of (Reddy *et al.* 1998) who found a 30% decrease in transpiration and similar water use per plant under ambient and elevated CO_2. What would happen in cotton crops in the field in Australia is unclear at this stage, but the implications for water use could be significant.

Temperature dependent processes

Temperature affects a range of developmental processes in cotton as it does with other crops. The temperature optimum for vegetative and reproductive growth of cotton is 26^{o}C (the average of 30/22°C day/night temperatures; see Figure 2) and this is altered by CO_2 enrichment. High temperatures shorten the development time, reducing the opportunity to accumulate solar radiation and hence lowering growth and yields. Temperatures above the optimum in particular shorten the boll growth period giving smaller bolls, lower yields and poor quality lint. High temperatures (>30^{o}C) just after flowering can cause boll drop regardless of CO_2 level. Consequently, cultivars that retain fruits at high temperatures could be more productive in present-day hot cotton-producing environments and would be even more desirable in a future warmer world (Reddy *et al.* 1998). High temperatures can also damage retained bolls.

Figure 2 The relationship between relative CO_2 response (yield at elevated CO_2 compared with yield at ambient CO_2) and average temperature (after Reddy *et al.* 1998).



Temperature also affects the start and end of the growing season of cotton, frequency of frosts and evaporative demand. Increased temperatures that increase the length of the growing season may be particularly beneficial in southern cotton-growing areas, with every extra week of growth potentially increase lint yield by 68 to 136 kg ha^{-1} (Bange and Milroy 2004) provided that adequate water is available. Where irrigation is inadequate, high crop canopy temperatures are likely, interacting with water stress to reduce growth and yield. Higher temperatures will also tend to increase evaporative demand with this increasing by 1 to 8% by 2030 (CSIRO 2007).

There is a strong interaction between temperature and CO_2 response with greater benefits from CO_2 occurring at the temperature optimum and these declining rapidly with higher temperatures (Figure 2). The implication of this is that with global warming, the benefits of elevated CO_2 in terms of cotton yield may be lessened substantially if there is not some ongoing means of keeping the crops growing in either seasons or places with favourable temperatures.

Pests and weeds

Pests such as *Helicoverpa* are a major issue in the cotton industry globally. Some experiments indicate that climate change and increases in atmospheric CO_2 may increase insect damage. This can occur as a result of compensatory feeding when elevated CO_2 reduces leaf nitrogen concentrations (i.e. the insect has to eat more to maintain nitrogen intake; Lincoln *et al.* 1986). In other cases, increased CO_2 results in increased concentrations of plant defensive compounds such as condensed tannins and this plus lowered nitrogen concentrations with elevated CO_2 can reduce insect herbivore weight gains, increase mortality and lower fecundity (e.g. Gao *et al.* 2008). In cotton, a combination of both of these situations has been observed, with three successive generations of cotton bollworm fed on cotton bolls grown under doubled CO_2 concentrations showing significantly significant higher relative consumption, but due to lower feed quality, lower efficiency of conversion of ingested food, lower relative growth rate and lower potential female fecundity and larval numbers (Wu *et al.* 2007b). Importantly, elevated CO_2 tends to decrease the production of transgenic proteins including *Bacillus thuringiensis* (Bt) by about 3% (Wu *et al*. 2007a), thus reducing the efficiency of transgenes against insect populations. In another experiment with cotton at elevated CO_2, the tendency for insects to consume more foliage from plants with lower nitrogen was not compensated for by the reduction in toxin production, reducing Bt effectiveness (Coviella *et al.* 2000). This effect was particularly pronounced in nitrogen limited systems. The outcome of these interactions in the field in Australia is unclear, particularly taking into account the potential impacts of predator species, integrated pest management and climate variations, but there appear to be potentially significant implications in particular for the use of transgenic varieties.

There are concerns that a range of weed species (especially summer-growing C_4 weeds) will increase their competitive advantage under elevated CO_2 and higher temperatures (e.g. IPCC 2007b). This may become even more problematic with firstly, emerging evidence that the widely-used herbicide could become less effective under elevated CO_2 (Ziska and Teasdale 2000) and secondly that the number of days suitable for spraying operations could reduce significantly (Howden *et al.* 2007).

