ANTARCTIC CLIMATE & ECOSYSTEMS CRC

climate futures for tasmania

THE SUMMARY & TECHNICAL REPORT

Future Fire Danger

Fox–Hughes P, Harris RMB, Lee G, Jabour J, Grose MR, Remenyi TA & Bindoff NL

October 2015

Climate Futures for Tasmania
Future Fire Danger – The Summary and The Technical Report

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The Future Fire Danger research was undertaken primarily for the Tasmania State Emergency Service, through the Natural Disaster Resilience Programme and the Tasmanian Fire Research Fund (representing Parks and Wildlife Service, Forestry Tasmania and the Tasmania Fire Service).

Citation

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Disclaimer

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Grose MR, Fox-Hughes P, Harris RMB & Bindoff, NL (2014) Changes to the drivers of fire weather with a warming climate — a case study of southeast Tasmania. *Climatic Change,* 124, 255–269.

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Climate Futures for Tasmania:
future fire danger

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Foreword

South–eastern Australia is one of the three most fire–prone areas in the world and Tasmanians know only too well the ravages of bushfires on communities. The 2012 Tasmanian State Natural Disaster Risk Assessment highlighted fire driven by changing weather and climate as one of the natural hazards most likely to cause significant damage and cost to Tasmania.

Building on the existing high quality fine–scale climate information and the capacity of the Climate Futures for Tasmania project, the Future Fire Danger study examined changes in bushfire meteorology and fire danger hazards and risks. A unique aspect of the study was to understand the changes in the risk of fire danger in Tasmania and to provide this information to the fire agencies that help communities prepare for emergencies.

The projections indicate a steady increase in fire danger, especially in spring; a lengthening of the fire season; and more days at the highest range of fire danger. The consequences of increased fire danger have social and political implications; influencing the pace and direction of fire policy, logistics and funding; alerting and acknowledging the need to build capacity in and among at–risk communities (community resilience); and giving communities time to adapt to lost or changing ecosystems.

With a projected increase in the number of total fire ban days, then, we must prepare. This study provides the Tasmanian Government with the best available scientific evidence for our bushfire management planning. The report contains the information for our fire agencies to confidently prioritise and develop future bushfire preparation strategies.

Led by Professor Nathan Bindoff and authored by Dr Paul Fox–Hughes and his colleagues from the University of Tasmania, this collaborative study has demonstrated innovative leadership by involving and engaging stakeholders on all levels. Tasmania's fire agencies have been actively involved with the research from the beginning, guiding the research questions. The outputs from the study are strong and robust, meaning the research is directly applicable to our decision–making processes.

Tasmanian communities will benefit from this study into future fire danger and all those involved in the research are congratulated for their valuable contribution to emergency management in Tasmania.

Gavin Freeman
Acting Chief Officer
Tasmania Fire Service

Fire danger in Tasmania: the next 100 years

Fire danger has increased in recent decades, and is projected to increase further with global warming. We assessed the regional changes in fire danger that are projected to occur in Tasmania through to 2100 under a high emissions scenario.

In contrast with previous continental–scale studies which show little change in Tasmanian fire danger, our results indicate an overall increase in fire danger, especially in spring, with more days per year likely to require total fire bans. This increase in fire danger will have social and political implications.

Projected changes to extreme weather events

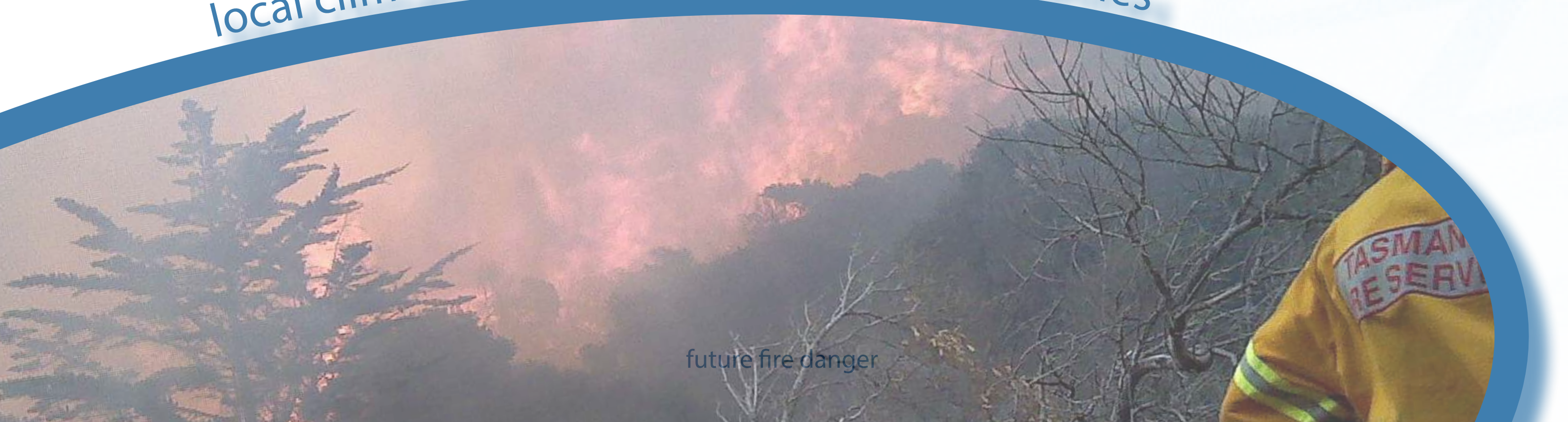
More extreme events have been recorded over the latter half of the 20th century, coinciding with changes to climate over that time. Higher maximum and minimum temperatures, more hot days and fewer cold days, and more intense rainfall events have all been observed and are expected to increase with future climate change.

The Intergovernmental Panel on Climate Change (IPCC), in its fifth assessment report (AR5), concluded with high confidence that climate change would lead to increases in the number of days with very high and extreme fire weather. The greatest increase is expected in regions where fire is not limited by the availability of fuel, such as in southern Australia. The IPCC identified increased fire weather, along with complex impacts on vegetation and biodiversity changes, as a key risk from climate change to people, property, infrastructure, ecosystems and native species.

The aim of the Future Fire Danger Project was to understand the changing risk of fire danger in Tasmania. This study builds on the scientific knowledge, fine–resolution climate simulations and the communication network generated by Climate Futures for Tasmania.

The study used observations and models to examine changes in fire danger over recent decades, then used climate model projections, including high–resolution simulations for Tasmania, to assess projected changes of fire risk in the future.

local climate information for local communities



- We now have fine–scale fire danger projections for Tasmania to 2100 under a high emissions scenario.
- The projections indicate:

  –> a steady increase in fire danger, especially in spring;

  –> a lengthening of the fire season;

  –> more days at the highest fire danger ratings at some locations.

What the science says...

The best available scientific evidence suggests the following changes by the end of the century:

- The type of strong weather system that brings the majority of the worst fire weather days to south–east Tasmania is projected to become more frequent.
- The total number of days per year categorised as 'Very High Fire Danger' is projected to increase by at least 120%. In the future, this is about a 10% per decade increase to 2100.
- Projected changes show strong regional and seasonal variations. Regions currently with the greatest risk of fire are projected to get worse most rapidly.
- The area of Tasmania under 'Total Fire Ban' conditions during summer due to fire weather is projected to increase by at least 75%. This is a 6% increase per decade.
- The average area of Tasmania in spring categorised as 'Very High Fire Danger' is projected to increase by at least 250%. This is a 20% increase per decade.
- There is no major change to the fire danger risk in autumn.
- The analysis suggests that all projections could be conservative estimates of future changes.

future fire danger

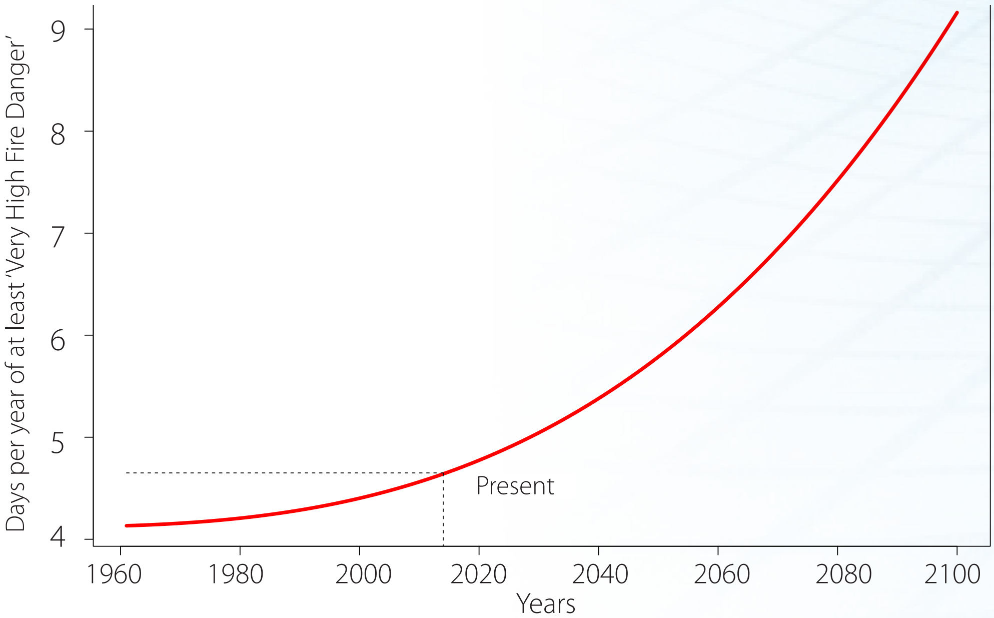
Increase in total fire ban days

There is an increase in both average and extreme (99th percentile) Forest Fire Danger Index projected through the century. The rates of change vary across Tasmania and are different in each season. Most notably there is an increase in high fire danger days projected to occur in spring. There is also a projected increase in the frequency of the weather systems associated with many of the most severe fire weather events, and increases to other large–scale drivers of fire risk, as well as projected increases in soil dryness.

