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Heat stress in dairy cattle in northern Victoria: responses to a changing climate

Climate Adaptation Flagship Working Paper #10

Helping Australia Adapt to a Changing Climate

Uday Nidumolu, Steven Crimp, David Gobbett, Alison Laing, Mark Howden and Stephen Little

Murray DAIRY
Making your dairy service levy work locally

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EXECUTIVE SUMMARY

As part of a broader body of work undertaken by Murray Dairy entitled "Accelerating uptake of strategies to manage heat stress in dairy cattle in Northern Victoria" research was undertaken to develop a better understanding of the changing nature of heat stress now and into the future, for the Murray Dairy region of Australia and the implications this will have on milk production.

Heat stress is a significant issue for the dairy industry. Increasing air temperature and humidity makes it more difficult for cows to cool themselves, increasing heat stress. Managing heat stress carries a high energy cost for affected dairy cows, and leads to altered metabolism, hormone and feed intake rates. This in turn can lead to reductions in milk production.

This report outlines changes in heat stress frequency and duration in the past that have been collected from interrogation of historical data, and projection of changes into the future using model estimates of global warming. It also contains an assessment of the impacts of changing heat stress on milk production, and an assessment of the benefits of two heat-stress reduction strategies (shading and water spraying) on milk production.

Assessing heat stress

The temperature-humidity index (THI) was used as a predictor of heat stress in dairy cattle. Three heat stress categories were used in the assessment: modest heat stress (THI 75–78), moderate heat stress (THI 78–82) and severe heat stress (THI >82).

During the period 1960–2008, the average occurrence of modest heat stress days exhibits a south-east (low) to north-west (high) gradient. During this period the south-east experienced on average 1 to 5 modest heat stress days per year, while the north-west experienced between 26 and 30 modest heat stress days per year. In the central area of the Murray Dairy region, the average number of modest heat stress days increased from around 28 to 32 days during the 1960-70 and 2000-08 period. Similar changes in the pattern of occurrence of moderate heat stress days occurred across five decadal periods.

The greatest change in consecutive heat stress days occurred where THI >75. The pattern of change showed a gradual increase in consecutive days encroaching from the north over successive decades. For the earliest decade the average number of consecutive days with THI > 75 was 3 to 4 across most of the northern part of the study area. By the latest decade (2000–2008) the mean consecutive number of days with THI >75 had almost doubled. Little change in the consecutive number of severe heat stress days was evident at the decadal timescale of this analysis.

Temperature and humidity data from five climate stations within the Murray Dairy region (Deniliquin, Echuca, Kyabram, Mangalore and Tatura) were analysed. These sites were selected based on length of record and homogeneity of the data. Across all sites the number of moderate heat stress days and severe heat stress days demonstrated an increasing linear trend with significant decadal variation. Across all sites the rate of increase in the number of moderate heat stress days has been most pronounced.

Projected future heat stress

By 2025 small changes in the number of days of heat stress are likely across the entire Murray Dairy region for low, mid and high emission futures. An additional 5 days of heat stress are simulated for both the modest heat stress range and the moderate heat stress range. An additional 5–15 days were simulated severe heat stress days.

By 2050 larger changes in the number of days of heat stress are likely across the entire Murray Dairy region for the low, mid and high emission futures. An additional 5–37 days of heat stress are simulated across each heat stress range. Largest increases are simulated for severe heat stress with up to 37 additional days of heat stress if the high greenhouse gas (GHG) emission scenario is realised. Modest and moderate heat stress was simulated to increase by 5–25 days, with greatest change occurring in the south-east of the Murray Dairy region under a high emission scenario.

Impact on milk production

The impact of increasing THI was translated into gross reductions in milk production using existing 'rules of thumb'. By 2025 milk production was simulated to decline by an additional 35 and 210 litres of milk per cow per year across the entire Murray Dairy region for the low, mid and high emission futures. By 2050 projected additional milk losses across the entire Murray Dairy region vary by 85 to 420 litres of milk per cow per year depending on both herd susceptibility and GHG emission scenario.

Shading and spraying to alleviate heat stress

To investigate the efficacy of shading and spraying to alleviate heat stress we installed weather stations on three treatment sites on a single farm in the vicinity of Kyabram: an 'open' paddock, with pasture but no shading, a 'shade' structure with concrete floor, and a 'spray' area with concrete floor. Maximum and minimum temperatures, wind speed and relative humidity were recorded and stored on data loggers. The temperature and relative humidity data from each treatment was then used to calculate heat stress.

The shade structure proved to be more successful at reducing moderate and severe heat stress occurrence than the spray treatment. There were 53% fewer moderate and 86% fewer severe heat stress events with the shade treatment. The spray treatment proved effective at reducing only the number of severe heat stress events. During the 182 day period 46% fewer severe heat stress events were measured for the spray treatment.

The shade structure proved to be successful at ameliorating calculated milk production loss across herds with different susceptibilities to heat stress. For low susceptibility herds simulated milk loss was 67% lower for the shade treatment and only 20% lower in the spray treatment.

Dairy farmer and Industry feedback on the project

A workshop was organised in Echuca (Victoria), April 21, 2010, with the dairy farmers and advisers to present the results of this project and gather farmer and industry feedback. This workshop was facilitated by Dairy Australia. Of the 15 people who attended the workshop 14 completed the pre-workshop questionnaire and 15 the post-workshop questionnaire. There was a high level of interest and engagement in the workshop from the attendees and much positive feedback received.

The majority of workshop attendees (57%) felt that understanding future regional climate projections and the implications of heat stress would have a substantial impact on the way they managed their farm businesses into the future. All participants planned to use the knowledge gained about climate change and variability to determine future farm business strategies: over 70% felt the knowledge gained would have a substantial or greater effect on their management strategies.

Overall, most participants found the workshop to be relevant, of a high quality, and well presented. Most attendees (77%) had a high understanding of the knowledge presented and felt they were able to address concerns and interact with the presenter and other participants positively. Informal comments after the workshop backed up this feedback and endorsed the positive views recorded in the questionnaire.

1. INTRODUCTION

Heat stress is a significant issue for many intensive-livestock enterprises, particularly for dairy. The impacts of heat stress on dairy cattle have been well documented (Chase 2006; Hansen and Arechiga 1999; Klinedist et al. 1993; Kadzere et al. 2002), and include:

- reduced feed intake but greater nutritional/energy requirements
- reduced fertility
- reduced milk production
- lower milk quality
- increased frequency of health-related issues e.g. mastitis, rumen acidosis and ketosis (Little and Campbell 2008).

These impacts can result in significant loss of income and increases in management costs. Recent estimates of average annual losses resulting from heat stress for the US dairy industry were conservatively estimated at about US$900 million per annum (St-Pierre et al. 2003). To reduce these costly impacts effective heat stress management programs are essential (Little and Campbell 2008; Miller et al. 2010). In order to identify when and where to modify current management practices it is important to understand the frequency and magnitude of heat stress.

1.1 Heat stress in dairy cattle

Increasing air temperature and humidity reduce the ability of cows to cool themselves. Increases in these climate variables lead to, or increase existing, heat stress in cattle (Klinedinst et al. 1993; Armstrong 1994; Rhoads et al. 2009; Silanikove et al. 2009; Verkerk 2009).

Managing heat stress carries a high energy cost for affected dairy cows, and leads to altered metabolism, hormone and feed intake rates. This in turn can lead to reductions in milk production and fertility (Chase 2006; Dikmen and Hansen 2008; Hansen and Arechiga 1999; Klinedist et al. 1993). Concurrently, cattle body temperatures rise and rates of respiration and sweating increase as cows attempt to thermo-regulate.

Cool night time temperatures which allow cows to dissipate heat gained during the day moderate heat stress in dairy cattle and can have a significant positive effect on the reduction in milk production losses (Correa-Calderon et al. 2004; Silanikove et al. 2009). Similarly, feeding cows in feedlots at night time rather than in the heat of the day can moderate heat stress and its effects on productivity (Holt et al. 2004).

Dairy cows which are less sensitive to heat stress are associated with lower mean milk yields and fertility rates (King et al. 2006) and for this reason they are not the first choice of dairy farmers in more heat stress prone regions. Temperate dairy cow breeds are generally less well adapted to cope with heat stress than breeds native to warmer and more humid climates (such as Sahiwal – origins in India/Pakistan, Milking Zebu – a cross between a Sahiwal and Sindihi, and Jersey Girolando – origins in Brazil), and those dairy breeds that are more heat tolerant (e.g. Jerseys) are likely to sweat and drink more in hot weather than other breeds (Espinoza et al. 2009; Verkerk 2009) and thus have high water demands. Smaller and younger cows are more easily able to lose heat and are likely to experience heat stress less rapidly than older or larger cows (Verkerk 2009).

Preventing and reducing the severity and duration of heat stress events before they occur is more effective, in terms of herd milk production, than managing the consequences once cows are heat stressed (Hansen and Arechiga 1999; Sanchez et al. 2009; Verkerk 2009); thus mapping environments in which heat stress is a key risk, and working to ameliorate the stress factors for cows, can reduce or even eliminate milk production losses (Armstrong 1994).

1.2 The temperature-humidity index – a predictor of heat stress

Heat stress is driven by four climate variables: air temperature, relative humidity, wind and solar radiation (Armstrong 1994). Of these, temperature and humidity are more readily measured and thus more easily accessible than the others. For this reason a common method of measuring heat stress has involved the development of a temperature-humidity index (THI) (Bohmanova et al. 2007).

The THI (Johnson et al. 1963; McDowell et al. 1976) has been shown to be a robust predictor of heat stress in cattle. It has been related to reduced liveweight gain in beef cattle (e.g. Petty et al 1998; Verwoerd et al. 2006), milk production in dairy cattle (Armstrong 1994; Hahn and Oosburn 1969; Tucker et al. 2008; Espinoza et al. 2009; Verkerk 2009), conception and mortality rates (Dikmen and Hansen 2008; Hahn 1981; Hahn and Mader 1997) and has been used for operationally for heat stress assessment and management in dairy cattle in South Africa and feedlot cattle in the US (e.g. Hahn and Mader 1997). In Australia, Mayer et al. (1999) used THI data to investigate the extent of heat load problems, caused by the combination of excessive temperature and humidity, in Holstein-Friesian cows. Turner et al. (2005) provide an overview of the impact of THI on dairy cattle in Queensland.

There is general agreement that, given generally available climate data, the THI is the optimum predictor of heat stress in dairy cattle. In semi-arid and Mediterranean climates weighting the THI towards temperature variables produces a more accurate indicator of heat stress, while in humid environments a THI weighted towards humidity variables is more appropriate (Bohmanova et al. 2007).

The THI has minimal input requirements and has been used in a variety of environments making it a suitable for broad scale risk assessment tool for both current and future climate conditions.

THI uses inputs of temperature and dewpoint. These variables are anticipated to change substantially over the next few decades in response to global warming. Furthermore, it is known that these variables have changed over the past several decades, resulting in increased frequency of days when heat stress (as measured by THI) is likely to occur (Howden and Turnpenny 1997; Klinedinst 1993). Over the period 1957 to 1996 heat stress in northern Australia had already increased by 60% (Howden and Turnpenny 1997).

Indices that combine environmental factors other than temperature and humidity (such as wind speed, rainfall, solar radiation) have been proposed as alternatives to the THI, however the large scale implementation (or even verification) of these indices is restricted by a paucity of data. As yet, no data demonstrate the general superiority of any other index above temperature and humidity based indices (Dikmen and Hansen 2008).

The critical THI threshold above which dairy cattle are heat stressed is 72 (Armstrong 1994; Bohmanova et al. 2007; Espinoza et al. 2009), although mild heat stress has been noted for THI as low as 68 (Howden and Turnpenny 1997; Silanikove 2000; Verkerk 2009). THI values greater than 80 indicate moderate to severe heat stress for cattle (Armstrong 1994; Howden and Turnpenny 1997; Silanikove 2000; Bohmanova et al. 2007; Verkerk 2009). Above a THI threshold of 72 there is evidence of a causal relationship between THI and body temperature, which leads to increased cattle mortality with increasing THI: most cattle deaths in summer are heat stress related (Verwoerd et al. 2006). When THI values are above 70 the number of heat-related deaths on dairy farms begins to increase, and risk of death is greatest above a THI of 77 (Vitali et al. 2009).

1.3 Alleviating heat stress

Verkek (2009) identified several processes used by dairy cattle to thermo-regulate. They are:

- seeking areas of pasture exposed to greatest air movement
- standing to increase body surface area exposed to air, and/or orientation with respect to the sun
- panting and/or sweating to transfer heat away
- stopping or reducing feed intake to reduce heat-generating metabolic processes
- seeking water
- seeking shade.

If no other source of shade is available cows will seek (minimal) shade from the herd itself.

To assist cattle, farmers may modify the dairy herd’s physical environment to manage or alleviate heat stress. The retention of trees in paddocks and the planting of shelter belts are strategies to provide shelter and minimise heat stress. These may also have other production, biodiversity, or environmental benefits. Other alleviation and management tactics can include breeding for heat-tolerant dairy cattle, and nutrition management (Armstrong 1994; Silanikove 2000). One simple and effective change is the introduction of shaded areas under which cows can graze. In more intensively managed environments cattle can be housed in pens in which they are exposed to evaporative cooling and spray and/or fan cooling.

Scientific literature provides a number of clear examples where the availability of shade for cattle can significantly reduce their heat load largely by reducing the solar radiation they receive (Armstrong 1994; Kendall et al. 2006; Fisher et al. 2008). The scientific literature that monitors animal behaviour also reports that cows with access to shade begin to preferentially use it when air temperatures rise above 25°C or when THI is above 73, and that uptake increases exponentially as air temperature increases (Kendall et al. 2006). Additional information about shading impacts on dairy health and productivity is included in Appendix 1.

Whilst shade has been shown to be an effective heat stress reduction strategy for the whole herd, few studies have examined the benefits of introducing shade structure with respect to milk production.

1.4 About this project

In this study we have assessed the changing nature of heat stress in the Murray Dairy region using THI to assess heat stress frequency and occurrence in the past as well as scenarios into the future.

We also placed climate recording equipment on three different paddocks of a farm located in the vicinity of Kyabram, north-eastern Victoria. This monitoring activity was to determine the impact of shading and spraying in ameliorating heat stress.

The research activities identified in this report form part of a broader body of work undertaken by Murray Dairy entitled “Accelerating uptake of strategies to manage heat stress in dairy cattle in Northern Victoria”.

2. STUDY AREA

This study was undertaken in the Murray Dairy region, one of the largest dairying regions in Australia. The region covers the Northern Irrigation and North-East regions of Victoria and the Riverina and Upper Murray regions of New South Wales.

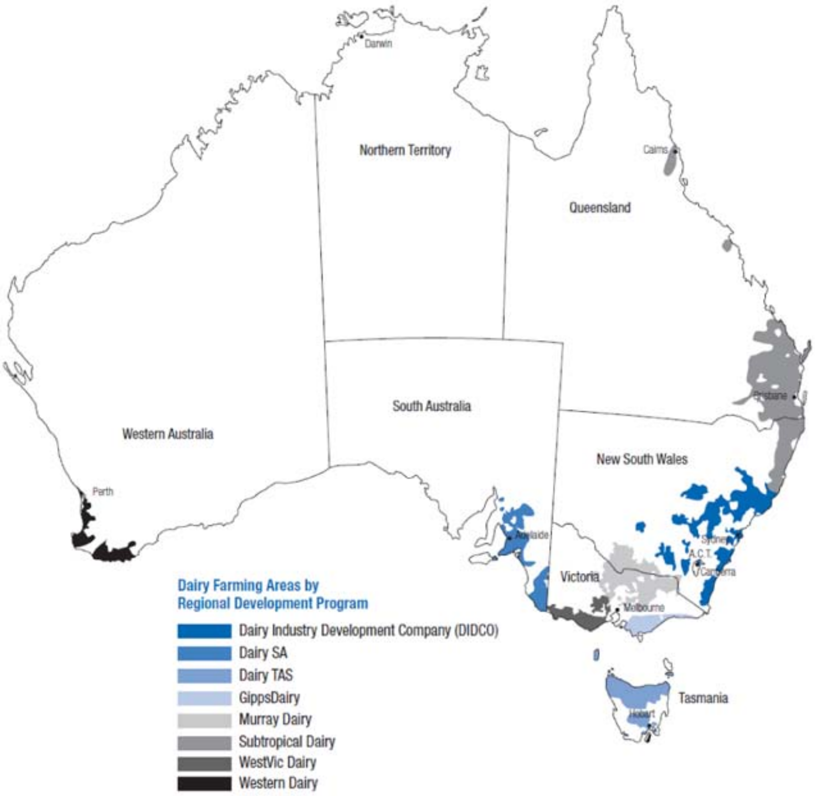

Figure 2.1 Map of Australian dairy regions (Source: Australian Dairy Industry in Focus 2008)

Temperature and rainfall vary across this region in a south-east to north-west gradient. In the relatively flat north-west (e.g. Deniliquin) annual rainfall is approximately 346 mm with 51 rain days per year, annual average maximum temperature is 23.6°C whilst minimum temperature is 9.5°C. In the south-east (e.g. Myrtleford) elevation is higher and annual rainfall is approximately 905 mm with 86 rain days per year, annual average maximum temperature is 21°C whilst minimum temperature is 6.5°C.

In 2006-07, 2300 dairy farms in this region produced 2.2 billion litres of milk, or 22.5% of national production. The estimated value of production at the farm gate was A$714 million. The region has 18 dairy factories, employing 7345 people (or about 10% of the total jobs market) directly and another 12,000 (a further 15%) indirectly in service industries (Murray Dairy 2010).

For the purposes of this project we have examined the impacts of heat stress at sub-regional scale viz.,West network, Central network, East network, Riverina network and North East network (Figure 2.2).

Figure 2.2 Sub-regions of the Murray Dairy area region (Source: Dairy Australia)

Individual station analyses were also undertaken to assess trends in heat stress (Figure 2.3). Five climate stations with climate records of sufficient quality and length to allow this analysis to be undertaken were chosen. Although one of the stations (Mangalore - south of Shepparton) fell outside of the Murray Dairy region, it was close enough to provide some useful insights into local trends in heat stress.

Figure 2.3: Murray Dairy region (Source: Dairy Australia & Google Earth). Areas circled in red represent locations where long-term trends in heat stress were examined.

3. METHODOLOGY

3.1 Historical heat stress duration and frequency changes

The Temperature Humidity Index (THI) was calculated for the Murray Dairy region for the period 1960-2008. The calculations used to derive the THI are provided in detail in Appendix 2.

Three THI ranges were defined, from literature and expert opinion, to capture varying physiological impacts on dairy cows in terms of milk production. These daily THI ranges are:

- 75 to 78 (low heat stress)
- 78 to 82 (moderate heat stress)
- greater than 82 (high heat stress).

The frequency of days within each of these ranges was calculated for the period September to March from the historical climate record.

Maps were generated depicting the (i) decadal mean number of days with THI and (ii) decadal mean consecutive days of THI in each of the three ranges.

To determine the pattern of consecutive days for each THI range we processed the THI dataset using a script written in R (R Development Core Team 2008). This script generated an output dataset in which the daily value of each cell indicated the number of consecutive days in which THI had exceeded a value of 75, 78 and 82. The output of this process was summarised using Climate Data Operators (CDO; Schulzweida 2009) by selecting the months September to March (inclusive) by decade (1960 to 1969, 1970 to 1979 etc.). Then, mean and standard deviations of only the days where the consecutive days count has a value greater than zero was calculated. The output summary files produced in this way were loaded into ArcGIS (ESRI 2008) and the Spatial Analyst, Zonal Statistics function was used to derive mean values for each subregion.

3.2 Future climate in the Murray Dairy region

Using climate change scenarios to examine potential changes in THI required post-processing of the historical climate data. The THI calculation requires daily time step information for both temperature and relative humidity. In many cases global climate model (GCM) based scenarios are expressed as annual or monthly changes relative to a baseline period. Daily climate change projection data can be derived in many different ways including modification of historical climate records, using historical records to ‘seed’ a weather generator that then includes climate changes in the output weather files, downscaling of GCM results, and direct use of GCM outputs or broad scenarios of change.

In this study, we have employed an approach that modifies historical daily climate files based on a simple scaling of daily temperature and relative humidity based on mean monthly change factors from GCMs.

The OzClim scenario generator developed by CSIRO Marine and Atmospheric Research (http://www.csiro.au/ozclim) was used to generate scenarios of future temperature and relative humidity change. OzClim generates future climate change scenarios based on 12 different GCMs and 18 different greenhouse gas emission projections (IPCC 2007). In this way it represents a comprehensive range of future climate uncertainties for use in climate change impact and adaptation research.

