Australia's National
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Victorian Climate Projections 2024

Addendum: future fire weather

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Energy,
Environment
and Climate Action

Contents

1 Introduction

This document describes projected future changes to fire weather for Victoria based on regional climate modelling from the NSW and Australian Regional Climate Modelling project (NARCliM2.0) under different scenarios of future greenhouse gas emissions. It is a supplement to the 2024 Victorian Climate Projections (VCP24) technical report (Round, et al., 2024), which omitted information on fire weather due to the required data from NARCliM2.0 being unavailable at the time. Hence, this document should be considered an internal addendum to the VCP24 technical report.

The analysis described in this report uses the Forest Fire Danger Index (FFDI), a traditional method for studying fire weather (McArthur, 1967). The approach used for calculating FFDI is similar to that employed for the previous Victorian Climate Projections VCP19 (Clarke, et al., 2019) and has been used in national fire projections in the past (e.g., National Environmental Science Programme (NESP) Earth Systems and Climate Change Hub, (Dowdy, 2018)). The FFDI method used here is a simplification of the traditional definition of FFDI. Traditionally, FFDI is based on concurrent values (e.g. at hourly timestep) of temperature, wind speed and relative humidity. The approach used here combines maximum daily temperature with 3pm wind speed and relative humidity. The existing VicClim climate fire products used for fire risk modelling in Victoria calculated a single daily maximum FFDI value, under the assumption that maximum FFDI coincides with the time of maximum daily temperature and that maximum wind-speed and relative humidity occur at the time of maximum temperature (Clark, et al., 2021; Clark, et al., 2021).

It should be stressed that there are a range of different approaches to providing fire weather projections which can have advantages over the daily FFDI approach used here. For example, the National Bushfire Intelligence Capability (NBIC) applies an enhanced and more data intensive approach for calculating fire weather potential which considers concurrent hourly weather data rather than an aggregation of non-concurrent daily maximum and minimums for a single daily value used in the Dowdy FFDI methods, producing more detailed and relevant estimates for potential fire threat.

Nevertheless, the results in this report can be indicative of how the projected changes in climate can influence generalised future fire weather trends predicted by NARCLiM2.0, when used in conjunction with other available lines of evidence. Further work would be required for profiling or estimating fire weather extremes and the relative risks associated with those extremes, or to develop a formal assessment of changes in specific fire danger ratings.

At the time of writing, there were no official fire weather projections provided by NARCliM2.0 and any such future publication may supersede fire weather projections contained in this report. In any event, we strongly recommend employing multiple lines of evidence for decision making to manage climate change impacts, such as fire modelling provided by NBIC.

Multiple lines of additional evidence should be used to address limitations of the future fire weather information presented in this addendum. Some of these limitations are listed below:

- Lack of bias corrected climate model data, limiting analysis to relative 'percentile' values (specifically the 95th percentile daily FFDI) rather than absolute values in the FFDI metric (e.g. days above a FFDI threshold of 50)
- A single modelling system, with one metric for fire weather (daily FFDI) and one set of regional climate modelling (NARCliM2.0)
- A single evaluation method of FFDI, with only daily FFDI non-concurrent values considered. An hourly FFDI analysis can more accurately describe the FFDI achieved at any given time of day or describe the daily maximum FFDI by modelling interactions between the dependant variables of temperature, humidity and wind over the course of a day
- Only the fire weather component of fire potential is assessed, and without assessment of extreme or sub-daily fire weather risk. Fire modelling which better captures fire weather extremes and accounts for landscape, terrain, fuel load and fuel condition can provide a much more complete picture of bushfire hazard at a particular location.

