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How will climate change impact climate variability in sugarcane growing regions?

Everingham, Y

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How will climate change impact climate variability in sugarcane growing regions?

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Executive Summary:

Sugarcane is the fastest growing, largest biomass and highest sucrose accumulated agricultural crop today that offers a valuable contribution to delivering a sustainable future (Skocaj, 2013). Aside from cereal crops, sugarcane is the largest contributor of carbohydrates for human consumption and the conversion of sugarcane to raw sugar produces a wide variety of important by-products such as bioenergy, biofuels, bioplastics, paper, animal feed and synthetic fertilizers. Climate is a key driver of sugarcane production and its by-products. Given the significant contribution sugarcane production systems make to economic growth and development, especially in poor countries where sugarcane contributes to the economy, it is critical to understand how this production system will be impacted by climate change.

The project team worked closely with researchers from Australia’s Bureau of Meteorology and the CSIRO to investigate the impact climate change will have on productivity and harvest practices. The productivity study was undertaken in three regions – Burdekin, Mackay and NSW, and the harvest study in seven regions – Tully, Herbert, Burdekin, Mackay, Bundaberg, Rocky Point and NSW. The project team assessed the change in projected climate across the industry on a grid as small as 5 km by 5 km. A small grid is very important when topography changes rapidly. This is pertinent to Australia’s sugarcane-growing regions that are wedged between high mountain ranges and the flat eastern coastline. This type of geography has an enormous affect on local climate patterns which are difficult to detect using coarse resolution projections. Further, our yield projections relied heavily on new project findings from a state-of-the-art glass house experiment (Project: CPI018) that grew sugarcane plants in a future climate with higher CO₂ levels. These projections were compared against the baseline period 1961 to 2000. Projections considered two climate scenarios B1 and A2. The latter scenario represents a future with a lower technological change, higher population growth and higher emission of greenhouse gases like carbon dioxide than the B1 scenario. To communicate our findings in a simple manner that maintained investigative rigour, the project team developed an original robust statistical procedure that differentiates between ‘plausible’ and ‘highly plausible’ system changes.

Based on our modelling design, yield projections recognised an increase was plausible for the Burdekin and Mackay under the B1 scenario and highly plausible for NSW under the A2 scenario. This is an important result as recent climate change research suggests the higher emissions future is more likely and modelled outputs for this scenario do not support a plausible increase in yields for Burdekin and Mackay. Under a high emissions future (A2) it is plausible for industry to plan for more harvest disruption in spring (Ingham) and less harvest disruptions in winter and spring (Burdekin) and winter in Bundaberg. Under a low emission future it is plausible for industry to plan for more harvestable days in winter (NSW). These changes were deemed subtle e.g. the change in the simulated number of unharvestable days averaged across the downscaled GCMs was typically less than a few days. However there were some regions (Tully, Bundaberg, Rocky Point and NSW) where individual models projected an increase of 5 to 21 unharvestable days which would have a dramatic effect on harvest operations, especially if yields were to increase along with pre-harvest (autumn) rainfall. Harvestability projections should be considered closely with yield projections and rainfall projections either side of the harvest window. Spatial projections revealed changes within a region are not always uniform and adaptation strategies may need to vary within a region.

Given the challenges of delivering sustainable solutions to feeding, fuelling and employing a society where growth and development are on the rise, it is timely and critical to understand the impact climate change will have on sugarcane industries across the globe. In the face of competing solutions and finite resources, the findings from this project can assist policy makers not only in Australia but around the world with developing robust adaptation strategies that minimise risk and maximize opportunities in response to the challenges associated with a changing climate.
Background:

Productivity Background

Sugarcane industries worldwide make a valuable contribution to sustainable development. Sugarcane has been grown under many different climates to produce raw and refined sugars. Aside from cereal crops, sugarcane is the largest contributor of carbohydrates for human consumption (Brumbley et al., 2008). The conversion of sugarcane to raw sugar produces a wide variety of important by-products such as bioenergy, biofuels, bioplastics, paper, animal feed and synthetic fertilizers (Barnes, 1974; Mackintosh, 2000; Alonso-Pippo et al., 2008; Brumbley et al., 2008; Goldemberg et al., 2008). Given the challenges of delivering sustainable solutions to employing, feeding and fuelling an increasing global population, it is timely and critical to understand the impact climate change will have on sugarcane production, especially since sugarcane is one of the most efficient crops in terms of solar radiation capture, photosynthesis and energy production (Goldemberg et al., 2008; Inman-Bamber et al., 2013).

Climate change impact studies project changes to productivity in a future world. Future climate data are generated from circulation models for a range of emission scenarios or ‘storylines’ (Nakicenovic and Swart., 2000) that describe future economic growth and development. Projections from general circulation models (GCMs) are often downscaled for impact studies where geographic features at a finer scale influence climate. Knox et al., 2012 modelled the impacts of climate change on 2050 Swaziland yields. DSSAT-Canegro (Jones et al., 2003) simulated biomass increased by 15% under an elevated CO2 A2 emission scenario while the increase was limited to 4%-5% for the A2 scenarios without increases in CO2. More recently, Marin et al. (2013) used DSSAT-Canegro with three harvest dates to project São Paulo stalk fresh matter yields for 2050. Climate scenarios (SRES A2 and B2) were derived from two GCMs, PRECIS and CSIRO. They found stalk fresh matter would increase by 1% (late harvest, PRECIS, B2) to 54% (early harvest, A2, PRECIS).

Several APSIM (Keating et al., 1999) driven impact studies have been conducted in Australia (Park et al., 2007, Webster et al., 2009 and Biggs et al. 2012). Park et al. (2007) simulated Maryborough sugarcane yields for 2030 and 2070. For 2030 the best modelled outcome was an increase in yield of approximately 7% and the worst a decrease of around 4%. By 2070 the largest increase was 7% but potential reductions of 47% were modelled.

Webster et al. (2009) projected yields for the Tully-Murray catchment in the far northern wet tropical sugarcane growing regions of Australia. Slight increases in sugarcane yield (maximum of +5 t/ha) for 2030 was projected for all rain-temperature scenarios. By 2070, only a low temperature increase in conjunction with average or high rainfall led to a projected yield improvement (up to +7 t/ha).

Biggs et al. (2012) used APSIM to investigate the impact of different management systems on sugarcane yield and nitrogen loss via deep drainage or runoff, under current climates and the different climate change projections. They derived the future climate change projections from three GCMs, in which an atmospheric CO2 concentration of 437 ppm for 2030 was assumed. Median sugarcane yields increased by 8% and 4% with weak and moderate climate change, respectively, but were reduced by 10% with strong climate change. They ran APSIM with and
without the effects of rising CO₂. Yields under elevated CO₂ were 10-14% larger than those produced with the identical climate scenario but without elevated CO₂.

These studies differ in the way that the CO₂ effects have been incorporated into the modelling procedures. Knox et al. (2010) rely on the CO₂ fertilisation switch which is integrated within CANEGRO-DSSAT but explanations about how this switch operates were limited. Marin et al. (2013) used an adjusted factor which depends on CO₂ to alter photosynthesis, stomatal resistance and transpiration. A series of personal communications explain the inbuilt CO₂ fertilisation algorithm in CANEGRO-DSSAT. Unlike CANEGRO-DSSAT, APSIM does not have an algorithm for the CO₂ effects at all, so Park et al. (2007), Webster et al. (2009) and Biggs et al. (2012) incorporated the CO₂ effects into APSIM by making the transpiration efficiency (TE) and radiation use efficiency (RUE) linear functions of atmospheric CO₂ concentration (Park et al., 2007).

Hence, this project addressed some deficiencies in the modelling design of previous climate change impacts studies on sugarcane production. This was achieved by capturing new experimental results from a glasshouse study on growing sugarcane in twice normal CO₂ levels and by using high resolution downscaled climate data from general circulation models to incorporate the variable geography which encapsulates the sugarcane-growing regions as part of a sophisticated multi-model statistical ensemble routine.

Rainfall Background

Climate change can impact productivity, and thus the number of days required to harvest the crop. Projections of rainfall related indices are needed. Park et al. (2007) chose two models from 15 to represent the 20th and 80th percentiles of rainfall changes for sugarcane-growing regions in Queensland and New South Wales. The models favoured a no change (0%) to a 60% decrease in harvest rainfall for Far North Queensland (spring and winter), the Herbert and Burdekin (spring) and Southern Queensland (spring) for 2070. Changes were less intensive for 2030 and ranged from 0% to minus 20% in Far North Queensland (spring and winter) and Southern Queensland (spring). Changes in other regions and seasons were more varied. The “2007 Climate Change in Australia” technical report which documented the 10th and 90th percentiles for rainfall projections from 23 climate models (Pearce et al., 2007), considered low, medium and high emissions for 2030, 2050 and 2070. Fiftieth percentile rainfall decreased by approximately 2% to 20% for most of coastal Queensland and NSW in autumn, winter and spring for the all three emission scenarios for 2050. In summer, changes were negative in central coastal Queensland and neutral elsewhere in coastal Queensland and NSW under low emissions. For the mid and high emission scenarios, the 50th percentile was projected to increase between 2% and 5% for central coastal NSW. However, the report stated “...in no region or season do models suggest a ‘likely’ increase in rainfall”, where ‘likely’ was defined as agreement among at least two thirds of the models. Several studies have investigated climate change impacts on rainfall but relatively few studies have extended this research to address unharvestable days which was done in this project.
Research Need Addressed by the Project

Two key research needs were addressed by this project. Firstly, this project examined climate change impacts on productivity by capitalising on new knowledge about CO₂ effects on sugarcane that emanated from a state-of-the-art glasshouse experiment. Secondly, a climate change impact study on harvestability that recognised the unique topography that surrounds the Australian sugar industry and the relevance of downscaled projections was undertaken.

Objectives:

It is imperative that researchers and industry explore the opportunities and risks associated with climate change across the industry value chain and develop appropriate plans to help industry develop sensible strategies to prepare for a changing climate. It is also important to recognise that industry operates under extremely variable climate conditions and that climate change will affect this variability. Therefore, the objectives of this project are to:

1. Estimate how climate change will affect the statistical distributions of key atmospheric variables relevant to crop production for selected sugarcane growing regions.

2. Integrate this knowledge into cropping simulation systems to estimate the climate impact on crop productivity and enhance understanding of the year to year variability in crop production.

3. Investigate the impact climate change will have on harvest disruption.

4. Link project findings with findings from other research and contribute to sensible pathways forward that will help the Australian sugar industry adapt to a changing and variable environment. This includes assessment of changes on productivity and addresses improved practices based on the potential effect of climate change.
A Statement of the Extent to Which Each Objective was Achieved:

1. Estimate how climate change will affect the statistical distributions of key atmospheric variables relevant to crop production for selected sugarcane growing regions.

Daily maximum temperature, minimum temperature, radiation and rainfall are attributes that effect crop growth. This project investigated the impact climate change will have on seasonal temperature, radiation and rainfall for seven sugarcane growing regions – Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Downscaled climate projections at a 5 km by 5 km resolution from 11 general circulation models were produced. Projections under the higher emission scenario (A2) were produced at the regional level (Figures 1 to 4) and at the 5 km resolution (Figures 5 to 8).

Temperature
Based on our modelling design, it is highly plausible for industry to consider the impact of increases in maximum and minimum temperature across all seven regions and all four seasons (Figures 1 and 2). Changes in the mean maximum temperature ranged from 0.5°C to 1.5°C (Figure 5). Changes in the mean minimum temperature are much higher and range from 0.5°C to more than 2°C. Changes in minimum temperature were more prominent in autumn and winter (Figure 6).