Water resources

In the cotton growing regions of the Murray-Darling Basin, the recent CSIRO Sustainable Yields Program has assessed likely changes in water availability as a result of climate change and future catchment development (www.csiro.au/partnerships/MDBSY.html). The combination of likely lower rainfall and higher potential evaporation is assessed as significantly reducing the availability of surface water and groundwater recharge across the cotton-growing areas although there remains a small probability of potential increases in water availability (Table 2). In that assessment, the ‘dry’ climate change scenarios typically show 25 to 30% reductions in water availability in the main cotton catchments and the ‘wet’ scenarios 19 to 38% increases. Whilst these seem approximately balanced, the ‘median’ scenarios all show decreases in water availability of 5 to 12%. This reflects an asymmetric distribution of probabilities – with a significantly higher likelihood of decreases in water availability (about a 2 in 3 chance) than increases (a 1 in 3 chance). Furthermore, as noted earlier, greenhouse emissions and other key indicators of climate change are at or exceeding the worst case scenarios and consequently the likelihood of climate changes being at the negative end of the spectrum is higher than would be indicated by this analysis.

Whilst the prospects for water availability look challenging for the northern Murray-Darling Basin catchments, they seem considerably better than for the southern catchments. For example, in the Goulburn-Broken catchment the last 10 years of rainfall and runoff are 15 to 45% lower than the long-term values (1895 to 2006). These values are similar to the ‘dry’ scenario values for 2030. Furthermore, even the ‘wet’ scenario has a reduction in surface water availability in the Goulburn-Broken.

The problematic changes in water availability may also impact on other regions globally such as southern and western USA, the Mediterranean, South Africa and western south America, whereas China may have increased water availability (IPCC 2007).

In addition to possible challenges arising from changes in water availability, there may also be reductions in water quality via increases in salt concentrations in some rivers (Beare and Heaney 2002).

Table 2. Catchments in the Murray-Darling Basin, the average area of cotton and the prospective changes in water availability under ‘dry’, median and ‘wet’ scenarios for 2030.

	Cotton area (ha)	Climate change (dry)	Climate change (median)	Climate change (wet)
Condamine-Ballonne	70 560	-26	-8	+19
Moonie	3 100	-29	-12	+24
Border Rivers	56 250	-28	-10	+20

Gwydir	85 000	-29	-10	+34
Namoi	78 400	-30	-5	+38
Barwon-Darling	57 900	-27	-8	+31
Macquarie-Castlereagh	52 400	-25	-6	+25
Lachlan	4 000	-30	-11	+6
Murrumbidgee	200	-28	-9	+13
Goulburn-Broken	-	-45	-14	-3

Next steps

This review, in conjunction with that of Bange and Constable (2008), provides a basis for discussion of actions and priorities for the Australian cotton industry. The growing evidence that human activities have already influenced global climate and the likelihood of rapid and substantial future climate changes means that the recent engagement by the industry is timely. There are two action points in the climate change domain: mitigation (reducing the emissions that are the driving agents of change) and adaptation (changing the options available for managers and policymakers to respond to the climate change impacts that occur). This paper has focussed on the potential climate changes in cotton-growing areas and the impacts of these climate and atmospheric changes. It identifies potentially significant impacts on cotton yields and quality, on water resources and the efficiency of their use and on pests and weeds. However, the next steps needed are to move beyond these climate and impact studies into assessing the adaptation actions that can offset risks and take advantage of opportunities – and placing these in the context of other strategic industry decisions. There has been a systematic analysis of such options across Australian agricultural industries (Stokes and Howden 2008) which has included a chapter on the cotton industry (Bange *et al.* 2008). That study identifies a large range of potential adaptation options at farm, catchment, industry and policy level that could provide a firm starting point to guide the cotton industry successfully in the uncertain climate ahead.

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