2 Data and methods

2.1 Climate model data

The FFDI analysis was conducted on data from the NSW and Australian Regional Climate Modelling project (NARCliM2.0). NARCliM2.0 is based on the internationally developed Weather Research and Forecasting (WRF) model, a dynamical regional climate model (RCM). NARCliM2.0 dynamically downscaled coarse resolution general circulation models (GCMs, also referred to as global climate models) to the Australasia domain at ~18–20km (AUS-18), followed by a second downscaling to a domain over the SE corner of Australia at a resolution of 0.0352 degrees or approximately 4km. For VCP24, a subset of the 4km data, clipped to cover a suitable area just beyond the extent of Victoria (140.5°, -33°) (151°, -39°), was provided by the NSW DCCEEW. The NARCliM2.0 data was provided on a rotated pole grid but was subsequently interpolated to a regular latitude/longitude grid using bilinear interpolation.

Five GCMs from the CMIP6 suite were downscaled by NARCliM2.0 using two different configurations of the WRF v4.12 RCM, providing 10 different GCM/RCM combinations. The two different configurations of the WRF model, referred to as "N20-WRF412R3" and "N20-WRF412R5" (Virgilio, et al., 2024) are not independent, differing only in their representation of boundary layer physics. They allow the effect of different boundary layer physics configuration on simulated climate change to be explored. Version N20-WRF412R3 and N20-WRF412R5 use the MYNN2 and ACM2 planetary boundary layer parameterization schemes, respectively. Both configurations of NARCliM2.0 use the same parameterisations for cloud microphysics, cumulus physics, shortwave and longwave radiation physics, land surface and dynamic vegetation. The N20-WRF412R3 and N20-WRF412R5 configurations were selected as superior performing by the NARCliM2.0 modelling team, following evaluation of numerous other configurations of (Ji, et al., 2024).

The VCP24 Technical Report provided climate projections based on a wide range of future climate modelling from both global climate models and regional climate models, including NARCliM2.0 but also regional climate modelling from three other regional models. A summary of the projected changes in temperature and rainfall over Victoria for 2080-2099 compared to a baseline of 1986-2005 is shown in Figure 1, where the results of NARCliM2.0 are shown alongside other CMIP6 climate projections under a high emissions scenario (SSP3-7.0). Figure 1 helps us assess how well the NARCliM2.0 simulations represent the broader projections space produced by the broader suite of modelling, with respect to average temperature and rainfall changes. It shows that the NARCliM2.0 simulations (green and blue points) represent the extreme hot and extreme dry ends of the projections space, more so than any of the other global or regional model simulations. As such, the FFDI projections associated with these hot and dry simulations are expected to capture the upper end of future increase in fire weather conditions, at least in terms of the temperature and rainfall components. Contrarily, the NARCliM2.0 simulations do not capture the possibility of significant increases in rainfall which are suggested by some of the other RCM simulations.