Radiation
Based on our modelling design, decreases in radiation were highly plausible for region 1 (winter and spring), region 2 (autumn, winter and spring), region 3 (autumn, winter and spring), region 4 (autumn, winter), region 5 (summer, autumn and winter), region 6 (summer, autumn and winter) and region 7 (summer, autumn and winter). Decreases were plausible for region 1 (autumn), region 4 (spring), region 5 (spring) and region 6 (spring). There was only one instance when a radiation increase was considered plausible – region 1 (summer). For more information see Figures 3 and 7.

Rainfall
Based on our modelling design, regional plots show an increase in summer rainfall is plausible for the Burdekin (region 3) and a decrease is plausible for summer in NSW (region 7) (Figure 4). An increase in spring rainfall is considered plausible for Tully (region 1) and for autumn rainfall in Ingham (region 2) (Figure 4). A potential emerging increasing trend in mean autumn rainfall from Ingham (region 2) to NSW (region 7) should be monitored closely (Figure 8).

Appendices 4 to 10 contain regional information about climate projections for key atmospheric variables relevant to crop production. The appendices include projections for both the low (B1) and high (A2) emissions scenario. For more details about rainfall projections see Everingham YL, Sexton J and Timbal B (2013b).
2. **Integrate this knowledge into cropping simulation systems to estimate the climate impact on crop productivity and enhance understanding of the year to year variability in crop production.**

The downscaled GCM projections of daily maximum temperature, minimum temperature, radiation and rainfall were supplied to the WaterSense sugarcane growth module to estimate changes in regional productivity. Based on our model design, yield projections recognised an increase was plausible for the Burdekin and Mackay under the B1 scenario and highly plausible for NSW under the A2 scenario (Figure 9). The variability in yield projections was highest in NSW (region 7) followed by Mackay (region 3) and the Burdekin (region 2). For more details about the methodology, the reader is referred to Everingham YL, Inman-Bamber NG, Sexton J, and Stokes C (2013a).

3. **Investigate the impact climate change will have on harvest disruption.**

The rainfall projections were converted to an index that defines a day to be harvestable or unharvestable (Sexton et al., 2013). Under a high emissions (A2) future it is plausible for industry to plan for more harvest disruptions in spring (Ingham) and less harvest disruptions in winter and spring (Burdekin) and winter only in Bundaberg (Figure 10). These projected changes were deemed subtle e.g. the simulated change in harvestable days averaged across the downscaled GCMs was usually of the order of 1 to 2 days (Figure 11). However there were individual models where the changes were not subtle. The downscaled GCM from the Max Plank Institute (MPI) projected an extra 15 unharvestable days in spring for Tully (region 1), while the downscaled CSIRO GCM projected an increase of 5, 6 and 9 extra unharvestable spring days in Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7), respectively (Figure 12). Developing an adaptive strategy on one model alone should be avoided, such increases in single model solutions can be used to guide the development of more robust adaptive strategies.

For a detailed overview of harvestability projections see Sexton et al., (2013) and Appendices 4 to 10 for a comprehensive set of region by region plots that depict the climate change impacts on harvestability.

4. **Link project findings with findings from other research and contribute to sensible pathways forward that will help the Australian sugar industry adapt to a changing and variable environment.** This includes assessment of changes on productivity and addresses improved practices based on the potential effect of climate change.

As per the steering committees recommendation, the project findings were presented at a number of industry forums that included ISSCT, ASSCT, SRDC Workshops in 2012 in the Burdekin and Ingham, 2013 SRDC workshops in Mackay, Bundaberg and NSW. The project team was fortunate to secure a general session at the ASSCT presentation which was well attended by industry members from all sectors. This created interest for the project team to meet with ASMC representatives to discuss in more detail the project findings. The steering committee recommended that industry should define the pathways forward based on the key project findings and recommendations. Industry representatives in southern regions showed interest in the possibilities of arranging planting and harvest of fallow crops such as soy beans to take advantage of warming conditions in winter. Representatives in northern regions were sensitive to the possibility of increased rainfall in autumn. Although results for autumn were inconclusive, increased rainfall was of concern as many farmers plant in autumn.
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95% CI on paired difference percentiles for Region: 1
A2 emissions scenario

95% CI on paired difference percentiles for Region: 2
A2 emissions scenario

95% CI on paired difference percentiles for Region: 3
A2 emissions scenario

95% CI on paired difference percentiles for Region: 4
A2 emissions scenario

95% CI on paired difference percentiles for Region: 5
A2 emissions scenario

95% CI on paired difference percentiles for Region: 6
A2 emissions scenario

95% CI on paired difference percentiles for Region: 7
A2 emissions scenario
**Figure 1:** Regional projections for the change in the 25\textsuperscript{th}, 50\textsuperscript{th} and 75\textsuperscript{th} percentiles of the (downscaled) GCM paired differences in maximum temperature. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Seven sugarcane-growing regions have been considered - Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario. We consider increasing maximum temperature to be ‘plausible’ when the confidence intervals for the 50th and hence the 75th percentile were greater than zero, and ‘highly plausible’ if the confidence intervals for the 25th and hence the 50th and 75th percentiles were all greater than zero. By extension, we consider decreasing maximum temperature to be ‘plausible’ when the confidence intervals for the 50th and hence the 25th percentiles were less than zero, and ‘highly plausible’ if the confidence intervals for the 75th and hence the 50th and 25th percentiles were all less than zero.
95% CI on paired difference percentiles for Region: 1
A2 emissions scenario

95% CI on paired difference percentiles for Region: 2
A2 emissions scenario

95% CI on paired difference percentiles for Region: 3
A2 emissions scenario

95% CI on paired difference percentiles for Region: 4
A2 emissions scenario

95% CI on paired difference percentiles for Region: 5
A2 emissions scenario

95% CI on paired difference percentiles for Region: 6
A2 emissions scenario

95% CI on paired difference percentiles for Region: 7
A2 emissions scenario
Figure 2: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in minimum temperature. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Seven sugarcane-growing regions have been considered - Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario. We consider increasing minimum temperature to be ‘plausible’ when the confidence intervals for the 50th and hence the 75th percentile were greater than zero, and ‘highly plausible’ if the confidence intervals for the 25th and hence the 50th and 75th percentiles were all greater than zero. By extension, we consider decreasing maximum temperature to be ‘plausible’ when the confidence intervals for the 50th and hence the 25th percentiles were less than zero, and ‘highly plausible’ if the confidence intervals for the 75th and hence the 50th and 25th percentiles were all less than zero.
95% CI on paired difference percentiles for Region: 1
A2 emissions scenario

95% CI on paired difference percentiles for Region: 2
A2 emissions scenario

95% CI on paired difference percentiles for Region: 3
A2 emissions scenario

95% CI on paired difference percentiles for Region: 4
A2 emissions scenario

95% CI on paired difference percentiles for Region: 5
A2 emissions scenario

95% CI on paired difference percentiles for Region: 6
A2 emissions scenario

95% CI on paired difference percentiles for Region: 7
A2 emissions scenario
Figure 3: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in radiation. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Seven sugarcane-growing regions have been considered - Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario. We consider increasing radiation to be ‘plausible’ when the confidence intervals for the 50th and hence the 75th percentile were greater than zero, and ‘highly plausible’ if the confidence intervals for the 25th and hence the 50th and 75th percentiles were all greater than zero. By extension, we consider decreasing radiation to be ‘plausible’ when the confidence intervals for the 50th and hence the 25th percentiles were less than zero, and ‘highly plausible’ if the confidence intervals for the 75th and hence the 50th and 25th percentiles were all less than zero.
95% CI on paired difference percentiles for Region: 1
A2 emissions scenario

95% CI on paired difference percentiles for Region: 2
A2 emissions scenario

95% CI on paired difference percentiles for Region: 3
A2 emissions scenario

95% CI on paired difference percentiles for Region: 4
A2 emissions scenario

95% CI on paired difference percentiles for Region: 5
A2 emissions scenario

95% CI on paired difference percentiles for Region: 6
A2 emissions scenario

95% CI on paired difference percentiles for Region: 7
A2 emissions scenario
Figure 4: Regional projections for the relative change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in rainfall (%). Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Seven sugarcane-growing regions have been considered - Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario. We consider increasing rainfall to be ‘plausible’ when the confidence intervals for the 50th and hence the 75th percentile were greater than zero, and ‘highly plausible’ if the confidence intervals for the 25th and hence the 50th and 75th percentiles were all greater than zero. By extension, we consider decreasing rainfall to be ‘plausible’ when the confidence intervals for the 50th and hence the 25th percentiles were less than zero, and ‘highly plausible’ if the confidence intervals for the 75th and hence the 50th and 25th percentiles were all less than zero.
Change in Average Maximum Temperature (degrees C)

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**Figure 5:** Projected change in average maximum temperature (°C) by 2046-2065 compared to the base period of 1961-2000 for seven sugarcane-growing regions - Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario and represent the mean of paired differences of 11 GCMs.
Change in Average Minimum Temperature (degrees C)

Region 1

Region 2

Region 3

Region 4

Region 5

Region 6

Region 7
Figure 6: Projected change in average minimum temperature (°C) by 2046-2065 compared to the base period of 1961-2000 for seven sugarcane-growing regions - Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario and represent the mean of paired differences of 11 GCMs.
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Change in Average Radiation (MJ/m²)
**Figure 7:** Projected change in radiation (Mj/m²) by 2046-2065 compared to the base period of 1961-2000 for seven sugarcane-growing regions - Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario and represent the mean of paired differences of 11 GCMs.
Figure 8: Projected change average seasonal rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for seven sugarcane-growing regions - Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario and represent the mean of paired differences of 11 GCMs.
95% CI on paired difference percentiles for regional Yield
B1(blue) and A2(red)
Figure 9: Regional projections for the relative change in the 25\textsuperscript{th}, 50\textsuperscript{th} and 75\textsuperscript{th} percentiles of the (downscaled) GCM paired differences in yields (tonnes of cane per hectare). Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Three sugarcane-growing regions have been considered - Burdekin (region 3), Mackay (region 4), and NSW (region 7). Projections have been made based on the lower (B1) and higher (A2) emissions scenario. We consider increasing yields to be ‘plausible’ when the confidence intervals for the 50th and hence the 75th percentile were greater than zero, and ‘highly plausible’ if the confidence intervals for the 25th and hence the 50th and 75th percentiles were all greater than zero. By extension, we consider decreasing yields to be ‘plausible’ when the confidence intervals for the 50th and hence the 25th percentiles were less than zero, and ‘highly plausible’ if the confidence intervals for the 75th and hence the 50th and 25th percentiles were all less than zero.
95% CI on paired differences for Region: 1
A2 emissions scenario

95% CI on paired differences for Region: 2
A2 emissions scenario

95% CI on paired differences for Region: 3
A2 emissions scenario

95% CI on paired differences for Region: 4
A2 emissions scenario

95% CI on paired differences for Region: 5
A2 emissions scenario

95% CI on paired differences for Region: 6
A2 emissions scenario

95% CI on paired differences for Region: 7
A2 emissions scenario
Figure 10:
Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in unharvestable days. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Three sugarcane-growing regions have been considered - Burdekin (region 3), Mackay (region 4), and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario. We consider increasing unharvestable days to be ‘plausible’ when the confidence intervals for the 50th and hence the 75th percentile were greater than zero, and ‘highly plausible’ if the confidence intervals for the 25th and hence the 50th and 75th percentiles were all greater than zero. By extension, we consider decreasing unharvestable days to be ‘plausible’ when the confidence intervals for the 50th and hence the 25th percentiles were less than zero, and ‘highly plausible’ if the confidence intervals for the 75th and hence the 50th and 25th percentiles were all less than zero.
Change in Average Number of Unharvestable Days

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<th>Winter</th>
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Change in Unharvestable Days
**Figure 11:** Harvestability spatial plots. Projected change in average number of unharvestable days by 2046-2065 compared to the base period of 1961-2000 for seven sugarcane-growing regions - Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario and represent the mean of paired differences of 11 GCMs.
Figure 12: Regional projections for the change in the (downscaled) GCM paired differences in unharvestable days. Positive values mean that values are higher for the 2046:2065 period compared to the 1961:2000 period. Seven sugarcane-growing regions have been considered – Tully (region 1), Herbert (region 2), Burdekin (region 3), Mackay (region 4), Bundaberg (region 5), Rocky Point (region 6) and NSW (region 7). Projections have been made based on the higher (A2) emissions scenario for winter and spring. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.
Methodology:

Process

An extensive desktop modelling approach was undertaken to deliver the projects outputs and outcomes. This approach was overseen by an external steering committee that comprised of representatives from the Managing Climate Variability Program, BSES, SRDC and the BOM. The project team met with the external steering committee twice during the project to present project deliverables and to seek guidance on future deliverables. Desktop modelling activities involved: (i) processing downscaled climate outputs from the general circulation models; (ii) generating radiation data that was not available from the downscaled models; (iii) converting rainfall projections to a harvestability index (iv) implementing a sophisticated statistical yield estimation routine (v) developing a robust statistical procedure to communicate model consensus of climate and yield outputs for initiating industry discussion and forward. We stress this project did not deal directly with the end-users. Motivated by the geographical domain of the sugarcane-growing regions, this project anticipated and developed a set of tools that could address industry needs as part of a future more targeted participatory approach study.