Taken together, all these factors provide a consistent story of increasing fire weather risks through the 21st century. This increase in risk factors will underlie the ongoing year–to–year and decade–to–decade variability of fire weather events in Tasmania.

Given the expected shorter return periods of bushfire events, emergency services may need to plan for more rapid repair of vital infrastructure and recovery of personnel to meet these increased risks.

Projected Frequency of the 'Very High Fire Danger Days' from 1961 to 2100



Smoothed projection of the number of days per year categorised as at least 'Very High Fire Danger' from 1961 to 2100. Forest Fire Danger Index values will increase into the future, with the majority of the increase after 2050.

local climate information for local communities

Modelling future climate

Global climate models provide the best estimates of change to our climate to the end of the 21st century. Recent advances in climate modelling techniques have enabled simulations of extreme climatic events at regional scales, like Tasmania.

- Climate Futures for Tasmania is the most complete regional climate change study of Tasmania for the 21st century.
- We used dynamical downscaling to generate climate projections over Tasmania at a finer scale than ever before.
- We simulated the complex processes that influence Tasmania's weather and climate, providing a detailed picture of Tasmania's future climate.
- The dynamical downscaling used in the project is an established technique that uses input from global climate models to generate high–resolution climate simulations.
- The successful validation of the climate simulations gives confidence in projections of future temperature and rainfall, and their use to analyse changes in extreme weather events.

Greenhouse emissions scenario

Climate Futures for Tasmania simulated future climate with six downscaled global climate models. Reported in this study is the A2 (high greenhouse emissions) scenario from the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios.

Dynamical Downscaling

Global climate model output at a resolution of 200 km to 300 km is too coarse for understanding changes in extreme events that occur at a relatively small spatial scale and short durations.

In Climate Futures for Tasmania, the global climate model output was used in another climate model (CSIRO's Cubic Conformal Atmospheric Model) to create fine–scale regional climate information. This process is called downscaling. Six global climate models were downscaled to a resolution of 0.1 degree (approximately 10 km). The results are presented as the mean of the six simulations, and the changes were assessed against the reference, or baseline, period of 1961–1980.

Bias–adjustment

All climate model simulations contain some intrinsic biases. Biases are errors that typically occur consistently and predictably. Often these biases are caused by the model's resolution. For example, the 10 km resolution of the Climate Futures for Tasmania simulations means that steep ridgelines may not be captured, resulting in the rain shadow on the downwind side of the ridge being under–estimated.

Most climate simulations therefore need to be 'bias-adjusted'. This is a standard scientific method for handling consistent differences between observations and simulations. Temperature and rainfall were bias–adjusted against observations from recent years in the Australian Water Availability Project (AWAP*) dataset. Wind and relative humidity were not bias–adjusted because these variables were not available in the AWAP dataset.

* AWAP is the Australian Water Availaibilty Project, a joint project between CSIRO and the Bureau of Meterology.

THE TECHNICAL REPORT

Climate Futures for Tasmania: future fire danger

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definitions of key terms

Climate prediction

A climate prediction, or climate forecast, is an attempt to produce a description or estimate of the most likely actual evolution of the climate in the future (for example, at seasonal, interannual, or long–term time–scales). A prediction is a probabilistic statement that something will happen in the future based on what is known today.

Climate projection

A climate projection is a model–derived description of possible future climates under a given set of plausible scenarios of climate forcings. Climate projections are distinguished from climate predictions to emphasise that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions about future socio–economic and technological developments that are subject to substantial uncertainty. A projection is therefore a probabilistic statement of what could happen if certain assumed conditions prevail in the future.

Climate scenario

A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as observations of current climate. A 'climate change scenario' is the difference between a climate scenario and the current climate.

A2 emissions scenario

In the Fourth Assessment Report (AR4), the IPCC addressed the uncertainty about future rates of greenhouse gas and aerosol emissions using emissions scenarios. The A2 scenario is one of the four socio–economic scenario families in the Special Report on emissions Scenarios (SRES) set (A1, A2, B1, and B2), each of which results in alternative levels of greenhouse gas emissions in the future.

The A2 emissions scenario assumes a world of independently operating, self–reliant nations in which population continues to increase. Economic development is regionally oriented and economic and technological development is relatively slow, compared to the other story lines. This results in global emissions at the higher end of the SRES emissions scenarios (but not the highest).

Definitions developed from IPCC AR5 Report:

http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Glossary_FGD.pdf

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FREQUENTLY USED ABBREVIATIONS

Fourth Assessment Report (IPCC)	AR4
Fifth Assessment Report (IPCC)	AR5
Australian Water Availability Project	AWAP
Cubic Conformal Atmospheric Model	CCAM
Carbon Dioxide	CO_2
Cumulative Forest Fire Danger Index	ΣFFDI
Forest Fire Danger Index	FFDI
Global Climate Model	GCM
Intergovernmental Panel on Climate Change	IPCC
Mean Sea Level Pressure	MSLP
National Center for Atmospheric Research	NCAR
National Centers for Environmental Prediction	NCEP
Soil Dryness Index	SDI
Special Report on Emissions Scenarios (IPCC)	SRES
Tasmanian Partnership for Advanced Computing	TPAC

1 Future Fire Danger Project

The 2012 Tasmanian State Natural Disaster Risk Assessment assessed the risk to Tasmanian communities from natural hazards, including floods, bushfires, landslides, severe storms, tsunamis and earthquakes. The assessment aimed to improve state emergency preparedness across Tasmanian communities and regions. Bushfires were identified as being one of the top two most significant hazards in Tasmania, along with flooding.

The Future Fire Danger Project was therefore initiated by the Tasmania State Emergency Service, through funding from the Natural Disaster Resilience Programme and the Tasmanian Fire Research Fund. The research used the climate projections generated by the Climate Futures for Tasmania project, and interpreted the new information to meet the needs of Tasmanian emergency services and fire agencies, in collaboration with the Tasmanian State Government.

The Climate Futures for Tasmania projections provided information about relevant processes at an appropriate temporal and spatial scale for Tasmania. This enabled seasonal and annual changes in fire danger to be identified, as well as changes in the synoptic climatology associated with fire weather in different regions of Tasmania under future climate conditions. This report summarises the results under the A2 emissions scenario through to 2100.

Fire danger was described using the McArthur Forest Fire Danger Index (FFDI), a standard index used by weather forecasters and fire services in eastern Australia to determine fire hazard and make operational decisions around fire management. The FFDI incorporates surface air temperature, relative humidity and wind speed, combined with an estimate of fuel dryness (Drought Factor, based on Soil Dryness Index and recent precipitation) to give an index of daily fire danger.

Daily values of McArthur Forest Fire Danger Index were generated at 10 km resolution over Tasmania, for the period 1961–2100. The project then examined patterns of mean sea level pressure and synoptic drivers of particularly high fire danger days. Together, these analyses gave an understanding of the weather patterns associated with the worst fire danger periods in the past (from 1961) and gave us the ability to project fire danger into the 21st century.

The modelled timeseries was separated into 20–year periods to quantify the changes in Forest Fire Danger Index into the future compared to historical conditions. Results are presented for three periods of interest, the historical period (1961–1980), the intermediate period (2041–2060), and the future period (2081–2100). Comparing the relative change of historical–to–present and historical–to–future provides context and scale.

The Tasmania Fire Service usually invokes a 'Total Fire Ban' when the FFDI is forecast to equal or exceed 38. This recognises that the difficulty of suppressing a fire is heightened by weather conditions such as high temperature, strong wind and low relative humidity. Bans might apply to the whole state or only to specific regions. Analyses of FFDI were produced for the Bureau of Meteorology weather forecast districts which are of most relevance to the operations of the Bureau and Tasmania Fire Service (Figure 1).

This report summarises some of the key findings of the project, which have been subject to the peer review process and published in the international scientific literature (Fox–Hughes et al. 2014 and Grose et al. 2014), including the results of models projecting cumulative Forest Fire Danger Index; the synoptic drivers of particularly dangerous days; and trends in soil moisture. Limitations and validation of these fire indices are summarised at the end of the report.