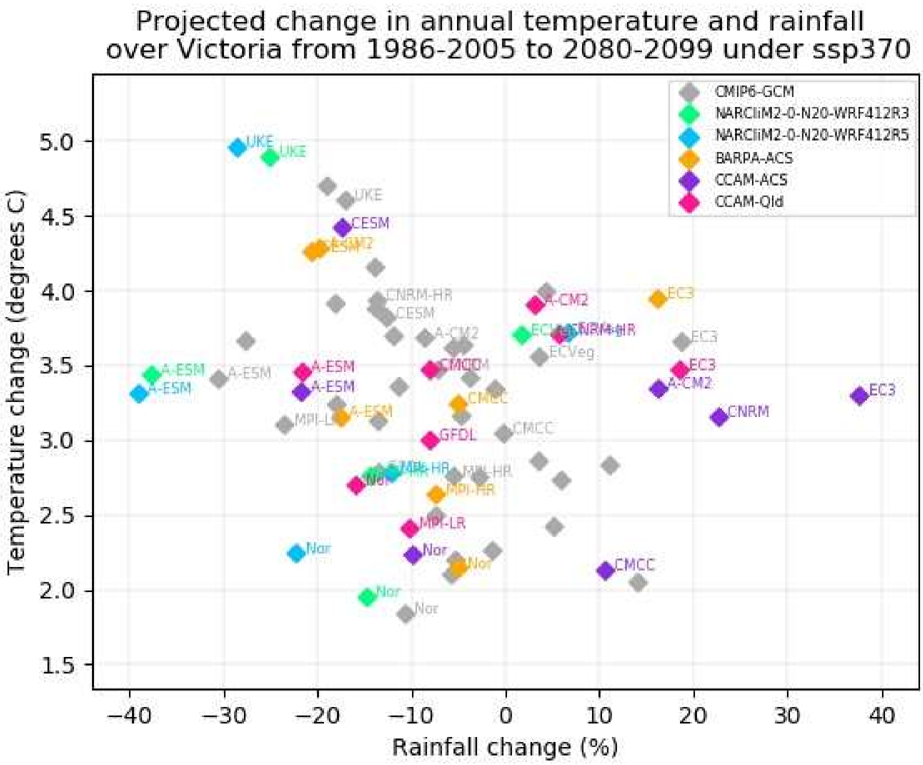

Figure 1 Projected change in mean annual rainfall (horizontal axis) and temperature (vertical axis) over Victoria under a high emissions scenario (SSP3.70), from a 1986-2005 baseline to a 2080-2099 future period. Each point represents a single model. GCMs are shown in grey and the different RCMs indicated by the coloured legend. Model names are shown for RCMs and host GCMs which were downscaled by RCMs.

Future change is modelled under two very different scenarios (Shared Socioeconomic Pathways, SSPs) for future global greenhouse gas emissions that ‘bracket’ or ‘bookend’ a plausible range of change (but exclude extreme outlier emissions scenarios):

- A low emissions scenario ‘SSP1-2.6’ under which global emissions are cut and reach net zero around 2075, with global average temperature stabilising at about 1.8 °C above pre-industrial levels by 2100 (roughly compliant with the goals of the 2015 Paris Agreement).

- A high emissions scenario 'SSP3-7.0', a high emissions scenario, under which annual global emissions continue to rise to roughly double present levels by 2100, and global average temperature reaches about 3.6 °C above pre-industrial levels by 2100.

2.2 Forest Fire Danger Index (FFDI)

Fire is produced when a range of conditions are satisfied including fire weather, fuel and ignition. Furthermore, fire weather itself depends on several factors such as temperature, rainfall, humidity and wind speed. An established approach to characterising fire weather is the Forest Fire Danger Index (FFDI) (Noble, et al., 1980). Traditionally, FFDI is based on concurrent wind speed, temperature and relative humidity aligned with other aggregate factors that relate to soil and vegetation dryness, however climate model output does not generally have continuous hourly data availability to calculate FFDI in this way.

The calculation of FFDI used here applies a simplified methodology which includes a drought factor, near-surface daily maximum temperature near surface (2 m) relative humidity at 3pm and 10 m wind speed at 3pm, rather than concurrent hourly data. The motivation for this approach has been for compatibility with climate models that only provide 6-hourly output, rather than hourly data. For this analysis we follow Dowdy et al (2009) and use the Keetch-Byram Drought Index (KBDI) (Keetch & Byram, 1968). The KDBI index aims to represent cumulative soil moisture deficiency and therefore indicate vegetation dryness. KDBI is formulated by calculating for each day the mean annual rainfall, maximum daily temperature, previous 20 hours rainfall and previous day's KDBI index (Finkele, et al., 2006; Dowdy, et al., 2009).

FFDI typically varies between 0 to 100, although exceeding 100 is possible. An FFDI value of between 25-49 is considered high fire danger, a value between 50-99 is considered extreme and a value of FFDI equal or above 100 is described as catastrophic. 96% of historic house and life loss has occurred during events where the FFDI was over 50. 60% of historic house and life loss has occurred during events where the FFDI was over 100 (Blanchi, et al., 2010) (Blanchi, et al., 2013). Although these FFDI ratings have been used for operational fire weather rating in the past, it is worth noting that there are now also new rating systems such as the Australian Fire Danger Rating System (AFDRS).