Evaluation

The success of the project can be evaluated in terms of (i) impact, (ii) capacity building opportunities and (iii) the implications of the project in guiding future R&D.

Impact

Prior to this project published studies on climate change for the Australian sugarcane industry were only available at a coarse resolution of 0.25 to 1 decimal degree (Pearce et al., 2007). This project has improved on this research by capitalising on climate projections at a much finer resolution of 5 km by 5 km (0.05 decimal degrees). Given the rapid changes in geography where sugarcane is grown, these finer resolution projections are very important for detecting changes in local climate. This is most recognisable in spatial plots like (i) summer NSW rainfall (region 7) where the magnitude of decreasing trends varies between the three mill regions and (ii) winter Bundaberg rainfall (region 5) where trends decrease in the north but increase in the south (Figure 8).

It is challenging to communicate climate risk accurately and simply. Rötter et al. (2011) and Power et al. (2012) recognised that decision makers need to have a level of certainty on which to guide their decisions and urged crop and climate modellers to quantify the degree to which models agree on the sign of the projected changes. We addressed Rötter et al.’s and Power et al.’s concerns by developing confidence plots of projections. Traditional approaches to displaying the projections have also been included (e.g. Boxplots of projected change in unharvestable days in Figure 12).

This project has also developed more accurate yield estimation routines that better integrate the carbon dioxide fertilisation effect with yield estimation routines. This project achieved this by taking advantage of new results from the elaborate glasshouse experiment that formed part of (CPI018) where sugarcane was grown under twice normal CO2 levels. Further we used the Penmon-Monteith approach to scale up from the effect of CO2 on stomatal conductance to a whole canopy conductance. Previous studies on CO2 fertilisation effects in sugarcane have ignored the scale up issue or have been vague about assumptions regarding this effect.
Capacity Building

The project linked with an honours project that developed baseline routines for measuring the amount of variability in the climate system. As climate projections improve by for example being better able to model the frequency of swings between El Niño to La Niña events, these techniques can be used to compare variability between time epochs. This research was presented and defended by a JCU honours student (Ms Madalyn Casey) at the 2011 Conference on Modelling and Simulation in Perth (Casey and Everingham 2011). Preliminary research findings on harvest disruption were also presented by a junior researcher (Mr Justin Sexton) at the Climate Change Research Strategy for Primary Industries conference in Melbourne (Sexton et al., 2012) and at SRDC regional workshops in 2013. Mr Sexton has senior authored and junior authored several research publication funded by this project. Both student researchers have progressed to higher degree studies at James Cook University. One student will undertake a Masters by research project which will utilise outputs and technologies developed as part of JCU032.

Future R&D

Future research will be dependent on the needs of industry. After reviewing outputs with industry decision makers the following needs and how these needs can be met were identified:

- Timescale of projections.
  After presenting preliminary results of harvest disruption at the CCRSPI conference, the timescale of projections was identified as a concern. This was also raised at the ASSCT presentation in 2013. Projections 40 years into the future may not hold a great deal of significance to farmers today. This was identified as a limitation of GCMs in the CMIP3 database. Models included in the CMIP5 may address this problem by providing continuous projections rather than discrete time periods.

- Effects of management under climate change.
  Improved crop modelling as a result of new knowledge gained from CPI018 and the development of a sophisticated yield estimation routine can be used to assess adaptation strategies and the effects of different management such as nutrient and irrigation strategies.

- Developing efficiencies in harvesting and milling practices.

- Breed varieties for future climates that are regional dependant, resistant to pests and disease and maximize opportunities from increased carbon dioxide levels.

- Develop a risk and opportunity framework that helps industry manage climate risk at short (e.g. weather forecasts), medium (e.g. seasonal climate forecasts) and long (e.g. climate change projections) timescales.

- Assess and manage the risk of outbreak of disease and pests under a changing climate.
Outputs:
(Including knowledge, skills, processes, practices, products and technology developed)

Outputs of the project are reported in the attached appendices on a region by region basis. General outputs of the project included high resolution distributions of atmospheric variables relevant to crop production (maximum temperature, minimum temperature, radiation and rainfall), statistically downscaled projections of atmospheric variables and projections of climate change impacts on yield, harvestability and key atmospheric variables. Specific outputs are listed below with reference to the appropriate appendix and/or publication.

Regional Climate Data

1. Historical baseline data extracted from Australian Water Availability Project (AWAP) atmospheric variables for the period 1961:2000 – Appendix 1
Daily rainfall and temperature data from the Australian Water Availability Project (AWAP) were sourced for the period 1961:2000 and processed for the seven sugarcane-growing regions. The AWAP data represent spatially interpolated weather station data (Jones et al., 2009). Individual pixels of 0.05 by 0.05 decimal degrees that occupy sugarcane were identified for each region (Tully: 77 pixels, Herbert: 58 pixels, Burdekin: 64 pixels, Mackay: 133 pixels, Bundaberg: 107 pixels, Rocky point: 7 pixels and NSW: 76 pixels). Sugarcane-growing regions were described by land use maps from the Department of Environment and Research Management and local industry spatial data. Radiation data were not available and were produced using the methodology of Liu and Scott (2001) as described in Appendix 2.

2. Atmospheric variables statistically downscaled based on 20th century forcings (20C3M) for 1961:2000 and low (B1) and high (A2) forcings for 2046:2065 – Appendix 1
Daily temperature and rainfall data for 11 General Circulation Models (GCMs) were extracted from the Coupled Model Intercomparison Project (CMIP3) under three emissions scenarios. For the period 1961:2000 GCMs operated under the 20C3M scenario which simulated 20th century forcings. For the period 2046:2065 GCM data were considered under the B1 and A2 emissions scenarios as described by the International Panel of Climate Change (IPCC). Temperature and rainfall data were downscaled from GCM outputs using the analogues methodology of Timbal et al. (2009) for pixels identified as sugarcane. Radiation data were not available and were produced from downscaled temperature and rainfall data.

3. New boundaries for Bureau Of Meteorology (BOM) climate regions defined for continuity in Mackay region – Appendix 1
The BOM statistical downscaling model defines 10 climatic regions (Figure A1.1) for which the optimisation of the model differs. The sugarcane-growing areas of eastern Australia fall within two of the 10 climate regions defined in Timbal et al. (2011). The Tully, Herbert and Burdekin regions lie in the Queensland climatic zone, while the Bundaberg, Rocky Point and New South Wales regions lie within the Northern Mid-East coast climatic zone. The Mackay sugarcane growing region was found to lie on the border between the Queensland and Mid-East coast climatic zones. Our project induced the BOM to produce new boundaries for climate regions that did not intersect sugarcane-growing regions. The Mackay region was considered entirely within the Queensland climatic zone for downsampling purposes.
4. **High resolution models of radiation produced from high resolution rainfall and temperature data – Appendix 2**

Daily radiation values were not available from the GCM downscaling procedure. Instead, daily radiation for 0.05 by 0.05 pixels, were calculated based on the AWAP and downscaled 20C3M, B1 and A2 data sets. Rainfall and temperature data were used to produce daily radiation values using the methodology of Liu and Scott (2001).

5. **Unharvestable days identified for winter and spring based on high resolution temperature and rainfall data**

The definition of an unharvestable day (Muchow et al., 1996) applied the following rule: If > 10 to ≤ 20 mm of rain occurred in one day, then that day was assumed to be unharvestable. If >20 to ≤ 40 mm of rain occurred, then that day and the next were assumed to be unharvestable. If > 40 mm of rain occurred, then that day and the next two days were assumed to be unharvestable. This rule identified each day as harvestable or unharvestable and the total number of unharvestable days for winter and spring were calculated for the AWAP and downscaled 20C3M, B1 and A2 data.

### Regional Productivity Data

6. **A more effective way of incorporating the carbon dioxide enhancement effect into climate change projections on yield – Everingham et al. 2013a (Appendix 12)**

The sugarcane growth module in the WaterSense program (Inman-Bamber et al., 2007) was used to simulate regional yield as tonnes of cane per hectare. The workbench version of WaterSense (Inman-Bamber et al., 2013) was modified to account for CO₂ concentrations of 345 ppm (20C3M), 459 ppm (B1) and 542 ppm (A2). Estimates of regional yield were obtained based on eleven statistically downscaled GCMs for the base period 1961 to 2000 (20C3M). Future GCM projections for 2046 to 2065 were then simulated for a low (B1) and high (A2) emissions scenario.

### Regional Projections: Validation, Spatial Variability and Projected Change

7. **Case Study: Burdekin – Interpreting regional outputs Appendix 3**

The Burdekin region was used to develop the interpretation of projected changes in maximum temperature, minimum temperature, radiation, rainfall, unharvestable days and regional yields. Cumulative distribution functions of AWAP and downscaled GCM data (20C3M) were compared for the period 1961:2000. The change in multi-model means (mean of all GCMs) for each 0.05 by 0.05 pixel were graphically displayed to identify spatial variation. The regional mean difference was calculated between the two time periods 2046:2065 – 1961:2000 for each downscaled GCM. The distribution of the 11 paired differences was then displayed graphically as a boxplot. A 95% bootstrapped confidence interval (Good, 1997) was then produced for the 25th, 50th and 75th percentiles of the paired regional mean differences. We considered an increase to be ‘plausible’ when the confidence intervals for the 50th and hence the 75th percentile were greater than zero, and ‘highly plausible’ if the confidence intervals for the 25th and hence the 50th and 75th percentiles were all greater than zero. By extension, we consider a decrease to be ‘plausible’ when the confidence intervals for the 50th and hence the 25th percentiles were less than zero, and ‘highly plausible’ if the confidence intervals for the 75th and hence the 50th and 25th percentiles were all less than zero.
8. Impacts of climate change on maximum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A4.1) and spatial variability in average projected change were analysed for B1 (Figure A4.2) and A2 (Figure A4.3) scenarios. Boxplots of simulated changes (Figure A4.4) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in maximum temperature was considered highly plausible for summer, autumn, winter and spring in Tully, under the B1 and A2 scenarios (Figure A4.5).