Forecast Districts Studied

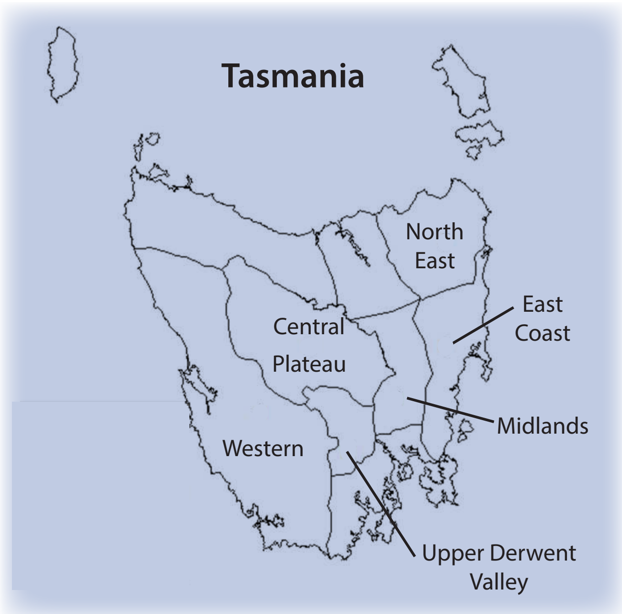

Figure 1 The Bureau of Meteorology weather forecast districts used in this study to provide a rough transect of Tasmania. The area within each district has a broadly similar climate. Un–labelled districts were not considered in the current study.

About Climate Futures for Tasmania

Climate Futures for Tasmania is the Tasmanian Government's most important source of climate change data at a local scale. It is a key part of Tasmania's climate change strategy as stated in the Tasmanian Framework for Action on Climate Change and is supported by the Commonwealth Environment Research Facilities as a significant project.

The project is unique in Australia. It was designed from conception to understand and integrate the impacts of climate change on Tasmania's weather, water catchments, agriculture and climate extremes, including aspects of sea level, floods and wind damage. In addition, through complementary research projects supported by the project, new assessments were made of the impacts of climate change on coastal erosion, biosecurity and energy production, and new tools developed to deliver climate change information for infrastructure asset managers and local government.

Climate Futures for Tasmania used data from six global climate simulations under the A2 emissions scenario. The global climate models were downscaled to a higher spatial resolution by including more localised information about Tasmanian weather systems. This downscaling enabled the project to obtain projections of Tasmanian climate on grids of approximately 10 km resolution at daily time steps through to 2100. The finer resolution captures regional variation in climate processes and the climate change signal. This is particularly valuable for understanding climate responses in Tasmania, which has a complex topography and coastline, and a range of regional climate influences.

The Climate Futures for Tasmania project complements climate analyses and projections done at the continental scale for the Fourth Assessment Report from the Intergovernmental Panel on Climate Change, at the national scale in the *Climate Change in Australia* report and data tool, as well as work done in the south–east Australia region in the *South Eastern Australia Climate Initiative*. The work also complements projections done specifically on water availability and irrigation in Tasmania by the *Tasmania Sustainable Yields Project*.

2 Results

2.1 Cumulative Forest Fire Danger Index

The Cumulative Forest Fire Danger Index is the sum of the daily maximum Forest Fire Danger Index across one year (July to June), incorporating a single fire season. Higher values indicate more days of high fire danger relative to other years or regions (Figure 2 and Figure 3). An increase in the Cumulative Forest Fire Danger Index can be interpreted as an increase in the potential incidence and/or severity of bushfire.

There is an increase in Cumulative Forest Fire Danger Index across Tasmania, as seen in Figure 2(c). The evidence points to an increase in Cumulative Forest Fire Danger Index in all regions during the next century, with the greatest increase in those districts already subject to a higher Cumulative Forest Fire Danger Index (that is, the East Coast, Midlands and Upper Derwent Valley). The values for future Cumulative Forest Fire Danger Index represent close to a 30% increase on 1961–1980 values.

The rate of change per decade and the variation across districts and between models is shown in Figure 3. The trend of the projections is distinctly positive, despite annual variations, in all weather forecast districts studied.

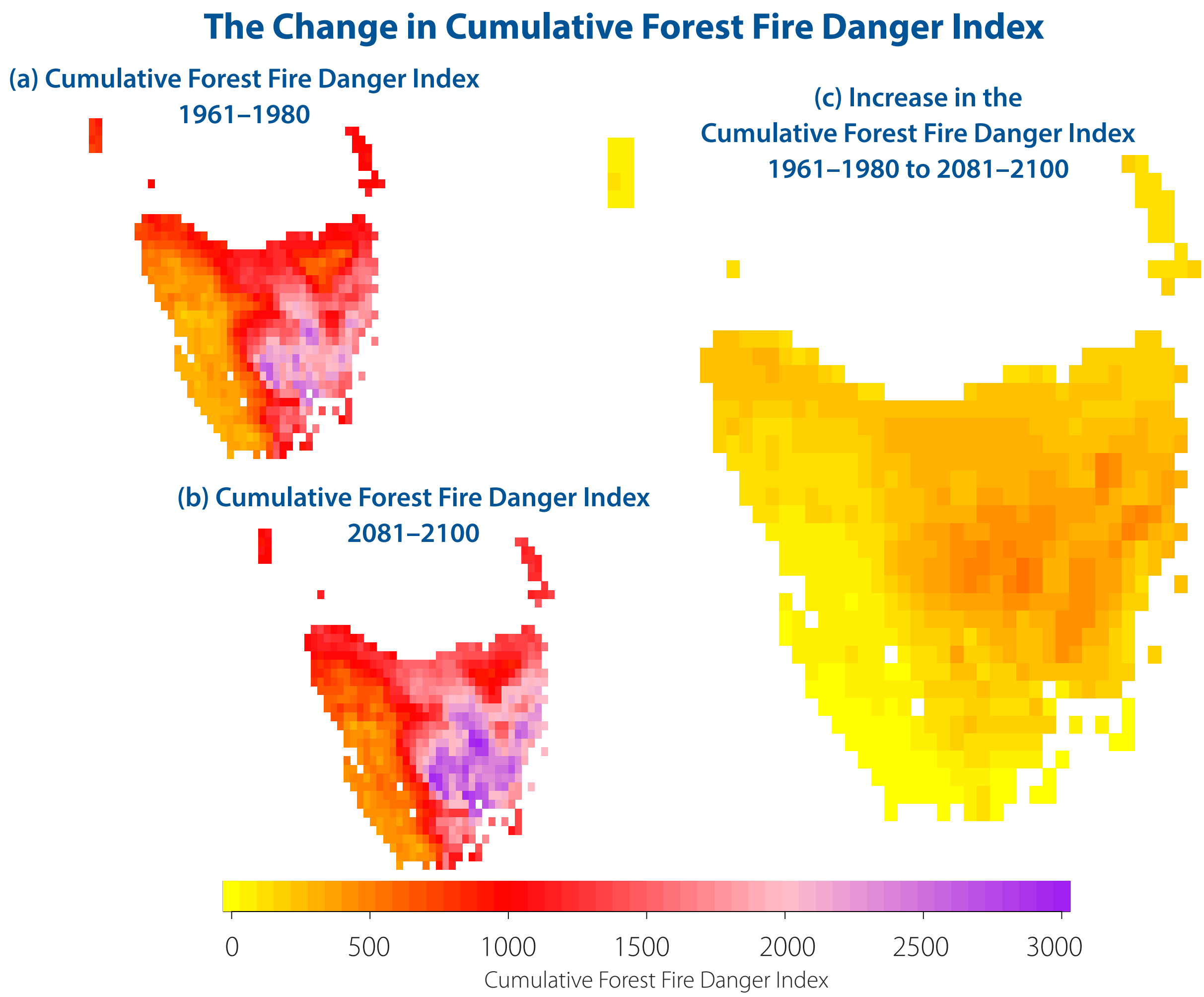

Figure 2 Multi-model mean Cumulative Forest Fire Danger Index values across Tasmania, averaged over (a) 1961–1980 and (b) 2081–2100 with (c) presenting the expected increase in Cumulative Forest Fire Danger Index from 1961–1980 to 2081–2100. The most rapid increases in Cumulative Forest Fire Danger Index (about a 30% increase on 1961–1980 values) are in the regions that already have the highest values: the East Coast, Midlands and Upper Derwent Valley.

