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VICTORIA FIRE WEATHER CLIMATOLOGY DATASET

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Cover: Smoke plumes at Mount Hotham, Victoria in 2013.

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ABSTRACT

Weather and climate are essential elements in understanding the risk of bushfire and managing the landscape to reduce risks. Spatially and temporally homogenous climate data are essential for optimising planned burning and land management strategies, and scenario planning for major fire events. This paper summarises the development of a homogeneous 41-year (1972–2012) hourly 4-km gridded climate dataset for the fire-prone state of Victoria, Australia. This dataset has been generated using a combination of mesoscale modelling, global reanalysis data, surface observations, and historic observed rainfall analyses. Outputs include surface weather variables such as hourly temperature, relative humidity, wind speed and wind direction. The output data are created using the Weather Research and Forecast (WRF) model. Outputs provide an almost limitless opportunity for hitherto unavailable analyses – such as identifying the frequency of extremes and identifying trends over the 41-year period. Furthermore, the hourly mesoscale wind fields provide a homogeneous long-period data set with which to drive fire spread models such as Phoenix. This paper describes generation of the dataset, evaluation of the outputs and highlights its use and relevance for fire management.

INTRODUCTION

Southeast Australia has had many socially disastrous fires (Gill et al. 2013). Bushfires in the state of Victoria have contributed to over 67% of all bushfire-related deaths that have occurred in Australia over the last 110 years (Blanchi *et al*. 2014). The list of destructive fires includes Black Friday in 1939, Ash Wednesday in 1983 and, more recently, Black Saturday in 2009 which resulted in the loss of 173 human lives (Teague *et al*. 2010). There is a need for a detailed understanding of the climatology of fire weather across the Australian landscape if strategic decisions to ameliorate the sometimes-extreme impacts of bushfires on the socio-economic wellbeing of the community are to be based on sound scientific evidence, and if variability and trends in this climatology are to be correctly interpreted.

In situ observation networks are rarely homogenous in time and space. Consequently, there are some considerable barriers to basing climatology on long-term meteorological observations, as shown by the relatively low number of reliable, long-term observation records available for such analyses (see Lucas *et al*. 2007). This has significant implications for fire weather applications. The bulk of observations are based near population centers and do not necessarily reflect the conditions in the forests where most of the major bushfires occur—in the slopes and valleys of the ranges through central and eastern Victoria. To fulfill the needs of fire management agencies, an ideal climatology would be based on a homogeneous high-resolution temporal (i.e. hourly) and spatially-gridded fire weather and fire danger dataset.

It is logistically possible to spatially interpolate between observing stations to obtain a regular grid of data using distance-weighted averages. However, ensuring physical consistency when interpolating across regions of varying elevation or land surface type requires additional statistical assumptions that rapidly lead to excessive complication. Furthermore, observations may not be available at hourly intervals so some form of interpolation in time is necessary if hourly fields are required. This also adds complication, as any assumptions regarding diurnal cycles of variables would generally ignore differences through the synoptic weather cycle.

An alternative approach is to use mesoscale Numerical Weather Prediction (NWP) model outputs as these outputs are physically constrained by the equations of motion and thermodynamics in the model, they include realistic topography for the grid resolution of the model and provide outputs for regular time and space intervals. Operational NWP outputs, while archived by most national weather services, suffer as these models are upgraded every few years, and so have major inhomogeneities if they are to be used for climatological studies. However, the emergence of global reanalysis data sets, such as the National Center for Environemental Protection/National Center (NCEP)/National Center for Atmospheric Research (NCAR) Reanalysis (NNR) data set from (Kalnay *et al*. 1996), provide large-scale homogeneous data-sets that can be used as initial and boundary conditions for mesoscale NWP model integrations, with multiple nests to achieve high spatial detail in the inner nests.

A model that has become increasingly popular for producing such outputs is the Weather Research and Forecasting (WRF) model (Skamarock *et al*. 2008). The use of this model is well established in simulations conducted globally (Andrys *et al*. 2015). Furthermore, the WRF model is now being used for similar purposes in forestry, fire and agriculture, albeit with varying results. For example, a recent study by Andrys *et al*. (2015) covering south western Australia over a 30-year period produced a gridded observational dataset of daily rainfall, minimum temperature and maximum temperature. They found the WRF model was able to simulate daily, seasonal and annual variations in temperature and precipitation including extreme events. They also found significant performance gains in modeling precipitation with higher grid resolution. A study by Simpson *et al*. (2013) used the WRF model to simulate fire weather conditions for one fire season (2009–2010) in New Zealand. The study simulated 12-hourly temperature, relative humidity, wind speed and direction along with daily rainfall, fire weather index and the continuous Haines index. They found that temperature and relative humidity were under-predicted and wind speed and rainfall were over-predicted. Unfortunately, they also found issues around under-prediction of extremes which limited the operational use of the dataset. Another study that used the WRF model to produce fire weather outputs simulated fire weather for south eastern Australia from 1985–2009 (Clarke *et al*. 2013). The authors compared their results to station-based observations of Forest Fire Danger Index (FFDI) and found the WRF model simulated the main features of the FFDI distribution and its spatial variation with an overall positive bias. They concluded that the errors in average FFDI were mostly caused by relative humidity whereas the errors in extreme FFDI were mostly driven by wind speed. In general they found better performance of the model when the grid spacing was reduced from 50 to 10 km.

While these studies have made major advancements using the WRF model to produce simulations useful for fire studies the fire weather climatology, the dataset produced in this study is the first of its kind to provide hourly values of meteorological variables on a regular, high spatial resolution grid for Victoria based on WRF model outputs. In this paper we will describe and evaluate the performance of WRF model outputs in simulating fire weather variables. This evaluation will be presented through statistics, meteorological case studies and climatological characteristics of the region. We will show that this unique dataset can provide baseline climatology information for risk management assessments and climate change adaptation planning.