In OzClim, regional scenarios are generated by linearly regressing the local seasonal mean temperature (or rainfall) against global average temperature, to generate a change (e.g. regional temperature or rainfall) per degree of global warming at each grid point. The grid point values can then be mapped to obtain a pattern of response that can be scaled according to an estimate of total global warming (Figure 3.1).

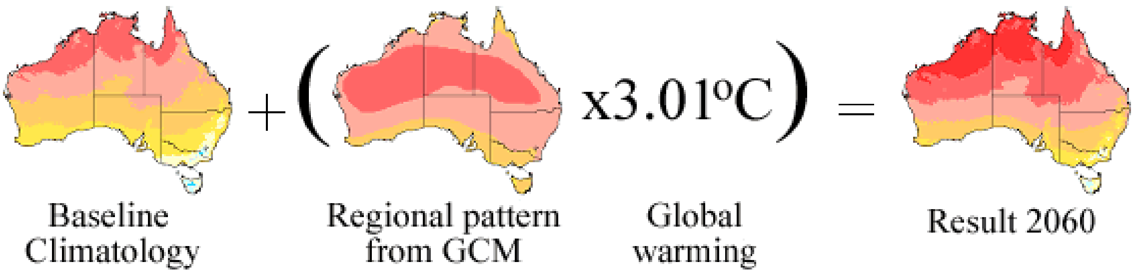

Figure 3.1 Schematic representation of the method employed to generate regional climate change projections (maps are indicative only). The global warming value of 3.01 is derived from the emission scenario SRES A1FI, and high global warming (source: www.csiro.au/ozclim).

The future climate change scenarios are thus very strongly related to the pattern of change determined by the climate model used as well as the extent of future global warming. For the purposes of this project we sampled across both of those elements of uncertainty.

Climate models

We examined the different patterns of change from two climate models: CCR:MIROC–H and the CSIRO Mk 3.5. These models were chosen based on the availability of projection information, model performance in Australia and patterns of future rainfall change.

The CSIRO Mk 3.5 model simulates a reduction in future rainfall over Australia (Figure 3.2). This model is highly sensitive to changes in greenhouse gas (GHG) concentrations, producing 3.17°C of warming for a doubling of GHG concentrations (i.e. from 260 to 520 ppm).

The CCR:MIROC–H climate model produces a relatively a 'wetter' future, simulating increased rainfall in eastern and mid-western Australia with decreases in rainfall in southern and northern Australia. This model is also highly sensitive to changes in GHGs, producing 4.31°C of warming for a doubling of GHG concentrations (Figure 3.3).

Although one model simulates a relatively wetter future across Australia and the other a relatively drier future, both models simulate drier conditions in the Murray Dairy region in the future (Figures 3.2 and 3.3).

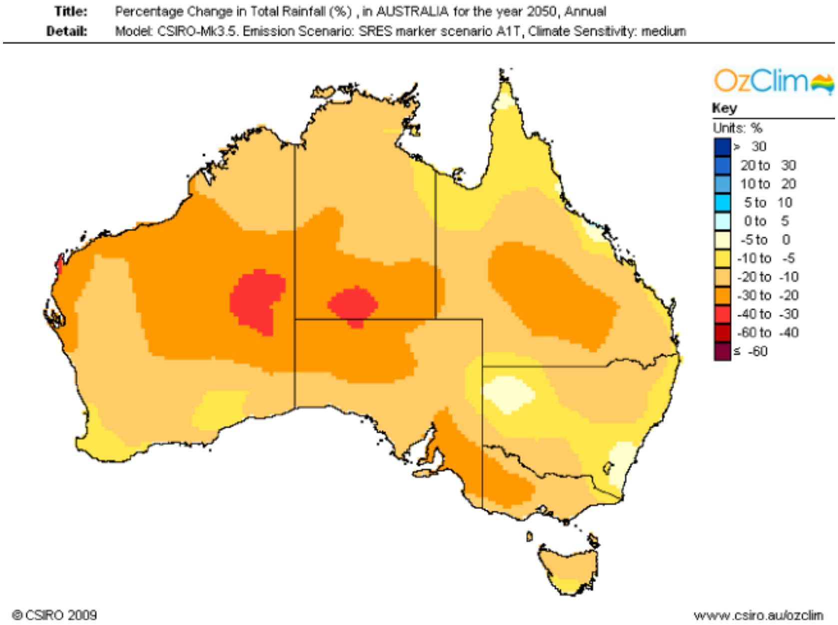

Figure 3.2 Percentage change in rainfall for 2050 (relative to 1990) generated by the CSIRO MK3.5 model in response to a moderate emission scenario (A1T).

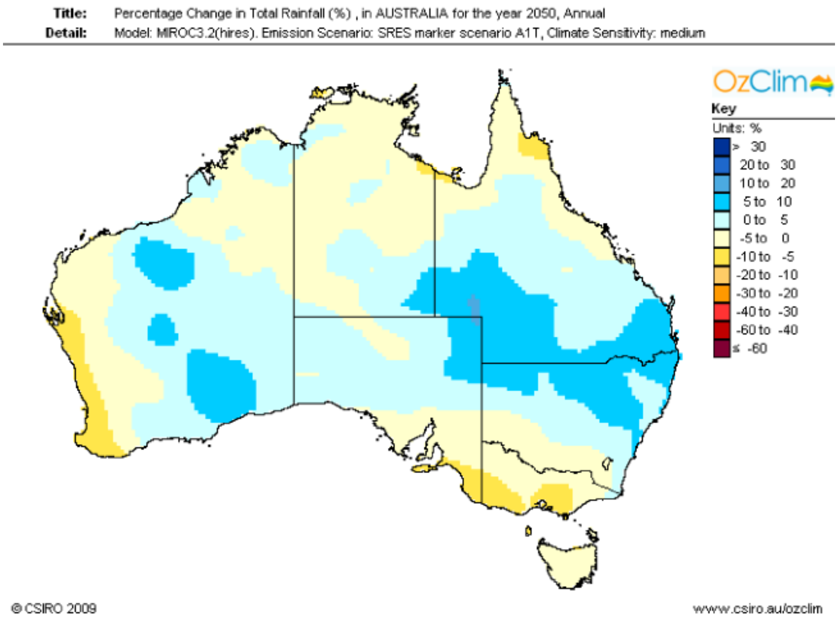

Figure 3.3 Percentage change in annual rainfall for 2050 (relative to 1990) generated by the CCR:MIROC–H model in response to a moderate emission scenario (A1T).

Extent of future warming

The second source of uncertainty, the extent of future global warming, is driven explicitly by the rate at which GHGs accumulate in the atmosphere over time. The future accumulation of GHGs will be driven by global population growth, economic development and technological advances. For this reason, when developing projections of future climate change, models are driven by the full range of emission scenarios to ensure both modest and extreme potential changes in GHG concentrations are captured.

For the purposes of this research we have examined three global warming trajectories aligned with low (A2), moderate (A1T) and high (A1FI) GHG concentrations in the future (Figure 3.4). The low emission scenario is associated with approximately 0.54°C of warming by 2030 and 1.2°C of warming by 2055. The moderate and high emission scenarios are associated with approximately with 0.7°C and 1°C of global warming by 2030 with 1.4°C and 2.7°C for 2055.

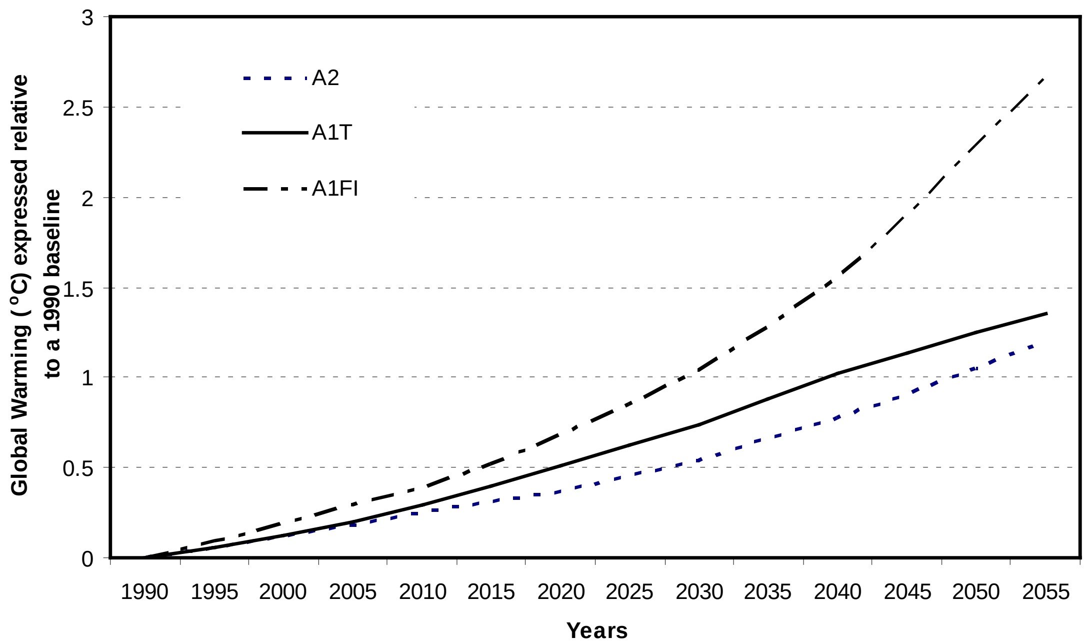

Figure 3.4 Annual global warming values (°C) (relative to 1990) for high (A1FI), moderate (A1T) and low (A2) emissions scenarios (after IPCC 2001).

The pattern of change in relative humidity and maximum temperature (the variables required to generate the THI) generated by the two different climate models and three different emission scenarios is presented in Figures 3.5 and 3.6.

There is little difference in the patterns of change in relative humidity between the two climate models (Figure 3.5). The extent of change varies between less than 1%, to 3% decline by 2025 and up to 6% decline by 2050.

Very broad patterns of change in maximum temperature are projected for both 2025 and 2050 with little spatial variation across the entire Murray Dairy region (Figure 3.6). By 2025 changes in maximum temperature range from 0.5°C to 1.5°C (relative to the 1980 to 1999 base period). By 2050, maximum temperatures are projected to increase by 1°C to 4°C (relative to the 1980 to 1999 base period) with greatest warming projected by the CSIRO Mk 3.5 model.

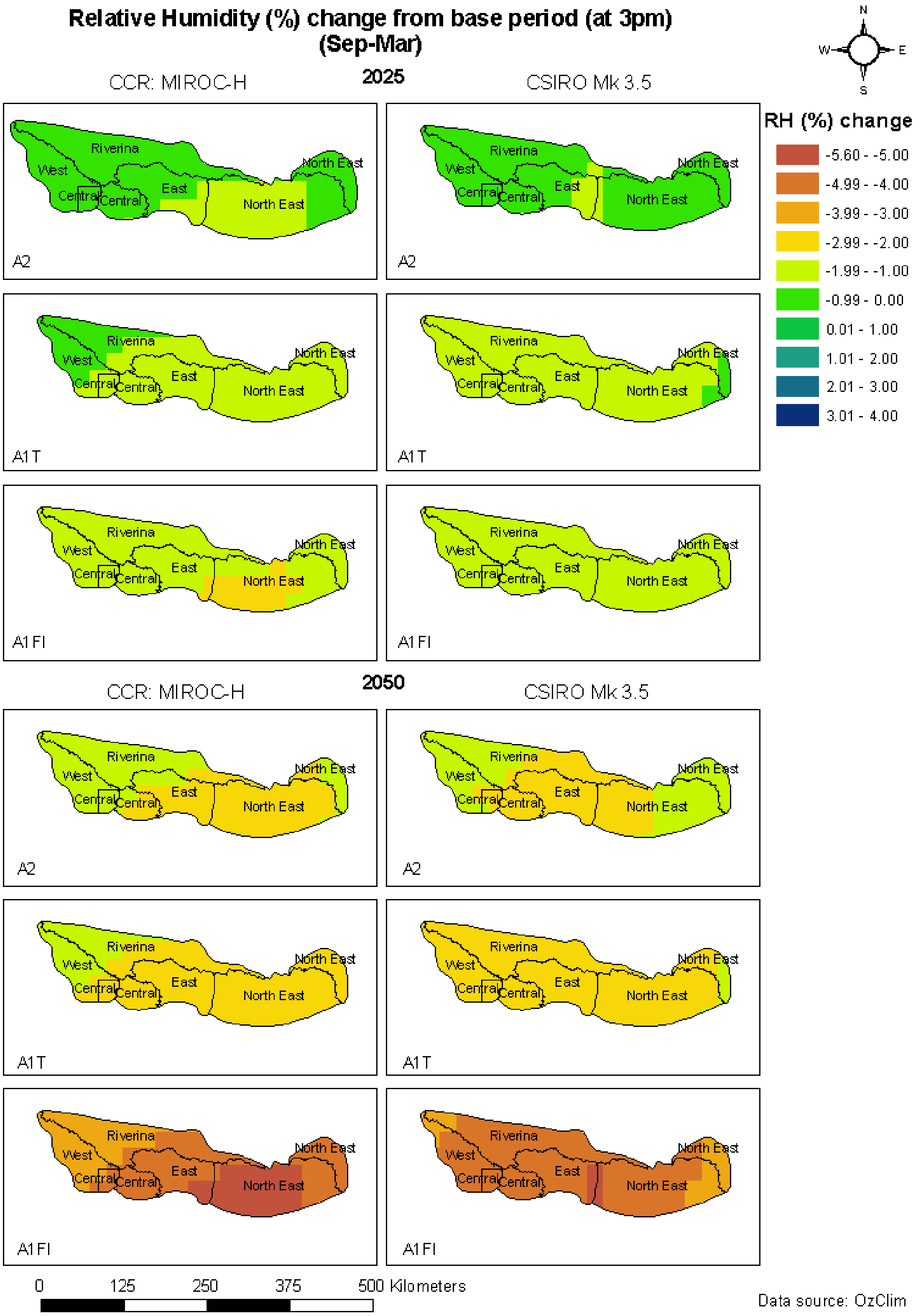

Figure 3.5 Percentage change (from 1980-1999 base period) in relative humidity for two time periods (2025 and 2050), two models (CCR:MIROC-H and CSIRO Mk 3.5) and three emissions scenarios (low–A2, moderate–A1T and high–A1FI)

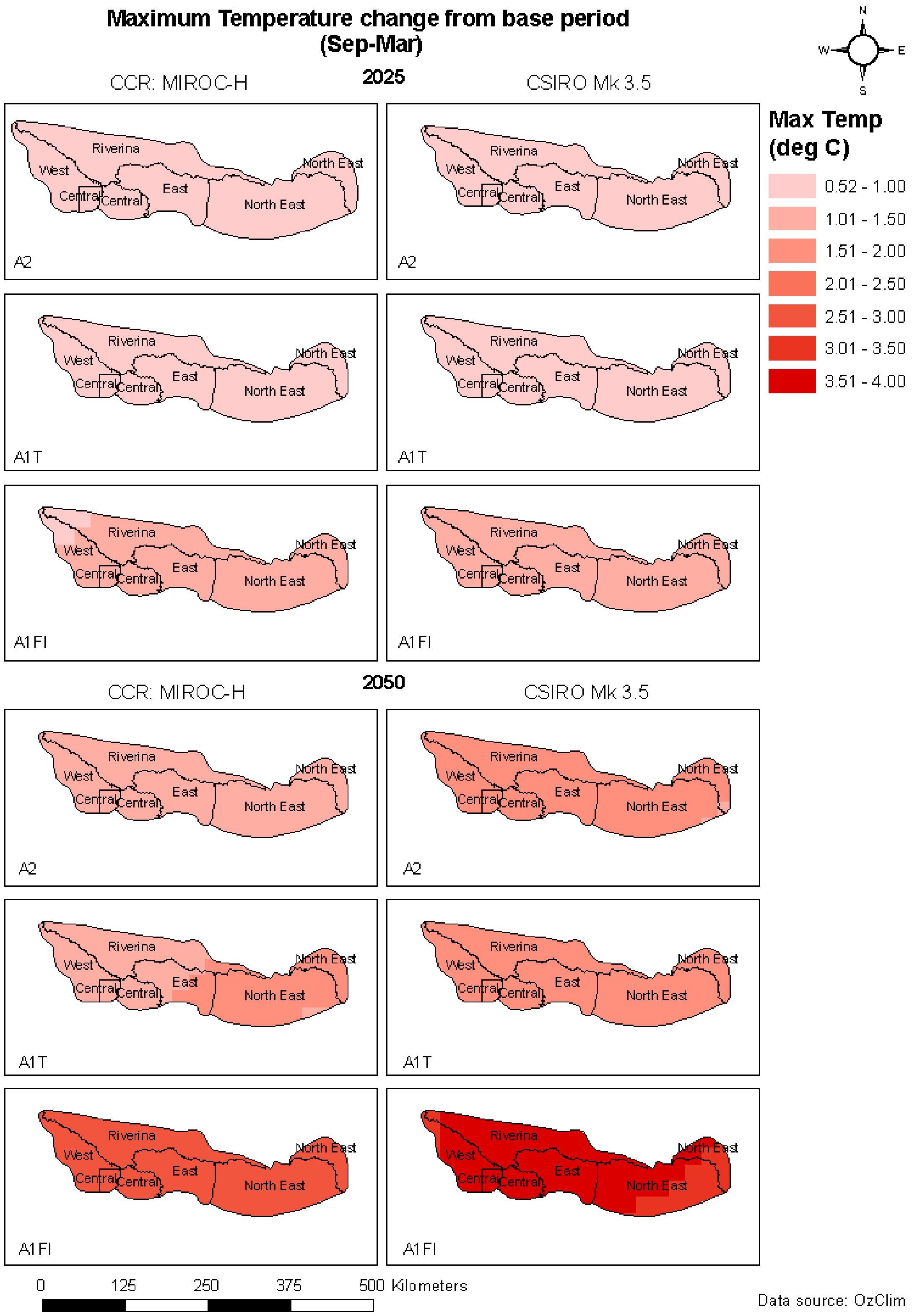

Figure 3.6 Percentage change (from 1980-1999 base period) in maximum temperature for two time periods (2025 and 2050), two models (CCR:MIROC-H and CSIRO Mk 3.5) and three emissions scenarios (low–A2; moderate–A1T and high–A1FI).

3.3 Impacts on milk production

In collaboration with Dr Steve Little (Dairy Australia) and Prof. Frank Dunshea (Melbourne University) we have linked the frequency, intensity and duration of heat stress days with estimates of milk production loss for the historical record (i.e. 1960–2008) and for the future (i.e. 2025 and 2050).

The impact of THI on dairy herd milk production was calculated using simple conversion factors for cows with different susceptibility to heat stress. Based on existing research we examined low susceptibility cows (i.e. a Brown Swiss Jersey producing less than 5500 L of milk per year), moderately susceptible cows (i.e. other European breeds or cross breeds producing 5500 L to 8000 L of milk per year) and highly susceptible cows (i.e. Large Holstein-Friesian producing more than 8000 L of milk per year) (Little and Campbell 2008). In all three cases, milk production losses were assumed to occur when daily THI values exceeded 75.

When THI exceeded this threshold the amount of milk lost in litres per cow per day was calculated by subtracting 75 from the daily THI value and multiplying this difference by a scaling factor – 0.6 for low susceptibility cows, 0.8 for moderately susceptible cows and 1 for highly susceptible cows. These factors were based on consultation with leaders of previous dairy heat stress research funded by Dairy Australia (S. Little 2010, pers. comm.). For example, on a day where the THI reaches 78, milk production losses would be 1.8 litres for a cow with low heat stress susceptibility, 2.4 litres for a moderately susceptible cow and 3 litres for a highly susceptible cow (Figure 3.7).