9. Impacts of climate change on minimum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A4.6) and spatial variability in average projected change were analysed for B1 (Figure A4.7) and A2 (Figure A4.8) scenarios. Boxplots of simulated changes (Figure A4.9) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in minimum temperature was considered highly plausible for summer, autumn, winter and spring in Tully, under the B1 and A2 scenarios (Figure A4.10).

10. Impacts of climate change on radiation
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A4.11) and spatial variability in average projected change were analysed for B1 (Figure A4.12) and A2 (Figure A4.13) scenarios. Boxplots of simulated changes (Figure A4.14) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A decrease in radiation was considered highly plausible for winter in Tully, under the B1 and A2 scenarios, plausible in spring (B1 and A2). An increase was considered plausible in summer for both the B1 and A2 scenarios (Figure A4.15).

11. Impacts of climate change on rainfall
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A4.16) and spatial variability in average projected change were analysed for B1 (Figure A4.17) and A2 (Figure A4.18) scenarios. Boxplots of simulated changes (Figure A4.19) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A relative increase in seasonal rainfall was considered plausible for winter (B1) and spring (A2) in Tully (Figure A4.20).

12. Impacts of climate change on harvestability
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A4.21) and spatial variability in average projected change were analysed for B1 (Figure A4.22) and A2 (Figure A4.23) scenarios. Boxplots of simulated changes (Figure A4.24) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. There was insufficient evidence to support a change in the number of unharvestable days in Tully (Figure A4.25).
13. Impacts of climate change on maximum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A5.1) and spatial variability in average projected change were analysed for B1 (Figure A5.2) and A2 (Figure A5.3) scenarios. Boxplots of simulated changes (Figure A5.4) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in maximum temperature was considered highly plausible for summer, autumn, winter and spring in the Herbert region, under the B1 and A2 scenarios (Figure A5.5).

14. Impacts of climate change on minimum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A5.6) and spatial variability in average projected change were analysed for B1 (Figure A5.7) and A2 (Figure A5.8) scenarios. Boxplots of simulated changes (Figure A5.9) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in minimum temperature was considered highly plausible for summer, autumn, winter and spring in the Herbert region, under the B1 and A2 scenarios (Figure A5.10).

15. Impacts of climate change on radiation
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A5.11) and spatial variability in average projected change were analysed for B1 (Figure A5.12) and A2 (Figure A5.13) scenarios. Boxplots of simulated changes (Figure A5.14) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A decrease in radiation was considered highly plausible for autumn, winter and spring in the Herbert region, under the B1 and A2 scenarios (Figure A5.15).

16. Impacts of climate change on rainfall
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A5.16) and spatial variability in average projected change were analysed for B1 (Figure A5.17) and A2 (Figure A5.18) scenarios. Boxplots of simulated changes (Figure A5.19) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A relative increase in seasonal rainfall was considered plausible for autumn under the A2 scenario in the Herbert region (Figure A5.20).

17. Impacts of climate change on harvestability
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A5.21) and spatial variability in average projected change were analysed for B1 (Figure A5.22) and A2 (Figure A5.23) scenarios. Boxplots of simulated changes (Figure A5.24) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in the number of unharvestable days was considered plausible for spring under the A2 scenario in the Herbert region (Figure A5.25).
18. Impacts of climate change on maximum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A6.1) and spatial variability in average projected change were analysed for B1 (Figure A6.2) and A2 (Figure A6.3) scenarios. Boxplots of simulated changes (Figure A6.4) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in maximum temperature was considered highly plausible for summer, autumn, winter and spring in Burdekin, under the B1 and A2 scenarios (Figure A6.5).

19. Impacts of climate change on minimum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A6.6) and spatial variability in average projected change were analysed for B1 (Figure A6.7) and A2 (Figure A6.8) scenarios. Boxplots of simulated changes (Figure A6.9) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in minimum temperature was considered highly plausible for summer, autumn, winter and spring in Burdekin, under the B1 and A2 scenarios (Figure A6.10).

20. Impacts of climate change on radiation
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A6.11) and spatial variability in average projected change were analysed for B1 (Figure A6.12) and A2 (Figure A6.13) scenarios. Boxplots of simulated changes (Figure A6.14) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A decrease in radiation was considered highly plausible for autumn, winter and spring in Burdekin, under the B1 and A2 scenarios and plausible for the B1 scenario in summer (Figure A6.15).

21. Impacts of climate change on rainfall
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A6.16) and spatial variability in average projected change were analysed for B1 (Figure A6.17) and A2 (Figure A6.18) scenarios. Boxplots of simulated changes (Figure A6.19) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A relative increase in seasonal rainfall was considered plausible for summer under the A2 scenario in Burdekin (Figure A6.20).

22. Impacts of climate change on harvestability
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A6.21) and spatial variability in average projected change were analysed for B1 (Figure A6.22) and A2 (Figure A6.23) scenarios. Boxplots of simulated changes (Figure A6.24) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A decrease in the number of unharvestable days was considered plausible for winter and spring under the A2 scenario in Burdekin (Figure A6.25).

23. Impacts of climate change on yield
Cumulative distribution functions of AWAP simulated and observed yields were compared (Figure A6.26). AWAP and GCM simulation (20C3M) distribution functions were also compared (Figure A6.27). Boxplots of simulated changes (Figure A6.28) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A relative increase in yield (TCPH) was considered plausible in the Burdekin under the B1 scenario (Figure A6.29).
24. Impacts of climate change on maximum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A7.1) and spatial variability in average projected change were analysed for B1 (Figure A7.2) and A2 (Figure A7.3) scenarios. Boxplots of simulated changes (Figure A7.4) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in maximum temperature was considered highly plausible for summer, autumn, winter and spring in Mackay, under the B1 and A2 scenarios (Figure A7.5).

25. Impacts of climate change on minimum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A7.6) and spatial variability in average projected change were analysed for B1 (Figure A7.7) and A2 (Figure A7.8) scenarios. Boxplots of simulated changes (Figure A7.9) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in minimum temperature was considered highly plausible for summer, autumn, winter and spring in Mackay, under the B1 and A2 scenarios (Figure A7.10).

26. Impacts of climate change on radiation
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A7.11) and spatial variability in average projected change were analysed for B1 (Figure A7.12) and A2 (Figure A7.13) scenarios. Boxplots of simulated changes (Figure A7.14) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A decrease in radiation was considered highly plausible for autumn and winter in Mackay, under the B1 and A2 scenarios and plausible for spring under the B1 and A2 scenarios (Figure A7.15).

27. Impacts of climate change on rainfall
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A7.16) and spatial variability in average projected change were analysed for B1 (Figure A7.17) and A2 (Figure A7.18) scenarios. Boxplots of simulated changes (Figure A7.19) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. There was insufficient evidence to support a relative change in seasonal rainfall in Mackay (Figure A7.20).

28. Impacts of climate change on harvestability
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A7.21) and spatial variability in average projected change were analysed for B1 (Figure A7.22) and A2 (Figure A7.23) scenarios. Boxplots of simulated changes (Figure A7.24) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. There was insufficient evidence to support a change in the number of unharvestable days in Mackay (Figure A7.25).

29. Impacts of climate change on yield
Cumulative distribution functions of AWAP simulated and observed yields were compared (Figure A7.26). AWAP and GCM simulation (20C3M) distribution functions were also compared (Figure A7.27). Boxplots of simulated changes (Figure A7.28) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A relative increase in yield was considered plausible in Mackay under the B1 scenario (Figure A7.29).
30. Impacts of climate change on maximum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A8.1) and spatial variability in average projected change were analysed for B1 (Figure A8.2) and A2 (Figure A8.3) scenarios. Boxplots of simulated changes (Figure A8.4) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in maximum temperature was considered highly plausible for summer, autumn, winter and spring in Bundaberg, under the B1 and A2 scenarios (Figure A8.5).

31. Impacts of climate change on minimum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A8.6) and spatial variability in average projected change were analysed for B1 (Figure A8.7) and A2 (Figure A8.8) scenarios. Boxplots of simulated changes (Figure A8.9) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in minimum temperature was considered highly plausible for summer, autumn, winter and spring in Bundaberg, under the B1 and A2 scenarios (Figure A8.10).

32. Impacts of climate change on radiation
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A8.11) and spatial variability in average projected change were analysed for B1 (Figure A8.12) and A2 (Figure A8.13) scenarios. Boxplots of simulated changes (Figure A8.14) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A decrease in radiation was considered highly plausible for summer, autumn and winter in Bundaberg, under the B1 and A2 scenarios and plausible in spring for the B1 and A2 scenarios (Figure A8.15).

33. Impacts of climate change on rainfall
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A8.16) and spatial variability in average projected change were analysed for B1 (Figure A8.17) and A2 (Figure A8.18) scenarios. Boxplots of simulated changes (Figure A8.19) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. There was insufficient evidence to support a relative change in seasonal rainfall in Bundaberg (Figure A8.20).

34. Impacts of climate change on harvestability
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A8.21) and spatial variability in average projected change were analysed for B1 (Figure A8.22) and A2 (Figure A8.23) scenarios. Boxplots of simulated changes (Figure A8.24) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A decrease in the number of unharvestable days was considered plausible for winter under the A2 scenario in Bundaberg (Figure A8.25).
Rocky Point regional outputs – Appendix 9

35. Impacts of climate change on maximum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A9.1) and spatial variability in average projected change were analysed for B1 (Figure A9.2) and A2 (Figure A9.3) scenarios. Boxplots of simulated changes (Figure A9.4) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in maximum temperature was considered highly plausible for summer, autumn, winter and spring at Rocky Point, under the B1 and A2 scenarios (Figure A9.5).

36. Impacts of climate change on minimum temperature
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A9.6) and spatial variability in average projected change were analysed for B1 (Figure A9.7) and A2 (Figure A9.8) scenarios. Boxplots of simulated changes (Figure A9.9) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in minimum temperature was considered highly plausible for summer, autumn, winter and spring at Rocky Point, under the B1 and A2 scenarios (Figure A9.10).

37. Impacts of climate change on radiation
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A9.11) and spatial variability in average projected change were analysed for B1 (Figure A9.12) and A2 (Figure A9.13) scenarios. Boxplots of simulated changes (Figure A9.14) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A decrease in radiation was considered highly plausible for summer and autumn, under the B1 and A2 scenarios. A decrease was also considered highly plausible in winter under the A2 scenario. A decrease was considered plausible in winter (B1) and spring (A2) (Figure A9.15).

38. Impacts of climate change on rainfall
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A9.16) and spatial variability in average projected change were analysed for B1 (Figure A9.17) and A2 (Figure A9.18) scenarios. Boxplots of simulated changes (Figure A9.19) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. There was insufficient evidence to support a relative change in seasonal rainfall at Rocky Point (Figure A9.20).

39. Impacts of climate change on harvestability
Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A9.21) and spatial variability in average projected change were analysed for B1 (Figure A9.22) and A2 (Figure A9.23) scenarios. Boxplots of simulated changes (Figure A9.24) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. There was insufficient evidence to support a change in the number of unharvestable days at Rocky Point (Figure A9.25).
40. Impacts of climate change on maximum temperature

Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A10.1) and spatial variability in average projected change were analysed for B1 (Figure A10.2) and A2 (Figure A10.3) scenarios. Boxplots of simulated changes (Figure A10.4) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in maximum temperature was considered highly plausible for summer, autumn, winter and spring in NSW, under the B1 and A2 scenarios (Figure A10.5).

41. Impacts of climate change on minimum temperature

Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A10.6) and spatial variability in average projected change were analysed for B1 (Figure A10.7) and A2 (Figure A10.8) scenarios. Boxplots of simulated changes (Figure A10.9) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in minimum temperature was considered highly plausible for summer, autumn, winter and spring in NSW, under the B1 and A2 scenarios (Figure A10.10).