Communicating changes in FFDI can be impacted by model biases in temperature, rainfall, humidity and winds. This can lead to errors in calculating absolute quantities like absolute FFDI thresholds or the number of days over a given FFDI threshold. An alternative to using an absolute threshold calculation is to instead use percentile based FFDI thresholds. The percentile approach has the advantage of being less susceptible to climate simulation biases, but does differ from more conventional interpretations of FFDI as described for the Very-high, Severe, Extreme and Catastrophic thresholds. Here we use the 95th percentile of daily FFDI values in the baseline climate as a threshold to represent "95th percentile fire danger days". The 95th percentile represents a fire danger level which is exceeded on average approximately 18 days per year in the baseline climate (1986-2005). For the future projected change, we calculate the increase in the number of these 95th percentile fire danger days. The 95th percentile threshold was also used in VCP19 (there referred to as 'fire days')(Clarke, et al., 2019) and also other studies where the percentile based approach was considered advantageous for dealing with spatial variability or data inconsistencies (Richardson, et al., 2021).

Figure 2 shows the observed value of the 95th percentile of daily FFDI observed over Victoria for the 1986-2005 baseline period, based on a climatology developed by Dowdy (2018). It shows higher values in the northwest of the state and lower values for the Victorian Alps and for southeastern Victoria. Table 1 shows the average observed value of the daily FFDI 95th percentile for the 1986-2005 baseline, for each of the 10 projections regions used in VCP24. The 95th percentile daily FFDI value ranges from 39 for the Mallee region (which would translate to a very high fire danger in the traditional FFDI danger rating) to 12 over the Gippsland region (moderate fire danger).

The simulated future changes provide an estimate of how many additional 95th percentile fire danger days there may be in the future, with the FFDI value of a 95th percentile fire danger day being location specific. The 95th percentile fire danger days are not intended as a representation of extreme fire weather days (which have FFDI of more than 50) but an indication of a general shifts in the number of days of high FFDI (with 'high' being relative to the local historical FFDI distribution).

We note that the future changes in fire danger which are reported here are made with respect to this 'baseline' FFDI and hence the changes for different locations are relative to different baseline values of 95th percentile FFDI. Interpretation of future changes in 95th percentile fire danger days should be made with knowledge of this baseline.

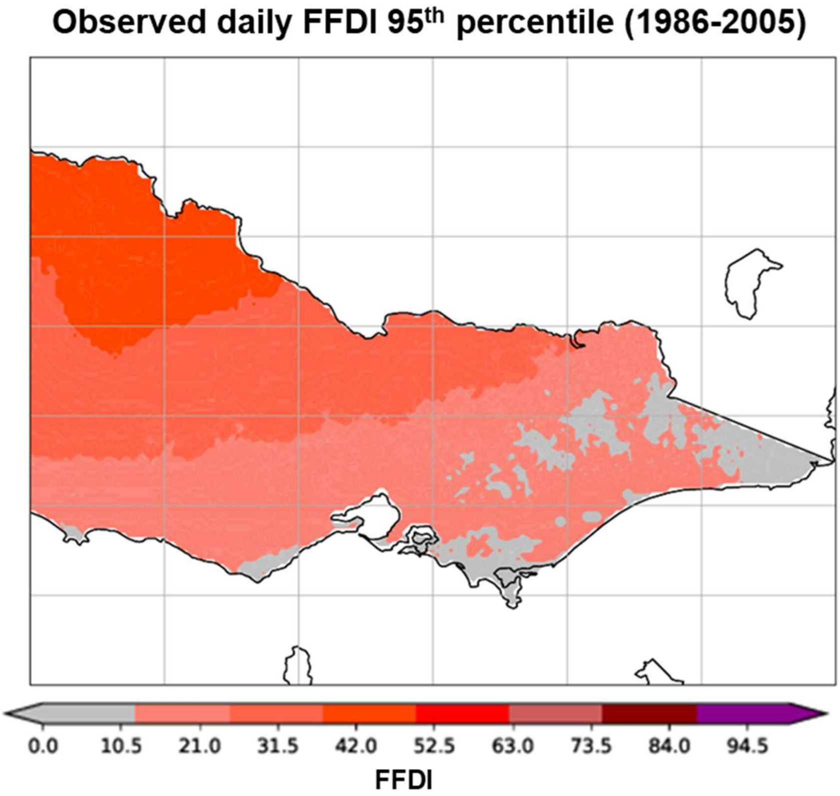

Figure 2 Observed 95th percentile daily FFDI for the 1986-2005 baseline period. The observed data is derived from the Dowdy 2018 dataset using the same method for calculating FFDI as used here.