Table 1

Conversion: Number of days per year to Percentile

1 day per year	99.7th Percentile
2 days per year	99.5th Percentile
3.65 days per year	99.0th Percentile
5 days per year	98.7th Percentile
10 days per year	97.3th Percentile
18.25 days per year	95.0th Percentile
90 days per year (that is, most of summer)	75.4th Percentile

The Change in Cumulative Forest Fire Danger Index

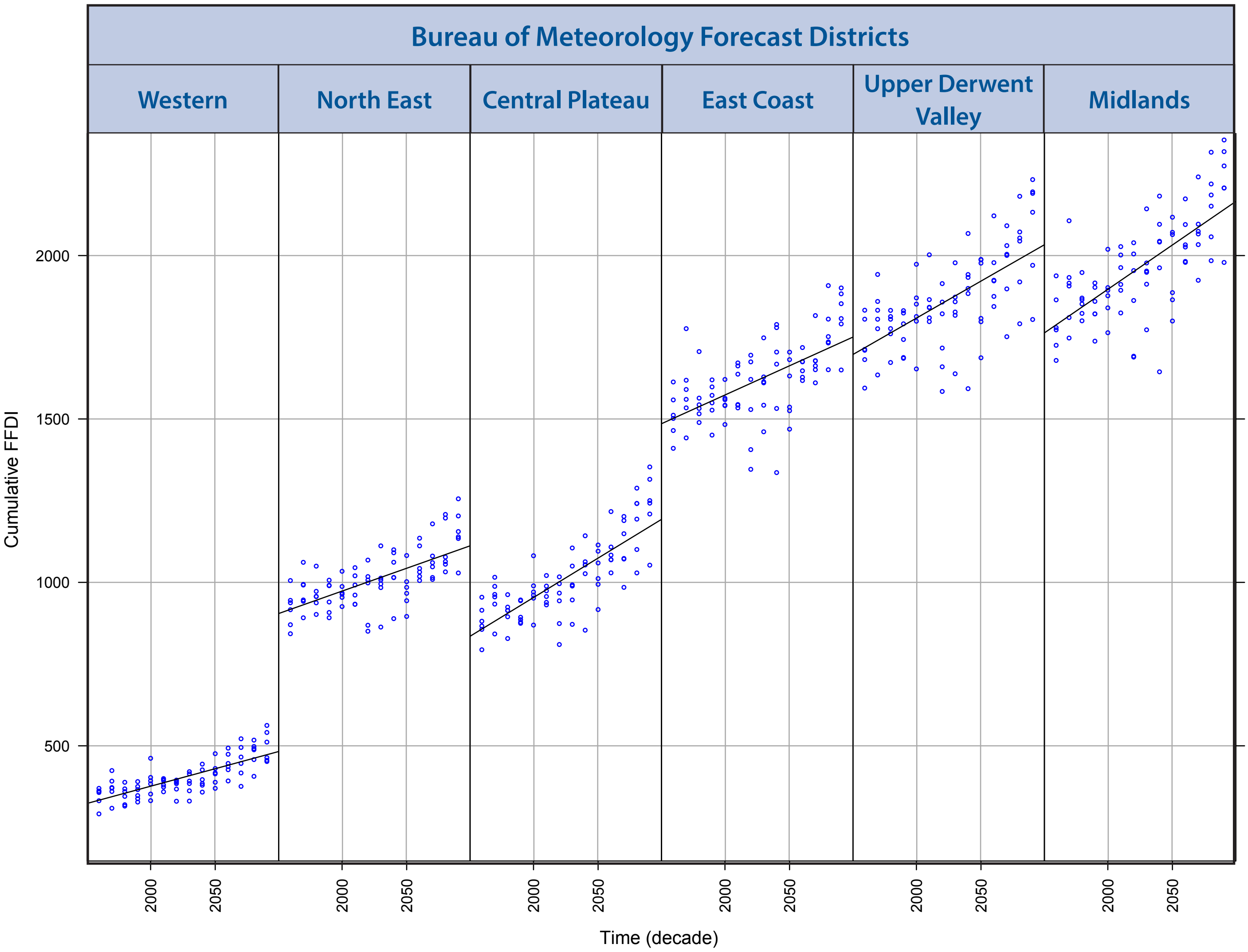

Figure 3 Cumulative Forest Fire Danger Index for the six regional climate models in this study, averaged by Bureau of Meteorology weather forecast district and by each decade from 1960 to 2090. Solid black line highlights the general trend, where a steeper slope indicates more rapid increase in Cumulative Forest Fire Danger Index values. All regions exhibit an increase in Cumulative Forest Fire Danger. The most rapid increases in Cumulative Forest Fire Danger Index (about a 30% increase on 1961–1980 values) are in the regions that already have the highest values: the East Coast, Midlands and Upper Derwent Valley.

2.2 High Fire Danger Days

The projections of Forest Fire Danger Index (FFDI) show significant increases in the area of Tasmania experiencing very high and extreme levels of fire danger. Table 4 shows how FFDI values are related to the Fire Danger Ratings that are commonly used for bushfire warnings and community information. Fire Danger Ratings above Very High Fire Danger indicate conditions when fires may be impossible to control, due to their intensity and rapid spread. The change in fire danger varies across regions and in different seasons (see Table 2 and Figure 4).

We use the 95th and 99th percentiles to describe changes to the extremes of the Forest Fire Danger Index. Percentiles indicate the value below which a given percentage of observations fall. For example, the 95th percentile is the value below which 95% of the observations were found, or the highest 5% of daily FFDI values. The 95th percentile value is likely to be experienced approximately once every three weeks, on average, during the fire season. The conversion table translates days per year into percentiles (Table 1).

The annual values for 95th and 99th percentile FFDI are seen in Figure 5. In the 1961–1980 baseline period the 99th percentile value of FFDI during the fire season was 'Very High' in 31% of the state. This is projected to increase to 36% by mid–century (2041–2060) and 46% by the end of the century (2081–2100) (Table 3). This means that in the next 30–50 years the area of land which represents the greatest risk and requires the most intensive fire management could increase by 16%. There is considerable regional variation across the state, and the overall pattern is maintained through time. The region of significant fire danger in the southeast gradually expands north through the lowlands and along the east coast.

In recent decades, east and south–east Tasmania has experienced an increase in the number of dangerous fire weather events in spring but not in autumn. Projected increases in the 99th percentile FFDI are consistent with these recent trends, showing an increase in spring but not autumn (Figure 4). The projections show that the fire season will begin earlier and last longer. The projected increase in spring FFDI is greater than the increase in summer, which is quite modest until the latter part of the century. This consistency with recent trends suggests that observed changes are driven by climate change and we can expect a continuation of these trends as the climate changes further.

Table 2 Proportion of Tasmania exceeding Forest Fire Danger Index (FFDI) thresholds during different seasons. The Tasmania Fire Service usually declares Total Fire Bans at FFDI 38 or higher, but may declare them at other thresholds if circumstances demand.

		1961–1980	2041–2060		2081–2100	
		Affected Area	Affected Area	Increase from 1961–1980	Affected Area	Increase from 1961–1980
FFDI ≥ 12 (HIGH)	Spring	51%	64%	25%	77%	51%
	Summer	98%	98%	0%	99%	1%
	Autumn	53%	61%	15%	72%	36%
	Winter	1%	2%	100%	6%	500%
FFDI ≥ 25 (VERY HIGH)	Spring	6%	13%	117%	21%	250%
	Summer	43%	49%	14%	65%	51%
	Autumn	0%	0%	0%	0%	0%
	Winter	0%	0%	0%	0%	0%
FFDI ≥ 38 (TOTAL FIRE BAN)	Spring	0%	0%	0%	0%	0%
	Summer	8%	9%	13%	14%	75%
	Autumn	0%	0%	0%	0%	0%
	Winter	0%	0%	0%	0%	0%