METHODS

DEVELOPING THE DATA SET

The mesoscale model used to develop the dataset was the WRF model (Skamarock *et al*. 2008). It is a well-supported and widely used non-hydrostatic model that includes a wide range of choices of physical parameterisation schemes. Three integration domains are used in our configuration with grid spacings of 36 km (outer mesh), 12 km (middle mesh), and 4 km (inner mesh). Each nest has 33 vertical model levels. Initial state and lateral boundary conditions for the outer mesh are provided by 6-hourly interval global reanalyses.

Three global reanalyses were utilised for initial state and lateral boundary conditions to start integrations using the WRF model and to nudge fields through a 15-day process, discarding the first day (Mills *et al*. 2013). The National Centers for Environmental Prediction (NCEP) FNL (Final) Operational Global Analysis (NCEP 2000) data, based on 1-degree by 1-degree grids prepared operationally every 6 hours, were used for the 2000–2012 period. The ERA-Interim (Dee *et al*. 2011) reanalysis dataset was used for 1979–1999 and the ERA40 reanalyses (Uppala *et al*. 2005) was used for 1972–1978. A list of the physical parameterisations used in this configuration of the WRF model is provided in Brown *et al*. (2015).

Observed data

The observed data used to assess the accuracy of the modelled output were the Automatic Weather Station (AWS) data from the Bureau of Meteorology. These data range temporally from 1-minute observations to daily observations and spatially with more stations located around populated regions and fewer stations in remote regions. The density of the network and the frequency of reporting have increased through the 1972–2012 period.

Qualitative and statistical evaluation of the dataset

There is no defined performance standard for a dataset such as the one developed in this project. It can be assumed that (1) the climate information in the dataset should reflect the temporal and spatial variability of the actual climate, and (2) the meteorology of actual (fire) weather events should be sufficiently realistic such that scenario investigations of these events using, for example, fire behaviour models should produce sensible outcomes. Subjective assessments were used to validate the meteorological integrity of the data for significant weather events and to identify any possible model deficiencies that could be mitigated by tuning the various parameters of the model. Objective statistics were used to further inform the meteorological integrity and to validate the fortnightly integration strategy to demonstrate stable characteristics of outputs from the WRF model across these periods. This was done as it is undesirable for the WRF model to show any drift in accuracy or variability through days 2–15 of a 15-day integration period.

In addition to the subjective assessment, root mean square (RMS)errors were calculated between model output and observed data (AWS) for each hour along with field variance of these quantities for each hour. Following this, cumulative distribution functions (CDFs) were calculated and compared for a combined 30-observation dataset and the corresponding model grid points for a 10-year period which includes all hours and days during this period.

RESULTS

CHARACTERISTICS OF THE DATASET

The surface data of primary interest generated by the WRF model included 4-km grid hourly temperature, relative humidity, wind speed and wind direction. All variables extended from January 1972–December 2012. Rainfall data were also generated but were not assessed in this study. Additionally, outputs from the WRF model include hourly three-dimensional fields of all atmospheric variables. This enables opportunities to assess the effect of climatology of above-surface weather on fire activity. It should be noted that this has never been possible at this scale for Victoria before. The upper levels had a horizontal spatial resolution of 4 x 4 km, hourly temporal resolution and 32 atmospheric pressure levels (hPa). A list of the upper level variables included are provided in Brown *et al*. (2015) and are not assessed in this paper.

EVALUATION OF THE DATASET

Temperature, relative humidity and wind speed

To inform the final model configuration and 15-day integration, the RMS error (RMSE) between observations and outputs from the WRF model for wind speed, temperature and relative humidity were calculated for each hour throughout the summer period for 2008–2009, together with WRF field variance of these quantities for each hour. There was no trend in error through the 14 days of integration. This was investigated further for each integration period with the bias and RMSE for all stations for each hour for the same summer period for 2008–2009. A subjective conclusion from these comparisons is that the integration gaps should have relatively little impact on the utility of the data set for climatological analyses. However, if a fire spread model is to be run across these periods, it is recommended that care should be taken to carefully assess the impacts of any possible inconsistencies.

The 15-day integrations and model field nudging produced remarkably small biases. Figure 1 shows CDFs for a combined 30-observation dataset and the corresponding model grid point for each station for the 10-year period from 2004–2013. This includes all hours and days during this period. Further analyses are being undertaken to assess diurnal, seasonal and elevation biases.

The WRF model produced simulations with slight under-prediction of wind speed during the day, slight over-prediction of temperature and a slight under-prediction of relative humidity during the day with opposite biases at night. The ability of these outputs to simulate extreme values has yet to be statistically analysed.