42. Impacts of climate change on radiation

Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A10.11) and spatial variability in average projected change were analysed for B1 (Figure A10.12) and A2 (Figure A10.13) scenarios. Boxplots of simulated changes (Figure A10.14) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A decrease in radiation was considered highly plausible for summer and autumn (B1 and A2) in NSW (Figure A10.15). A decrease in radiation was also considered highly plausible in winter under the A2 scenario and plausible under the B1 scenario.

43. Impacts of climate change on rainfall

Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A10.16) and spatial variability in average projected change were analysed for B1 (Figure A10.17) and A2 (Figure A10.18) scenarios. Boxplots of simulated changes (Figure A10.19) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. A relative decrease in seasonal rainfall was considered plausible for winter (B1) and summer (A2) in NSW (Figure A10.20).

44. Impacts of climate change on harvestability

Cumulative distribution functions of AWAP and downscaled GCMs (20C3M) were compared (Figure A10.21) and spatial variability in average projected change were analysed for B1 (Figure A10.22) and A2 (Figure A10.23) scenarios. Boxplots of simulated changes (Figure A10.24) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. There was insufficient evidence to consider a change in the number of unharvestable days in NSW (Figure A10.25).

45. Impacts of climate change on yield

Cumulative distribution functions of AWAP simulated and observed yields were compared (Figure A10.26). AWAP and GCM simulation (20C3M) distribution functions were also compared (Figure A10.27). Boxplots of simulated changes (Figure A10.28) and bootstrapped 95% confidence intervals of the 25th, 50th and 75th percentile of paired differences were analysed. An increase in yield was considered highly plausible under the A2 scenario in NSW (Figure A10.29).
Environmental and Social Impacts:

Environmental Impacts

This project consisted of a desktop analysis and therefore conducting the project posed no significant environmentally or socially adverse impacts. The outputs of this project are largely orientated towards furthering industry discussion of the future of the Australian sugar industry under a changing climate. By identifying climate change impacts at a high resolution, specific regional and sub-regional strategies can be developed. For example our model design suggested it was plausible for the Herbert region to plan for an increase in the number of unharvestable days. As well as shortening the harvest window, heavy rainfall events can cause nutrient runoff and soil erosion (Park, 2003). Nitrogen loss from farming is a threat to the Great Barrier Reef marine park (Biggs et al., 2012). Recent studies have concluded that climate change may not greatly affect the improvement in farming practices needed to meet water quality goals (Biggs et al., 2012) and that water quality improvements are likely to come from adoption of best management practices (Webster et al., 2009). However, Biggs et al. (2012) found that “without any interventions, the frequency of years with very high [nitrogen] losses, and hence extreme ecological risk, was predicted to increase.” These results may indicate an increase in heavy rainfall events such as the increase in unharvestable days found in this study. An Increase in minimum temperature has the potential to lengthen the growing season and reduce the risk of frost damage in southern and western regions (Park, 2007). However, increasing temperature and rainfall may also lead to increases in pests and diseases such as smut. These conditions have to be considered when interpreting projections of yield. A delicate balance must be struck between potential gains from productivity, losses through environmental variability and the economic impact of any potential adaptation strategy. The results of this study can help raise awareness of the importance of climate change to the Australian sugar industry.

Social Impacts

Climate is a key driver of sugarcane production and all its by-products. Given the challenges of delivering sustainable solutions to employing, feeding and fuelling an increasing global population, it is timely and critical to understand the impact climate change will have on sugarcane production. The methodologies developed in this project along with key project findings can guide policy makers in the development of robust solutions for sustainable production industries and a food secure future under a changing climate.
Expected Outcomes:

- Enhanced industry preparedness to climate change by exploring the benefits and highlighting risks of anthropogenic forcings on the climate.

- Improved industry planning at the farming, harvesting, milling and marketing components of the value chain resultant of a more thorough understanding of regional crop responses to elevated CO₂ levels and through the development of robust and climate ready harvesting and milling strategies.

- A more resilient and environmentally sustainable sugar industry.

Future Research Needs:

- Extend harvest disruption analyses to incorporate spatial variability in soils. This will be highly relevant if the emerging increasing trend in autumn rainfall intensifies.

- Projections of yield were only produced for the Burdekin, Mackay and NSW. Extend the yield projection research to include Tully, Ingham and Bundaberg. Develop technology to implement randomization procedures within the ensemble methods across all regions.

- Investigate how climate change will impact extreme events.

- Develop a strategy to provide yield projections at a high resolution so that precision agriculture principles can support climate adaptation strategies.
**Recommendations:**

- Our findings in this report should be routinely updated regularly (e.g. in line with IPCC reporting), to capture improvements in modelling designs and data sets.

- Assist industry manage climate risk through integration and acknowledgement of seasonal climate forecasts. Industry will be more able to adapt to a changing climate if they have learnt the risk and opportunity management skills to cope with natural swings in climate variability forecasted by seasonal prediction models.

- More participatory focus on climate change research. This project offered a desktop study to develop outputs to initiate industry dialogue.

- Continued investment on developing climate ready varieties that maximise benefits of elevated CO$_2$ levels.

- Industry vigilantly monitors emerging trends in autumn rainfall.

- Invest in harvesting and milling efficiencies.

- Investigate the climate change impacts on fibre and other important components of the plant.

- Industry should develop a robust risk and opportunity management plan to cope with climate uncertainties at short, medium and long-time scales.

- As part of future risk management activities we stress that climate, yield and harvestability projections capture only a subset of future uncertainty.
List of Publications:

(Copies of substantive publications from the project should be included as Appendices. Where the project involves a student and the thesis is relevant to the project this should be referred to in the report and an electronic copy of the thesis sent with the report or as soon as it is available.)


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References


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The Research Organisation is not a partner, joint venture, employee or agent of SRDC and has no authority to legally bind SRDC, in any publication of substantive details or results of this Project.
Four main data sets were constructed for analysis of region climatology and the analysis of climate change impacts on climate variables (maximum temperature, minimum temperature, radiation and rainfall) as well as harvestability and yields. Table A1 lists the data sets developed for the project. Australian Water Availability (AWAP) based data and statistically downscaled General Circulation Models (GCMs), using the analogue Statistical Downscaling Model (SDM) of the Bureau Of Meteorology (BOM). Data were analysed for each region, season, GCM, pixel and year.

Table A1: High resolution data sets

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Period</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWAP</td>
<td>1961-2000</td>
<td>Spatially interpolated high quality weather station data at a 0.05° by 0.05° pixel resolution.</td>
</tr>
<tr>
<td>BOM SDM 20C3M</td>
<td>1961-2000</td>
<td>GCM data under 20\textsuperscript{th} century forcings (20C3M) were supplied to the Bureau Of Meteorology (BOM) Statistical Downscaling Model (SDM) to produce simulated historical downscaled daily climate data at a 0.05° by 0.05° pixel resolution.</td>
</tr>
<tr>
<td>BOM SDM B1</td>
<td>2046-2065</td>
<td>GCM Projection data based on low anthropogenic forcings (B1) were supplied to the Bureau Of Meteorology (BOM) Statistical Downscaling Model (SDM) to produce simulated historical downscaled daily climate data at a 0.05° by 0.05° pixel resolution.</td>
</tr>
<tr>
<td>BOM SDM A2</td>
<td>2046-2065</td>
<td>GCM Projection data based on high anthropogenic forcings (A2) were supplied to the Bureau Of Meteorology (BOM) Statistical Downscaling Model (SDM) to produce simulated historical downscaled daily climate data at a 0.05° by 0.05° pixel resolution.</td>
</tr>
</tbody>
</table>

**A1.1 Australian Water Availability (AWAP) Data 1961:2000**

Daily rainfall and temperature data from the Australian Water Availability Project (AWAP) were sourced and processed for the seven sugarcane-growing regions. The AWAP data represent spatially interpolated weather station data (Jones et al., 2009). Individual pixels of 0.05 by 0.05 decimal degrees that are used to farm sugarcane were identified for each region (Tully: 77 pixels, Herbert: 58 pixels, Burdekin: 64 pixels, Mackay: 133 pixels, Bundaberg: 107 pixels, Rocky point: 7 pixels and NSW: 76 pixels). Sugarcane-growing regions were described by land use maps from the Department of Environment and Research Management and local industry spatial data. Data used as baseline historical data for the period 1961:2000. Radiation data were not available and were produced using the methodology of Liu and Scott (2001) as described in Appendix 2.
A1.2 Downscaled Data Sets

A1.2.1 General circulation models and downscaled climate data

GCM data were extracted from the Coupled Model Intercomparison Project (CMIP3) based on the B1 and A2 emission scenarios (Meehl et al., 2007). Eleven GCMs that had rainfall and temperature data on a daily time step were selected from the CMIP3 database. These GCMs are identified as CCM (Canadian Climate Centre), CNRM (Metro-France), CSIRO (Commonwealth Scientific and Industrial Research Organisation), CSIRO2 (Commonwealth Scientific and Industrial Research Organisation), GFDL1 (Geophysical Fluid Dynamics Lab), GFDL2 (Geophysical Fluid Dynamics Lab), GISSR (NASA/Goddard Institute for Space Studies), ISPL (Institute Pierre Simon Laplace), MIROC (Centre for Climate Research), MPI (Max Planck Institute for meteorology DKRZ), MRI (Meteorological Research Institute). General Circulation Model (GCM) data were downscaled using an analogues methodology (Timbal et al., 2009).

A1.2.2 BOM SDM 20C3M, BOM SDM A2 and BOM SDM B1 data

GCM outputs for the period 1961:2000 were downscaled under the 20C3M scenario which used observed trends in greenhouse gas emissions for the 20th century (PCMDI, 2002). Data were downscaled based on the 11 GCMs for daily temperature and rainfall data. Radiation data were not available and daily values were produced for each GCM using the methodology outlined in appendix 2. BOM SDM data were used in the analysis of temperature, rainfall, harvestability and yield. Rainfall and temperature projections for the 11 GCMs were extracted for the period 2046:2065. A low (B1) and high (A2) scenario were considered, as described by the IPCC (Nakicenovic and Swart, 2000).

A.1.2.4 Correction to the Mackay region

On an Australia wide scale the analogue statistical downscaling model defines 10 climatic regions (Figure A1.1) for which the optimisation of the model differs. The sugarcane growing areas of eastern Australia fall within two of the 10 climate regions defined in Timbal et al. (2011). The Tully, Herbert, Burdekin and Mackay regions lie in the Queensland climatic zone, while the Bundaberg, Rocky Point and New South Wales regions lie within the Northern Mid-East coast climatic zone. The optimal choice of predictors differs between the two regions. For the example of rainfall, the Queensland climatic region relies solely on the rainfall from the GCM which was found to be the only successful large-scale predictor of the localised rainfall. Further south in the northern Mid-East coast zone, the optimum combination of predictors comprised moisture information with other indicators of the large-scale dynamics: i.e. in winter Relative humidity at 850 hPa combined with Mean Sea Level Pressure and the meridional wind at 850 hPa while in spring, Relative humidity at 850 hPa is combined with the zonal wind at 850 hPa and the maximum surface temperature. The Mackay sugarcane growing region was found to lie on the border between the Queensland and Mid-East coast climatic zones. The BOM data sets (BOM 20C3M, BOM B1 and BOM A2) were downscaled to define the Mackay region entirely within the Queensland climatic zone. This removed the spatial discontinuity (Figure A1.2).
Figure A1.1: Ten climate zones defined by Timbal et al. (2011), used to downscale climate data. The Mackay sugar region lies on the border between the QLD and MEC zones at approximately longitude 189.725 decimal degrees.