Change in the Forest Fire Danger Index 99th Percentile Values

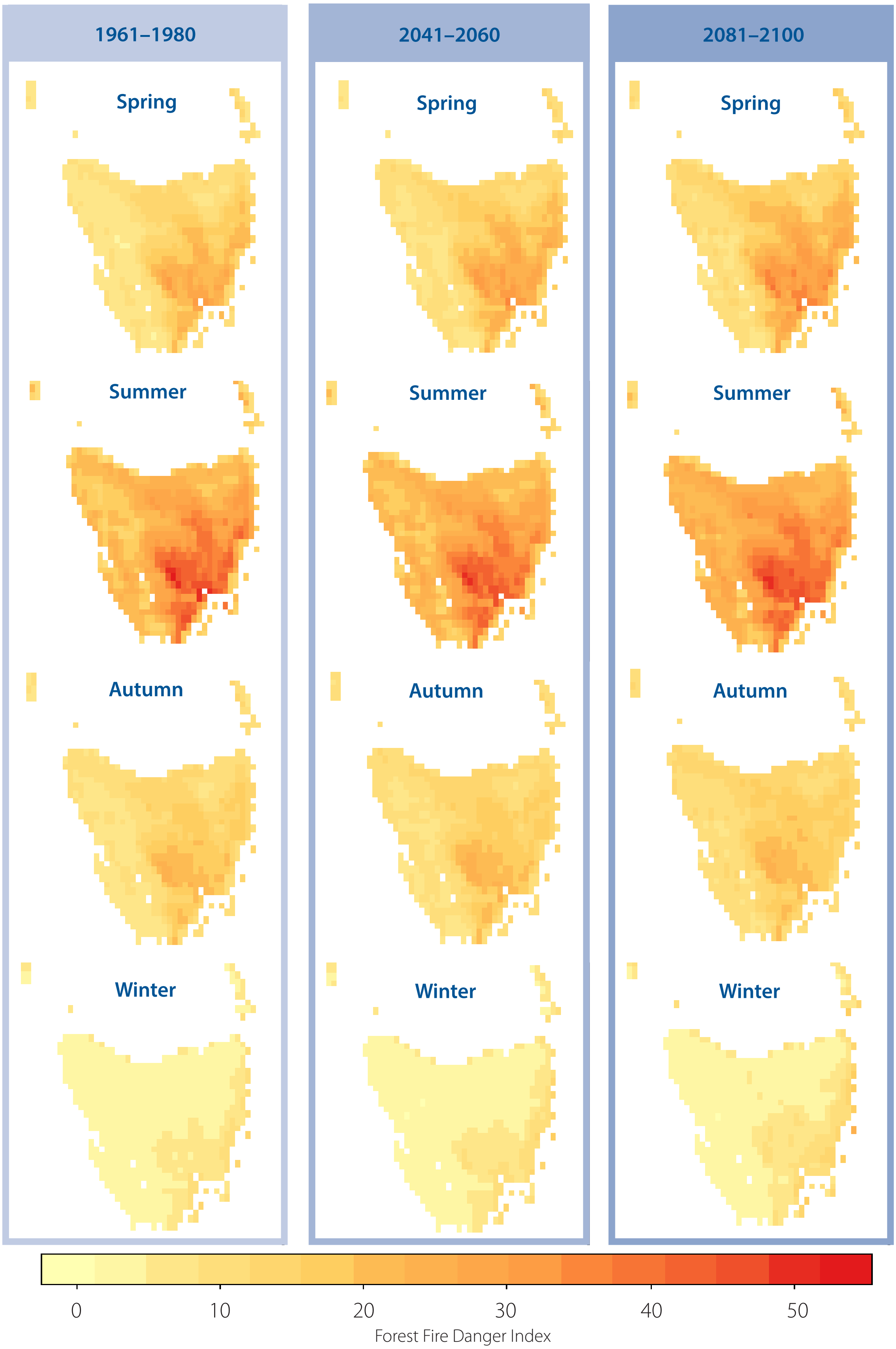

Figure 4 The 99th (3 days each year) percentile Forest Fire Danger Index values during each season at each location (grid cell) across Tasmania during the periods 1961–1980; 2041–2060 and 2081–2100. Spring exhibits a much greater increase in the 99th percentile values in comparison to other seasons. This indicates an earlier start to the fire season by 2081–2100.

Change in the Forest Fire Danger Index 95th and 99th Percentile Values

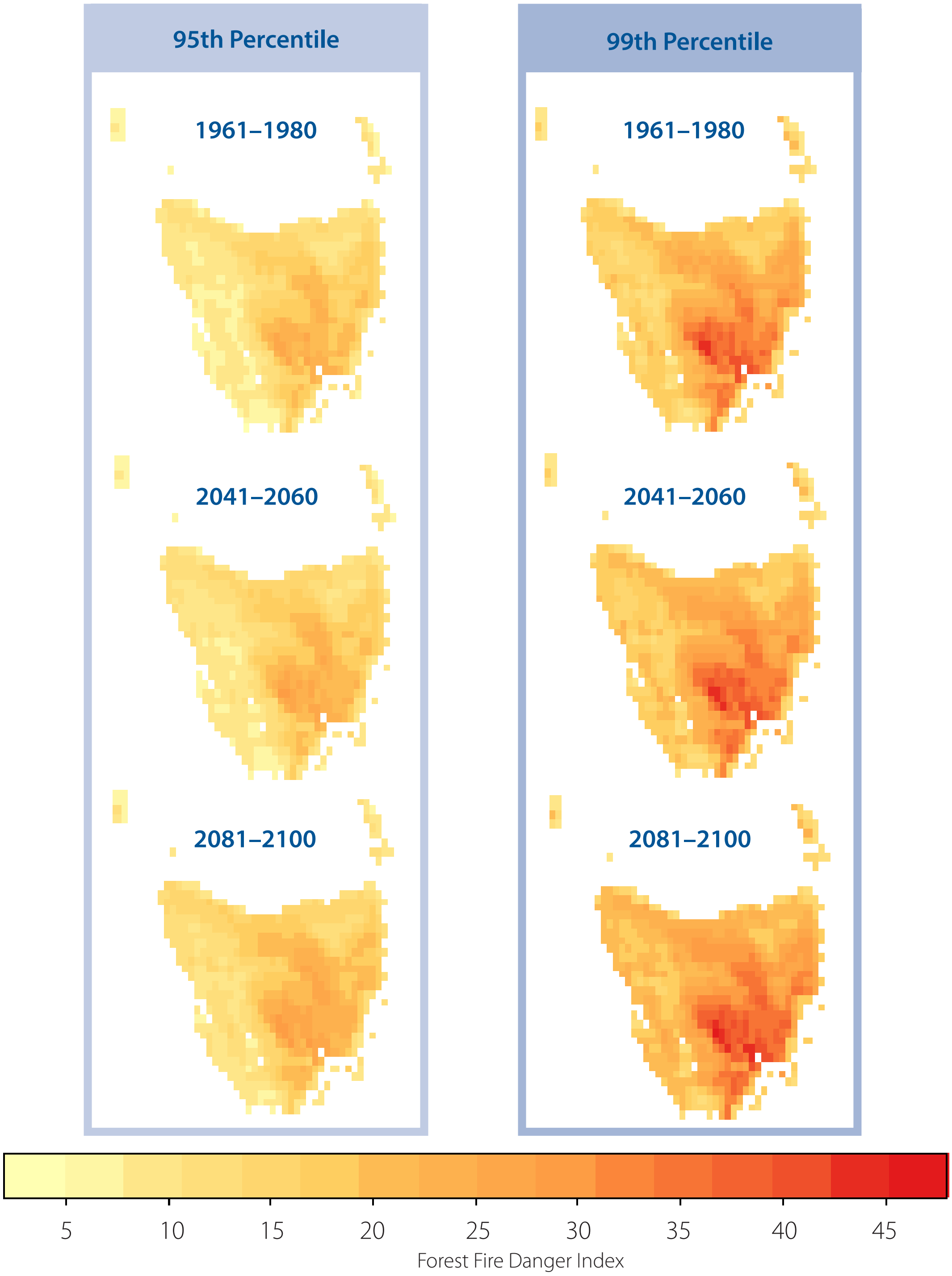

Figure 5 The 95th and 99th (3 days each year) percentile Forest Fire Danger Index annual values at each location (grid cell)across Tasmania during the periods 1961–1980; 2041–2060 and 2081–2100. These percentiles represent values that would occur 18 and 3 days each year (95th and 99th percentiles respectively). There is significant regional variability, with the highest 95th and 99th percentile values observed in the south–east corner of Tasmania, which are associated with those regions that are known to be at higher risk of bushfire. The regional pattern does not change very much into the projected future, although the 95th and 99th percentile values do increase over time.

Table 3 Proportion of Tasmania exceeding Forest Fire Danger Index (FFDI) thresholds during the fire season (October–March). Total Fire Bans can be declared at values lower than 38. Percentiles relate to the frequency of FFDI values of equal or greater severity. The 95th is equivalent to at least 18 events per year and the 99th is equivalent to at least 3 events per year.

	Percentile	1961–1980	2041–2060		2081–2100	
		Affected Area	Affected Area	Increase from 1961–1980	Affected Area	Increase from 1961–1980
FFDI ≥ 12 (HIGH)	95th	56%	64%	14%	79%	41%
	99th	96%	97%	1%	99%	3%
FFDI ≥ 25 (VERY HIGH)	95th	2%	4%	100%	9%	35%
	99th	31%	36%	16%	46%	48%
FFDI ≥ 38 (TOTAL FIRE BAN)	95th	0%	0%	NA	0%	NA
	99th	2%	3%	50%	6%	200%

Table 4 Conversion of Forest Fire Danger Index to Fire Danger Ratings

Conversion: 'Forest Fire Danger Index' to 'Fire Danger Rating'

Forest Fire Danger Index	Fire Danger Rating
0–11	Low–Moderate
12–24	High
25–49	Very High
≥ 38	TOTAL FIRE BAN in Tasmania
50–74	Severe
75–99	Extreme
>100	Catastrophic

2.3 Synoptic drivers of particularly dangerous days

The previous sections discussed projections of fire danger based on the Forest Fire Danger Index (FFDI). To understand the processes behind days of very high FFDI, and assess potential changes in fire weather into the future, the synoptic weather patterns associated with high fire danger in Tasmania were also examined, and future changes to these were assessed.

First we tested whether there were any consistent synoptic weather patterns associated with extreme fire danger ('Severe', 'Extreme' and 'Catastrophic' fire danger classifications) in Tasmania. We looked for the presence of an atmospheric pattern associated with many of the worst fires in south–east Australia and Tasmania, where a deep cold front with strong prefrontal winds brings hot, dry air down from the Australian continent over Tasmania. The presence of such a weather pattern can be diagnosed by a strong gradient in temperature over Bass Strait and Victoria at 850 hPa. This test was devised by Mills (2005) after examining the weather system present on Ash Wednesday, 1983.