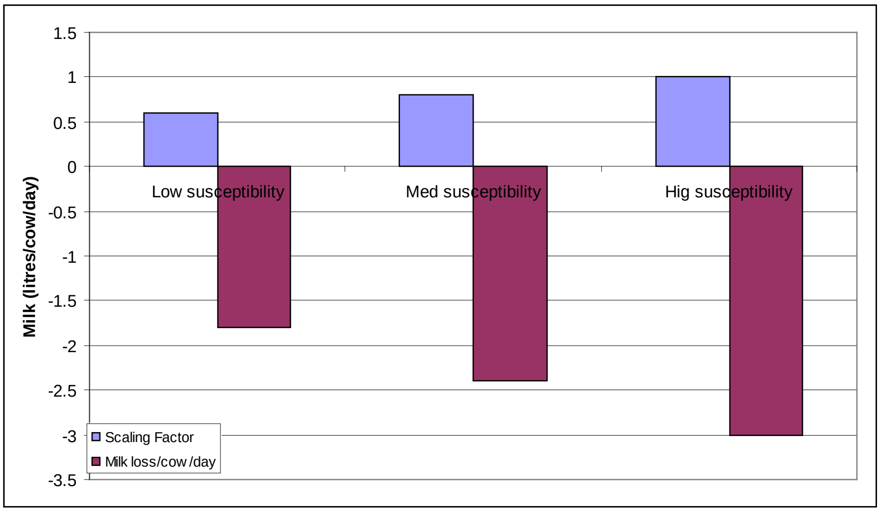

Figure 3.7 Translating THI changes into impacts on milk production

3.4 Shading and spraying to combat heat stress

In this project we monitored heat stress on a single case study farm in the vicinity of Kyabram, north-eastern Victoria. We installed weather-monitoring equipment that measured maximum and minimum temperatures, wind speed and relative humidity at three-hourly intervals. The data were stored on data loggers and downloaded periodically during the six months of monitoring.

Weather monitors were established on three treatment sites: an ‘open’ paddock, with pasture but no shading; an open ‘shade’ structure with concrete floor and high, well ventilated roof; and an unshaded ‘spray’ area with concrete floor (Figure 3.8).

Figure 3.8 Images of the weather stations in each of the three treatments

Two weather monitors were set up in the shade and open treatments, and one in the spray treatment area. Variations in temperature, relative humidity and wind were monitored and recorded for a 182 day period from 22 October 2009 to 22 April 2010. Where possible, data from the two loggers in each treatment were aggregated to derive a single set of mean values for each treatment.

The temperature and relative humidity data from each treatment were used to calculate heat stress using the THI formulation described previously.

4. RESULTS

4.1 Trends in historical heat stress occurrence

Historical trends in heat stress were analysed at five individual climate station locations within the Murray Dairy region: Deniliquin, Echuca, Kyabram, Mangalore and Tatura. The stations were selected based on the length of the available record and homogeneity of the data. The Deniliquin site forms part of the Australian Bureau of Meteorology's high quality climate station network (CLIMARC), with temperature records back to 1910. The other stations recorded temperature data from 1960 onwards.

The trends in THI for these stations over the period of available data are presented in Figures 4.1 to 4.5. Each time series has been smoothed, using a five year running mean. This allows each of the three THI time series, for each location, to be placed on the same graph.

Across all the sites analysed, the number of days between THI 78–82 and THI >82 demonstrated an increasing linear trend. These trends were statistically significant at the 0.02 to 0.15 level for Deniliquin, Echuca, Tatura and Mangalore (Figures 4.1 to 4.5).

For the Kyabram, Tatura and Mangalore sites, the trend in the number of days between THI 75 to 78 has remained unchanged or declined (Tatura). Across all sites the smoothed THI data (five year running mean) shows a peak in the number of days above THI 82 across the period 1980–1986. This is driven largely by extensive drought conditions in the 1982–1983 period (i.e. on average all sites experienced in excess of 27 days at or above THI 82).

The longer term climate record from Deniliquin shows some periods of similar THI 82 frequency in the earlier part of the record, i.e. 1922 and 1940. In the later part of the record 1981 and 2000 demonstrate comparable frequencies (Figure 4.1).

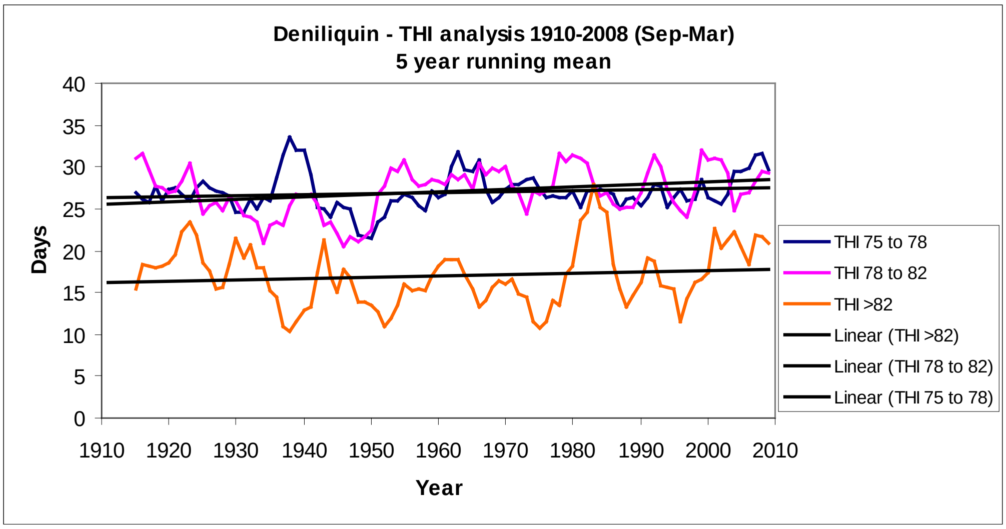

Figure 4.1 Deniliquin – 5 year running mean of THI (Sep-Mar)

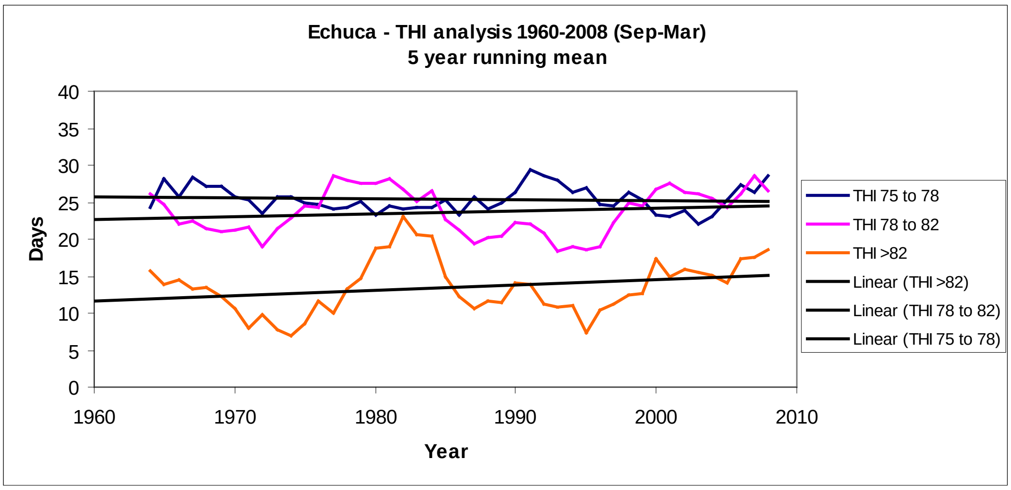

Figure 4.2 Echuca – 5 year running mean of THI (Sep-Mar)

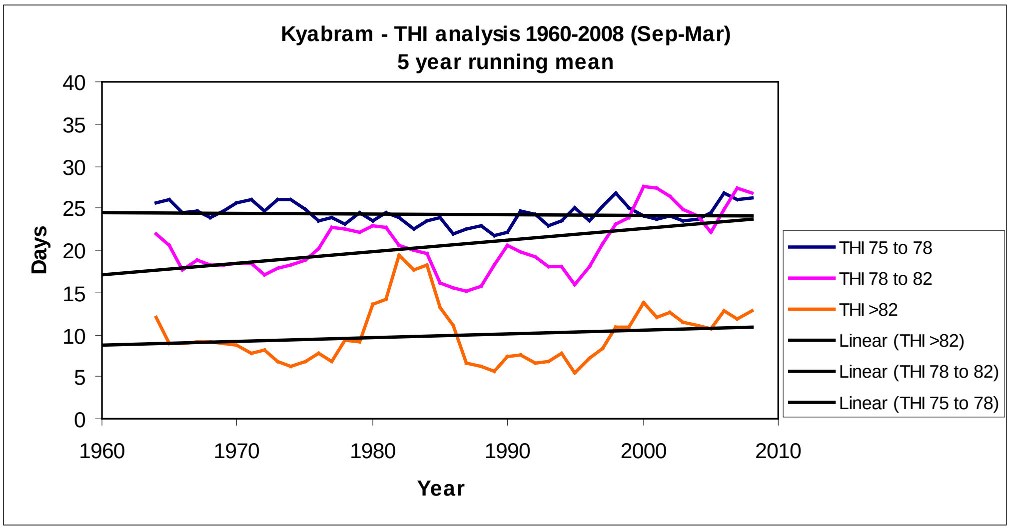

Figure 4.3 Kyabram – 5 year running mean of THI (Sep-Mar)

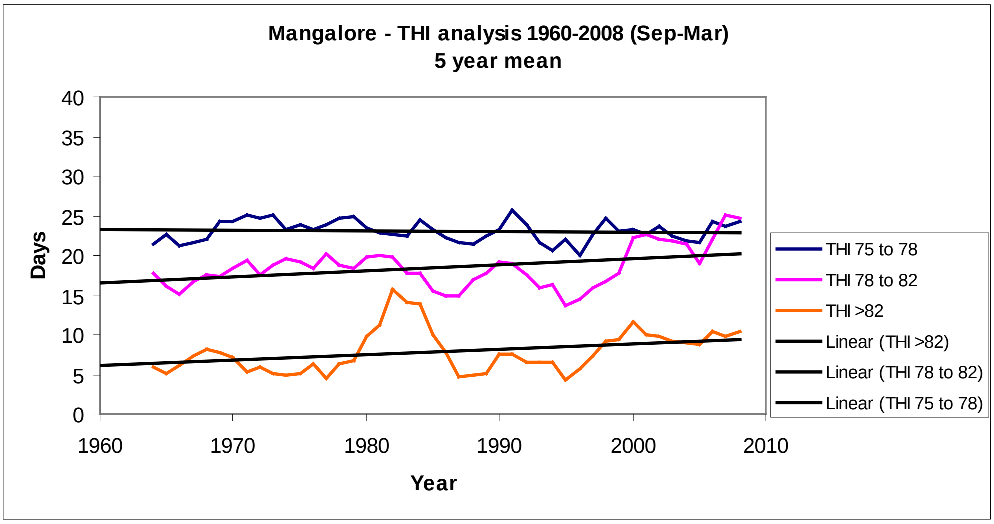

Figure 4.4 Mangalore – 5 year running mean of THI (Sep-Mar)

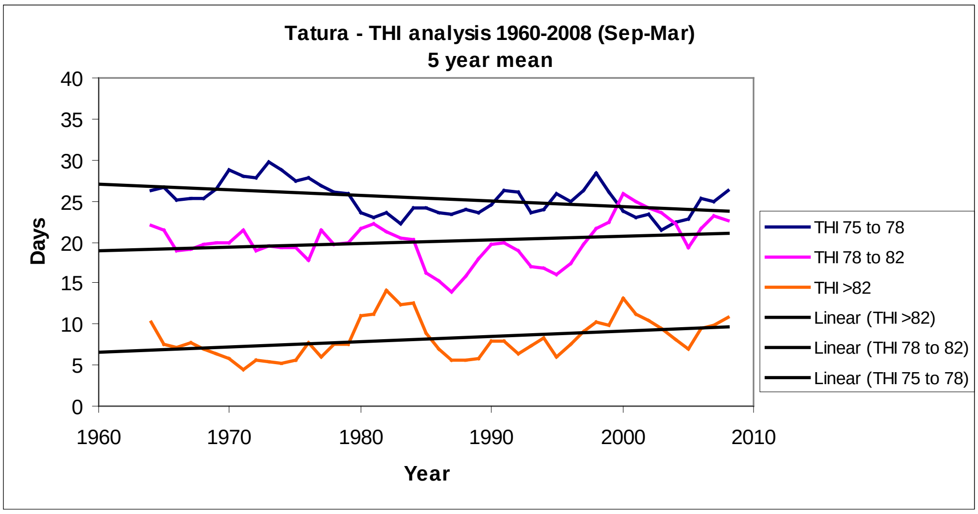

Figure 4.5 Tatura – 5 year running mean of THI (Sep-Mar)

4.2 Spatial trends in heat stress occurrence

Historical trends were analysed across a continuous gridded climate surface (5 km^2 spatial resolution) for the entire Murray Dairy region. The continuous climate surfaces were sourced from the Queensland Climate Change Centre of Excellence (QCCCE) and are referred to elsewhere in this document as SILO datasets. The surfaces are derived by interpolating the Bureau of Meteorology's station records using splining and kriging techniques (Jeffery et al. 2001).

Number of days with high THI

Figure 4.6 shows a southerly shift in the incidence of THI range 75–78. Over the period 2000–2008 the 26–30 day average frequency has moved well south of the Murray Dairy region compared with the earlier decades. Similarly the 31–35 day frequency of this THI range is also further south than in previous decades, although similar in extent to the 1960–1969 and 1970–1979 periods.

In the THI ranges of 78–82 and >82 a similar increase in frequency can be seen in the south. For example, the Shepparton region recorded between 21 and 24 days (between September and March) in the THI range 78–82 over the 40 years prior to 2000. In the period 2000–2008 the frequency increased to 28 days per year.

In the THI range >82, locations such as Barooga, Cobram, Yarrawonga and Finley have also experienced increases in the frequency of days above THI 82. Over the past 40 years the average frequency of days above 82 has been 12 days (between September and March) whereas in the 2000–2008 period this had increased on average to 18 days (Figure 4.6).

Consecutive days with high THI

Changes in the number of consecutive days of heat stress days have also occurred across the Murray Dairy region over the past 50 years. The changes are particularly evident in the THI range 75–78 (Figure 4.7). The number of consecutive days in this THI range has progressively increased over the last 50 years demonstrating a southward progression over time.

Locations such as Corowa, Rutherglen and Yarrawonga experienced on average 3–4 consecutive days in the THI range 75–78 during the 1960–1969 period. By the last period of analysis (2000–2008) the number of consecutive days in the THI range 75–78 had increased by 2 days for all these locations.

A similar southward increase in the length of consecutive heat stress was found for the THI range 78–82 (Figure 4.7). By the 2000–2008 period the consecutive number of days in the THI range 75–78 has increased from 2 days in the previous 40 years to 4 days in the last 8 years.

No explicit change in the spatial pattern of consecutive days above 82 was identified except in the far south-eastern extent of the Murray Dairy region. In this area the number of consecutive days above 82 had increased by 1 day (Figure 4.7).

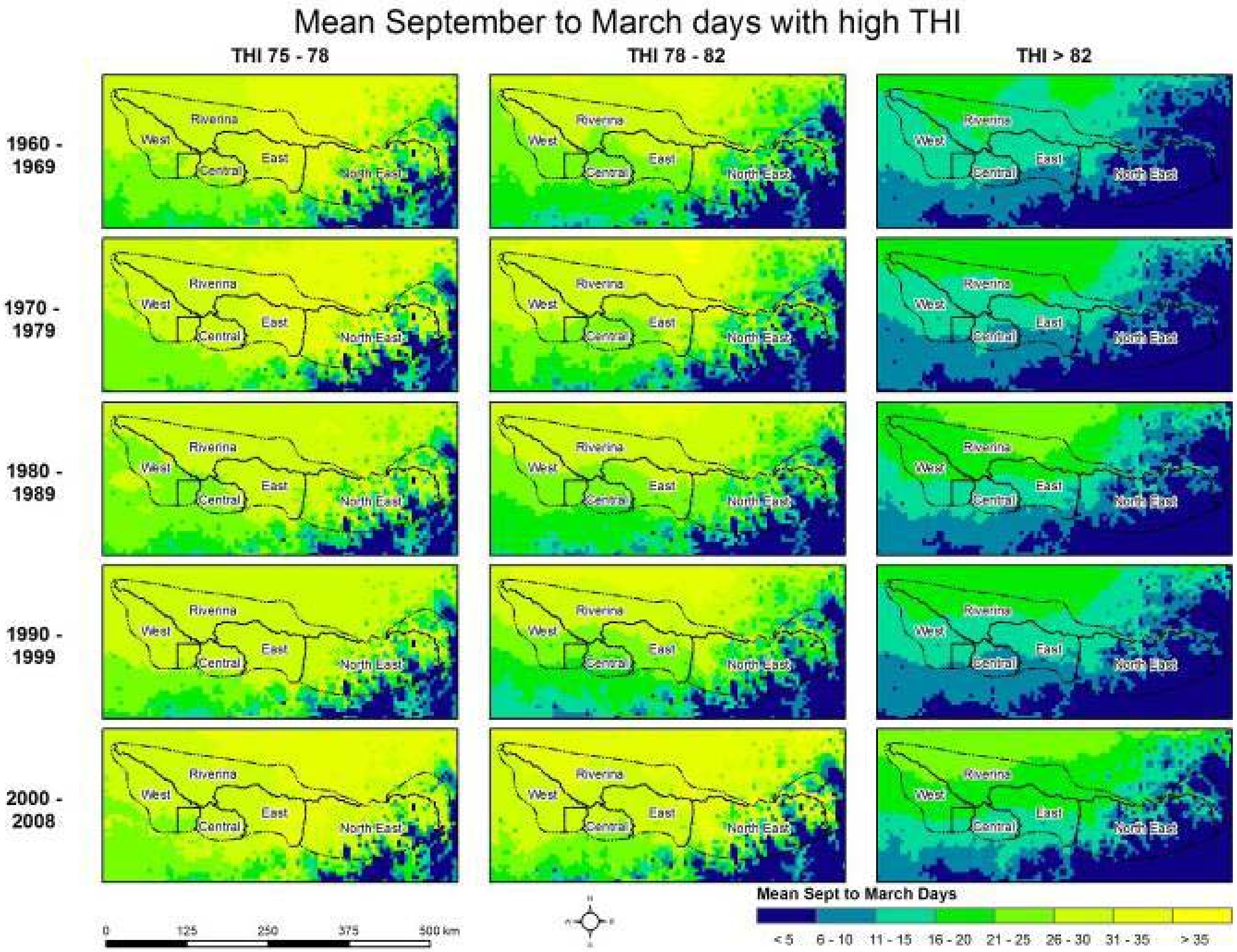

Figure 4.6 Decadal mean number of days of heat stress with THI in the range 75–78, 78–82 and >82.

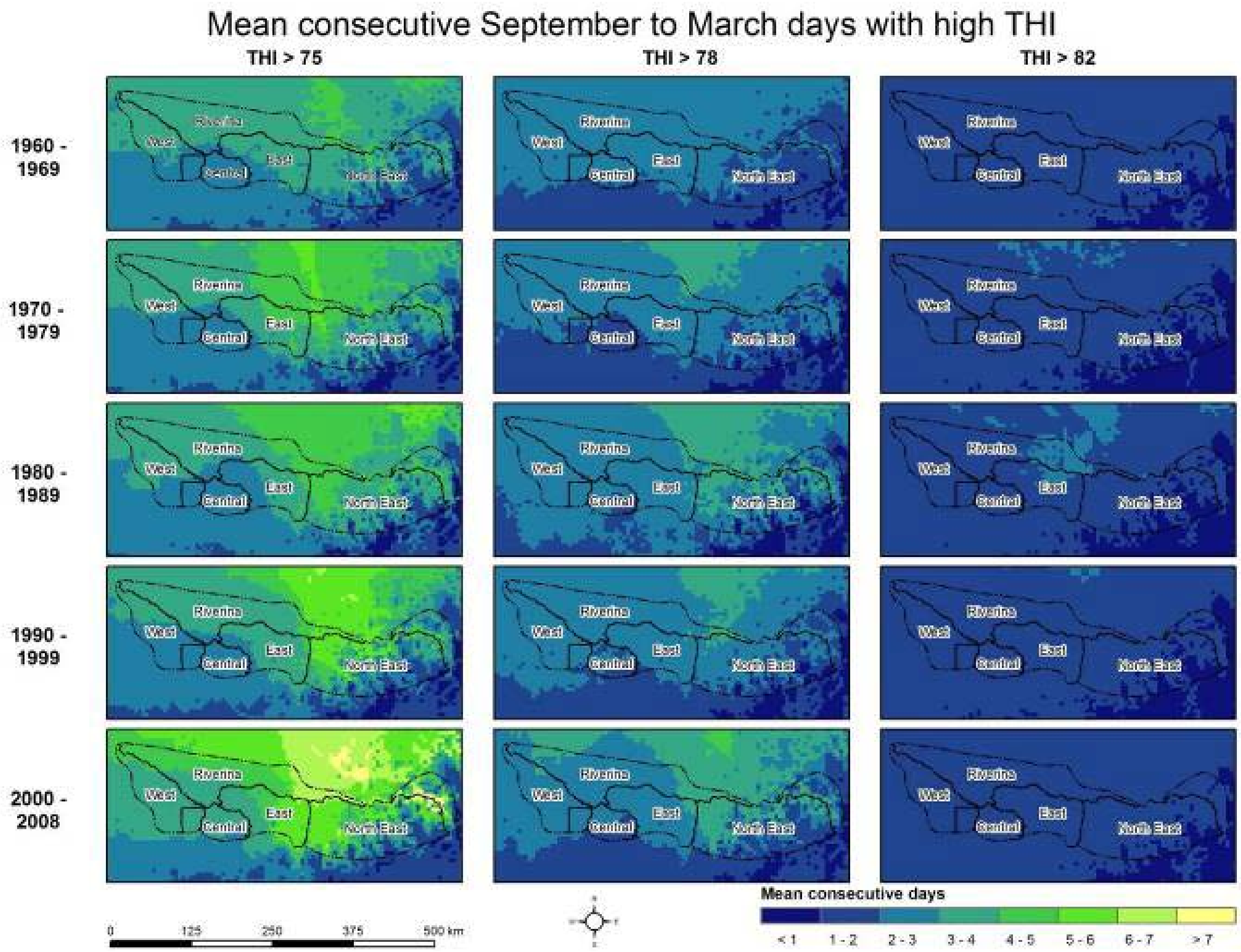

Figure 4.7 Decadal mean consecutive heat stress days in the THI ranges of 75–78, 78–82 and >82

4.3 Future changes (2025 and 2050)

4.3.1 Heat stress

CCR:MIROC-H model

Number of days of heat stress – 2025 and 2050

By 2025, small changes in the number of days of heat stress are likely across the entire Murray Dairy region for the low, mid and high emission futures. An additional 5 days of heat stress are simulated for both the 75–78 THI (modest heat stress) range and 78–82 (moderate heat stress) THI range. For the THI range >82 (severe heat stress) an additional 5 to 10 days was simulated (Figure 4.8).