Figure A1.2: Average total rainfall (mm) for summer in the Mackay region under different climate scenarios. (a), (b) and (c) were produced using the original BOM SDM data sets while (d),(e) and (f) were produced with the entire Mackay region considered part of the QLD climate zone. The dashed line represents the apparent discontinuity at 189.725 decimal degrees.
APPENDIX 2: MODELLING DAILY RADIATION

Downscaled daily rainfall and temperature data were obtained on a 0.05 by 0.05 decimal degree grid for sugarcane regions across Queensland and northern New South Wales. Daily radiation values however, were not available on this grid. To produce radiation values to match rainfall and radiation data, this project used the methodology of Liu and Scott (2001). The equation used is noted as equation 8 in the 2001 paper and uses temperature and rainfall parameters as well as total daily solar flux (clear sky radiation) to predict the total daily radiation on a horizontal surface.

Daily radiation \( Q_j \) was calculated

\[
Q_j = Q0_j \times a(1 - \exp(-bD_j))(1+dR_{j-1} + eR_j +fR_{j+1}) + g
\]

For each region, GCM and pixel of each high resolution data set. \( Q0_j \) was the total daily solar flux calculated using the methodology of Duffie and Beckman (1991). \( R_j \) identified if rainfall on day \( j \) was > 5 mm. Similarly, \( R_{j-1} \) and \( R_{j+1} \) identified if rainfall the day before ( \( j - 1 \) ) and the day after ( \( j + 1 \) ) were > 5mm. \( D_j \) was calculated as the difference between daily maximum temperature and average daily minimum temperature of day ( \( j \) ) and day ( \( j + 1 \)).

\[
D_j = T_{\text{max}}(j) - \frac{T_{\text{min}}(j) + T_{\text{min}}(j+1)}{2}
\]

Weather station data for the period 1957:2008 from the SILO Patched Point Data archive (Jeffery et al., 2001), were used to estimate parameters \( a, b, c, d, e, f \) and \( g \) on a region by region basis. Parameter estimates were derived using a non-linear least-squares approach. A linear bias was fitted to radiation estimates in order to keep approximations as close to station data records as possible. Several weather stations from each region were considered and the parameters developed for each region were recorded (Table A2.2).

**Table A2.1**: Regional parameter estimates for radiation calculations.

<table>
<thead>
<tr>
<th>Region</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tully</td>
<td>0.597</td>
<td>0.044</td>
<td>1.615</td>
<td>0.002</td>
<td>-0.052</td>
<td>-0.082</td>
<td>4.367</td>
</tr>
<tr>
<td>2. Herbert</td>
<td>0.673</td>
<td>0.069</td>
<td>1.417</td>
<td>-0.021</td>
<td>-0.077</td>
<td>-0.104</td>
<td>2.126</td>
</tr>
<tr>
<td>3. Burdekin</td>
<td>0.757</td>
<td>0.09</td>
<td>1.229</td>
<td>-0.02</td>
<td>-0.079</td>
<td>-0.11</td>
<td>0.196</td>
</tr>
<tr>
<td>4. Mackay</td>
<td>0.682</td>
<td>0.079</td>
<td>1.409</td>
<td>-0.012</td>
<td>-0.08</td>
<td>-0.125</td>
<td>1.612</td>
</tr>
<tr>
<td>5. Bundaberg</td>
<td>0.698</td>
<td>0.032</td>
<td>1.8</td>
<td>0.006</td>
<td>-0.053</td>
<td>-0.122</td>
<td>1.179</td>
</tr>
<tr>
<td>6. Rocky Point</td>
<td>0.683</td>
<td>0.033</td>
<td>1.763</td>
<td>0.02</td>
<td>-0.049</td>
<td>-0.108</td>
<td>1.504</td>
</tr>
<tr>
<td>7. NSW</td>
<td>0.675</td>
<td>0.056</td>
<td>1.504</td>
<td>0.021</td>
<td>-0.039</td>
<td>-0.115</td>
<td>1.152</td>
</tr>
</tbody>
</table>
Four sets of outputs were generated in analysing changes in maximum and minimum temperature (degrees C), radiation (Mj/m²), rainfall (%), unharvestable days (days) and yield (%) between GCM simulations of 1961:2000 and 2046:2065.

1. Validation
   Cumulative distribution functions of AWAP and downscaled GCM data (20C3M) were compared for the period 1961:2000 to validate downscaled data.

2. Spatial variability
   The change in multi-model mean (mean of all GCMs) for each 0.05 by 0.05 pixel were graphically displayed to identify spatial variation.

3. Projected change - Boxplots
   For each region, the regional mean difference was calculated between the two time periods 2046:2065 – 1961:2000 for each downscaled GCM. The distribution of the 11 paired differences was displayed graphically as a boxplot.

4. Projected change - Percentiles
   A 95% bootstrapped confidence interval was then produced for the 25th, 50th and 75th percentiles of the paired regional mean differences temperature, radiation and rainfall were analysed for summer, autumn, winter and spring. Unharvestable days were analysed for winter and spring. Simulations of yield were produced as annual yield in tonnes of cane per hectare (TCPH).

A3.1 Validation

Empirical cumulative distribution functions (CDFs) were produced from the average (mean) of all pixels in a region. CDFs for AWAP and each GCM were graphically examined for each season relevant to the variable. AWAP data were compared to downscaled GCM data for the period 1961:2000. For example, in the Burdekin region for spring (Figure A3.1), GCMs tended to underestimate rainfall and unharvestable days (GCM distribution functions (coloured) shifted left of AWAP distribution function (black)) and overestimate radiation (GCMs shifted right of AWAP distribution function). For variables such as yield, GCM distribution functions graphically compared well with little spread about the AWAP generated distribution function.
Figure A3.1: Empirical cumulative distribution functions of regional means for spring in region 3 (Burdekin). The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A3.2 Spatial Variability – Regional Plots

For each pixel in a region, the mean simulated value for 20C3M (1961:2000), B1 (2046:2065) and A2 (2046:2065) were calculated for each GCM. For temperature, radiation and harvestability data, the paired difference was then computed between 20C3M and B1 and 20C3M and A2 for each GCM (for example B1 – 20C3M). For rainfall and yield the relative difference was computed as a percentage (for example (B1 – 20C3M)/20C3M *100). For each pixel the multi-model mean difference was then calculated as the mean of all GCM differences. The multi-model mean difference for each pixel was graphed spatially to identify variability within each region. For example in the Burdekin in spring (Figure A3.2), there is little variability in temperature and unharvestable days. Under the A2 scenario there is an east to west trend of decreasing rainfall for the Burdekin in spring.
Figure A3.2: Projected changes in average (multi-model mean) for spring in region 3 (Burdekin). Negative values represent a decreasing trend from simulations using 20th century forcings (20C3M) while positive values represent an increasing trend. Temperature, radiation and unharvestable days are calculated as the difference (e.g. 20C3M – A2). Rainfall represents relative change as a percentage (e.g. (20C3M – A2 / A2)*100).
For each pixel in a region, the mean simulated value for 20C3M (1961:2000), B1 (2046:2065) and A2 (2046:2065) was calculated for each GCM. The spatio-temporal mean was then computed as the mean of all pixels in a region. For temperature, radiation and harvestability data, the paired difference was calculated between 20C3M and B1 and 20C3M and A2 for each GCM (for example B1 – 20C3M). For rainfall and yield the relative difference was computed as a percentage (for example (B1 – 20C3M)/20C3M *100). The spatio-temporal mean difference for each GCM was graphed for B1 and A2 emission scenarios. For example in the Burdekin in spring (Figure A3.3), all of the 11 GCMs, simulated an increase for temperature variables under both the B1 and A2 scenario. In comparison, the spread of GCMs for rainfall and unharvestable days, include models that simulate a decrease and models that simulate an increase.
Figure A3.3: Regional projections for the change in the (downscaled) GCM paired differences for region 3 (Burdekin). Positive values mean that the values are higher for the 2046:2065 period. Temperature, radiation and unharvestable days are calculated as the difference in spatio-temporal means (e.g. 20C3M – A2). Rainfall and yield represent relative difference as a percentage (e.g. (20C3M – A2 / A2)*100). The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box.
A3.4 Projected Change – Percentiles

Separate 95% confidence intervals for the 25th, 50th and 75th population percentiles were computed using bootstrapped samples (Everingham et al., 2011; Good, 1997). For example, the 95% confidence interval for the 50th percentile was obtained by drawing 1000 samples with replacement from the 11 spatio-temporal mean differences. For each bootstrapped sample, the 50th percentile was computed. These 1000 computations of the 50th percentile were arranged from smallest to largest. The value in position 26 was defined as the lower bound of the 95% confidence interval, and the value in position 975 was defined as the upper bound of the 95% confidence interval. The computations for the 95% confidence interval for the 25th and 75th percentiles follow an equivalent procedure.

We consider an increase to be ‘plausible’ when the confidence intervals for the 50th and hence the 75th percentiles were greater than zero, and ‘highly plausible’ if the confidence intervals for the 25th and hence the 50th and 75th percentiles were all greater than zero. By extension, we consider a decrease to be ‘plausible’ when the confidence intervals for the 50th and hence the 25th percentiles were less than zero, and ‘highly plausible’ if the confidence intervals for the 75th and hence the 50th and 25th percentiles were all less than zero. For example the Burdekin region (Figure A3.4) in summer autumn winter and spring, an increase in temperature (maximum and minimum) was considered highly plausible for both the B1 (blue) and A2 (red) emission scenario. A decrease in radiation was also highly plausible in autumn, winter and spring under the B1 and A2 scenario. A decrease in unharvestable days in winter and spring was considered plausible for the Burdekin under the A2 scenario (red), as the 95% confidence intervals for the 50th and 25th percentiles captured only negative values. An increase in yield under the B1 scenario was considered plausible.
Figure A3.4: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Blue bars represent change under the B1 scenario while red bars represent change under A2 scenario.
A4.1 Impacts of Climate Change on Maximum Temperature

A4.1.1 Validation

Figure A4.1: Empirical cumulative distribution functions of regional mean maximum temperature for summer, autumn, winter and spring in Tully. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20\textsuperscript{th} century forcings (20C3M).
A4.1.2 Spatial variability - Regional plots

Figure A4.2: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Tully. Projections have been made based on the lower (B1) emissions scenario.

Figure A4.3: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Tully. Projections have been made based on the higher (A2) emissions scenario.
A4.1.3 Projected change

Figure A4.4: Regional projections for (downscaled) GCM paired differences in maximum temperature for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25\textsuperscript{th}, 50\textsuperscript{th} and 75\textsuperscript{th} percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A4.5: Regional projections for the change in the 25\textsuperscript{th}, 50\textsuperscript{th} and 75\textsuperscript{th} percentiles of the (downscaled) GCM paired differences in maximum temperature for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A4.2 Impacts of Climate Change on Minimum Temperature

A4.2.1 Validation

Figure A4.6: Empirical cumulative distribution functions of regional mean minimum temperature for summer, autumn, winter and spring in Tully. The black line represents the distribution function of AWAP data (1961-2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
Figure A4.7: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Tully. Projections have been made based on the lower (B1) emissions scenario.

Figure A4.8: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Tully. Projections have been made based on the higher (A2) emissions scenario.
A4.2.3 Projected change

**Figure A4.9:** Regional projections for (downscaled) GCM paired differences in minimum temperature for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A4.10:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in minimum temperature for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A4.3 Impacts of Climate Change on Radiation

A4.3.1 Validation

Figure A4.11: Empirical cumulative distribution functions of regional mean radiation for summer, autumn, winter and spring in Tully. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A4.3.2 Spatial variability - Regional plots

**Figure A4.12:** Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Tully. Projections have been made based on the lower (B1) emissions scenario.