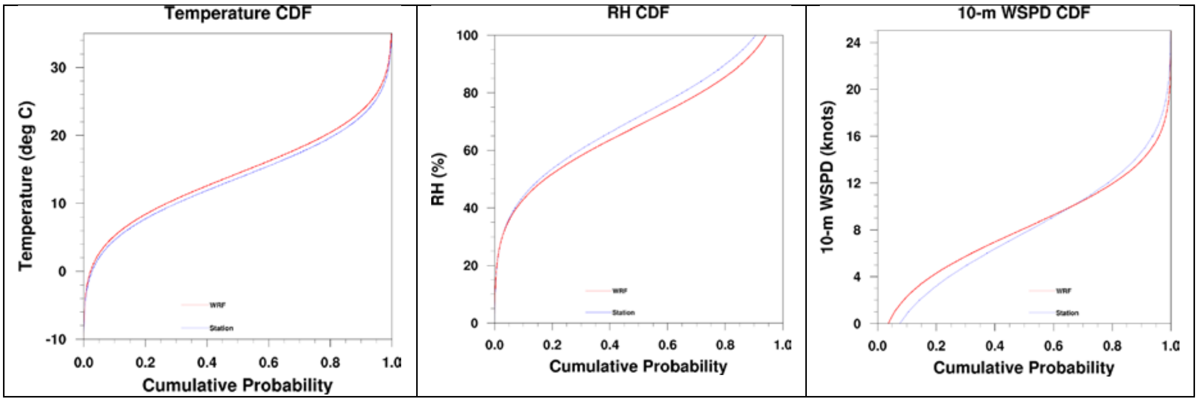


FIGURE 1: CUMULATIVE DISTRIBUTION FUNCTIONS FOR 30 STATIONS (RED LINE) AND CORRESPONDING MODEL GRID POINTS (BLUE LINE) FOR ALL HOURS AND DAYS 2004–2013 FOR TEMPERATURE, RELATIVE HUMIDITY AND WIND SPEED.

Synoptic evaluation

A large number of hourly charts were examined, both for random periods and major fire weather events. Overall, many interesting or notable events and mesoscale circulation systems were very well simulated, including foehn wind events, wind changes, major fire weather events and land-sea circulations. Two fire weather case studies are presented below and additional examples are presented in Brown *et al.* (2015).

METEOROLOGICAL INTEGRITY: CASE STUDIES

Major fire events: observed versus modelled

A number of fire events were examined as case studies, both subjectively in terms of synoptic pattern and evolution throughout the fire, and using comparison of point values at observation sites. Table 1 lists these events, together with the date, time and observation location used for these point comparisons. A subjective comment based on inspection of the simulated state-wide patterns of wind, temperature and humidity on these days is also included. Data for these variables can be found in Brown *et al.* (2015).

Subjectively, the simulations appear to be excellent, with well matched patterns of extreme fire weather simulated for most of the days examined, albeit with a tendency for slightly lower quality early in the period. This is likely due to changes in the global observing system over 41 years affecting the quality of the initialisation grids.

Point-by-point comparisons show that the temperatures are almost unbiased for this comparison, whereas relative humidity is over-predicted (too humid) by an average of approximately 5%. Wind speeds were lower by some 14 km hr^{-1}, but there are some reservations regarding the values for cases for Streatham and East Gippsland as these are quoted values rather than observations from the Bureau of Meteorology. A more realistic estimate of wind speed would be an under-prediction of around 9 km hr^{-1}. More detailed evaluations of simulations of extremes in individual elements will be conducted in further work.

TABLE 1. DETAILS OF FIRE WEATHER EVENTS, REPRESENTATIVE VALUES FROM THE WRF MODEL (WRF) AND COMPARISONS WITH OBSERVATION (OBS) AND BRIEF SUBJECTIVE COMMENTS. 'UTC' INDICATES XXX.

EVENT	DATE (YEAR, MONTH, DAY)	TIME (UTC)	LOCATION	WRF/OBS TEMPERATURE (°C)	WRF/OBS RELATIVE HUMIDITY (%)	WRF/OBS WIND SPEED (KM HR^{-1})	COMMENTS
BLACK SATURDAY	2009 02-07	0200	MELBOURNE AIRPORT	42.6/44.1	12/7	51/48	EXCELLENT SIMULATION. WIND CHANGE GENERALLY WITHIN 1 HOUR AT MOST OBSERVATION STATIONS.
BRISBANE RANGES	2006 01-22	0400	SHEOAKS	41.0/40.3	18/22	38/48	OBSERVED COOL CHANGE AT SHEOAKS BETWEEN 0800 AND 0830 UTC - WRF AN HOUR EARLY AT AROUND 0700 UTC. TEMPERATURE, HUMIDITY AND WIND APPEAR EXCELLENT FOR MAJOR FIRE PERIOD.
ALPINE BREAKOUT	2003 01-30	0100	MT HOTHAM	28.2/20.2	29/34	46/59	WRF SIMULATED OVERNIGHT STRONG WINDS, DAYTIME STRONG WINDS OVER THE MT HOTHAM AREA. ALSO EXCELLENT SIMULATIONS OF COOL CHANGE STRUCTURE AND TIMING BOTH NORTH AND SOUTH OF THE RANGES.
CANBERRA	2003 01-18	0400	CANBERRA AIRPORT	36.8/36.9	16/8	32/48	SOUND SIMULATION OF MAJOR FIRE WEATHER PERIOD AROUND MIDDLE OF THE DAY. EXCELLENT SIMULATION OF EVENING EASTERLY COOL CHANGE IN TERMS OF TIMING AND STRUCTURE. ALSO SHOWED EFFECTS OF MID-TROPOSPHERIC DRY BAND MIXING TO THE SURFACE.
KING ISLAND SMOKE	2001 01-11	0300	GROVEDALE	38.3/39.4	16/12	30/41	FIRE WEATHER SIMULATED WELL IN TERMS OF PATTERN, BUT SLIGHTLY LOW FOR TEMPERATURE, RELATIVE HUMIDITY AND WIND SPEED IN UNCORRECTED WRF. WIND CHANGE TIMING AT GROVEDALE AND MOORABBIN EXCELLENT.
LINTON	1998 12-02	0300	LINTON	26.5/28.0	39/24	36/44	METEOROLOGICAL PARAMETERS WELL SIMULATED DURING AFTERNOON FIRE RUN. OUTSTANDING TIMING FOR WIND CHANGE SIMULATION.
DANDENONG RANGES	1997 01-27	0300	SCORESBY	33.7/36.2	29/17	25/33	EXCELLENT SIMULATION, PARTICULARLY FOR STRUCTURE AND TIMING OF WIND CHANGE.
BERRINGA	1995 02-25	0400	BERRINGA	36.1/37.0	15/5	18/30	GOOD SIMULATION OVERALL AND EXCELLENT SIMULATION OF TIMING AND STRUCTURE OF MESOSCALE WIND CHANGE.
STRATHBOGIE	1990 12-27	0400	BENALLA	38.0/35.0	12/15	46/65	EXCELLENT SIMULATION OF EXTREME FIRE WEATHER, INCLUDING INVERSION BREAKING AND RAPID CHANGES IN WIND SPEED AND RELATIVE HUMIDITY.
BEMM RIVER	1988 10-14	0200	ORBOST	28.8/30.0	28/27	40/95	INTERESTING FOEHN CIRCULATIONS LEADING TO ENHANCED FIRE WEATHER.
ASH WEDNESDAY	1983 02-16	0500	MELBOURNE AIRPORT	41.1/42.0	13/5	36/44	GOOD SIMULATIONS OF TEMPERATURE AND WIND SPEED DURING THE AFTERNOON. WINS SPEED BIASED LOW LATER IN THE DAY. EXCELLENT WIND CHANGE TIMING AND STRUCTURE ACROSS THE STATE, PARTICULARLY IN WEST AND ON SURF COAST.
MELBOURNE DUST STORM	1983 02-08	0400	MELBOURNE AIRPORT	42.4/41.0	10/3	34/42	GOOD SIMULATION OF TEMPERATURE AND WIND SPEED DURING THE AFTERNOON. WIND SPEED BIASED LOW LATER IN THE DAY. EXCELLENT WIND CHANGE TIMING AND STRUCTURE ACROSS THE STATE.
WESTERN DISTRICT FIRES	1977 02-12	0500	STREATHAM	37.4/38.0	19/15	42/55	GOOD SIMULATION OF EXTREME FIRE WEATHER AHEAD OF COOL CHANGE, BUT TIMING OF COOL CHANGE WAS POOR.