By 2050 larger changes in the number of days of heat stress are likely across the entire Murray Dairy region for the low, moderate and high emission futures. An additional 5 to 25 days of heat stress are simulated across each THI level. The largest increases are simulated for severe heat stress, with up to 25 additional severe heat stress days if the high GHG emission scenario is realised. Modest and moderate heat stress are simulated to increase by 5 to 15 days, with the greatest change occurring in the south-east of the region under a high emission scenario (Figure 4.9).

Examples of possible changes in the number of heat stress days (derived from Figures 4.8 and 4.9) are given in Table 4.1.

Table 4-1 Examples of the possible changes in the number of heat stress days in the Murray Dairy region (CCR: MIROC-H)

	Modest heat stress			Moderate heat stress			Severe heat stress		
	1971–2000	2025	2050	1971–2000	2025	2050	1971–2000	2025	2050
Deniliquin	27	32	32-42	32	37	37-47	22	27–37	27-47
Tatura	25	30	n/a	26	31	n/a	16	21–26	n/a
Moama	27	32	32-42	26	31	31-41	21	21–26	26-46

n/a – not available

Number of consecutive heat stress days – 2025 and 2050

By 2025, the results from the CCR:MIROC-H climate model suggests that the consecutive number of heat stress days may increase by up to 2 days across each of the three stress levels. The largest changes may occur in the number of consecutive modest heat stress days with little change apparent in consecutive severe heat stress (Figures 4.10 and 4.11). The consecutive number of heat stress days is also projected to increase on average by between 0.5 and 4.25 days by 2050. The largest changes are simulated in the number of consecutive modest heat stress days with smaller changes simulated for moderate heat stress. There is little change apparent for severe heat stress.

Examples of possible changes in the number of consecutive heat stress days (derived from Figures 4.10 and 4.11) are given in Table 4.2.

Table 4-2. Examples of the possible changes in the number of consecutive heat stress days in the Murray Dairy region (CCR: MIROC-H)

	Modest heat stress			Moderate heat stress			Severe heat stress		
	1971–2000	2025	2050	1971–2000	2025	2050	1971–2000	2025	2050
Deniliquin	5	6.25	n/a	3	5	n/a	2.5	3	n/a
Tatura	4	4.5-5.25	n/a	3.5	4	n/a	2.5	3	n/a
Moama	4	5.25	5.25-6.5	2.5	3	4	1.5	2	2.5

n/a – not available

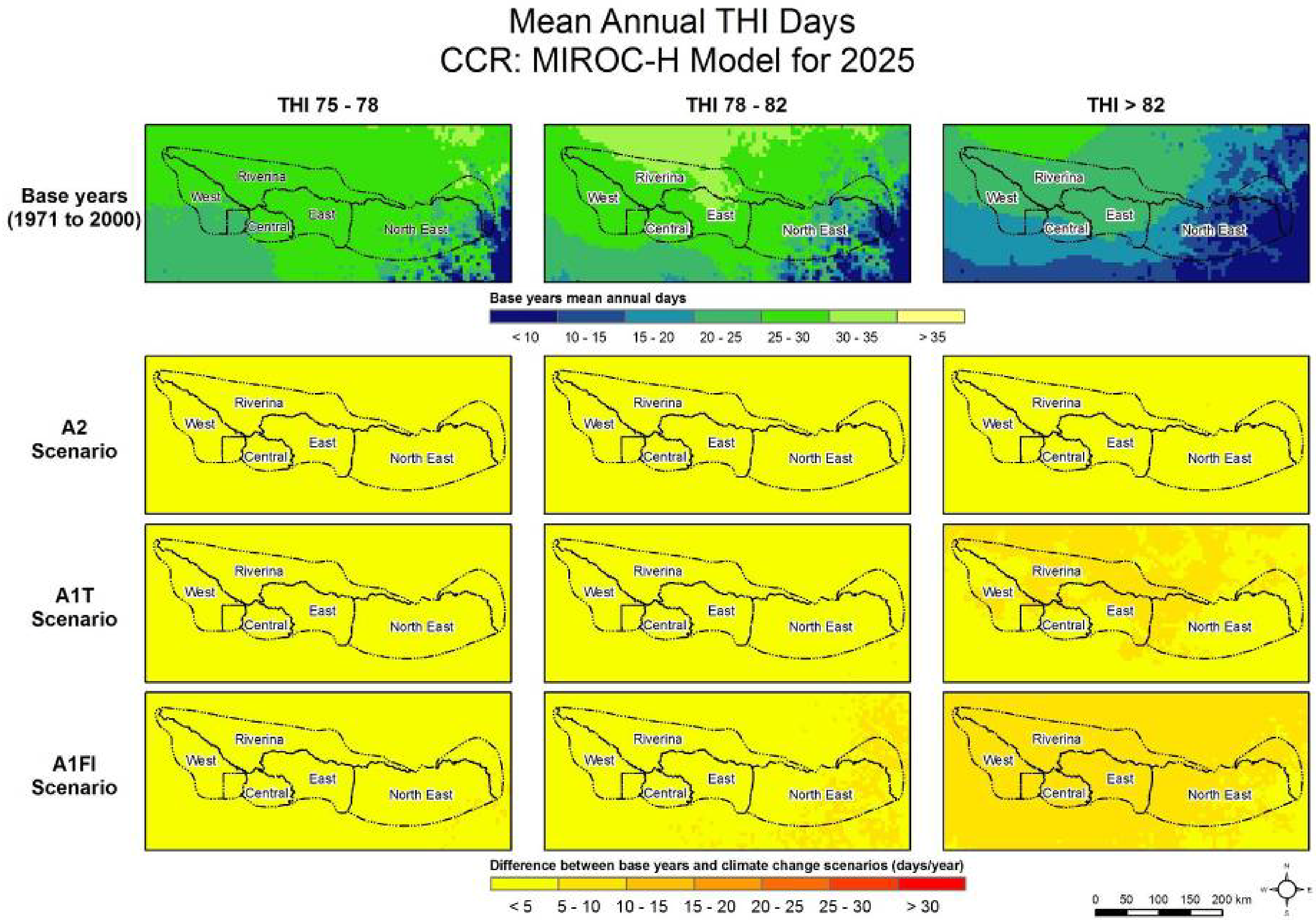

Figure 4.8 Changes in the numbers of days (relative to 1971–2000) of heat stress in high THI ranges for 2025 under the A2, A1T and A1FI emission scenarios (CCR:MIROC-H climate model).

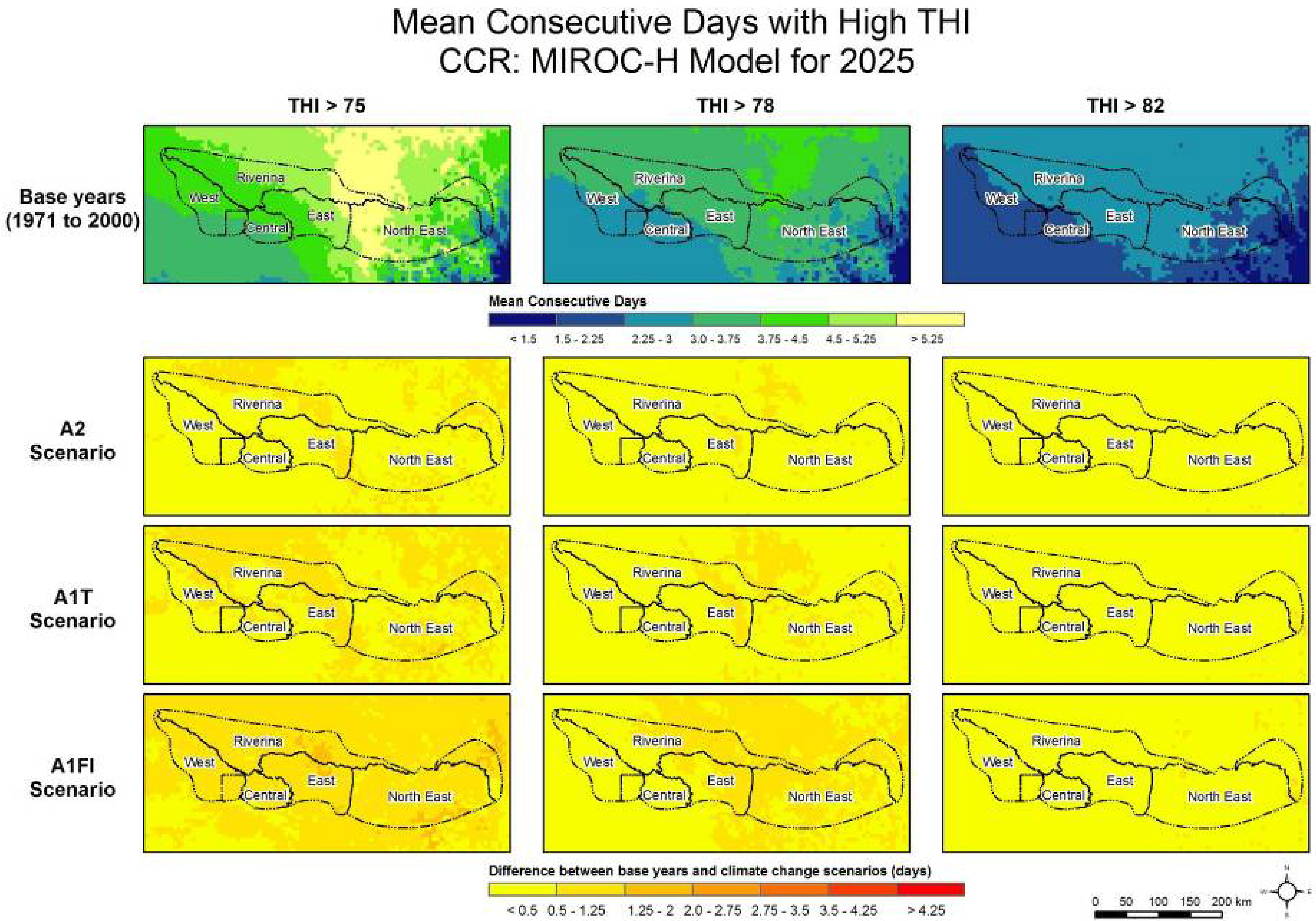

Figure 4.9 Changes in the number of days of heat stress (relative to 1971–2000) in high THI ranges for 2050 under the A2, A1T and A1FI emission scenarios (CCR:MIROC-H climate model)

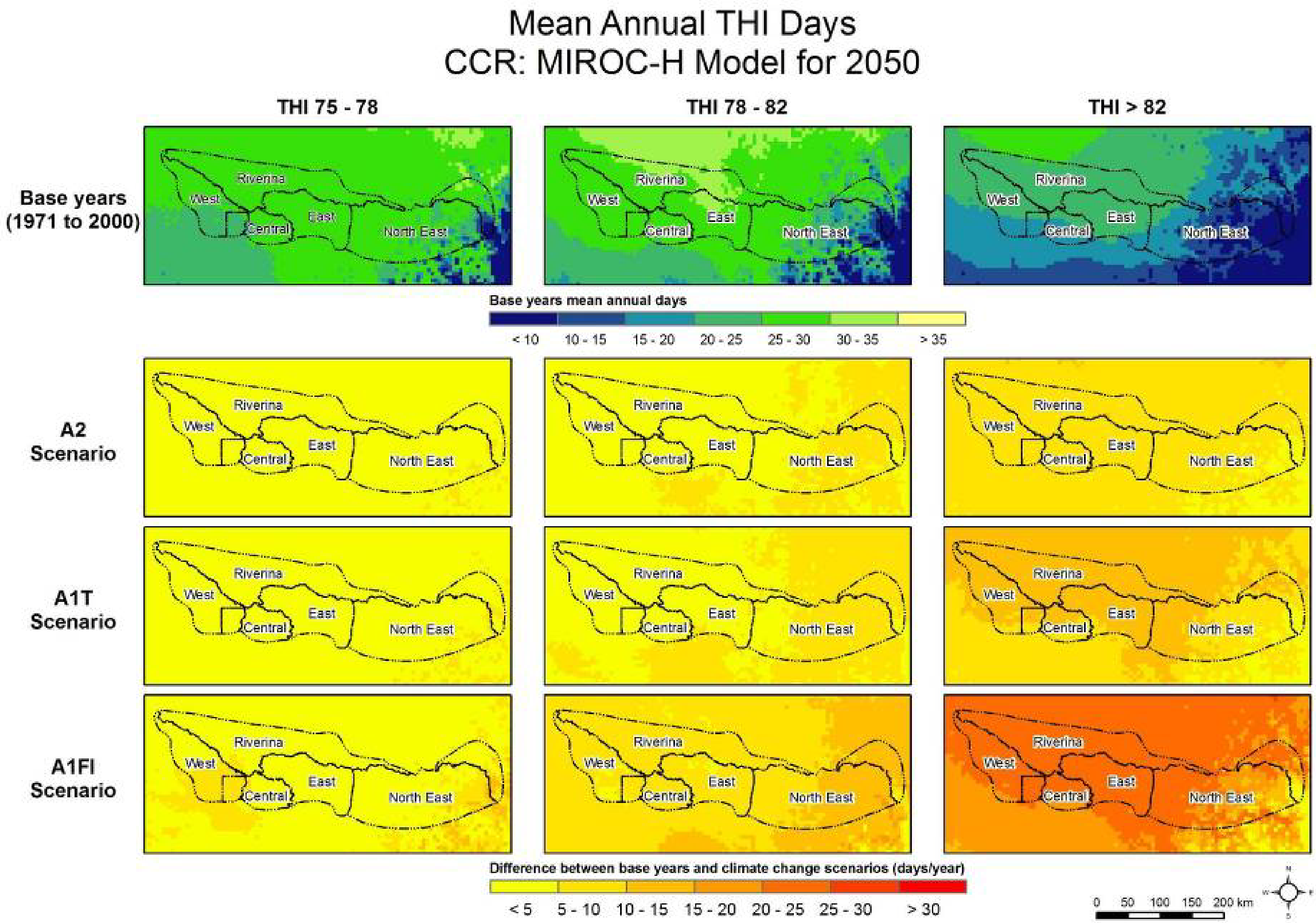

Figure 4.10 Changes in the numbers of consecutive days (relative to 1971–2000) of heat stress in high THI ranges for 2025 under the A2, A1T and A1FI emission scenarios (CCR:MIROC-H climate model).

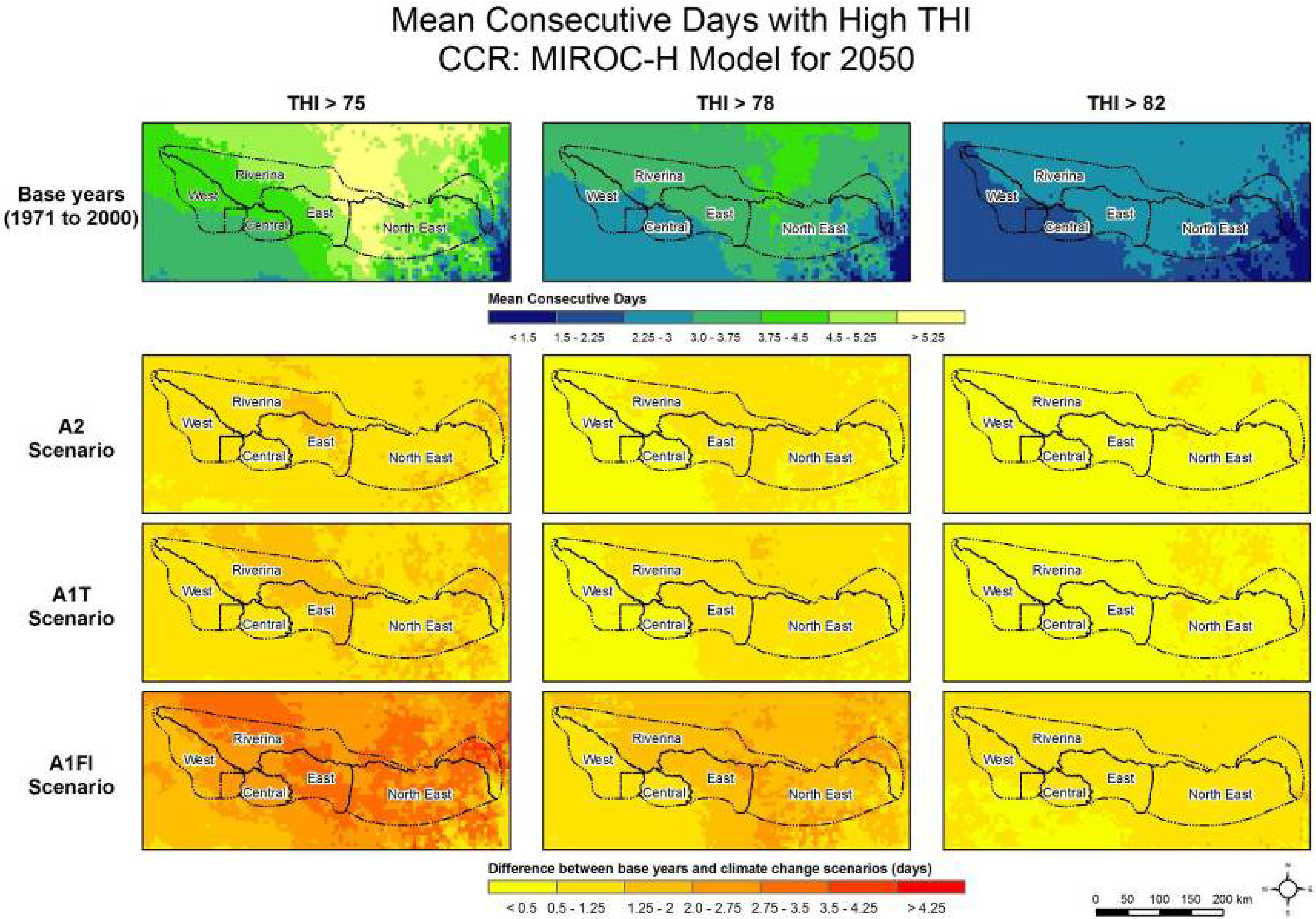

Figure 4.11 Changes in the numbers of consecutive days (relative to 1971–2000) of heat stress in high THI ranges for 2050 under the A2, A1T and A1FI emission scenarios (CCR:MIROC-H climate model).

CSIRO Mk 3.5 model

Number of heat stress days – 2025 and 2050

As with the CCR:MIROC-H climate model, the CSIRO Mk 3.5 climate model simulates a small increase in the overall number of heat stress days by 2025 across the entire Murray Dairy region for the low, mid and high emission futures. As with the previous climate model an additional 5 days of heat stress are simulated for both the 75–78 THI (modest heat stress) range and 78–82 (moderate heat stress) THI range. For the THI range >82 (severe heat stress) an additional 10–15 days was simulated.