Table 1 Observed historical baseline values of the 95th percentile daily FFDI for the ten sub-regions used for the VCP24 projections. The average 95th percentile daily FFDI over the whole of Victoria is 25.

Regionally averaged 95th percentile daily FFDI observed baseline 1986-2005									
Barwon	Central Highlands	Gippsland	Goulburn	Great South Coast	Loddon Campaspe	Mallee	Greater Melbourne	Ovens Murray	Wimmera Southern Mallee
14	22	12	25	20	29	39	16	20	34

2.3 Model evaluation: simulation of baseline climate for Victoria

Prior to calculating the simulated FFDI for Victoria under different emissions scenarios, it is useful to first evaluate how well the NARCliM2.0 downscaling of different global climate models can simulate the observed FFDI conditions during the baseline period. Figure 3 shows the 95th percentile for daily FFDI for different downscaled GCMs between the baseline period of 1986-2005, which can be compared to the observed climatology in Figure 2. We note that there is a range in the simulated 95th percentile of daily FFDI, which is determined both by the choice of host GCM as well as the NARCliM2.0 configuration (i.e., N20-WRF412R3 or N20-WRF412R5). Nevertheless, there are examples where NARCliM2.0 simulated the observed 95th percentile of

FFDI between 1986-2005 reasonably well, such as MPI-ESM1-2-HR and EC-Earth3Veg with N20-WRF412R3, as well as NorESM2-MM and UKESM1-0-LL with N20-WRF412R5. However, there are also examples where N20-WRF412R3 underestimates the 95th percentile for daily FFDI and N20-WRF412R5 overestimates it. The biases are not unexpected, considering the biases present in simulating temperature and rainfall, presented in the VCP24 Technical Report (Round, et al., 2024).

The impact of any biases on the future projected changes in FFDI presented in this report is reduced through using a time-slice approach to computing future change, relative to the model simulated historical baseline. This is consistent with the methods used by the IPCC's Sixth Assessment Report (IPCC, 2021) and previous Victorian and National projections. As the future change is calculated with reference the modelled past, rather than the observed past, the model bias against observed data is not as relevant. However, the biases are of concern if one looks at absolute FFDI values or absolute thresholds, rather than percentiles. This is why the percentile approach, looking at days above the historical 95th percentile FFDI, has been used here. Model output which has been bias corrected would be recommended for any analysis relying on absolute values.