The fire weather events associated with high fire danger days were identified within three different models, the National Centres for Environmental Prediction model (NCEP), the Australian Water Availability Project model (AWAP) and the Climate Futures for Tasmania model. This comparison was used to assess the inter–model variability, and validate the Climate Futures for Tasmania outputs against observations. This successful validation allows for great confidence to be placed in the Climate Futures for Tasmania projections.

The synoptic patterns identified by Mills (2005) as being diagnostic for extreme fire weather were found to have been present during many of the worst fires in Tasmania, including the fires on 'Black Tuesday' on 7 February 1967 in south–east Tasmania, the 12 February 1982 and the fires of 4 January 2013 (Figure 6). The highest fire dangers in south–east Tasmania were also found to be associated with a typical pattern of mean sea level pressure (Figure 8).

Weather pattern on 04 January 2013 Bushfires

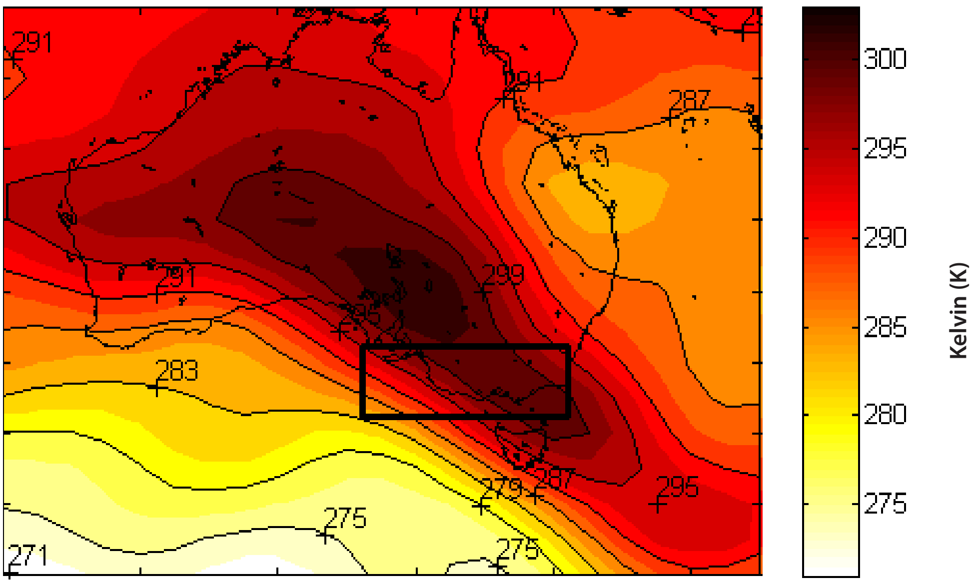

Figure 6 A strong cold front that draws hot air down over Tasmania is associated with many of the highest fire danger days. This was the case on the 4 January 2013 shown here, indicated by the temperature (in Kelvin) of the atmosphere at 850 hPa level. Also shown is the box over Victoria used to detect the strong gradient.

Secondly, we assessed whether these large–scale weather patterns may change in the future. There was considerable variability in the frequency of these systems from decade to decade, and a range in results from different climate models. However, we found that the higher resolution of the downscaled simulations gave a more realistic depiction of these systems than many GCMs, and represented the observed patterns well.

The analysis identified a clear signal that these systems are projected to occur more frequently on average, with an increase in frequency of at least 10% by the end of the century. A steady increase in the temperature associated with extreme fire weather was observed, indicating an increase in the severity of these events. This can be seen in temperature at 850 hPa during these events from the past into the future (Figure 7).

The results add greater detail and understanding at the regional scale, in support of previous studies that suggest fire weather risks in Tasmania will increase in response to changes in large–scale climate processes. For example, areas burned in western Tasmania each year show a correlation with rainfall in the preceding October to March (Nicholls & Lucas 2007), and there is a projected decrease in rainfall during this season. Positive Indian Ocean Dipole (IOD), a large–scale climate phenomenon in the Indian Ocean, can pre–condition fuel for bushfire, and the number of positive IOD events is projected to increase.

Overall, Climate Futures for Tasmania modelling projections indicate an increase in the frequency and the severity of fire weather events into the future. Further, the magnitude of the temperature gradient is maintained in future projections, indicating that the synoptic pattern remains similar. These results suggest that our current understanding of how weather influences fire danger and risk will remain applicable into the future.

Weather patterns associated with high Forest Fire Danger Index

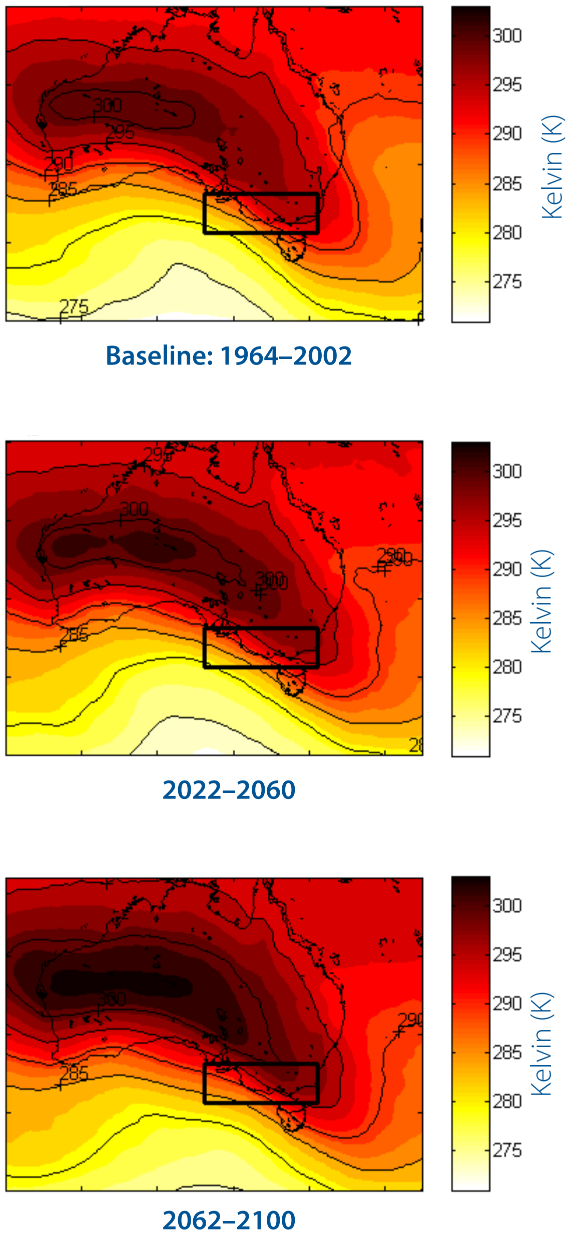

Figure 7 The air temperature at the 850 hPa level during events of strong prefrontal winds and severe fire weather in Tasmania modelled in periods in the past and projected into the future. All the events in each period are averaged to make a composite. Note that in each period the strength of the temperature gradient does not change markedly but the temperature of the air mass increases.

Modelled composite weather pattern associated with high Forest Fire Danger Index Values 1961–1980

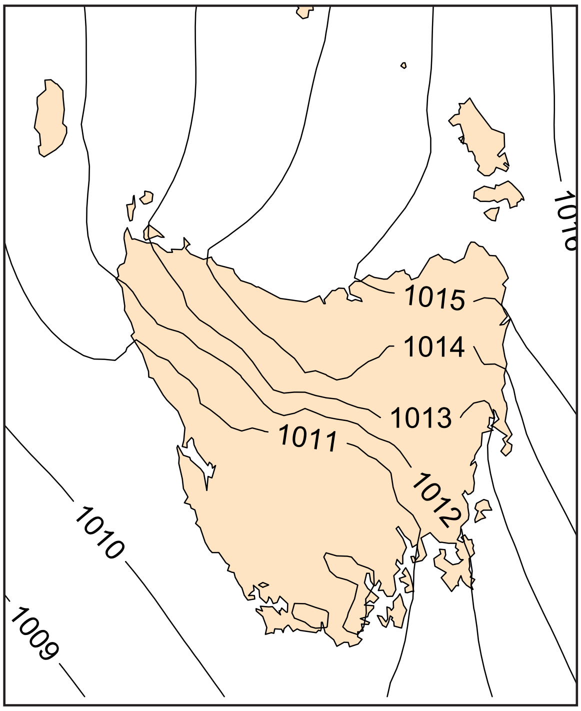

Figure 8 Modelled composite mean sea level pressure pattern for elevated Forest Fire Danger Index in south–east Tasmania for 1961–1980.

2.4 Trends in soil moisture

The Soil Dryness Index is one component in the calculation of the drought factor, which is used to estimate fuel dryness within the Forest Fire Danger Index. It is also a useful index in its own right, used as a broad indication of the flammability of different forest types.