By 2050 larger changes in the number of days of heat stress were simulated across the entire Murray Dairy region for the low, moderate and high emission futures. An additional 5 to 37 days of heat stress are simulated across respective THI levels. Largest increases were simulated for severe heat stress with up to 37 additional days of heat stress if the high GHG emission scenario is realised. Modest and moderate heat stress days are simulated to increase by 5 to 25 days, with the greatest change occurring in the south-east of the region under a high emission scenario (Figures 4.12 and 4.13).

Examples of possible changes in the number of consecutive heat stress days (derived from figures 4.12 and 4.13) are given in Table 4.3.

Table 4-3 Examples of the possible changes in the number of heat stress days in the Murray Dairy region (CSIRO Mk 3.5)

	Modest heat stress			Moderate heat stress			Severe heat stress		
	1971–2000	2025	2050	1971–2000	2025	2050	1971–2000	2025	2050
Deniliquin	27	32	32-52	32	37	37-57	22	32-37	27-59
Tatura	25	30	31-51	26	31	30-50	16	26-31	21-53
Moama	27	32	32-52	26	31	31-51	21	31-36	26-58

Number of consecutive heat stress days – 2025 and 2050

The results from the CSIRO Mk 3.5 climate model suggest that by 2025 the consecutive number of heat stress days may increase by up to 2 days across each of the three stress levels. The largest changes occur in the number of consecutive modest heat stress days with little change apparent in consecutive severe heat stress (Figure 4.14). These results are the same as those produced by the CCR:MIROC-H climate model.

The consecutive number of heat stress days will also increase on average by between 0.5 and 4.25 days by 2050. The largest changes occur in the number of consecutive modest heat stress days with smaller changes simulated to moderate heat stress days, and little change apparent in severe heat stress days.

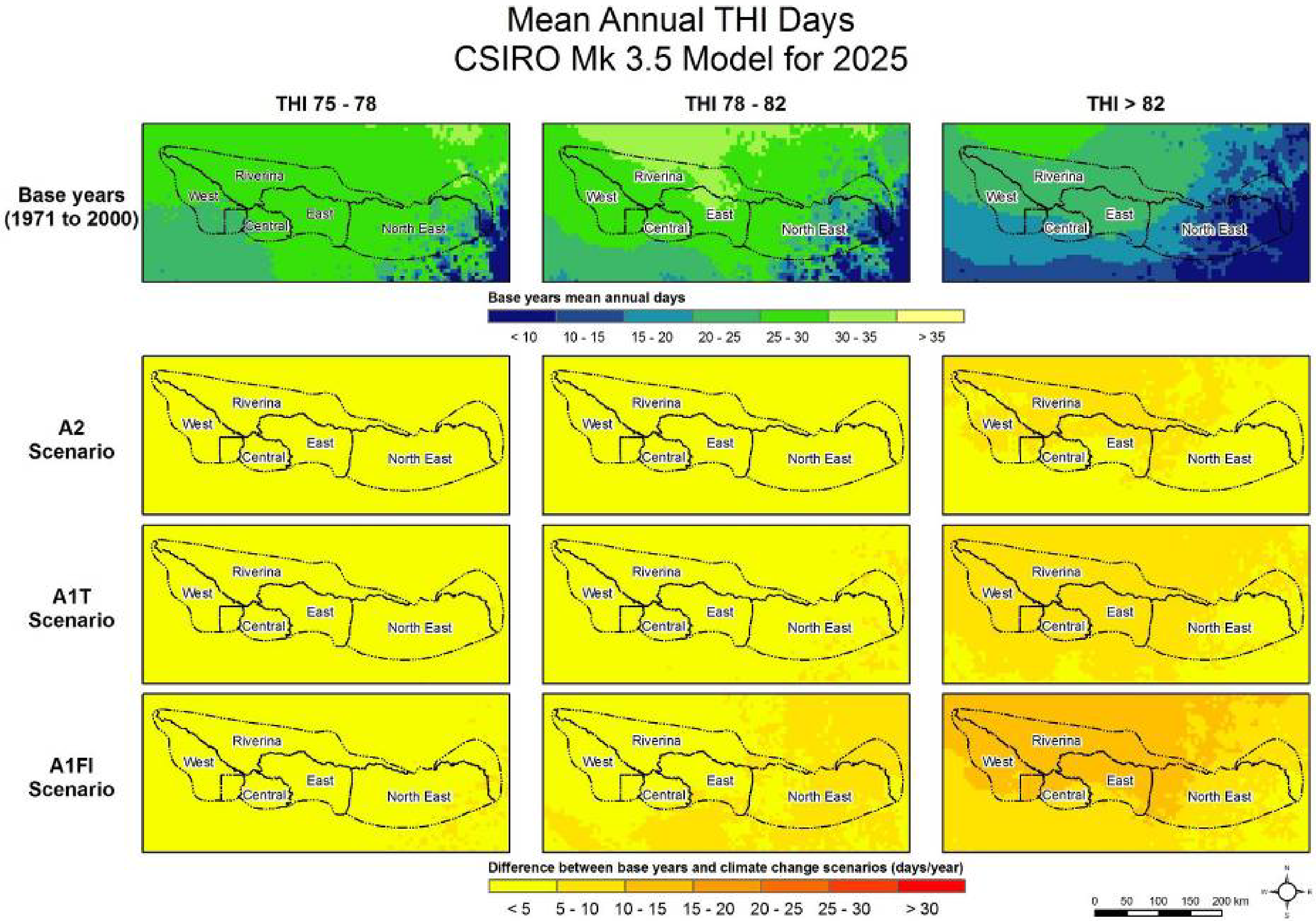

Figure 4.12 Changes in the numbers of heat stress days (relative to 1971–2000) in high THI ranges for 2025 under the A2, A1T and A1FI emission scenarios (CSIRO Mk 3.5 climate model).

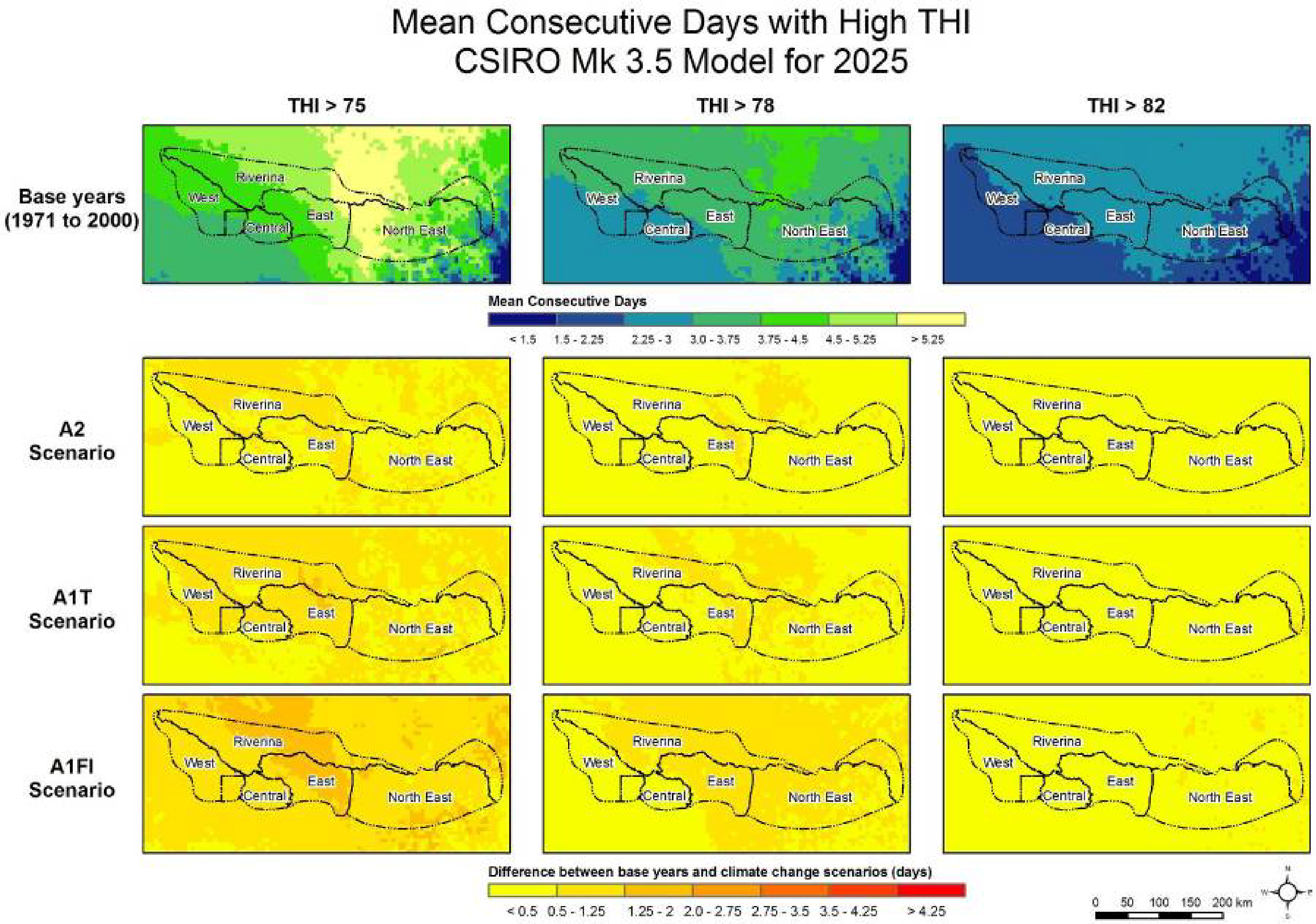

Figure 4.13 Changes in the numbers of heat stress days (relative to 1971–2000) in high THI ranges for 2050 under the A2, A1T and A1FI emission scenarios (CSIRO Mk 3.5 climate model).

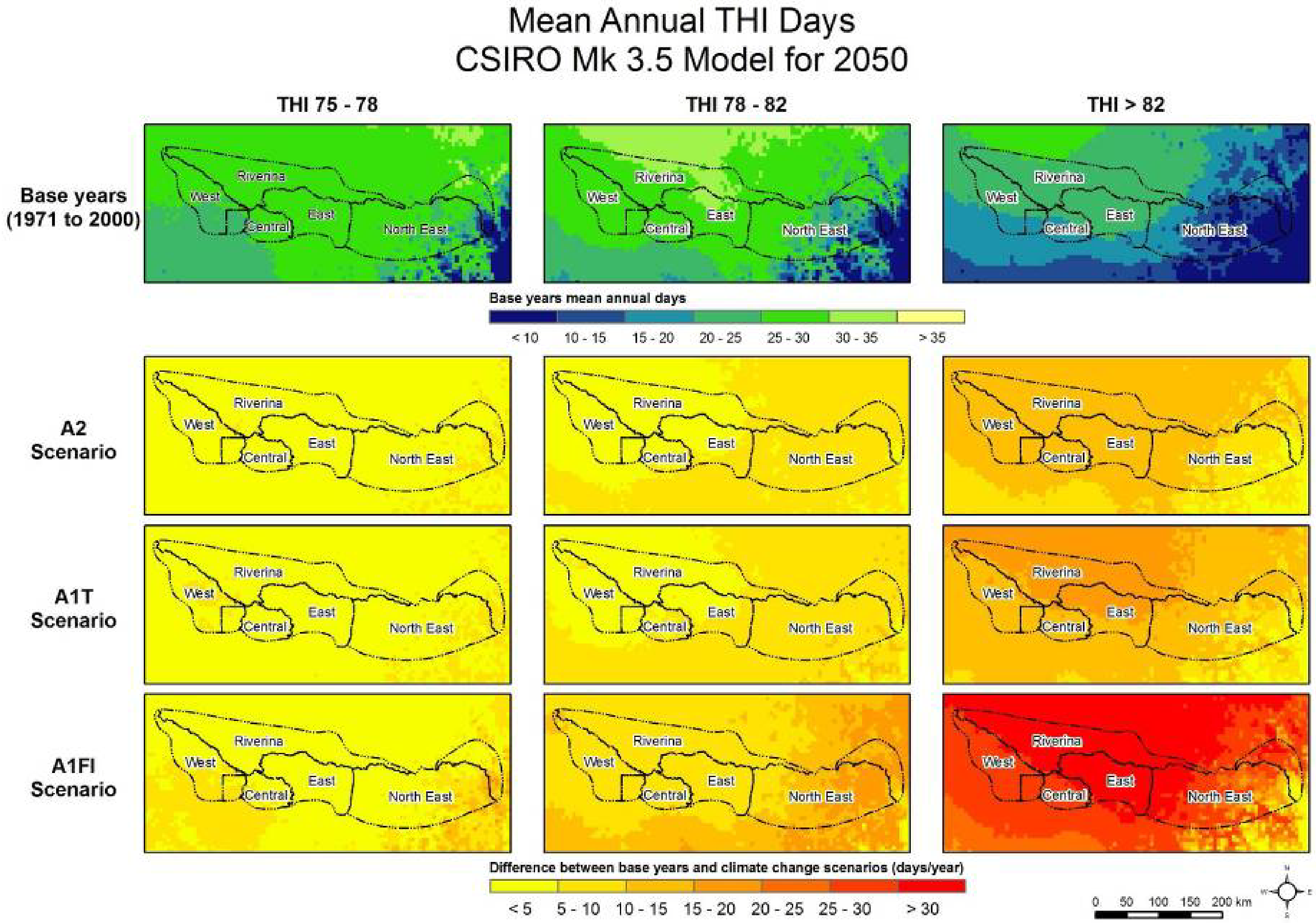

Figure 4.94 Changes in the number of consecutive heat stress days (relative to 1971–2000) in high THI ranges for 2025 under the A2, A1T and A1FI emission scenarios (CSIRO Mk 3.5 climate model).

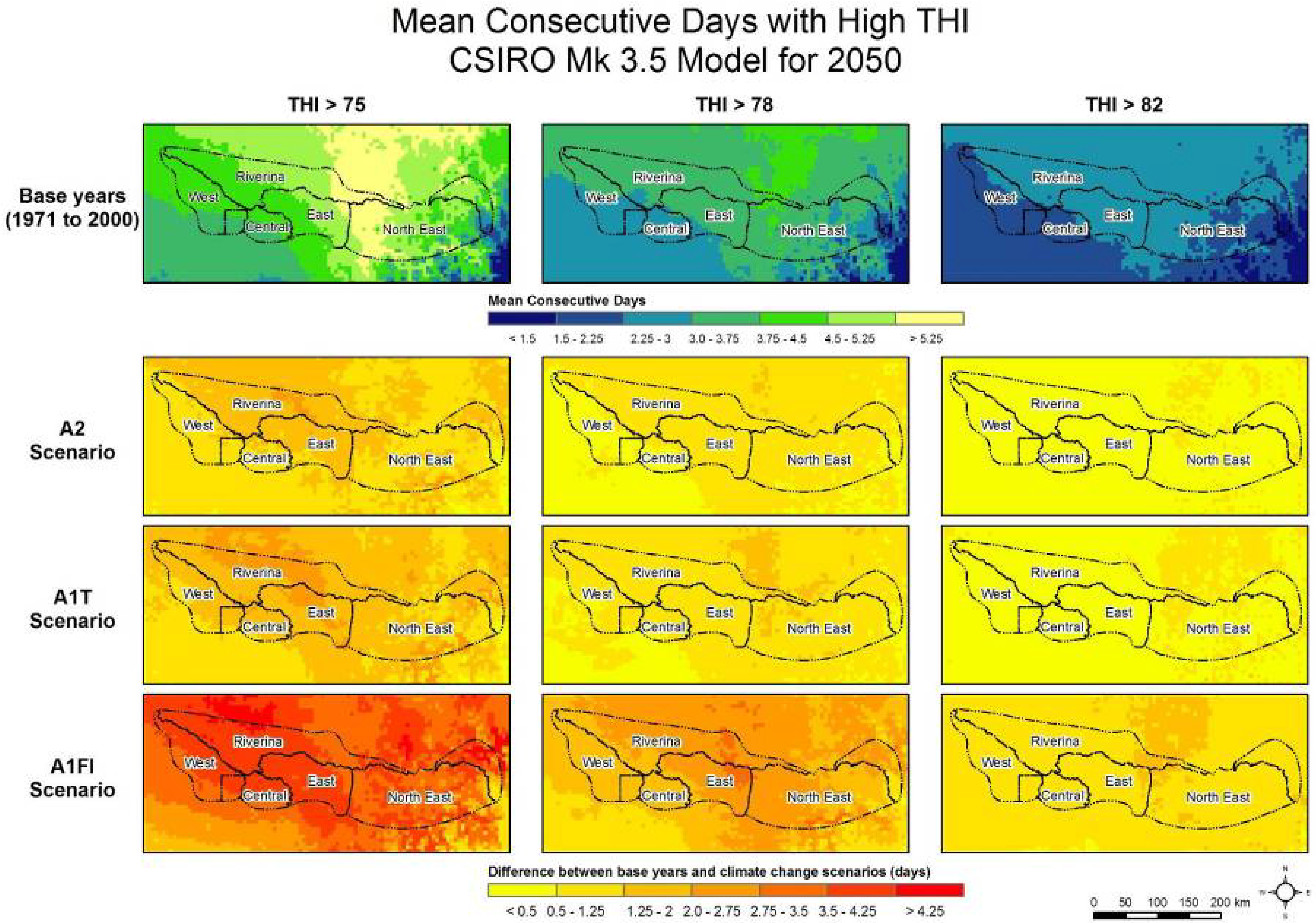

Figure 4.15 Changes in the number of consecutive heat stress days (relative to 1971–2000) in high THI ranges for 2050 under the A2, A1T and A1FI emission scenarios (CSIRO Mk 3.5 climate model).

4.3.2 Milk production

CCR:MIROC-H model

By 2025 milk production was simulated to decline by an additional 35–85 litres of milk per low susceptibility cow per year across the entire Murray Dairy region for the low, mid and high emission futures (Figure 4.16).

This means that a low susceptibility herd around the Deniliquin region may experience annual milk losses of between 305–355 litres per cow (compared to 270 litres of milk lost annually per cow for 1971–2000). A moderately susceptible herd in this area may lose an additional 55–85 litres of milk per cow. This would mean a total average annual loss of between 350–460 litres of milk per cow (compared to 320 litres of milk lost annually per cow for 1971–2000). A highly susceptible herd in this area may lose an additional 85–135 litres of milk per cow. This would mean a total average loss of between 460–585 litres of milk per cow per year (compared to 400 litres of milk lost annually per cow for 1971–2000).

By 2025 in Tatura, a herd with low heat stress susceptibility may experience annual milk losses of between 215–265 litres per cow (compared to 180 litres of milk lost annually per cow for 1971–2000). A moderately susceptible herd in this area may lose an additional 85 litres of milk per cow. This would mean a total average annual loss of approximately 355 litres of milk per cow (compared to 270 litres of milk lost annually per cow for 1971–2000). A highly susceptible herd in this area may lose an additional 135–210 litres of milk per cow. This would mean a total average loss of between 455–530 litres of milk per cow per year (compared to 320 litres of milk lost annually per cow for 1971–2000).

By 2050 projected additional milk losses across the entire Murray Dairy region vary by 85–330 litres of milk per cow per year, depending on both herd susceptibility and GHG emission scenario (Figure 4.17).

This would mean that a low susceptibility herd around the Deniliquin region may experience annual milk losses of 320–480 litres per cow (compared to 270 litres of milk lost annually per cow for 1971–2000). A moderately susceptible herd in this area may lose an additional 85–330 litres of milk per cow. This would mean a total average annual loss of between 405–650 litres of milk per cow (compared to 320 litres of milk lost annually per cow for 1971–2000). A highly susceptible herd in this area may lose an additional 85–330 litres of milk per cow. This would mean a total average loss of between 485–730 litres of milk per cow per year (compared to 400 litres of milk lost annually per cow for 1971–2000).

By 2050 in Tatura, a herd with low heat stress susceptibility may experience annual milk losses of between 265–390 litres per cow (compared to 180 litres of milk lost annually per cow for 1971–2000). A moderately susceptible herd in this area may lose an additional 210–330 litres of milk per cow. This would mean a total average annual loss of approximately 480–600 litres of milk per cow (compared to 270 litres of milk lost annually per cow for 1971–2000). A highly susceptible herd in this area may lose an additional 210–330 litres of milk per cow. This would mean a total average loss of between 530–650 litres of milk per cow per year (compared to 320 litres of milk lost annually per cow for 1971–2000).