Black Saturday – 7th February 2009

Black Saturday was a devastating fire that led to the loss of 173 lives in Victoria on 7th February 2009. On this day many parts of the state experienced record breaking maximum temperatures and strong winds that grew as the day progressed and with the cool change came a wind change that greatly intensified the fires and the danger (Teague *et al.* 2010). The temperature and relative humidity at 0400 UTC (3pm local time) is shown in Figure 2 when the cool change was just inland from the coastline in western Victoria, and temperatures above 42°C and relative humidities below 15% are simulated over much of western and central Victoria ahead of the cool change. Figure 2 also shows the wind direction and speed. The timing and structure of the change is excellent, with the faster movement of the southern portion of the change, and the areas of stronger post-change winds, well represented.

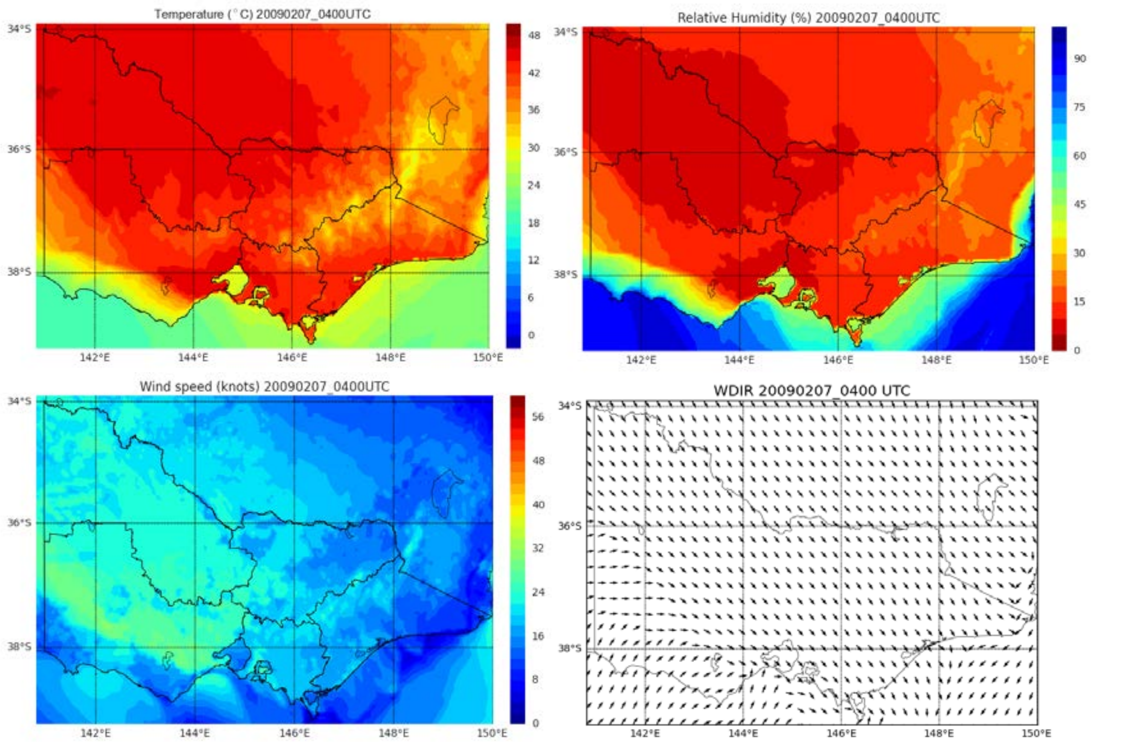


FIGURE 2: TEMPERATURE, RELATIVE HUMIDITY, WIND SPEED AND WIND DIRECTION AT 0400 UTC ON 7TH FEBRUARY 2009 (3 PM LOCAL TIME).