**Figure A4.13:** Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Tully. Projections have been made based on the higher (A2) emissions scenario.
A4.3.3 Projected change

**Figure A4.14:** Regional projections for (downscaled) GCM paired differences in radiation for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A4.15:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in radiation for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A4.4 Impacts of Climate Change on Rainfall

A4.4.1 Validation

Figure A4.16: Empirical cumulative distribution functions of regional mean rainfall for summer, autumn, winter and spring in Tully. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20\textsuperscript{th} century forcings (20C3M).
A4.4.2 Spatial variability - Regional plots

Figure A4.17: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Tully. Projections have been made based on the lower (B1) emissions scenario.

Figure A4.18: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Tully. Projections have been made based on the higher (A2) emissions scenario.
A4.4.3 Projected change

Figure A4.19: Regional projections for (downscaled) GCM paired relative differences in rainfall (%) for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A4.20: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in rainfall (%) for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A4.5 Impacts of Climate Change on Harvestability

A4.5.1 Validation

Figure A4.21: Empirical cumulative distribution functions of regional mean number of unharvestable days for summer, autumn, winter and spring in Tully. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A4.5.2 Spatial variability - Regional plots

**Figure A4.22:** Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Tully. Projections have been made based on the lower (B1) emissions scenario.

**Figure A4.23:** Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Tully. Projections have been made based on the higher (A2) emissions scenario.
A4.5.3 Projected change

Figure A4.24: Regional projections for (downscaled) GCM paired differences in unharvestable days for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A4.25: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in unharvestable days for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A5.1 Impacts of Climate Change on Maximum Temperature

A5.1.1 Validation

Figure A5.1: Empirical cumulative distribution functions of regional mean maximum temperature for summer, autumn, winter and spring in Herbert. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20\textsuperscript{th} century forcings (20C3M).
A5.1.2 Spatial variability – Regional plots

**Figure A5.2**: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Herbert. Projections have been made based on the lower (B1) emissions scenario.

**Figure A5.3**: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Herbert. Projections have been made based on the higher (A2) emissions scenario.
A5.1.3 Projected change

Figure A5.4: Regional projections for (downscaled) GCM paired differences in maximum temperature for Herbert. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A5.5: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in maximum temperature for Herbert. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A5.2 Impacts of Climate Change on Minimum Temperature

A5.2.1 Validation

Figure A5.6: Empirical cumulative distribution functions of regional mean minimum temperature for summer, autumn, winter and spring in Herbert. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A5.2.2 Spatial variability - Regional plots

Figure A5.7: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Herbert. Projections have been made based on the lower (B1) emissions scenario.

Figure A5.8: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Herbert. Projections have been made based on the higher (A2) emissions scenario.
A5.2.3 Projected change

**Figure A5.9:** Regional projections for (downscaled) GCM paired differences in minimum temperature for Tully. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25\(^{th}\), 50\(^{th}\) and 75\(^{th}\) percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A5.10:** Regional projections for the change in the 25\(^{th}\), 50\(^{th}\) and 75\(^{th}\) percentiles of the (downscaled) GCM paired differences in minimum temperature for Herbert. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
Figure A5.11: Empirical cumulative distribution functions of regional mean radiation for summer, autumn, winter and spring in Herbert. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A5.3.2 Spatial variability - Regional plots

Figure A5.12: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Herbert. Projections have been made based on the lower (B1) emissions scenario.

Figure A5.13: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Herbert. Projections have been made based on the higher (A2) emissions scenario.
A5.3.3 Projected change

**Figure A5.14:** Regional projections for (downscaled) GCM paired differences in radiation for Herbert. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the "box" represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A5.15:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in radiation for Herbert. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A5.4 Impacts of Climate Change on Rainfall

A5.4.1 Validation

Figure A5.16: Empirical cumulative distribution functions of regional mean rainfall for summer, autumn, winter and spring in Herbert. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A5.4.2 Spatial variability - Regional plots

Figure A5.17: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Herbert. Projections have been made based on the lower (B1) emissions scenario.

Figure A5.18: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Herbert. Projections have been made based on the higher (A2) emissions scenario.
A5.4.3 Projected change

**Figure A5.19:** Regional projections for (downscaled) GCM paired relative differences in rainfall (%) for Herbert. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A5.20:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in rainfall (%) for Herbert. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A5.5 Impacts of Climate Change on Harvestability

A5.5.1 Validation

**Figure A5.21:** Empirical cumulative distribution functions of regional mean number of unharvestable days for summer, autumn, winter and spring in Herbert. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A5.5.2 Spatial variability - Regional plots

Figure A5.22: Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Herbert. Projections have been made based on the lower (B1) emissions scenario.

Figure A5.23: Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Herbert. Projections have been made based on the higher (A2) emissions scenario.
A5.5.3 Projected change

Figure A5.24: Regional projections for (downscaled) GCM paired differences in unharvestable days for Herbert. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A5.25: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in unharvestable days for Herbert. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A6.1 Impacts of Climate Change on Maximum Temperature

A6.1.1 Validation

**Figure A6.1**: Empirical cumulative distribution functions of regional mean maximum temperature for summer, autumn, winter and spring in Burdekin. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A6.1.2 Spatial variability - Regional plots

Figure A6.2: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Burdekin. Projections have been made based on the lower (B1) emissions scenario.

Figure A6.3: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Burdekin. Projections have been made based on the higher (A2) emissions scenario.
A6.1.3 Projected change

Figure A6.4: Regional projections for (downscaled) GCM paired differences in maximum temperature for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A6.5: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in maximum temperature for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A6.2 Impacts of Climate Change on Minimum Temperature

A6.2.1 Validation

Figure A6.6: Empirical cumulative distribution functions of regional mean minimum temperature for summer, autumn, winter and spring in Burdekin. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A6.2.2 Spatial variability - Regional plots

**Figure A6.7:** Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Burdekin. Projections have been made based on the lower (B1) emissions scenario.

**Figure A6.8:** Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Burdekin. Projections have been made based on the higher (A2) emissions scenario.
A6.2.3 Projected change

**Figure A6.9**: Regional projections for (downscaled) GCM paired differences in minimum temperature for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A6.10**: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in minimum temperature for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A6.3 Impacts of Climate Change on Radiation

A6.3.1 Validation

Figure A6.11: Empirical cumulative distribution functions of regional mean radiation for summer, autumn, winter and spring in Burdekin. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A6.3.2 Spatial variability - Regional plots

Figure A6.12: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Burdekin. Projections have been made based on the lower (B1) emissions scenario.

Figure A6.13: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Burdekin. Projections have been made based on the higher (A2) emissions scenario.
A6.3.3 Projected change

**Figure A6.14:** Regional projections for (downscaled) GCM paired differences in radiation for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the "box" represent the 25\(^{th}\), 50\(^{th}\) and 75\(^{th}\) percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A6.15:** Regional projections for the change in the 25\(^{th}\), 50\(^{th}\) and 75\(^{th}\) percentiles of the (downscaled) GCM paired differences in radiation for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
Figure A6.16: Empirical cumulative distribution functions of regional mean rainfall for summer, autumn, winter and spring in Burdekin. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A6.4.2 Spatial variability - Regional plots

Figure A6.17: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Burdekin. Projections have been made based on the lower (B1) emissions scenario.

Figure A6.18: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Burdekin. Projections have been made based on the higher (A2) emissions scenario.
A6.4.3 Projected change

Figure A6.19: Regional projections for (downscaled) GCM paired relative differences in rainfall (%) for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A6.20: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in rainfall (%) for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A6.5 Impacts of Climate Change on Harvestability

A6.5.1 Validation

**Figure A6.21:** Empirical cumulative distribution functions of regional mean number of unharvestable days for summer, autumn, winter and spring in Burdekin. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A6.5.2 Spatial variability - Regional plots

**Figure A6.22:** Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Burdekin. Projections have been made based on the lower (B1) emissions scenario.

**Figure A6.23:** Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Burdekin. Projections have been made based on the higher (A2) emissions scenario.
A6.5.3 Projected change

Figure A6.24: Regional projections for (downscaled) GCM paired differences in unharvestable days for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A6.25: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in unharvestable days for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A6.6 Impacts of Climate Change on Yield

A6.6.1 Validation

Figure A6.26: Empirical cumulative distribution functions of regional mean yield (TCPH) in Burdekin. The black line represents the distribution function generated from AWAP data (1961:2000) and the red line represents CDF of recorded yield.

Figure A6.27: Empirical cumulative distribution functions of regional mean number of yield in Burdekin. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A6.6.2 Projected change

**Figure A6.28:** Regional projections for (downscaled) GCM paired relative differences in yield (TCPH) for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A6.29:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in yield (TCPH) for Burdekin. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A7.1 Impacts of Climate Change on Maximum Temperature

A7.1.1 Validation

Figure A7.1: Empirical cumulative distribution functions of regional mean maximum temperature for summer, autumn, winter and spring in Mackay. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A7.1.2 Spatial variability - Regional plots

**Figure A7.2:** Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Mackay. Projections have been made based on the lower (B1) emissions scenario.

**Figure A7.3:** Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Mackay. Projections have been made based on the higher (A2) emissions scenario.
A7.1.3 Projected change

**Figure A7.4**: Regional projections for (downscaled) GCM paired differences in maximum temperature for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A7.5**: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in maximum temperature for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A7.2 Impacts of Climate Change on Minimum Temperature

A7.2.1 Validation

Figure A7.6: Empirical cumulative distribution functions of regional mean minimum temperature for summer, autumn, winter and spring in Mackay. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A7.2.2 Spatial variability - Regional plots

Figure A7.7: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Mackay. Projections have been made based on the lower (B1) emissions scenario.

Figure A7.8: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Mackay. Projections have been made based on the higher (A2) emissions scenario.
A7.2.3 Projected change

**Figure A7.9:** Regional projections for (downscaled) GCM paired differences in minimum temperature for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A7.10:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in minimum temperature for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A7.3 Impacts of Climate Change on Radiation

A7.3.1 Validation

Figure A7.11: Empirical cumulative distribution functions of regional mean radiation for summer, autumn, winter and spring in Mackay. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A7.3.2 Spatial variability - Regional plots

**Figure A7.12:** Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Mackay. Projections have been made based on the lower (B1) emissions scenario.

**Figure A7.13:** Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Mackay. Projections have been made based on the higher (A2) emissions scenario.
A7.3.3 Projected change

Figure A7.14: Regional projections for (downscaled) GCM paired differences in radiation for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the "box" represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A7.15: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in radiation for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A7.4 Impacts of Climate Change on Rainfall

A7.4.1 Validation

Figure A7.16: Empirical cumulative distribution functions of regional mean rainfall for summer, autumn, winter and spring in Mackay. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A7.4.2 Spatial variability - Regional plots

**Figure A7.17:** Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Mackay. Projections have been made based on the lower (B1) emissions scenario.

**Figure A7.18:** Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Mackay. Projections have been made based on the higher (A2) emissions scenario.
A7.4.3 Projected change

**Figure A7.19:** Regional projections for (downscaled) GCM paired relative differences in rainfall (%) for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A7.20:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in rainfall (%) for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A7.5 Impacts of Climate Change on Harvestability

A7.5.1 Validation

Figure A7.21: Empirical cumulative distribution functions of regional mean number of unharvestable days for summer, autumn, winter and spring in Mackay. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A7.5.2 Spatial variability - Regional plots

**Figure A7.22:** Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Mackay. Projections have been made based on the lower (B1) emissions scenario.

**Figure A7.23:** Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Mackay. Projections have been made based on the higher (A2) emissions scenario.
A7.5.3 Projected change

Figure A7.24: Regional projections for (downscaled) GCM paired differences in unharvestable days for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A7.25: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in unharvestable days for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A7.6 Impacts of Climate Change on Yield

A7.6.1 Validation

Figure A7.26: Empirical cumulative distribution functions of regional mean yield (TCPH) in Mackay. The black line represents the distribution function generated from AWAP data (1961:2000) and the red line represents CDF of recorded yield.