In the Yarrawonga area, a herd with low heat stress susceptibility may experience annual milk losses of 355–480 litres per cow (compared to 270 litres of milk lost annually per cow for 1971–2000). A moderately susceptible herd in this area may lose an additional 210–330 litres of milk per cow. This would mean a total average annual loss of approximately 550–660 litres of milk per cow (compared to 330 litres of milk lost annually per cow for 1971–2000). A highly susceptible herd in this area may lose an additional 210–330 litres of milk per cow. This would mean a total average loss of between 620–740 litres of milk per cow per year (compared to 410 litres of milk lost annually per cow for 1971–2000).

The heat stress milk production relationships presented here are modelled values that need to be tested preferably under several different adaptations with control of no adaptation.

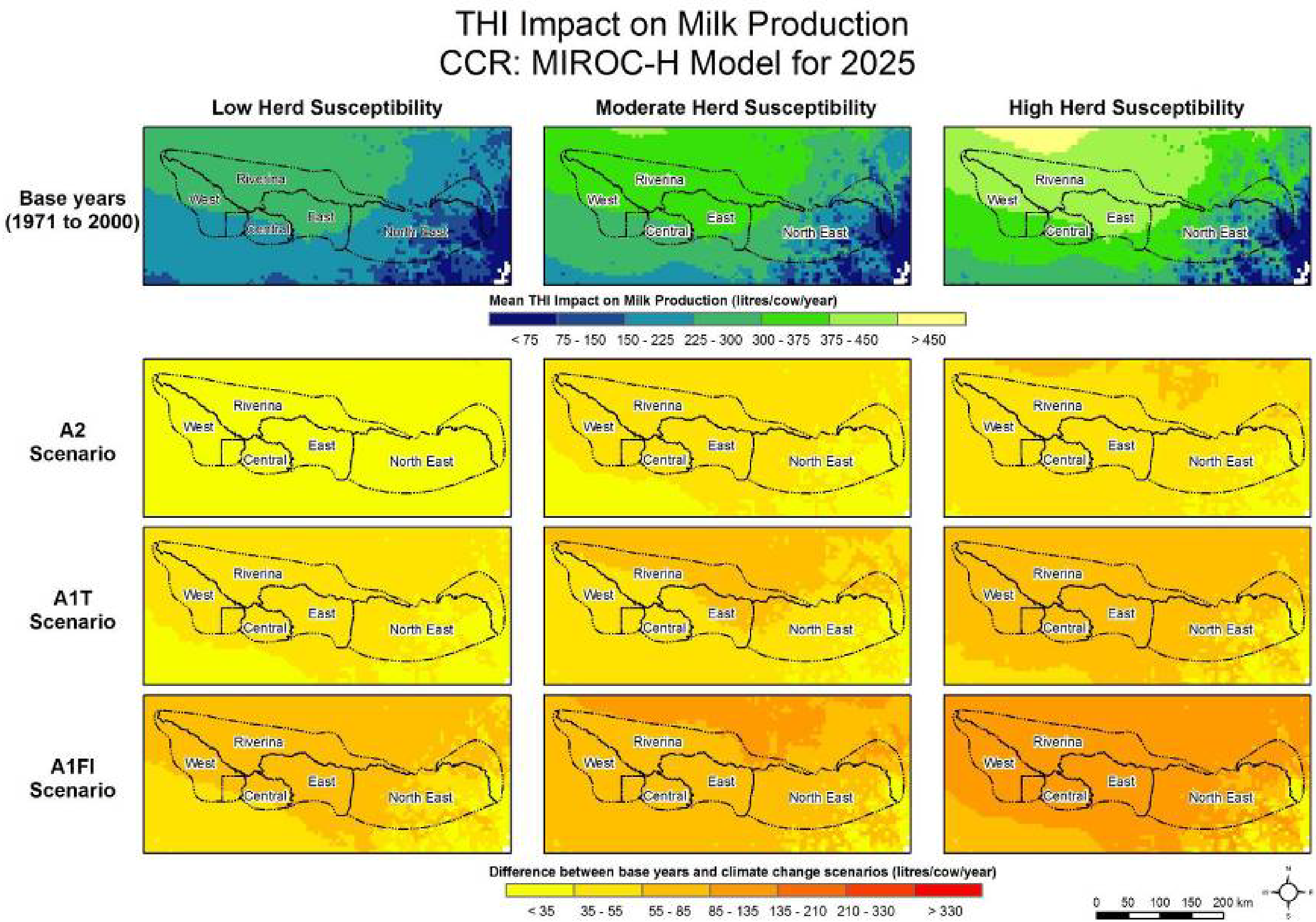

Figure 4.10 Changes in milk production for low, moderate and ‘high susceptibility herds for 2025 under the A2, A1T and A1FI emission scenarios (CCR:MIROC-H climate model).

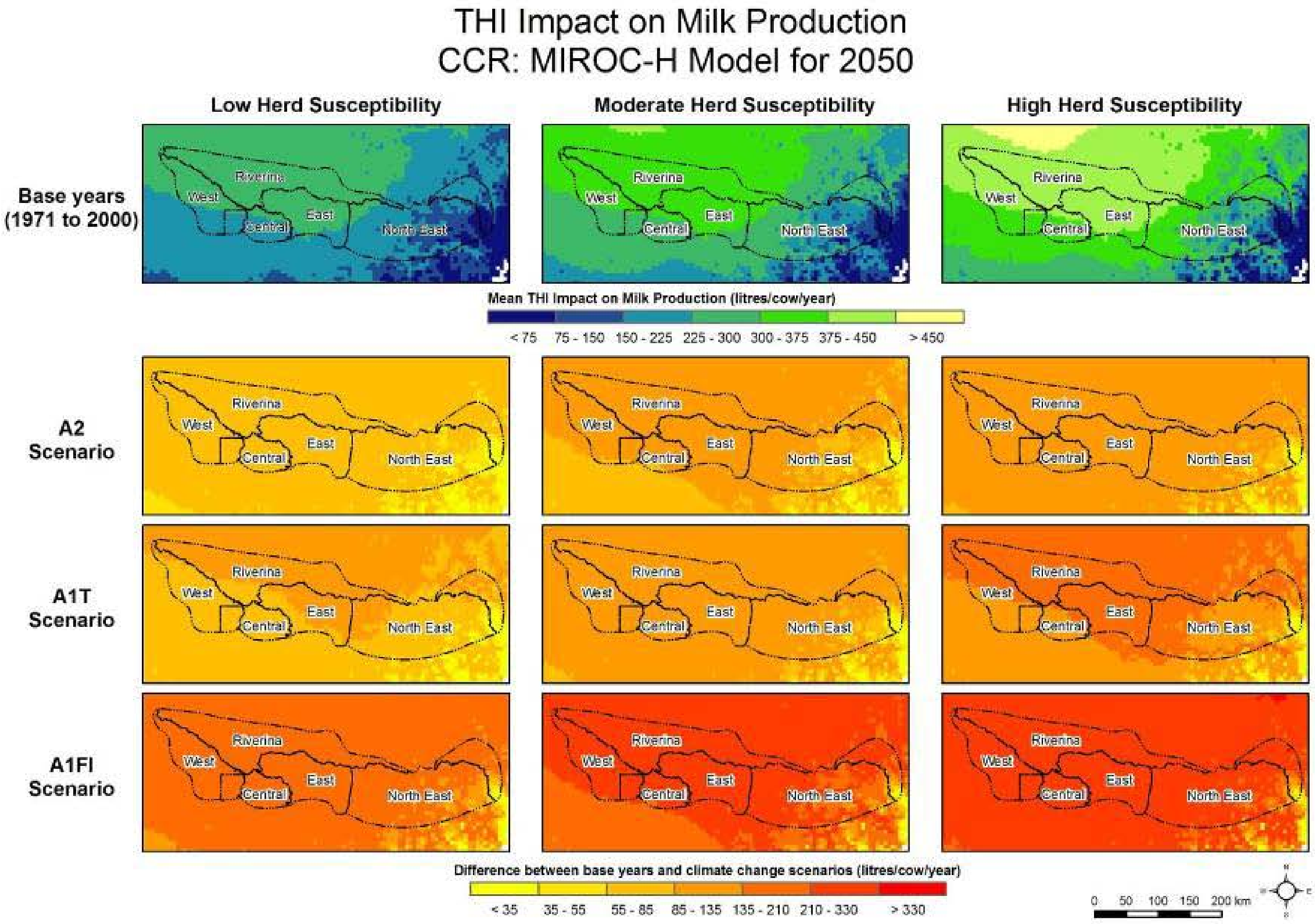

Figure 4.11 Changes in milk production for low, moderate and high susceptibility herds for 2050 under the A2, A1T and A1FI emission scenarios for the (CCR:MIROC-H climate model)..

CSIRO Mk3.5 model

The climate change scenarios generated by the CSIRO Mk 3.5 model result in more extensive loss of milk production by 2025 and 2050 than the CCR:MIROC-H climate model.

By 2025 milk production was simulated to decline by an additional 55–210 litres of milk for the three herd types examined (Figure 4.18).

This would mean that a low susceptibility herd around the Deniliquin region may experience annual milk losses of 325–405 litres per cow (compared to 270 litres of milk lost annually per cow for 1971–2000). A moderately susceptible herd in this area may lose an additional 85–135 litres of milk per cow. This would mean a total average annual loss of 405–455 litres of milk per cow (compared to 320 litres of milk lost annually per cow for 1971–2000). A highly susceptible herd in this area may lose an additional 135–210 litres of milk per cow. This would mean a total average loss of 435–485 litres of milk per cow per year (compared to 400 litres of milk lost annually per cow for 1971–2000).

In Tatura, a herd with low heat stress susceptibility may experience annual milk losses of 235–265 litres per cow (compared to 180 litres of milk lost annually per cow for 1971–2000). A moderately susceptible herd in this area may lose an additional 85–135 litres of milk per cow. This would mean a total average annual loss of approximately 355–405 litres of milk per cow (compared to 270 litres of milk lost annually per cow for 1971–2000). A highly susceptible herd in this area may lose an additional 135–210 litres of milk per cow. This would mean a total average loss of 455–530 litres of milk per cow per year (compared to 320 litres of milk lost annually per cow for 1971–2000).

By 2050 projected additional milk losses across the entire Murray Dairy region vary by 85–420 litres per cow per year, depending on both herd susceptibility and GHG emission scenario (Figure 4.19).

This would mean that a low susceptibility herd in the Deniliquin region may experience annual milk losses of 405–480 litres per cow (compared to 270 litres of milk lost annually per cow for 1971–2000). A moderately susceptible herd in this area may lose an additional 85–135 litres of milk per cow. This would mean a total average annual loss of 405–455 litres of milk per cow (compared to 320 litres of milk lost annually per cow for 1971–2000). A highly susceptible herd in this area may lose an additional 85–330 litres of milk per cow. This would mean a total average loss of between 610–820 litres of milk per cow per year (compared to 400 litres of milk lost annually per cow for 1971–2000).

By 2050 in Tatura, a herd with low heat stress susceptibility may experience annual milk losses of 315–510 litres per cow (compared to 180 litres of milk lost annually per cow for 1971–2000). A moderately susceptible herd in this area may lose an additional 135–210 litres of milk per cow. This would mean a total average annual loss of approximately 405–480 litres of milk per cow (compared to 270 litres of milk lost annually per cow for 1971–2000). A highly susceptible herd in this area may lose an additional 210–420 litres of milk per cow. This would mean a total average loss of 530–740 litres of milk per cow per year (compared to 320 litres of milk lost annually per cow for 1971–2000).

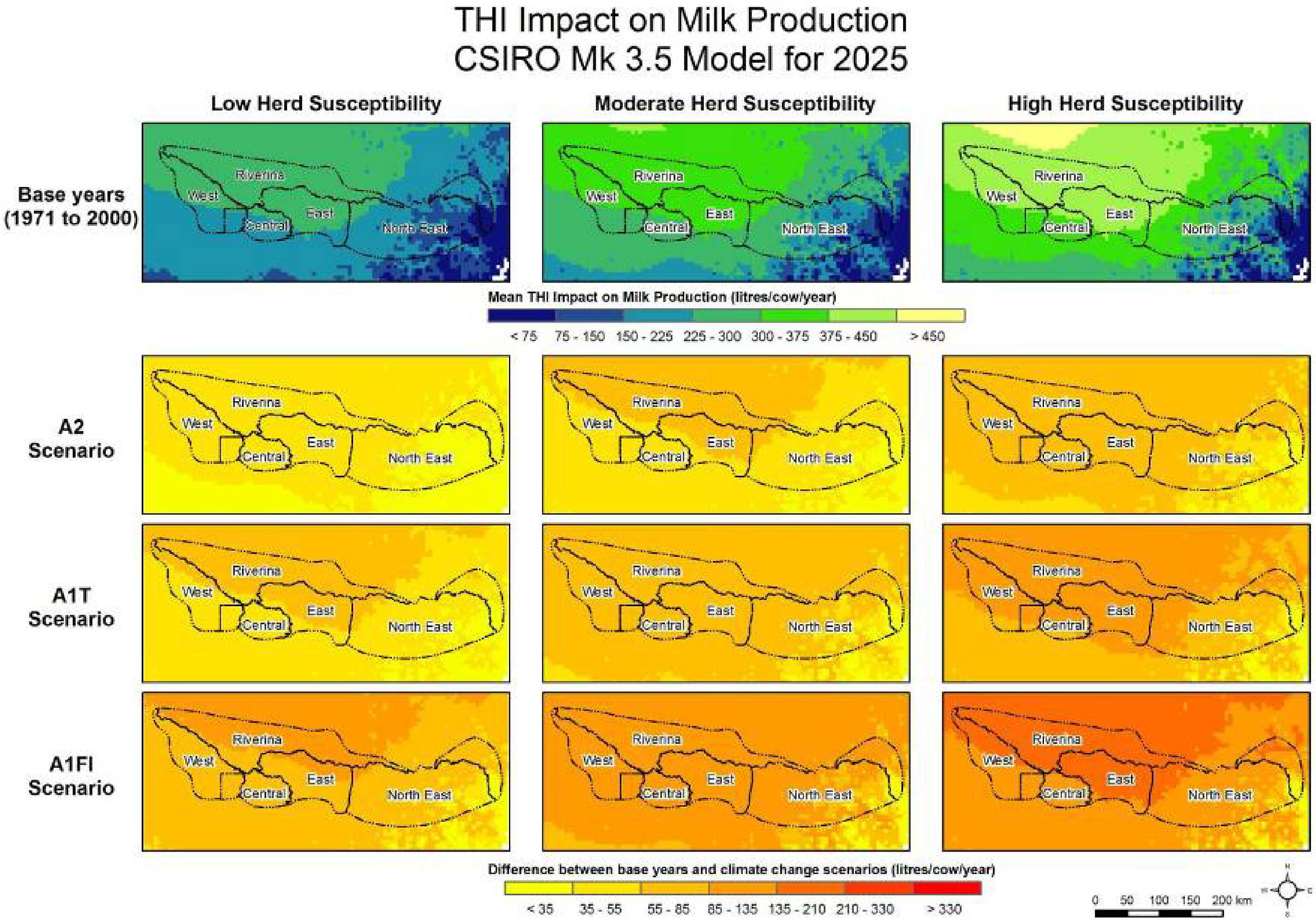

Figure 4.12 Changes in milk production (relative to 1971–2000) for low, moderate and high susceptibility herds for 2025 under the A2, A1T and A1FI emission scenarios (CSIRO Mk 3.5 climate model).

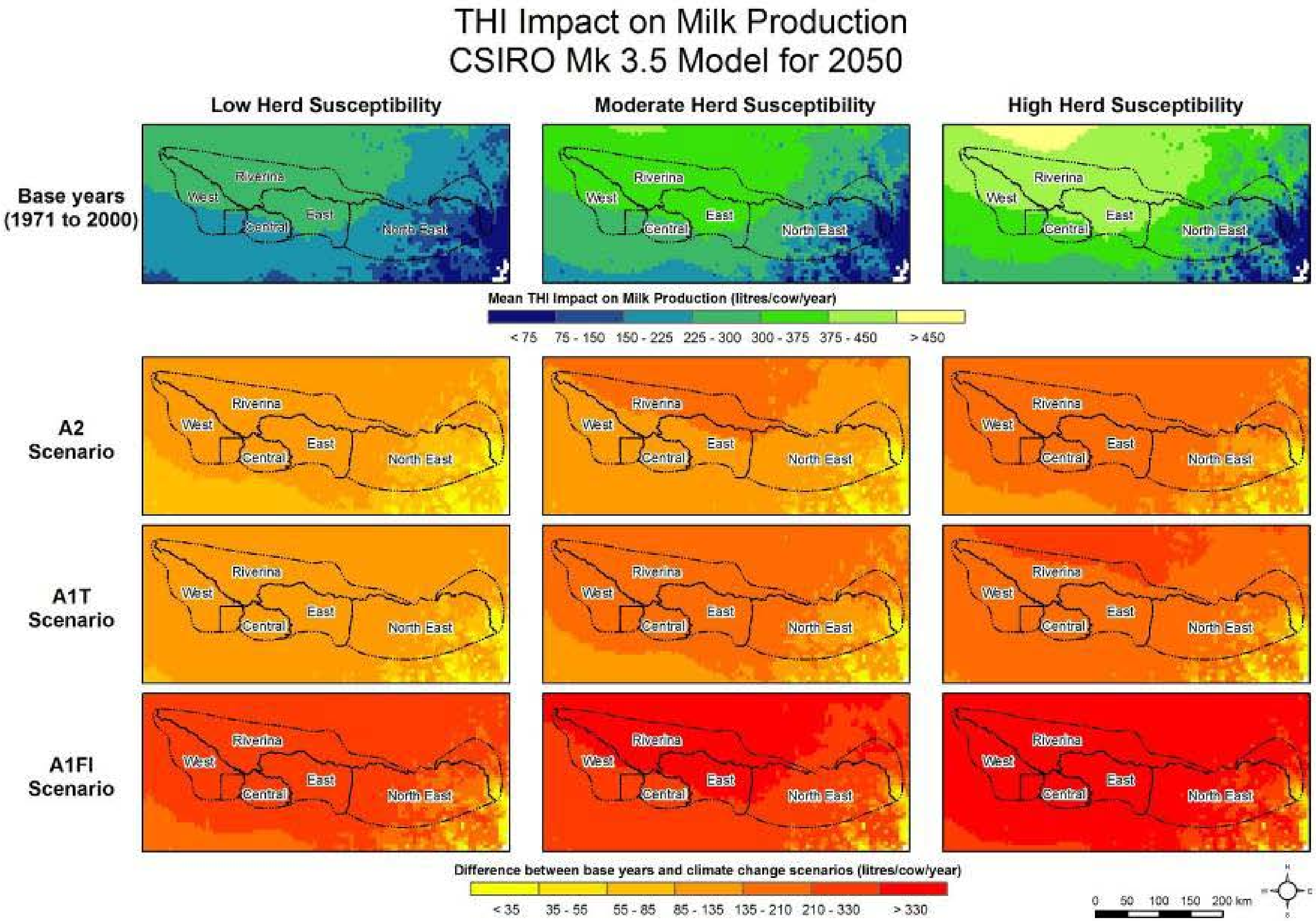

Figure 4.13 Changes in milk production (relative to 1971–2000) for low, moderate and high susceptibility herds for 2050 under the A2, A1T and A1FI emission scenarios (CSIRO Mk 3.5 climate model).

4.4 Shading and spraying to combat heat stress

A plot of the resultant average daily THI values for the three treatments (spray, shade and open) is shown in Figure 4.19.