Ash Wednesday – 16th February 1983

The Ash Wednesday fires were a series of fires that occurred in south eastern Australia in which 75 people across Victoria and South Australia lost their lives (Pyne, 1991). Figure 3 shows very high temperatures and low relative humidity across Victoria, apart from the far east, on the afternoon of Ash Wednesday (4pm local time - 0500 UTC). In addition, very strong winds are developing in the west of state, with only weak backing in far west at this time (10pm local time - 1100 UTC). Importantly, the incipient development of a coastal change between Portland and Warrnambool is simulated in the fields from the WRF model. This was not resolvable with the 3-hourly observations available at the time.

Furthermore promising results were found in regards to wind direction. The simulation of wind change timing at a large number of stations across the state using the WRF model were very good on Ash Wednesday (see Table 2).

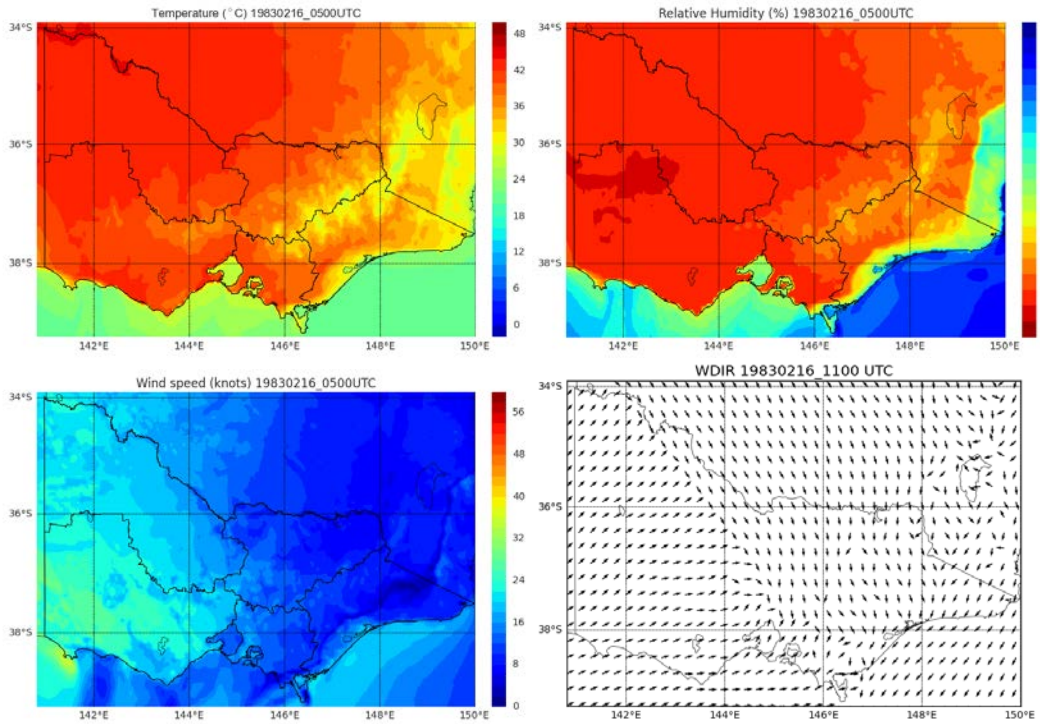


FIGURE 3: TEMPERATURE, RELATIVE HUMIDITY AND WIND SPEED AT 0500 UTC ON 16 FEBRUARY 1983 (4 PM LOCAL TIME) AND WIND DIRECTION AT 1100 UTC (10 PM LOCAL TIME).

TABLE 2. OBSERVED (BUREAU OF METEOROLOGY 1984) AND INTERPOLATED WRF CHANGE TIMES

STATION	CHANGE TIME (EDST)	CHANGE TIME (UTC)	WRF TIME (UTC)
HAMILTON	1800	0700	0700
NHILL	1800	0700	0700
CAPE OTWAY	1810	0710	0600
HORSHAM	1823	0723	0730
LORNE	1900	0800	0700–0800
ANGLESEA	1924	0824	0800–0900
AVALON	1958	0858	0930
MELBOURNE AIRPORT	2040	0940	1030
EAST SALE	2230	1130	1200
MANGALORE	2230	1130	1130
ORBOST	2400	1300	1500
MILDURA	2035	0935	1115

CLIMATOLOGY OUTPUTS – APPLICATIONS OF THE DATASET

Diurnal cycle

Figures 4 and 5 show mean temperature and relative humidity at midday (12 pm) and midnight (12 am) in January. There is a clear contrast between day and night with higher temperature and lower humidity during the day with the largest contrast between day and night occurring closer to the coast for the period. For both day and night, the mean temperature increases with distance inland, ranging at night from 10–15°C near the coast to 25–30°C inland and, during the day, ranging from 15–20°C near the coast to 30–35°C inland. Relative humidity decreases from the coast to inland with night time humidity at 100% near the coast decreasing to 30–40% inland. During the day the mean relative humidity was as high as 60–70% in some small regions near the coast and decreased to 20–30% inland.

Information on the diurnal cycle can inform when the fire weather peaks (when the hottest, windiest and driest conditions occur), and when and for how many hours temperatures are high and humidity is low. Furthermore, the diurnal cycle is also important for understanding the weather conditions in the shoulder periods, when conditions are less extreme, and also overnight, as these conditions also contribute to the fire danger.