The Soil Dryness Index calculated here is based on a constant value for 'canopy class', an indication of the density of the current vegetation at the site where Soil Dryness Index is calculated. We used current values because there is no widely agreed method for projecting vegetation community changes through time in response to climate change.

An indication of regional and seasonal variability in the Soil Dryness Index is presented as the multi–model mean in Figure 9. The inter–model spread across regions and seasons is presented in Figure 9 and Figure 10. Inter-model variability presents a range of plausible futures.

Over time, for each season, in all regions and across Tasmania, there is a trend towards higher Soil Dryness Index compared to the 1961–1990 baseline (Figure 9). This is one of the driving factors of increases in the Forest Fire Danger Index.

The Soil Dryness Index for the East Coast District is projected to increase in spring and summer by 2100 (Figure 10). The trend for winter, however, is less clear, with several models showing little change over time, and one model indicating a substantial increase by the end of the century.

Similarly, there is a clear trend towards increasing values of the Soil Dryness Index in all seasons over time in the Central Plateau District, with a spread in the strength of the trend in winter across the models.

In the Western District, all models project an increase in Soil Dryness Index in all seasons except winter, when little change occurs.

These seasonal and regional patterns are consistent with projections of rainfall and synoptic patterns described in previous Climate Futures for Tasmania reports.

2.5 Validation and Limitations

To check that the simulations were providing realistic FFDI values, we calculated daily FFDI for the period 2002–2012 from observations from Tasmanian Bureau of Meteorology Automatic Weather Stations. We compared both the values and the spatial distribution of multi–model mean 99th percentile FFDI with the observed values. The modelled synoptic patterns associated with high fire danger were also compared to those observed, to assess the realism of model scenarios of high fire danger.

The multi–model mean fire danger validated well against observations for 2002–2012, with 99th percentile fire dangers having the same distribution and largely similar values to those observed over the observational period. The models also reproduce the synoptic patterns associated with observed high fire danger days, giving us confidence that the models are correctly characterising the changes in fire danger in Tasmania during this century.

However, the modelled values of FFDI tend to underestimate the observed values (observations are above the 'observations equals modelled values' line in Figure 11). This is at least partly due to the different scales of the 10 km grid compared to the single point location of the observations. Local and site scale processes can lead to higher peaks in variables such as wind speed compared to the average calculated over a 10 km grid. The differences may also partly be due to a consistent underestimation of some variables, such as wind, by the model. Wind and relative humidity could not be bias–adjusted because values of these variables were not available in the gridded observational data. This suggests that the projected fire danger may be a conservative estimate of the future.

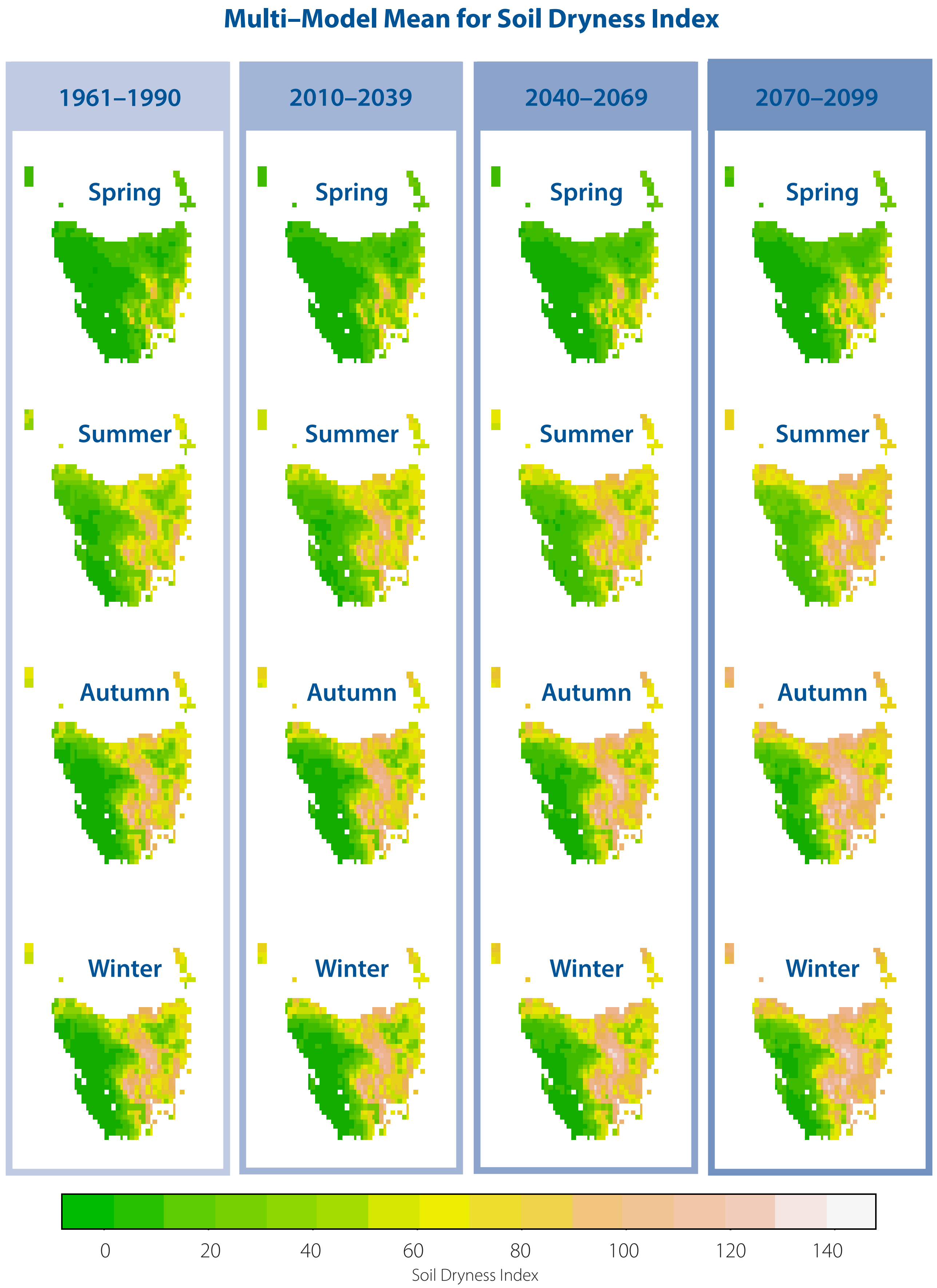

Figure 9 Projected multi–model mean seasonal Soil Dryness Index in 30–year average blocks. Higher values indicate an increased risk of fire (the Soil Dryness Index is used as an input to calculate the Forest Fire Danger Index). Both spring and summer were projected to exhibit the most rapid increases in Soil Dryness Index.