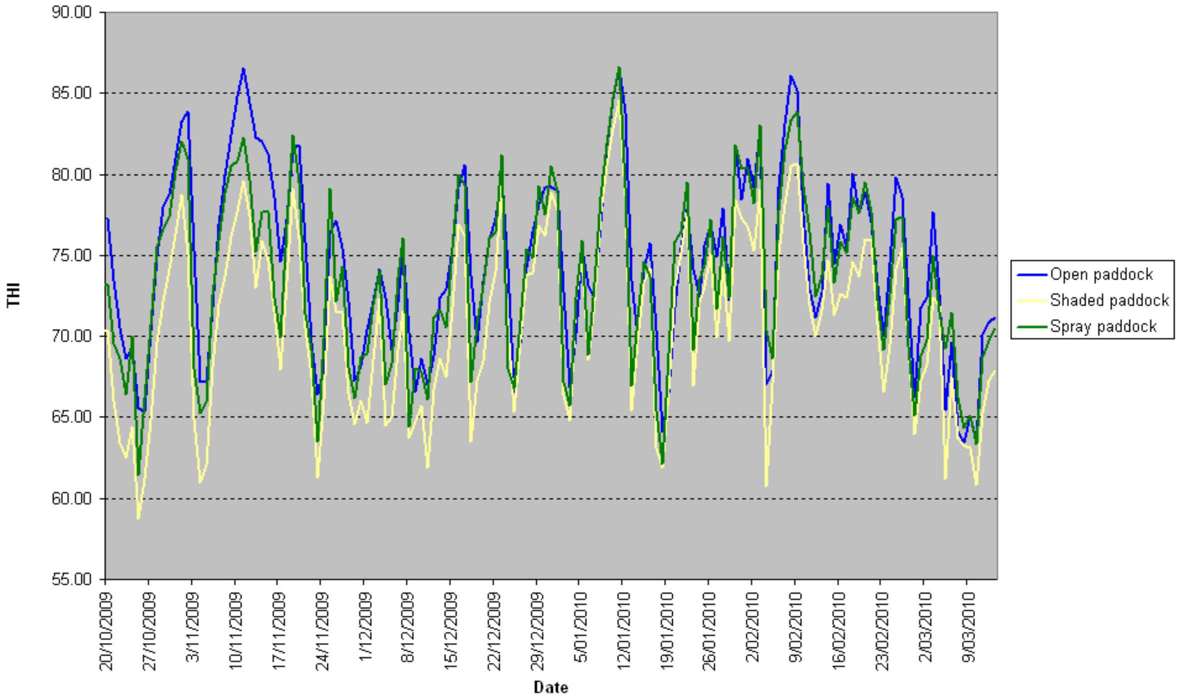

Figure 4.14 Average daytime THI values for each of the three treatments

The October 2009 to April 2010 period was marked with considerable daily variability. A number of periods were characterised by prolonged periods of moderate to severe heat stress. These included:

- 29 October to 3 November 2009
- 6 November to 13 November 2009
- 6 January to 12 January 2010
- All but a 4 day period between 2 February to 22 February 2010.

Across the entire 182 day period the shade treatment consistently recorded lower THI values than either the spray or open treatments (Figure 4.22). For the most part the spray treatment recorded lower THI values than the open treatment although a number of days recorded THI values higher than those in the open treatment (Figure 4.22). The mean THI value over the 182 day period for the open treatment was 74.3, whilst for the spray treatment the mean THI value was 73.4. For the shade treatment the mean THI value was 70.1 over the 182 day period.

To provide consistency with the longer term analyses (described in Section 5.2), heat stress was again calculated for three THI ranges (75–78, 78–82 and >82). The incidence of days within each of these three THI ranges is displayed in Table 4.5. Little difference was measured for modest heat stress events across the three treatments with 32 days of modest heat stress recorded in the open treatment, 33 in the spray treatment and 25 in the shade treatment.

The shade structure proved to be successful at reducing moderate and severe heat stress occurrence with the shade treatment, recording 64% fewer moderate and 88% fewer severe heat stress events than the open treatment (Table 4.4).

The spray treatment proved effective at reducing only the number of severe heat stress events. During the 182 day period 44% fewer severe heat stress events were measured for the spray treatment than for the open treatment.

The results suggest that in this specific case study, the shade structure was far more effective at ameliorating moderate to severe heat stress than the spray treatment.

Table 4-4 Modelled effects of amelioration options on THI over the 182 day experiment (number of days)

Treatment	THI 75–78	THI 78–82	THI >82
Open	32	33	16
Spray	33	32	9
Shade	25	12	2

Based on the established relationship between THI and milk production, a series of calculations were made to estimate the likely impacts of the cooling treatments on milk production. We again examined low susceptibility cows (i.e. a Brown Swiss Jersey producing less than 5500 litres of milk per year), moderately susceptible cows (i.e. other European breeds or cross breeds producing 5500–8000 litres of milk per year) and highly susceptible cows (i.e. Large Holstein-Friesian producing more than 8000 litres of milk per year) (Little and Campbell 2008).

The total milk production losses assume that herds were kept exclusively in one of the three treatments. We realise that in reality this would not occur and so a more accurate estimate of lost milk production would need to account for periods grazing in open areas, standing in the spray area prior to milking, etc.

The shade structure proved to be successful at ameliorating milk production loss across the three different herd susceptibilities. For low susceptibility herds' milk loss was 72% lower for the shade treatment and only 21% lower in the spray treatment compared to the open treatment (Table 4.5). Similar proportional differences were recorded for both the moderate and high susceptibility herds (Table 4.4).

Table 4-5 Effects of THI on milk production for each of the three treatments (values expressed as litres per cow for the 182 day period)

Treatment	Low herd susceptibility	Moderate herd susceptibility	High herd susceptibility
Open	215	286	358
Spray	169	226	282
Shade	60	80	101

Given the potential for less irrigation water being available in the future and the relatively limited success the spray treatment had on this case study farm we could not recommend spraying as the primary means of reducing heat stress.

5. DISCUSSION

The calculations of heat stress, milk production loss and changes in herd reproductive performance were based on sound expert and industry knowledge and linked to changes in maximum temperature and relative humidity. These estimates should be viewed as conservative estimates of potential impacts of heat stress as they do not:

- take into consideration the cumulative effects of heat stress over time
- consider potential changes in the protein content and bulk milk cell count of the milk produced, which may have considerable impacts on the value of each kilogram of milk, and therefore economic returns
- consider the potential increased incidence of cow health problems e.g. mastitis, ruminal acidosis, laminitis, which may impact on milk production and require significant cost to treat and control
- Consider the cost-benefit ratio of constructing structures versus accepting occasional reduced productivity due to heat stress.

The potential impacts of heat stress on herd reproductive performance have been calculated by examining seasonal average THI. This approach results in relatively low impacts on conception rates as this approach does not take into consideration the impacts of extreme heat stress at discrete joining periods.

Importantly, the full benefits of some heat stress alleviation methods may not be measureable by the THI – for example, the heat-stress-reduction impact of introducing shade structures, which directly and significantly reduce the amount of solar radiation received by dairy cattle (Fisher et al. 2008) may be underestimated by an index which measures only temperature and humidity. To overcome this limitation in the current project, in-situ measurements were taken to compare heat stress for a shaded, sprayed and open paddock that have not been placed in Stevenson screens. This is an attempt to capture the direct and indirect radiative effects on temperature. These temperature measurements are used to calculate difference in THI between the three paddocks. This approach more readily accounts for the shading effects.

The results from the monitoring experiment are for one location only and as such are meant to be illustrative only, as more extensive monitoring would be required across time and across a number of locations to determine if the benefits of shading are as regionally extensive as suggested by this case study.

5.1 Mean number of high THI days

The average occurrence of days with THI 75–78 exhibits a south-east to north-west gradient varying from 1 to 5 days in the south-east, to 26 to 30 days in the north-west. Over the period 1960–2008 this gradient has varied on both annual and decadal timescales.

At the decadal timescale, the decades from 1960, 1970 as well as the slightly shorter 2000–2008 period demonstrate an increase in the average occurrence of THI 75–78 in the central area of the Murray Dairy region. During these periods the average number of days with THI 75–78 increased from around 28 to 32 days. For the period 2000–2008 the greatest change in this THI value occurred in the North East region with a significant increase in daily occurrence in the central and north-western areas of this sub-region.

Similar changes in the pattern of occurrence of THI 78–82 occurred across five decadal periods. For this THI range a significant increase in the number of days occurred for the period 2000–2008 across most of the south-western portion of the Murray Dairy region.

The pattern of average number of days above 82 also has increased for the period 2000–2008, with values increasing from 18 to 22 from the previous decade (i.e. 1990–1999). This change was most pronounced in the northern Riverina and West sub-regions of the study area.

5.2 Consecutive number of THI days

The greatest change in consecutive heat stress days occurred where THI >75. The pattern of change shows a gradual increase in consecutive days encroaching from the North over successive decades. For the earliest decade the average number of consecutive days with THI >75 was 3 to 4 across most of the northern part of the study area. By the latest decades (i.e. 2000–2008) the mean consecutive number of days with THI >75 had almost doubled. This is particularly apparent for the East and North East sub-regions.

Similar patterns of change are present in the THI >78 analysis with the East and North East sub-regions the average consecutive occurrence increasing to 4 days.

Modest change in the consecutive number of days with THI >82 was evident at the decadal timescale of this analysis. While there was little change in the consecutive number of days above THI 82, analyses undertaken of daily data at specific locations in the study area showed that the frequency of individual events increased across all locations analysed.

5.3 Analysis of station data

Across all sites the number of days with THI 78–82 and THI >82 demonstrates an increasing linear trend with significant decadal variation. Across all sites the rate of increase in the number of days with THI 78–82 has been most pronounced.

For the Kyabram, Tatura and Mangalore sites the trend in the number of days with THI 75–78 has remained unchanged or declined (Tatura). Across all sites the smoothed THI data (five year running mean) shows a peak in the number of days with THI >82 across the period 1980–1986. This is driven largely by the record occurrence of THI >82 days in 1982 (i.e. on average all sites experienced in excess of 27 days at or above THI 82).

The longer term climate record from Deniliquin shows some periods of similar THI 82 frequency in the earlier part of the record, i.e. 1922 and 1940. In the later part of the record 1981 and 2000 demonstrate comparable frequencies.

5.4 Future change in heat stress

By 2025 small changes in the number of days of heat stress are likely across the entire Murray Dairy region for the low, mid and high emission futures. An additional five days of heat stress are simulated for both the 75–78 THI (modest heat stress) range and 78–82 (moderate heat stress) THI range. For the THI range >82 (severe heat stress) an additional 5–15 days were simulated for both the models used in this analysis.

By 2050 larger changes in the number of days of heat stress are likely across the entire Murray Dairy region for the low, mid and high emission futures. An additional 5 to 37 days of heat stress are simulated across each THI level. Largest increases are simulated for severe heat stress, with up to 37 additional days of heat stress if the high GHG emission scenario is realised.

Modest and moderate heat stress were simulated to increase by 5 to 25 days, with the greatest change occurring in the south-east of the Murray Dairy region under a high emissions scenario.

5.5 Future change in milk production

By 2025 milk production was simulated to decline by an additional 35 and 210 litres of milk per cow per year across the entire Murray Dairy region for the low, mid and high emission futures. By 2050 projected additional milk losses across the entire Murray Dairy region vary by 85 to 420 litres of milk per cow per year depending on both herd susceptibility and GHG emission scenario.

5.6 Impact of spraying and shading on THI and milk production

We assessed two adaptation options to heat stress: spraying and shade. The shade treatment was more effective than the spray treatment at reducing heat stress. The mean THI value over the 182 day period for the open treatment was 74.3, whilst for the spray treatment the mean THI value was 73.4. For the shade treatment the mean THI value was 70.1 over the 182 day period.

More importantly, the shade structure proved to be successful at reducing moderate and severe heat stress occurrence, with the shade treatment recording 64% fewer moderate and 88% fewer severe heat stress events than the open treatment. The spray treatment proved effective at reducing only the number of severe heat stress events. During the 182 day period 44% fewer severe heat stress events were measured for the spray treatment than for the open treatment.

The results suggest that on this specific case study farm the shade structure was far more effective at ameliorating moderate to severe heat stress than was the spray treatment.

The shade structure proved to be successful at ameliorating milk production loss across herds with low, medium and high susceptibility to heat stress. Milk production losses were ameliorated by 72% under the shade treatment but only 21% under the spray treatment for all three notional herd types. Over the 182 period of measurement this would equate to 60 litres of milk lost per cow for a low susceptibility herd, 80 litres of milk per cow for a moderate susceptibility herd and 101 litres of milk per cow for a high susceptibility herd.

Milk losses under the spray treatment were estimated at 169 litres of milk lost per cow for a low susceptibility herd, 226 litres of milk per cow for a moderate susceptibility herd and 282 litres of milk per cow for a high susceptibility herd. In the open paddock, over the 182 day period, loss of milk production was estimated at 215 litres per cow, 286 litres per cow and 358 litres per cow respectively.

6. FARMER AND INDUSTRY FEEDBACK

In April 2010 a workshop was organised in Echuca to present the results of this project and gather farmer and industry feedback. This workshop was facilitated by Dairy Australia and attended by dairy farmers and advisers. Workshop attendees showed a high level of interest and engagement, and much positive feedback received.

In a pre-workshop questionnaire some attendees noted that they had responded to reductions and changes in rainfall patterns, and temperature increases over the past 10 years with altered management regimes. The management changes were aimed at increasing water efficiency and at reducing heat stress on cattle, as well as securing adequate cattle fodder over the summer in the face of limited pasture availability. The management changes included changing irrigation practices; decreasing the ratio of pasture to feed, particularly over summer; and providing more shade structures for cattle. All who had made changes assessed them to be either moderately or substantially successful.

The majority of workshop attendees felt that understanding future regional climate projections and the implications of heat stress would have a substantial impact on the way they managed their farm businesses into the future.

All participants planned to use the knowledge gained about climate change and variability to determine future farm business strategies.

Full results from the workshop are included in Appendix 3.

7. NEXT STEPS

Heat stress is a significant issue for many intensive-livestock enterprises such as dairy, resulting in significant loss of income and increases in management costs. Understanding the frequency and occurrence of heat stress is important in order to modify current management practices. The Australian dairy industry is concerned that under current and future climates heat stress is reducing production and wants to know what adaptation can be employed to respond now. This study is an attempt to improve our understanding of the occurrence and impacts of heat stress at a regional scale, both for historical and projected climate data for the Murray Dairy region. The study developed equations to link heat stress to milk production and applied these at two spatial scales – a regional analysis to aid the dairy industry to discuss strategic options and at farm scale for dairy farmers to take tactical decisions. An important component of the project was setting-up data loggers to monitor daily climate variables at farm-scale with different adaptation options. Farmers, due to the loss of water allocations, are moving away from spraying cattle to reduce stress, to building shade structures. Taking the results of this study to a practical application, Dairy Australia have since embedded this work in the "Cool Cows" website to provide farmers with an assessment of the payback period for constructing shade structures. A phase 2 of this project has been funded and is underway (2010-12) where the methodology employed in this project has been extended to all the dairy regions in Australia.

This study also provided insights into the future course of research in this area. Some of the key next steps identified are:

- Longer period of measurement of THI on farms in different regions with different adaptations
- Linkage of THI with loss in milk production via regional data or farm by farm data
- Linkage of THI to changes in other key characteristics of milk such as fat content and milk solids
- Linkage of the adaptations to changes in other production factors. For example, shade-cloth covers will not only reduce summer heat stress but also likely reduce winter cold stress. Both will increase production and improve animal health
- Use of the above to undertake simple cost-benefit analyses of adaptations for heat stress under historical climate and future climate scenarios

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APPENDIX 1 – SHADING IMPACTS ON DAIRY HEALTH AND PRODUCTIVITY

The availability of shade for cattle can significantly reduce their heat load, largely by reducing the solar radiation they receive (Armstrong 1994; Kendall et al. 2006; Fisher et al. 2008). Cows with access to shade begin to preferentially use it when air temperature rises above 25°C or when THI is above 73; water uptake increases exponentially as air temperature increases (Kendall et al. 2006). Shade is an effective heat stress mitigation strategy provided sufficient shade is available to the whole herd (Fisher et al. 2008; Marcillac-Embertson et al. 2009; Schutz et al. 2009b).

Many options exist for providing animals with shade, including tree belts (along fence lines), and shade structures, usually constructed from shade cloth or metal (Verkerk 2009). Shade structures need to be large enough to be adequately ventilated, particularly in the case of metal structures, which store heat under the roof. Armstrong (1994) recommends about 3.5–4.5 m^2/cow as the optimum amount of shade and Verkerk (2009) concurs with 4 m^2/cow, however Fisher et al. (2008) caution that more than one structure, or more than the minimum amount of shade per cow, is advisable, in particular to allow for herd hierarchy dynamics. Cows preferentially spend more time in communal larger (e.g. 9.6 m^2) shaded areas over smaller (e.g. 2.4 m^2) shaded areas. Adequate space, or the provision of more than one shelter, reduces aggressive intra-herd behaviour (Fisher et al. 2008).

With increasing heat load the positive effects of a large shaded area become more pronounced (Schutz et al. 2009b). Cows are likely to all seek shade when solar radiation levels are highest, and thus sufficient shade to shelter the entire herd simultaneously is important (Tucker et al. 2008). Shade structures which provide at least 50% protection from solar radiation are most efficacious at reducing heat stress (Schutz et al. 2009a). Shade uptake by dairy cattle increases as protection from solar radiation increases from 0% to 25%, 50% and 99%. As well, greater protection from solar radiation results in lower minimum cattle body temperatures which allows greater potential recovery from heat stress events (Tucker et al. 2008).

There is no significant difference in grazing, standing, or lying times per 24 hour period between cows with and without access to shade, however cows with access to shade are more likely to graze at night and during cooler periods of the day, whereas cows without shade graze more in the mid afternoon (Kendall et al. 2006; Fisher et al. 2008; Tucker et al. 2008). Cows spend more time under shade on hotter days and on days with greater solar radiation (Schutz et al. 2009a). Cows without access to shade spend more time around water sources than cows with shade (Schutz et al. 2009b).

Cows with access to shade produce more milk and have lower peak and mean body temperatures than cows without shade, though there are no changes in milk composition as a result of access to shade. As well, shaded cows have higher feed intakes and lower respiratory rates and body temperatures than unshaded cows, particularly between 10am and 3pm. The benefits of shade may be tempered or enhanced by cow breed and, to a limited extent, by coat colour and environmental conditions (Kendall et al. 2006; Fisher et al. 2008; Marcillac-Embertson et al. 2009; Schutz et al. 2009b).

The pre-milking holding area is the most stressful area for dairy cows; particular efforts to alleviate heat stress experienced in this area are likely to result in higher average milk production (Armstrong 1994). Cows sprayed while awaiting milking have lower average body temperatures and higher average milk production than unsprayed cows over summer months (Armstrong 1994).

Other cooling methods may have greater impacts on cattle heat stress than shade structures but are less easy to retrofit to existing Australian farm landscapes. A comparison of three types of cooling methods (spray-and-fan cooled cows, evaporatively cooled cows and cows with access to shade only) demonstrated that both groups of proactively-cooled cattle suffered reduced heat stress (they were cooler, had lower respiration rates and smaller hormonal changes) than those cows with access to shade only (Correa-Calderon et al. 2004; Turner et al, 2005). Evaporative cooling is most effective in enclosed structures and thus is impractical for the rain-fed and irrigated pasture-based dairying operations throughout Australia. As well, the efficacy of evaporative cooling methods depends in part on the climate of the cooled environment: evaporative cooling becomes less efficacious as humidity and/or temperature increase (Berman 2009).

Shade structures are an effective method for cooling cattle, particularly in conditions similar to those experienced in Australian pastures. Cattle pastured under heat stress conditions and provided with shade structures are less adversely affected and better able to maintain performance and physiological indicators than similar cows sprayed with water to alleviate heat stress: the shaded cows have higher feed intakes and greater feed conversion efficiencies than those cooled by water sprinkling only (Marcillac-Embertson et al. 2009).

APPENDIX 2 – TEMPERATURE-HUMIDITY INDEX CALCULATIONS

The Temperature-Humidity Index (THI) was calculated using the well established equation from Johnson et al. (1963). This equation is expressed as follows:

$$\mathbf{THI = T_{max} + 0.36\ T_d + 41.2} \qquad \text{(eq 1)}$$

where T_{max} is daily maximum dry bulb temperature measured in degrees Celsius (^oC) and T_d is daily dewpoint temperature (^oC). Daily climate data for T_{max} and vapour pressure (VP - measured in hectopascals hPa) were accessed from the SILO climate surfaces (Carter et al. 1996; Jeffery et al. 2001) to give values on a 5 km grid across the Murray Dairy region (bounded by latitudes 34.0˚ S and 38.0˚ S and longitudes 143.0˚ E and 149.0˚ E) for the period 1960 to 2009. Calculation of THI and summary analyses from these daily time series gridded datasets was carried out using Climate Data Operators (CDO; Schulzweida 2009). CDO provides functions to apply calculations across each cell of the gridded datasets, and outputs the results in the same gridded format.