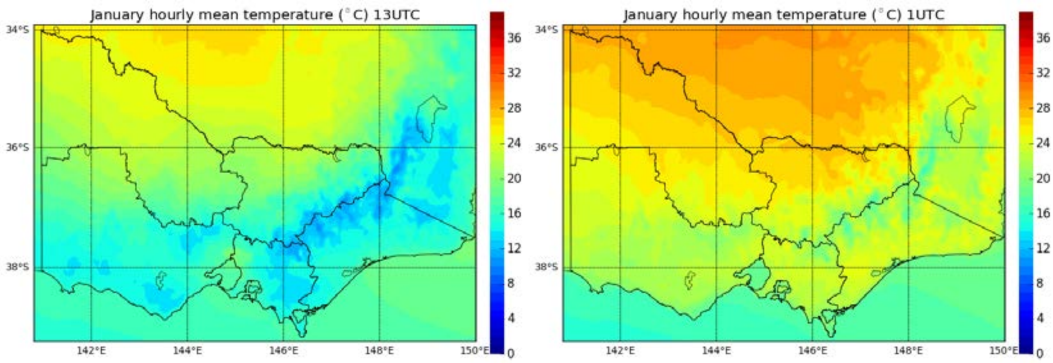


FIGURE 4: MEAN JANUARY TEMPERATURE AT 12 AM AND 12 PM (LOCAL TIME) (1972-2012)

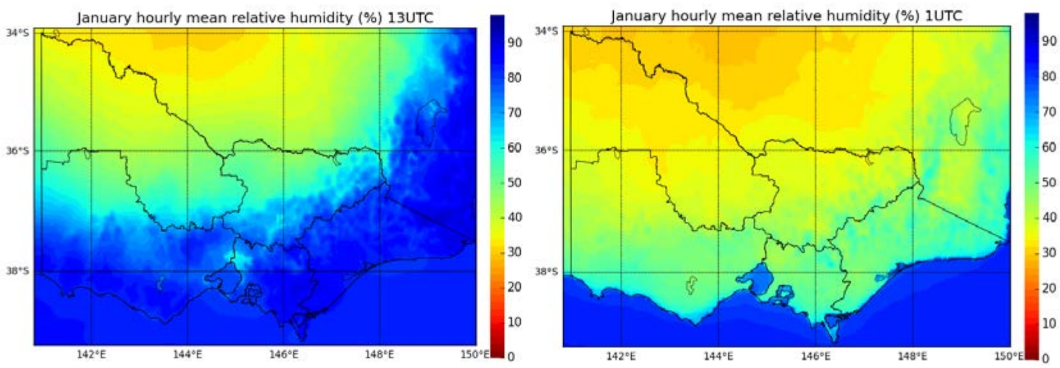


FIGURE 5: MEAN JANUARY RELATIVE HUMIDITY AT 12 AM AND 12 PM (LOCAL TIME) (1972-2012)

Interannual variability

Time series analyses are useful for identifying changes between months, seasons and years and to identify any longer term climate patterns and relationships with other features such as climate oscillations. For example, time series plots for Victoria (Figure 6) reveal the interannual variability in monthly maximum temperatures. Over the last 41 years, the mean monthly maximum for Victoria is 26.5°C for the study area (study area range can be viewed in Figure 5 and included areas of ocean and other states outside Victoria) with a standard deviation of 6.5°C. The hottest monthly maximum of 39°C was experienced in 2009. The average monthly minimum relative humidity is 32.5% with a standard deviation of 8% (Figure 7). The lowest average minimum relative humidity across the study area was 18% in 2009.

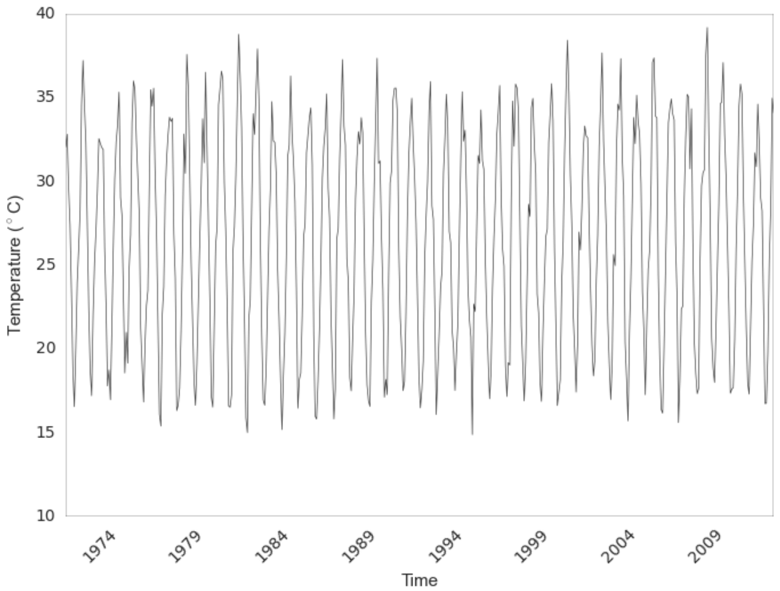


FIGURE 6: MONTHLY MAXIMUM TEMPERATURE (°C) AVERAGED ACROSS STUDY AREA 1972-2012.

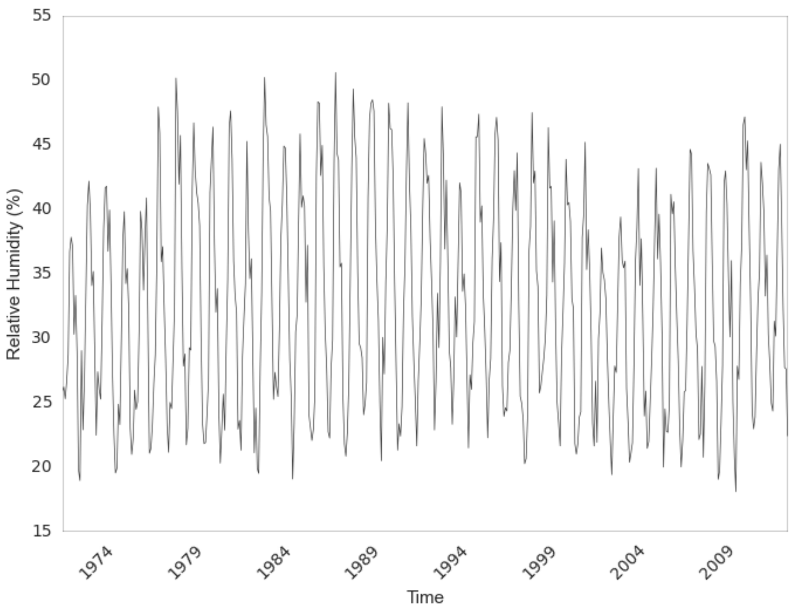


FIGURE 7: MONTHLY MINIMUM RELATIVE HUMIDITY (%) AVERAGED ACROSS STUDY AREA 1972-2012.