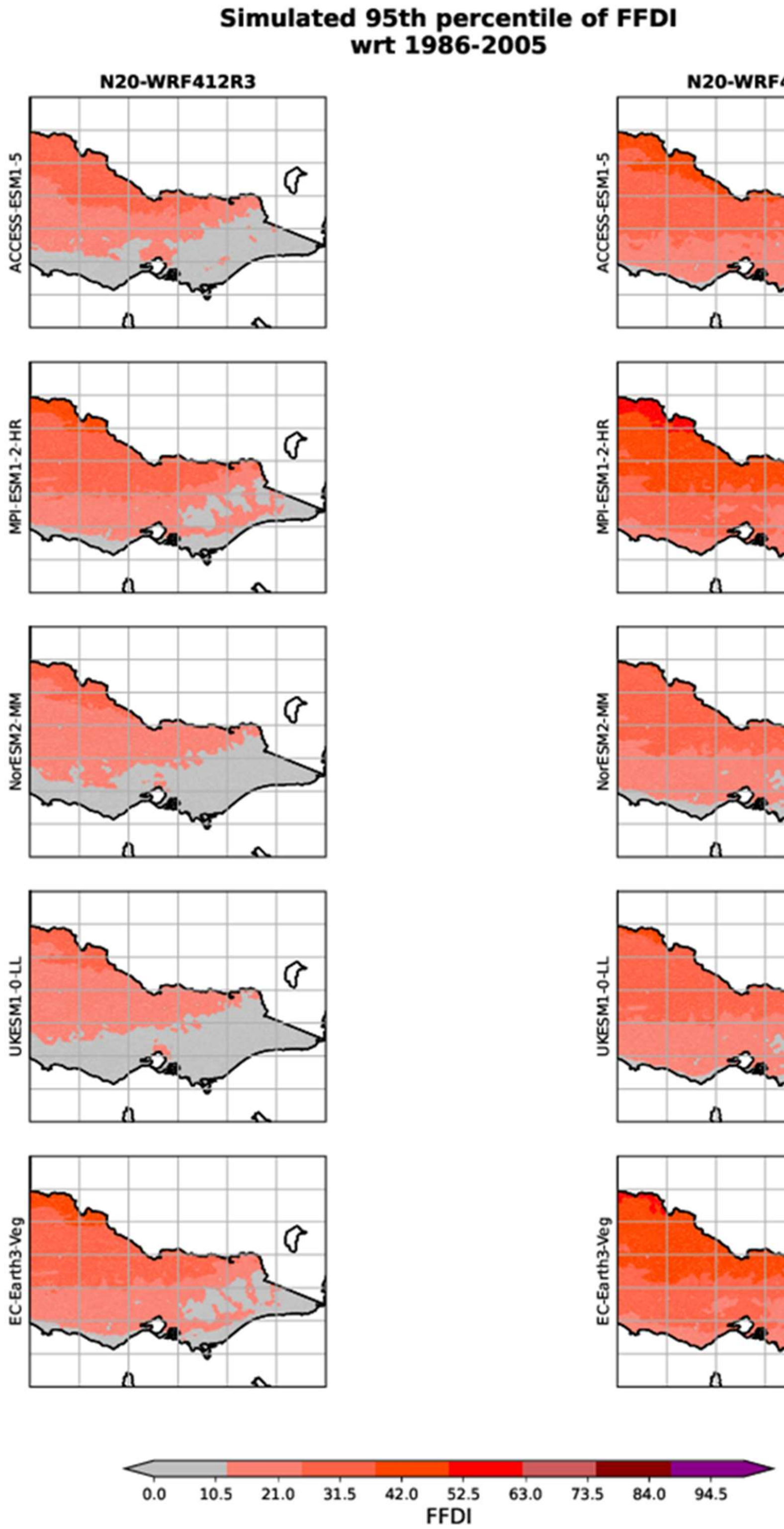

Figure 3 Simulated 95th percentile of daily FFDI for different NARCliM2.0 downscaled modelling, for the baseline period between 1986-2005. The rows show the 5 different downscaled GCMs and the two columns show the different downscaling model configurations. This can be compared to the actual observed values in Figure 2.

3 Future change in FFDI for Victoria

As discussed in section 2, this report calculates projected future changes in the number of 95th percentile fire danger days. This approach was used to reduce the impact of simulation biases, as well as for consistency with previous studies including VCP19. Nevertheless, a comprehensive analysis of changes in future fire weather will require the use of multiple lines of evidence, such as sub-daily calculations as employed by NBIC.

Figure 4 shows the projected changes in the average number of 95th percentile fire danger days per year by 2090 (2080-2099) under the low (SSP1-2.6) and high (SSP3-7.0) emissions scenarios. Changes are shown for each of the NARCliM2.0 simulations. These future changes are on top of a baseline of approximately 18 days per year in the 1986-2005 baseline. Projected changes in the number of 95th percentile fire danger days vary depending on the NARCliM2.0 configuration, the choice of host GCM and the emissions pathway, with significantly larger increases under the high emissions scenario. Under both emissions scenarios, the ACCESS-ESM1-5 and UKESM1-0-LL GCMs predict the greatest increase for both configurations of NARCliM2.0. These models show the greatest drying and warming, respectively.

Under the low emissions scenario, the largest increases shown are up to 40 days per year in some regions (e.g., the northeast and east of the state for UKESM1-0-LL), on top of the baseline 18 days per year. However, the other downscaled GCMs predict smaller increases, typically less than 10 days per year. In some cases, the downscaled GCMs predict a small decrease in fire weather days in some locations.