Dewpoint temperature was calculated using the method below:

$$T_d = (b * \gamma(T,RH)) / (a - \gamma(T,RH)) \qquad \text{(eq 2)}$$

where

$$\gamma(T,RH) = ((a * T)/(b + T)) + ln(RH / 100) \qquad \text{(eq 3)}$$

$$a = 17.271$$

$$b = 237.7$$

Where mean temperature (T) was measured in ^oC using the equation

$$T_{avg} = (T_{min} + T_{max}) / 2 \qquad \text{(eq 4)}$$

Saturated vapour pressure (E_s) was calculated using the equation

$$E_s = 6.112 * exp ((17.67 * T_{avg})/(T_{avg} + 243.5)) \qquad \text{(eq 5)}$$

Relative humidity (RH) was calculated from the vapour pressure dataset (VP) and E_s

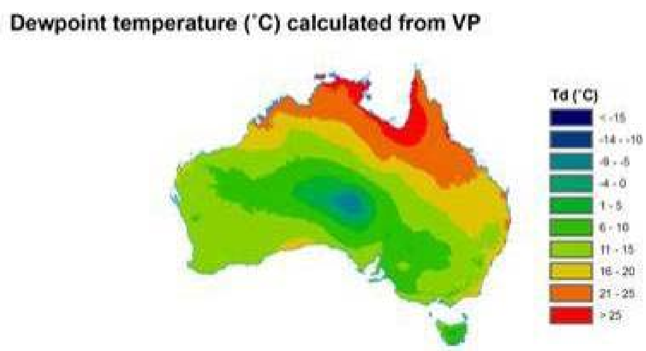
$$RH = (VP / E_s) * 100 \qquad \text{(eq 6)}$$

This approach was used as opposed to more traditional ways of calculating T_d i.e.

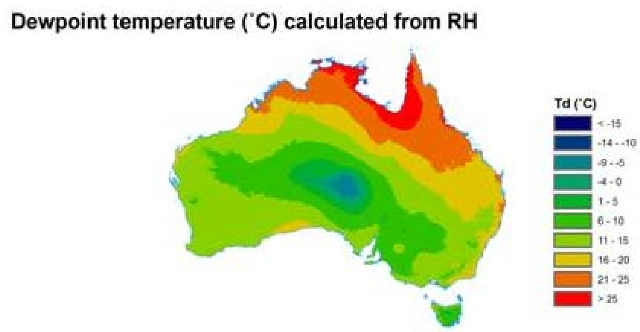
$$T_d = (234.5 * ln(VP / 6.112))/(17.67 – ln(VP / 6.112)) \qquad \text{(eq 7)}$$

As VP was not available from the suite of global climate models (GCMs) used to determine projected climate changes we used RH data which was readily available. An examination of the difference in THI derived from both methods was undertaken across the whole of Australia by comparing daily T_d values at a national scale across each month of the year. The comparison showed that across all days and months of the year the difference in T_d was less than 0.1°C. Figure 9.1 shows the pattern of T_d for 1 January 1960 generated from VP (Figure A2.1a) and from RH (Figure A2.1b). Figure A2.1c shows the absolute difference between the VP and RH approaches. This result has validated our selection RH to calculate the dew point temperature (since VP was not available in projected climate data sets).

(a)



(b)



(c)

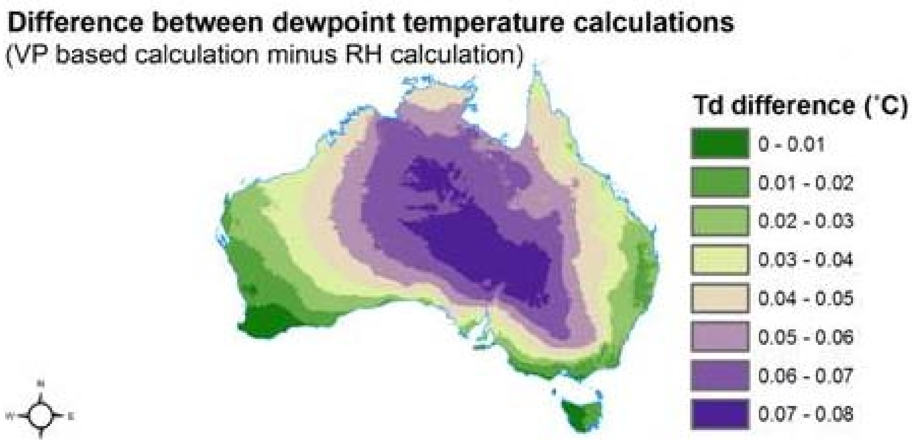


Figure A2.1 Dew point calculation for 1 January 1960 using (a) vapour pressure (VP) and (b) relative humidity (RH). Plot (c) compares the two difference in the calculations.

APPENDIX 3 – FARMER AND INDUSTRY FEEDBACK WORKSHOP RESULTS

A workshop was organised with the dairy farmers and advisers in Echuca on 21 April 2010 to present the results of this project and gather farmer and industry feedback. This workshop was facilitated by Dairy Australia. Of the 15 people attending the workshop 14 completed the pre-workshop questionnaire and 15 the post-workshop questionnaire. There was a high level of interest and engagement in the workshop from the attendees and much positive feedback received.

Attendees came from 8 different postal regions in NSW and Victoria and most had been involved with dairy farming for at least 11 years. A third of attendees had been engaged for 16-20 years, while over half had more than 20 years experience. While most of the workshop participants were dairy farmers, a significant minority (4 out of 14 responses) had an advisory role to dairy farm businesses. None of the attendees were unconnected with dairying.

Pre-workshop questionnaire results

Most attendees self-assessed their knowledge of a range of issues surrounding climate change, mitigation, adaptation, and likely impacts on their businesses as moderate. In their comments on the pre-workshop questionnaire workshop participants demonstrated a familiarity with common concepts and technical jargon used to describe climate change and climate variability.

In their comments, attendees noted reductions and changes in rainfall patterns, and temperature increases over the past 10 years. In response to these changes, 9 attendees had altered their management regimes, while 2 had not made any changes. The management changes were aimed at increasing water efficiency and at reducing heat stress on cattle, as well as securing adequate cattle fodder over the summer in the face of limited pasture availability, and included changing irrigation practices; decreasing the ratio of pasture to feed, particularly over summer; and providing more shade structures for cattle. All who had made changes assessed them to be either moderately (55%) or substantially (45%) successful.

Most attendees commented that they expected the climate to get warmer over the next 20 years. Expectations of rainfall differed: some respondents anticipated reductions, others increases in variability, while others expected overall increases in rainfall associated with decreases in winter/spring rainfall and increases in summer rainfall.

While respondents recognised the value of adding to their knowledge of the likely impacts of future climate and climate variability there was no clear indication of what would help reduce uncertainties for the dairying industry.

The majority of respondents felt that climate change and climate variability were important issues for Australia, while approximately 21% were unsure or did not believe that these were issues of importance.

Most respondents believed that communities and governments should act to address climate change, while opinion was divided as to how much farmer groups should be expected to do to contribute to climate change action (Figure A3.1). Opinions were more polarised in these questions than in most others.

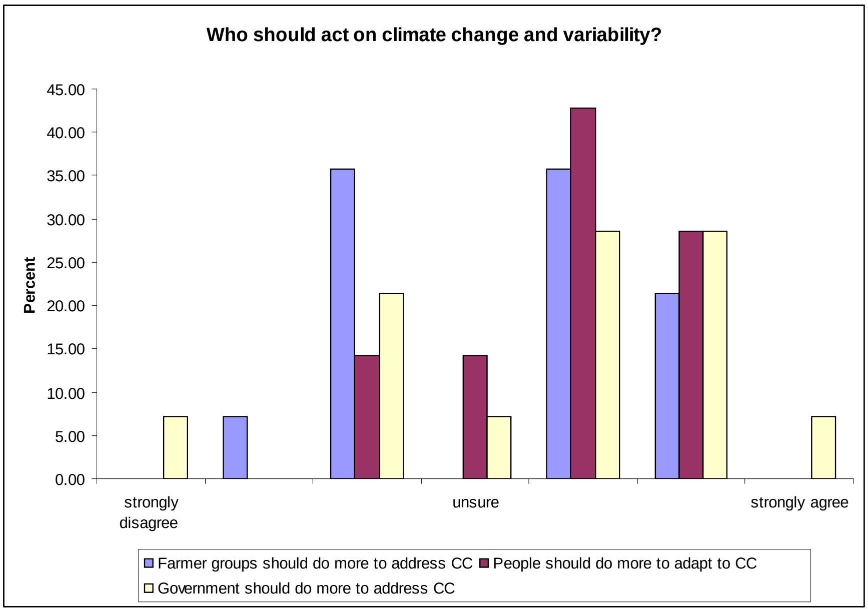


Figure A3.1 Perceived responsibility for action on climate change and variability

All attendees believed that farmers would be able to adapt to future climate change and variability, in particular to small gradual changes in climate (Figure A3.2). There was less certainty that farmers would be able to adapt to climate change under ongoing drought conditions or if the frequency of extreme events increased; in each instance a majority of farmers believed farmers would struggle to stay in business.

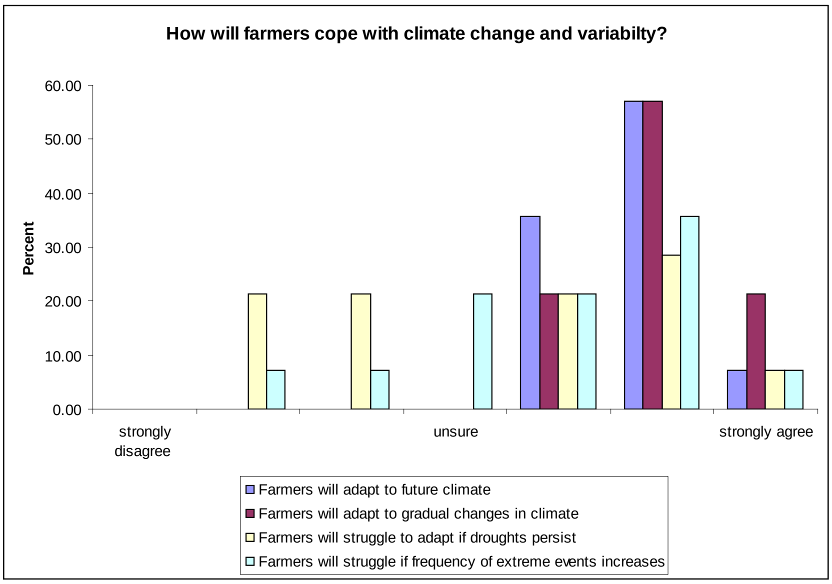


Figure A3.2 Expectations of farmers' ability to cope with climate change and variability

Post-workshop questionnaire results

All workshop attendees felt the workshop had contributed to their increased understanding of climate variability and change. Most participants (60%) felt that their knowledge had increased a substantial or significant amount (Figure A3.3).

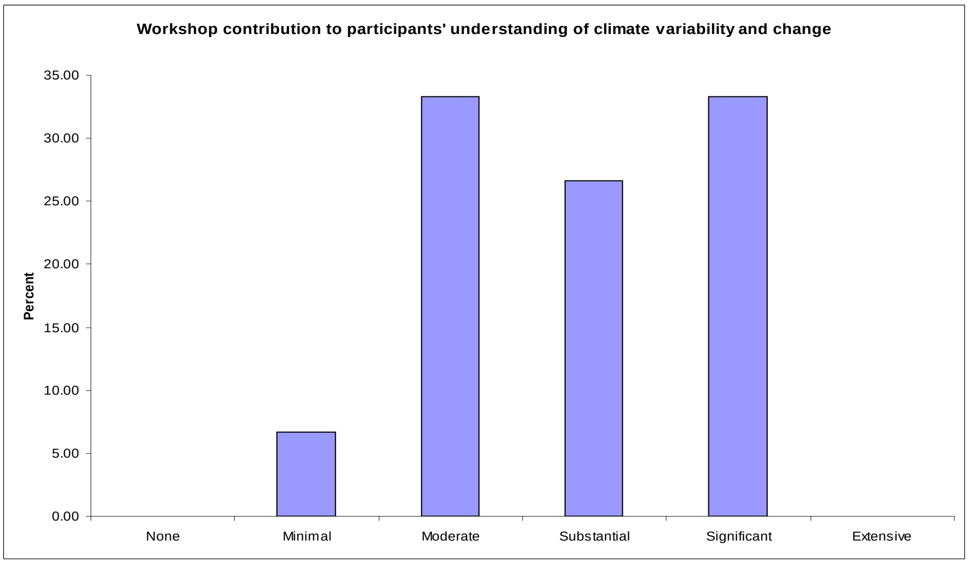


Figure A3.3 The extent to which participants felt this workshop contributed to their understanding of climate variability and change

The majority of workshop attendees (57%) felt that understanding future regional climate projections and the implications of heat stress would have a substantial impact on the way they managed their farm businesses into the future (Figure A3.4).

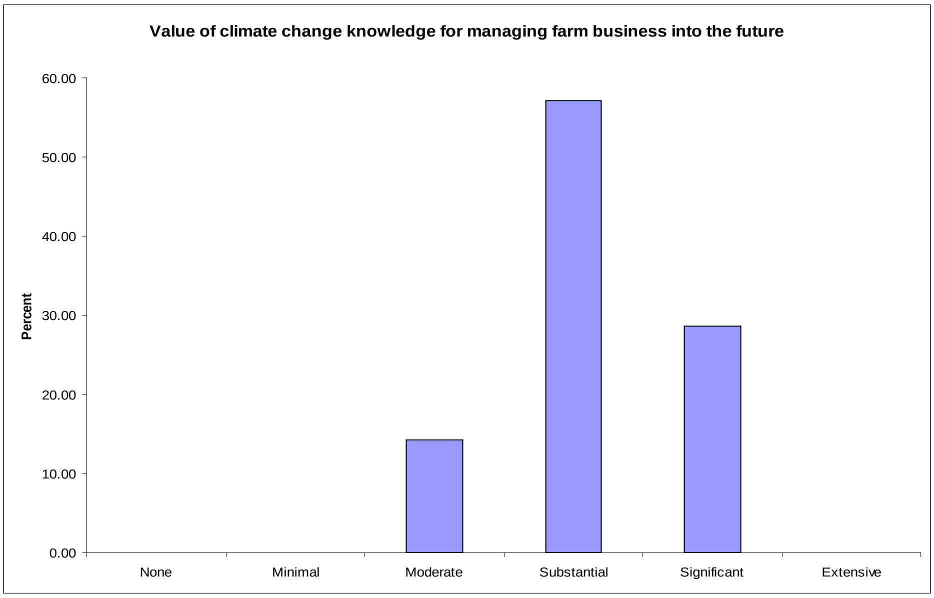


Figure A3.4 The value attendees place on climate change knowledge for effective management of farm businesses into the future

All participants planned to use the knowledge gained about climate change and variability to determine future farm business strategies: over 70% felt the knowledge gained would have a substantial or greater effect on their management strategies (Figure A3.5).

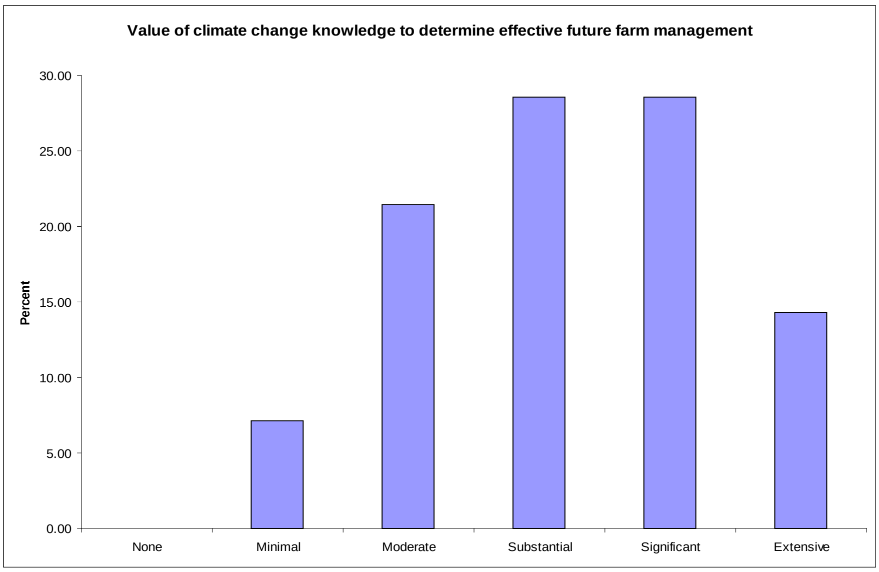


Figure A3.5 The extent to which attendees will use knowledge gained from the workshop to alter farm management strategies

Overall, most participants found the workshop to be relevant, of a high quality and well presented (Figure A3.6). Most attendees (77%) had a high understanding of the knowledge presented and felt they were able to address concerns and interact with the presenter and other participants positively (Figure A3.7). Informal comments after the workshop backed up this feedback and endorsed the positive views recorded in the questionnaire.

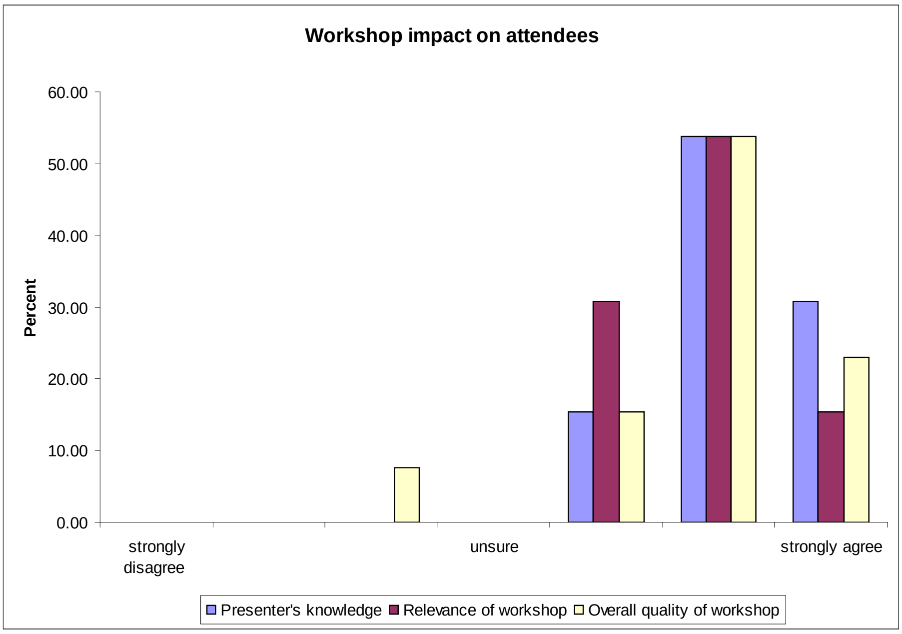


Figure A3.6 Attendees' views on workshop quality and relevance

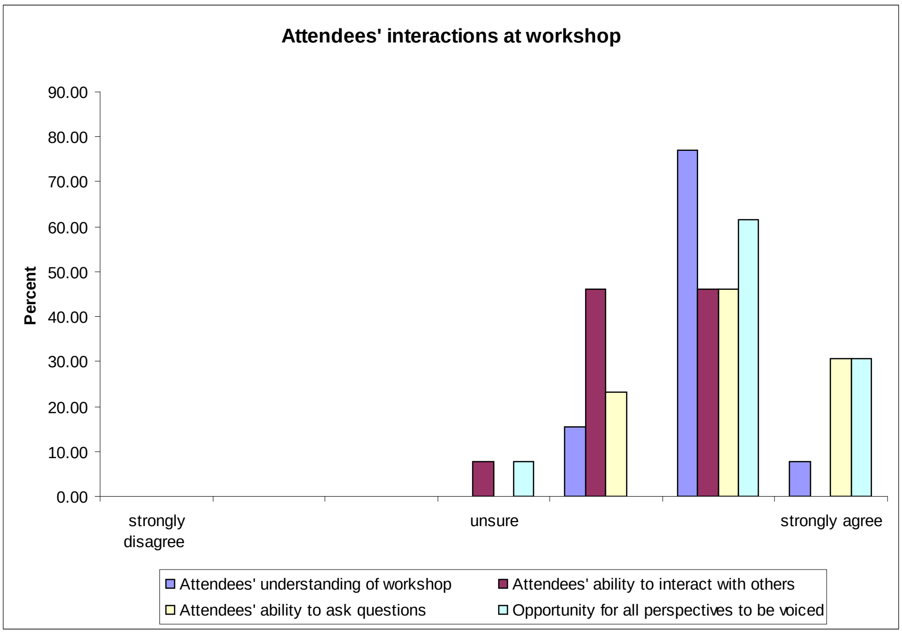


Figure A3.7 The extent to which attendees understood and were comfortable interacting at the workshop

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