Extremes

Contour plots of extremes allows for assessment of the spatially variability of the extreme values. Across Victoria, the lowest maximum temperature reached in December, January or February (DJF) for the period 1972–2012 was 30°C (Figure 8). However, there was large spatial variability—in mountainous regions the maximum temperature range was 30–35°C, in coastal regions the range was 35–40°C, and in inland areas temperatures were up to 45°C. In contrast, the minimum relative humidity for some parts of inland Victoria was less than 5%, with most of Victoria experiencing less than 15% at some stage in the summer months over the 41-year period (Figure 8). Further work will assess these extremes in comparison to AWS data and other gridded weather products such as the Australian Water Availability Project (AWAP) dataset.

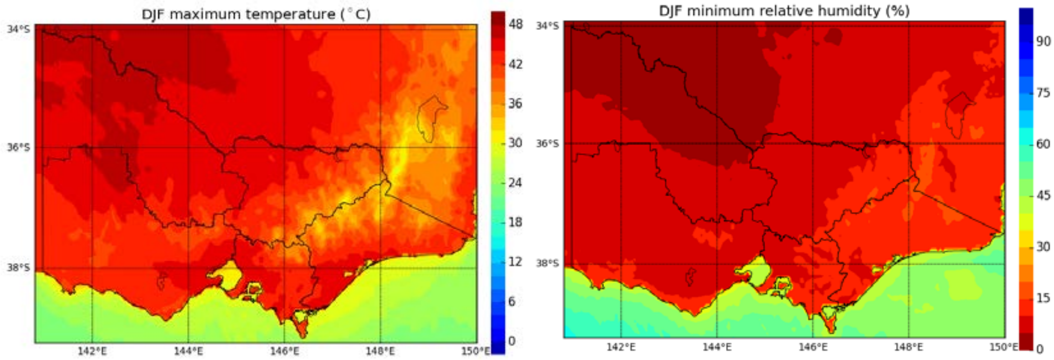
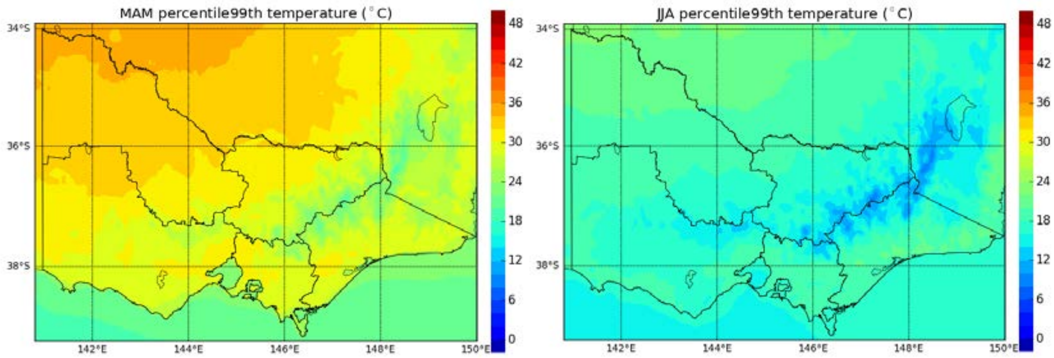


FIGURE 8: MAXIMUM TEMPERATURE AND MINIMUM RELATIVE HUMIDITY FOR DECEMBER, JANUARY OR FEBRUARY (1972–2012)

Knowledge of maximum and minimum conditions is important for preparing for worst-case situations. However, using percentiles may be more useful for planning and preparedness and working with different scenarios. As an example, Figure 9 shows the 99th percentile of temperature for 1972–2012 for each season. Temperatures are obviously higher in the DJF period and cooler in the June, July, August (JJA) period and the spatial variability is evident for all seasons. This type of information could also be included in optimising planned burning schedules by identifying periods where conditions are most favourable for burning.



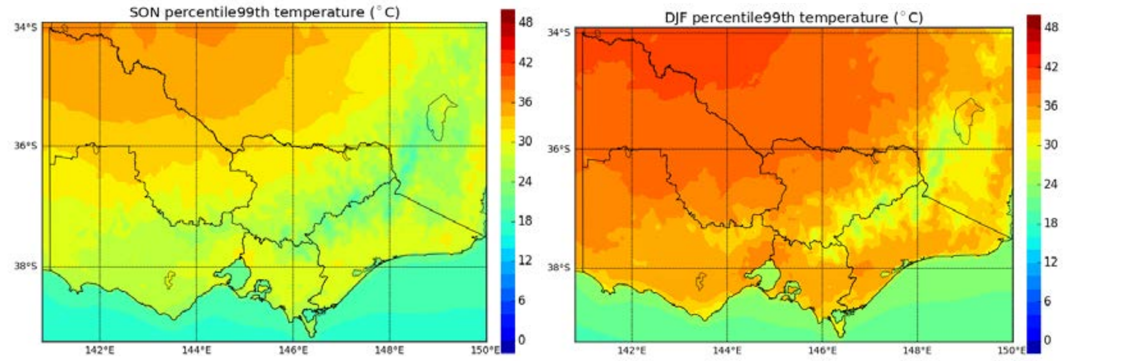


FIGURE 9: THE 99TH PERCENTILE OF TEMPERATURE FOR EACH SEASON 1972–2012 – MARCH, APRIL, MAY (MAM), JUNE, JULY, AUGUST (JJA), SEPTEMBER, OCTOBER, NOVEMBER (SON) AND DECEMBER, JANUARY, FEBRUARY (DJF)