Under the high emissions scenario, all the simulations show an increase in the number of 95th percentile fire danger days. As was the case for the SSP1-2.6 emission pathway, ACCESS-ESM1-5 and UKESM1-0-LL predict the largest increases, especially in the northeast of the state. This is expected as simulations from these two GCMs show the largest amount of drying and warming, respectively. Increases of more than 70 days are seen in some locations and models, although increases between 10 and 60 days are more typical. Note that these increases are on top of a historical average of 18 days per year. There are examples of downscaled projections with smaller increases (i.e., less than 10 additional fire weather days), such as MPI-ESM1-2-HR and NorESM2-MM, although the results also vary with the choice of the NARCliM2.0 configuration.

The projections presented here are broadly consistent with the fire weather projections presented in VCP19 (Clarke, et al., 2019), although these projections simulated future climate under a different emissions scenario (RCP8.5, very high emissions). The VCP19 simulations generally showed the largest increases in days above the 95th percentile FFDI over northeastern Victoria and in particular the Victorian Alps. At the most extreme, simulations showed an increase of 60–90 days over the Victorian alps and 20–40 over other regions.

Fire weather depends in multiple factors including temperature, precipitation, wind speed and relative humidity. Increases in temperature and reductions in rainfall predicted by NARCliM2.0 are likely to be dominant factors in the projected increase in the number of fire weather days about the baseline 95th percentile of FFDI. Nevertheless, further analysis would be needed to quantify the relative contributions of these variables to the changes in fire weather.