Comparison of Model Spread — Soil Dryness Index

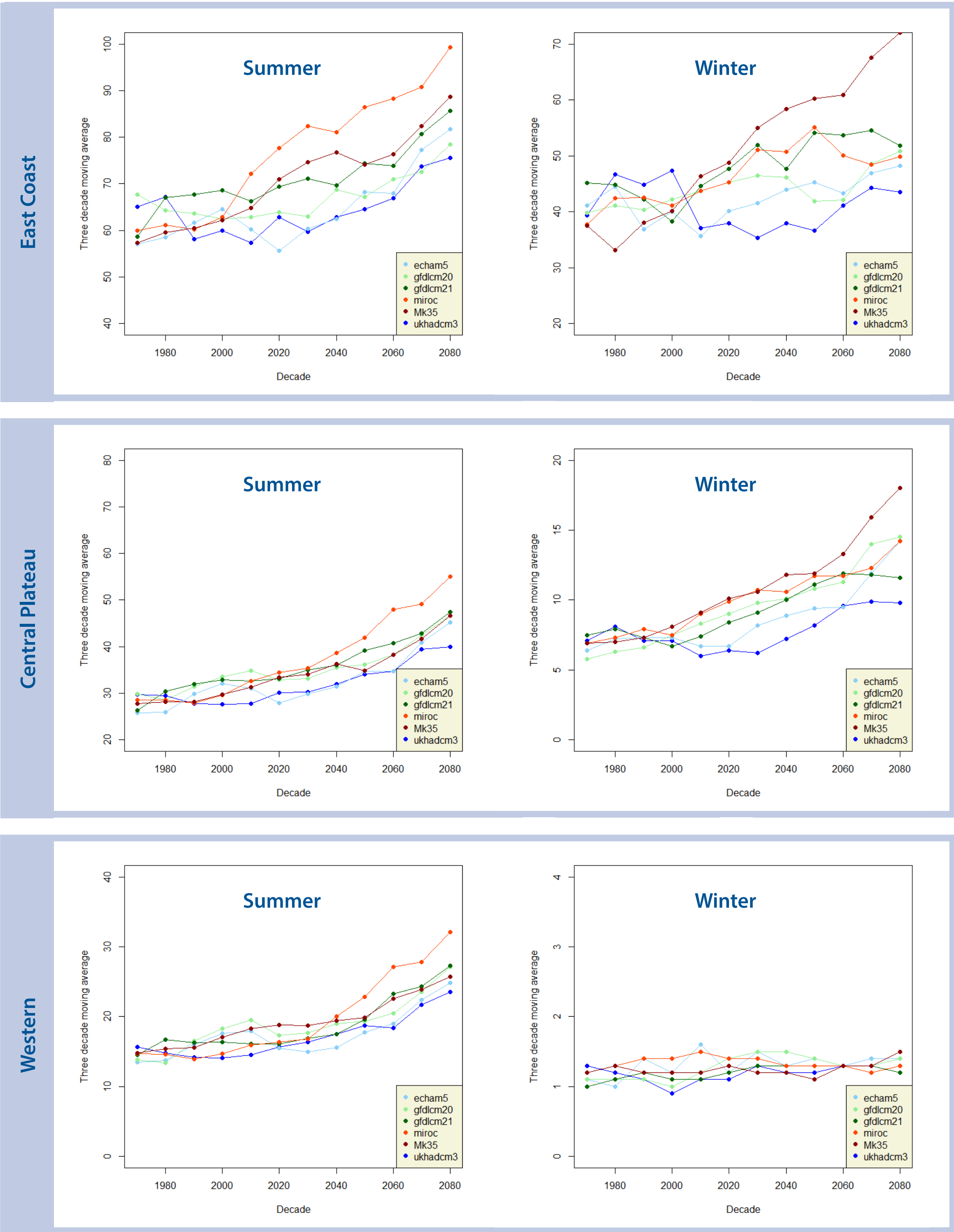

Figure 10 Comparison of the model spread for the six different models which were used to calculate average Soil Dryness Index over three Bureau of Meteorology forecast districts (Western, Central Plateau and East Coast). Note different scales.

2.5 Validation and Limitations, cont.,

We have used FFDI as a general index of fire danger, based on a standard 12.5 tonnes/hectare of available fuel. However fuel load is influenced at the landscape scale by community structure and composition (for example grassland versus forest) and at more local scales by vegetation growth rates, fuel age, structure and composition, and rates of decomposition, which affect the litter depth, structure and composition.

A comprehensive calculation of site–specific fire danger would require observations about particular regimes of fuel accumulation, past fire history, environmental factors such as slope and aspect and variations in atmospheric stability. The extensive empirical data this would require were not available for this project.

Projecting future changes in fuel load is not feasible even with such knowledge of current conditions, because of the unknowable influence of altered fire regime (frequency, intensity and timing of fire) and plant growth, due to factors such as changing CO_2 levels.

This report is based on climate projections and therefore should not be interpreted as a prediction of the future (see definitions of climate predictions and climate projections on page 10). The intention of climate projections is not to make accurate predictions regarding the future state of the climate system at any given point in time, but to represent the range of plausible futures and establish the envelope that the future climate could conceivably occupy.

The science underpinning this report was completed prior to the release of the Fifth Report of the Intergovernmental Panel on Climate Change in 2014 (AR5). The results are based on climate models and SRES emissions scenarios used in the AR4 Coupled Model Intercomparison Project archive (CMIP3). However, the global temperature changes projected in the more recent CMIP5 archive are very similar to those in the CMIP3 archive once the different scenarios are taken into account. Regional comparisons of projections from the CMIP5 and CMIP3 models have found surface temperature, wind, and rainfall patterns to be highly consistent between the archives. The release of the CMIP5 archive models has therefore not made the CMIP3 models redundant. RCP8.5 projects a similar acceleration in temperature to SRES A2, although median temperatures are consistently higher in the RCP8.5.

Observed versus Modelled FFDI Values for Automatic Weather Station Locations

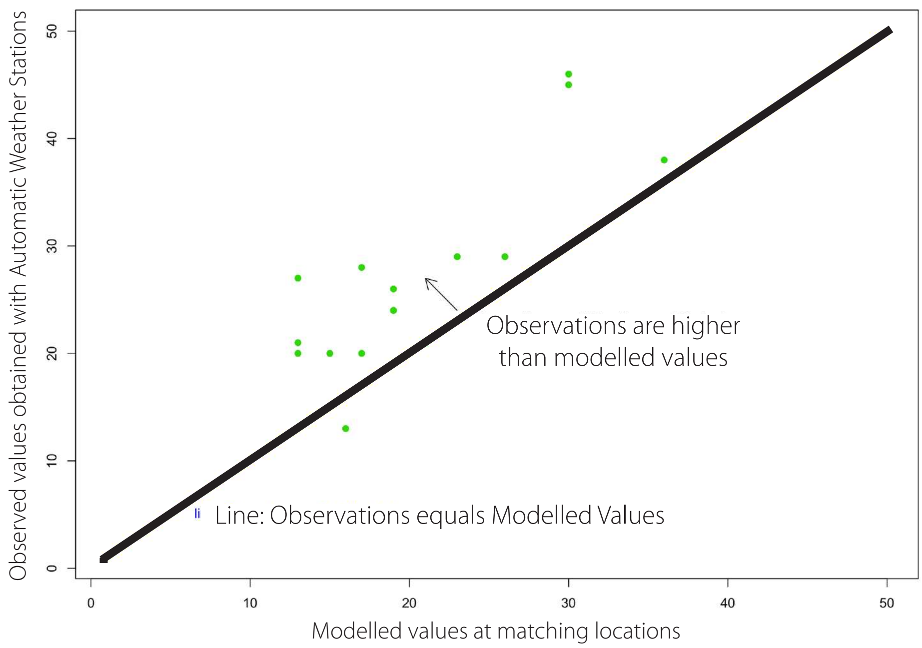

Figure 11 Comparison of the multi–model mean of annual 99th percentile Forest Fire Danger Index with corresponding values from automatic weather stations for the period 2002–2012. Modelled values agree well with observations, but observed values tend to be higher than modelled values. This suggests the model is most likely an underestimate of the Forest Fire Danger Index. Differences between observations and modelled values can be attributed to the different spatial scales. Modelled data are an estimate of broad regions, where an automatic weather station observes precise measurements at a single site.

3 Conclusions

Analysis of observed datasets as well as the Climate Futures for Tasmania fine–scale modelling outputs were used to examine future fire danger in Tasmania through the century (under a scenario of high greenhouse gas emissions). Model outputs were directly used in the calculation of Forest Fire Danger Index to produce results with realistic temporal and spatial variability for the present climate. This gives confidence that they produce useful projections of the future.

The modelled time series was separated into 20-year periods to quantify the projected changes in Forest Fire Danger Index into the future compared to historical conditions. There were three major periods of interest; the historical period (1961–1980), the intermediate period (2041–2060), and the future period (2081–2100). Comparing the relative change of historical–to–intermediate and historica–to–future provides context and scale.

The projected changes to regional–scale, synoptic–scale and large–scale drivers of fire weather were also examined. There is projected to be more frequent strong fronts that can bring severe fire weather to Tasmania, with the increase largely driven by an increase in air temperatures. Regional effects such as channelling by topography are expected to continue, enhancing fire dangers in south–east Tasmania.

The projected changes were used to generate a range of metrics of fire danger in Tasmania, all of which show a projected increase. The metrics of greatest interest include: the area of Tasmania under 'Total Fire Ban' conditions; the area of Tasmania in each Fire Danger Rating category per season; the total number of days per year categorised as 'Very High Fire Danger'; the change in Cumulative Forest Fire Danger Index; and the regional differences for each of these observed around Tasmania.

The area of Tasmania under 'Total Fire Ban' conditions during summer due to fire weather is projected to increase by at least 75% to 2081–2100 under a high emissions scenario. This is a 6% increase per decade, compared to an increase of 13% over recent decades.

The total number of days per year categorised as 'Very High Fire Danger' , is projected to increase by at least 120%. This is 10% per decade, compared to an increase of 10% over recent decades. Organisations with day–to–day operations in forested areas have operational protocols that are triggered by thresholds of indices such as the Forest Fire Danger Index or the Fire Danger Rating. The number of days when operations may be restricted per year is projected to double (Table 3 on page 19 and figure on page 6).

The area of Tasmania categorised in spring as 'Very High Fire Danger', is projected to increase by at least 250% by 2081–2100. This is about 20% per decade. This indicates an earlier start to the annual fire season, resulting in shorter preparation and recovery cycles. Modest increases were observed during the other seasons.

There is considerable regional variation around Tasmania. Regions that currently experience the highest forest fire danger are projected to have the most rapid increase in future values of the Forest Fire Danger Index.

Bushfires already cause extensive damage and concern in Tasmania. An increase in fire danger, or shifts in the frequency, intensity or timing of fires, will have widespread consequences for human communities and natural systems. This study provides supporting evidence for stakeholders to prioritise and develop future bushfire preparation strategies.

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The research used the climate projections generated by the Climate Futures for Tasmania project, and in collaboration with the Tasmania State Government, interpreted the new information to meet the needs of Tasmanian emergency services and fire agencies.

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Climate Futures for Tasmania is possible with support through funding and research of a consortium of state and national partners (see back cover).

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