DISCUSSION AND CONCLUSION

The Victoria fire weather climatology dataset described here is the only hourly long-term 4-km dataset containing temperature, relative humidity, wind speed and wind direction that is currently available. This paper summarises the development and potential applications of this spatially- and temporally-homogenous dataset. The results of evaluations, observation-fitting statistics, application of case-studies and climatological assessments show that the quality of the data set is such that there is great potential with a number of applications and analyses to which this data set might be usefully applied.

This study found that the simulations using the WRF model slightly under-predicted wind speed during the day. Temperature was slightly over-predicted and relative humidity was slightly under-predicted during the day, with opposite biases at night. The ability of the WRF model to simulate extremes have yet to be fully evaluated, however, case studies indicated promising results. Overall, these results are impressive for such high temporal and spatial resolution. Other models can only simulating daily outputs, often for shorter periods and coarser spatial resolutions. Further assessment will be done to review any diurnal, seasonal and elevation biases.

In planned future work, a bias correction will be applied to address any anomalies identified in the dataset. In addition, we will assess outputs from the WRF model in relation to precipitation. From this, a dataset containing daily drought factors, the Keetch-Byram drought index and a highly-anticipated hourly Forest Fire Danger Index will be constructed. The opportunities to use this dataset for research purposes and for fire management are immense, with the outputs providing an almost limitless opportunity for analyses. Furthermore, as the WRF model can produce hourly 3-dimensional fields of all atmospheric variables, there is the opportunity to assess the climatology of above-surface weather on fire activity at a scale and resolution that has not been possible for Victoria before.

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REFERENCES

1. Andrys J, Lyons TJ, Kala J. Multidecadal evaluation of WRF downscaling capabilities over Western Australia in simulating rainfall and temperature extremes. *Journal of Applied Meteorology and Climatology* 2015 54, 370–395.
2. Blanchi R, Leonard J, Haynes K, Opie K, James M, de Oliveira F. Environmental circumstances surrounding bushfire fatalities in Australia 1901–2011. *Environmental Science & Policy* 2014 37, 192–203.
3. Brown T, Mills G, Harris S, Podnar D, Reinbold H, Fearon M. Fire weather climatology dataset. 2015 *Report for the Department of Environment, Land, Water and Planning*. Victoria.
4. Clarke H, Evans JP, Pitman AJ. Fire weather simulation skill by the Weather Research and Forecasting (WRF) model over south-east Australia from 1985 to 2009. *International Journal of Wildland Fire* 2013 22, 739–756.
5. Dee, D. P., and 35 co-authors. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Quarterly Journal Royal Meteorological Society*, 2011 137, 553-597.
6. Gill AM, Stephens SL, Cary GJ . The worldwide 'wildfire' problem. *Ecological Applications* 2013 23, 438–454.
7. Jones D, Wang W, Fawcett R. A high quality spatial historical data set for Australia. *Australian Meteorological and Oceanographic Journal* 2009 58, 233–248.
8. Kalnay E and co-authors. The NCEP/NCAR 40-year reanalysis project. Bulletin of the American Meteorological Society, 1996 77, 437-471.
9. Lucas, C. On developing a historical fire weather data-set for Australia. *Australian Meteorological and Oceanographic Journal*, 2010 60, 1-14.
10. Mills, G.A., and McCaw, L. *Atmospheric Stability Environments and Fire Weather in Australia – extending the Haines Index*. 2010 CAWCR Technical Report No20, 158pp. CSIRO and Bureau of Meteorology, Victoria
11. Mills, G., Brown, T., Harris, S., Podnar, D. and Reinbold, H. A 40-year mesoscale gridded fire weather climatology for Victoria – an overview. *20th International Congress on Modelling and Simulation*, Adelaide, Australia, 2013 1-6 December 2013 p207-213 www.mssanz.org.au/modsim2013
12. National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce, 2000: *NCEP FNL Operational Model Global Tropospheric Analyses, continuing from July 1999*. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory, Boulder, CO. [Available online at http://dx.doi.org/10.5065/D6M043C6.]
13. Pyne,S. Burning Bush. A Fire History of Australia. *Allen and Unwin*,1991 Sydney
14. Simpson, C. C., Pearce, H. G., Sturman, A. P. and Zawar-Reza, P. Verification of WRF modelled fire weather in the 2009-10 New Zealand fire season. International Journal of Wildland Fire 2013 23, 34-45
15. Skamarock, W., Klemp, J., Dudhia, J., Gill, D., Barker, D., Duda, M., Wang, W. & Powers, J. A Description of the Advanced Research WRF Version 3, 2008 *NCAR Technical Note NCAR/TN-475+STR.*
16. Teague, B., Mcleod, R., and Pascoe, S., 2009 Victorian Bushfires Royal Commission Report. 2010 Government Printer for the State of Victoria, Melbourne, Australia.
17. Tolhurst K.G., Shields, B.J. and Chong, D.M. PHOENIX: development and application of a bushfire risk management tool. *Australian Journal of Emergency Management* 2008 23, 47-54.
18. Uppala, S.M., and coauthors. The ERA-40 re-analysis. *Quarterly Journal Royal Meteorological Society*, 2005 131, 2961-3012.doi:10.1256/qj.04.176