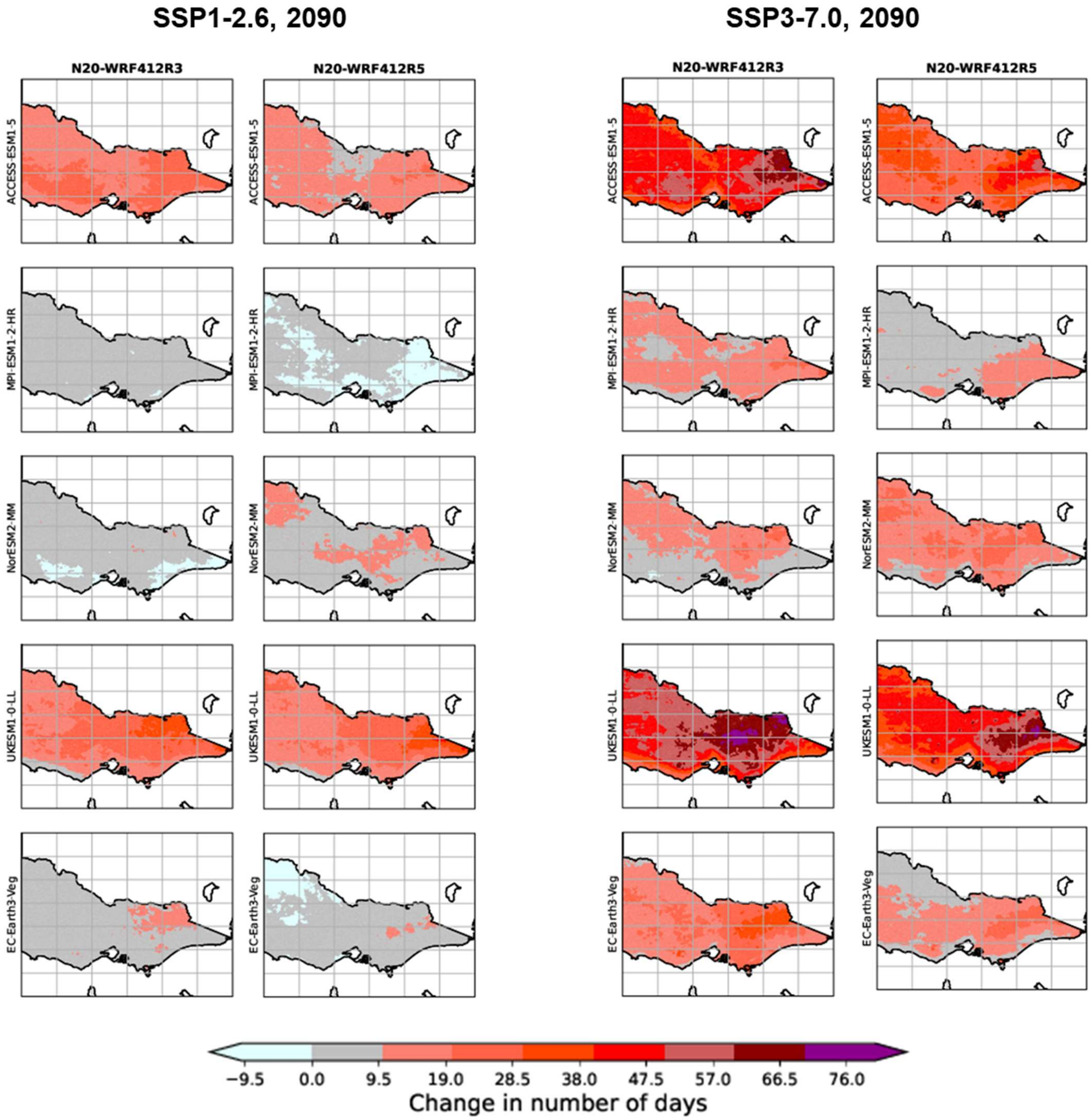

Figure 4 Projected changes in the number of days above the historical (1986-2005) 95th percentile daily FFDI, for a low emissions scenario (SSP1-2.6, left 2 columns) and high emissions scenario (SSP3-7.0, right 2 columns) between 2080-2099, after downscaling CMIP6 GCMs with NARCliM2.0. The rows show the 5 different downscaled GCMs and the pairs of columns show the different downscaling model configurations.

Some caution is advised when using the projected changes in fire weather described in this report. There are multiple ways to quantify fire weather appropriate for different situations, and different regional models may have a different range of projections. Hence, we strongly recommend drawing on multiple sources of fire weather projections as they become available. Nevertheless, the results for NARCliM2.0 described in this report generally suggest an increasing fire weather risk across the entire state, although the size of the increase depends on the emission pathway and the projected changes due to the host GCM.

4 Conclusions

This report provides a preliminary assessment of some aspects of the changes in future fire weather for Victoria as simulated by the NARCliM2.0 ensemble of downscaled GCMs. We have used the method of Dowdy et al (2009) to estimate the daily FFDI, consistent with the approach used in VCP19. We use the 95th percentile of FFDI for the baseline 1986-2005 period as a reference for future changes in the number of 95th percentile fire danger days. With this approach we find a range of results depending on the emission pathway, the choice of CMIP6 host GCM being downscaled and the configuration of NARCliM2.0.

The analysis generally shows future increases in the number of 95th percentile fire danger days, especially under the high emissions scenario, on top of a historical baseline of approximately 18 days per year. In the most extreme case for end of the century under high emissions, simulations show around 70 additional 95th percentile fire danger days in the northeast of Victoria. More typical changes ranged from an increase of 10 to 60 days per year by 2080-2099, although there were some examples of a slight decrease for the lower SSP1-2.6 emission pathway. NARCliM2.0 indicated the northeast of Victoria tended to have the largest increases in fire weather days under the scenarios considered in this report. They are broadly consistent with the VCP19 projections.

This report is based on a single and simplified method for assessing future fire weather, using daily FFDI non-concurrent values rather than an hourly FFDI analysis which can more accurately represent daily FFDI extremes. It neglects sub-daily changes in fire weather and relies entirely on the NARCliM2.0 projections. We strongly recommend taking additional lines of evidence such as that provided by NBIC or future fire weather projections from NARCliM2.0 when interpreting the increased risk of fire weather due to climate change.

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Contact us

1300 363 400

+61 3 9545 2176

csiro.au/contact

csiro.au