Figure A7.27: Empirical cumulative distribution functions of regional mean yield in Mackay. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A7.6.2 Projected change

**Figure A7.28:** Regional projections for (downscaled) GCM paired relative differences in yield (TCPH) for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A7.29:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in yield (TCPH) for Mackay. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
APPENDIX 8: BUNDABERG REGIONAL OUTPUTS

A8.1 Impacts of Climate Change on Maximum Temperature

A8.1.1 Validation

Figure A8.1: Empirical cumulative distribution functions of regional mean maximum temperature for summer, autumn, winter and spring in Bundaberg. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A8.1.2 Spatial variability - Regional plots

Figure A8.2: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Bundaberg. Projections have been made based on the lower (B1) emissions scenario.

Figure A8.3: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Bundaberg. Projections have been made based on the higher (A2) emissions scenario.
A8.1.3 Projected change

**Figure A8.4**: Regional projections for (downscaled) GCM paired differences in maximum temperature for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A8.5**: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in maximum temperature for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
Figure A8.6: Empirical cumulative distribution functions of regional mean minimum temperature for summer, autumn, winter and spring in Bundaberg. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20\textsuperscript{th} century forcings (20C3M).
A8.2.2 Spatial variability - Regional plots

Figure A8.7: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Bundaberg. Projections have been made based on the lower (B1) emissions scenario.

Figure A8.8: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Bundaberg. Projections have been made based on the higher (A2) emissions scenario.
A8.2.3 Projected change

**Figure A8.9:** Regional projections for (downscaled) GCM paired differences in minimum temperature for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A8.10:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in minimum temperature for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A8.3 Impacts of Climate Change on Radiation

A8.3.1 Validation

Figure A8.11: Empirical cumulative distribution functions of regional mean radiation for summer, autumn, winter and spring in Bundaberg. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A8.3.2 Spatial variability - Regional plots

Figure A8.12: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Bundaberg. Projections have been made based on the lower (B1) emissions scenario.

Figure A8.13: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Bundaberg. Projections have been made based on the higher (A2) emissions scenario.
A8.3.3 Projected change

**Figure A8.14:** Regional projections for (downscaled) GCM paired differences in radiation for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A8.15:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in radiation for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A8.4 Impacts of Climate Change on Rainfall

A8.4.1 Validation

**Figure A8.16:** Empirical cumulative distribution functions of regional mean rainfall for summer, autumn, winter and spring in Bundaberg. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A8.4.2 Spatial variability - Regional plots

Figure A8.17: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Bundaberg. Projections have been made based on the lower (B1) emissions scenario.

Figure A8.18: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Bundaberg. Projections have been made based on the higher (A2) emissions scenario.
A8.4.3 Projected change

**Figure A8.19:** Regional projections for (downscaled) GCM paired relative differences in rainfall (%) for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A8.20:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in rainfall (%) for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A8.5 Impacts of Climate Change on Harvestability

A8.5.1 Validation

Figure A8.21: Empirical cumulative distribution functions of regional mean number of unharvestable days for summer, autumn, winter and spring in Bundaberg. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A8.5.2 Spatial variability - Regional plots

**Figure A8.22:** Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Bundaberg. Projections have been made based on the lower (B1) emissions scenario.

**Figure A8.23:** Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Bundaberg. Projections have been made based on the higher (A2) emissions scenario.
A8.5.3 Projected change

**Figure A8.24:** Regional projections for (downscaled) GCM paired differences in unharvestable days for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A8.25:** Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in unharvestable days for Bundaberg. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A9.1 Impacts of Climate Change on Maximum Temperature

A9.1.1 Validation

Figure A9.1: Empirical cumulative distribution functions of regional mean maximum temperature for summer, autumn, winter and spring in Rocky Point. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
Figure A9.2: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Rocky Point. Projections have been made based on the lower (B1) emissions scenario.

Figure A9.3: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for Rocky Point. Projections have been made based on the higher (A2) emissions scenario.
A5.1.3 Projected change

**Figure A9.4**: Regional projections for (downscaled) GCM paired differences in maximum temperature for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A9.5**: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in maximum temperature for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A9.2 Impacts of Climate Change on Minimum Temperature

A9.2.1 Validation

**Figure A9.6:** Empirical cumulative distribution functions of regional mean minimum temperature for summer, autumn, winter and spring in Rocky Point. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20\textsuperscript{th} century forcings (20C3M).
A9.2.2 Spatial variability - Regional plots

**Figure A9.7:** Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Rocky Point. Projections have been made based on the lower (B1) emissions scenario.

**Figure A9.8:** Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for Rocky Point. Projections have been made based on the higher (A2) emissions scenario.
A9.2.3 Projected change

Figure A9.9: Regional projections for (downscaled) GCM paired differences in minimum temperature for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A9.10: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in minimum temperature for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A9.3 Impacts of Climate Change on Radiation

A9.3.1 Validation

Figure A9.11: Empirical cumulative distribution functions of regional mean radiation for summer, autumn, winter and spring in Rocky Point. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A9.3.2 Spatial variability - Regional plots

Figure A9.12: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Rocky Point. Projections have been made based on the lower (B1) emissions scenario.

Figure A9.13: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for Rocky Point. Projections have been made based on the higher (A2) emissions scenario.
A9.3.3 Projected change

Figure A9.14: Regional projections for (downscaled) GCM paired differences in radiation for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A9.15: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in radiation for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A9.4 Impacts of Climate Change on Rainfall

A9.4.1 Validation

Figure A9.16: Empirical cumulative distribution functions of regional mean rainfall for summer, autumn, winter and spring in Rocky Point. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A9.4.2 Spatial variability - Regional plots

Figure A9.17: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Rocky Point. Projections have been made based on the lower (B1) emissions scenario.

Figure A9.18: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for Rocky Point. Projections have been made based on the higher (A2) emissions scenario.
A9.4.3 Projected change

Figure A9.19: Regional projections for (downscaled) GCM paired relative differences in rainfall (%) for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A9.20: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in rainfall (%) for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A9.5 Impacts of Climate Change on Harvestability

A9.5.1 Validation

Figure A9.21: Empirical cumulative distribution functions of regional mean number of unharvestable days for summer, autumn, winter and spring in Rocky Point. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A9.5.2 Spatial variability - Regional plots

Figure A9.22: Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Rocky Point. Projections have been made based on the lower (B1) emissions scenario.

Figure A9.23: Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for Rocky Point. Projections have been made based on the higher (A2) emissions scenario.
A9.5.3 Projected change

Figure A9.24: Regional projections for (downscaled) GCM paired differences in unharvestable days for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A9.25: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in unharvestable days for Rocky Point. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A10.1 Impacts of Climate Change on Maximum Temperature

A10.1.1 Validation

Figure A10.1: Empirical cumulative distribution functions of regional mean maximum temperature for summer, autumn, winter and spring in NSW. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
Figure A10.2: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for NSW. Projections have been made based on the lower (B1) emissions scenario.

Figure A10.3: Projected change in average maximum temperature by 2046-2065 compared to the base period of 1961-2000 for NSW. Projections have been made based on the higher (A2) emissions scenario.
A10.1.3 Projected change

**Figure A10.4**: Regional projections for (downscaled) GCM paired differences in maximum temperature for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

**Figure A10.5**: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in maximum temperature for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A10.2 Impacts of Climate Change on Minimum Temperature

A10.2.1 Validation

Figure A10.6: Empirical cumulative distribution functions of regional mean minimum temperature for summer, autumn, winter and spring in NSW. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A10.2.2 Spatial variability - Regional plots

Figure A10.7: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for NSW. Projections have been made based on the lower (B1) emissions scenario.

Figure A10.8: Projected change in average minimum temperature by 2046:2065 compared to the base period of 1961:2000 for NSW. Projections have been made based on the higher (A2) emissions scenario.
A10.2.3 Projected change

Figure A10.9: Regional projections for (downscaled) GCM paired differences in minimum temperature for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A10.10: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in minimum temperature for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A10.3 Impacts of Climate Change on Radiation

A10.3.1 Validation

Figure A10.11: Empirical cumulative distribution functions of regional mean radiation for summer, autumn, winter and spring in NSW. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A10.3.2 Spatial variability - Regional plots

Figure A10.12: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for NSW. Projections have been made based on the lower (B1) emissions scenario.

Figure A10.13: Projected change in average radiation by 2046-2065 compared to the base period of 1961-2000 for NSW. Projections have been made based on the higher (A2) emissions scenario.
A10.3.3 Projected change

Figure A10.14: Regional projections for (downscaled) GCM paired differences in radiation for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the "box" represent the 25\textsuperscript{th}, 50\textsuperscript{th} and 75\textsuperscript{th} percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A10.15: Regional projections for the change in the 25\textsuperscript{th}, 50\textsuperscript{th} and 75\textsuperscript{th} percentiles of the (downscaled) GCM paired differences in radiation for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A10.4 Impacts of Climate Change on Rainfall

A10.4.1 Validation

Figure A10.16: Empirical cumulative distribution functions of regional mean rainfall for summer, autumn, winter and spring in NSW. The black line represents the distribution function of AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A10.4.2 Spatial variability - Regional plots

Figure A10.17: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for NSW. Projections have been made based on the lower (B1) emissions scenario.

Figure A10.18: Projected relative change in rainfall (%) by 2046-2065 compared to the base period of 1961-2000 for NSW. Projections have been made based on the higher (A2) emissions scenario.
Figure A10.19: Regional projections for (downscaled) GCM paired relative differences in rainfall (%) for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A10.20: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in rainfall (%) for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A10.5 Impacts of Climate Change on Harvestability

A10.5.1 Validation

Figure A10.21: Empirical cumulative distribution functions of regional mean number of unharvestable days for summer, autumn, winter and spring in NSW. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20\textsuperscript{th} century forcings (20C3M).
A10.5.2 Spatial variability - Regional plots

Figure A10.22: Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for NSW. Projections have been made based on the lower (B1) emissions scenario.

Figure A10.23: Projected change in unharvestable days by 2046-2065 compared to the base period of 1961-2000 for NSW. Projections have been made based on the higher (A2) emissions scenario.
A10.5.3 Projected change

Figure A10.24: Regional projections for (downscaled) GCM paired differences in unharvestable days for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A10.25: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired differences in unharvestable days for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.
A10.6 Impacts of Climate Change on Yield

A10.6.1 Validation

**Figure A10.26:** Empirical cumulative distribution functions of regional mean yield (TCPH) in NSW. The black line represents the distribution function generated from AWAP data (1961:2000) and the red line represents CDF of recorded yield.

**Figure A10.27:** Empirical cumulative distribution functions of regional mean number of yield in NSW. The black line represents the distribution function generated from AWAP data (1961:2000) and coloured lines represent CDFs of individual downscaled GCMs under 20th century forcings (20C3M).
A7.6.2 Projected Change

Figure A10.28: Regional projections for (downscaled) GCM paired relative differences in yield (TCPH) for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the lower (B1) and higher (A2) emissions scenario. The lower, middle and upper bounds of the “box” represent the 25th, 50th and 75th percentiles respectively. Whiskers extend to the most extreme data point no more than 1.5 times the length of the box from the box.

Figure A10.29: Regional projections for the change in the 25th, 50th and 75th percentiles of the (downscaled) GCM paired relative differences in yield (TCPH) for NSW. Positive values mean that values are higher for the 2046-2065 period compared to the 1961-2000 period. Projections have been made based on the B1 (blue) and A2 (red) emissions scenario.