

ON DETERMINING THE IMPACT OF INCREASING ATMOSPHERIC CO₂ ON THE RECORD FIRE WEATHER IN EASTERN AUSTRALIA IN FEBRUARY 2017

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February 2017 saw a broad region with record fire weather across central-eastern Australia. A hybrid attribution technique using modified observations and a seasonal forecast framework did not give a clear signal as to the influence of increasing atmospheric CO₂ on the fire weather.

INTRODUCTION. Studies of the climate change influence on the potential for wildfires (bushfires, as they are called in Australia) require an association to be made between meteorological and land surface metrics and wildfire risk factors such as fire weather conditions, fuel conditions, and ignition factors, as well as fire behavior, severity, or extent. Some studies assess the availability and dryness of the fuel or proxies thereof (Nicholls and Lucas 2007; Yoon et al. 2015; Partain et al. 2016; Abatzoglou and Williams 2016). Aspects of the weather of relevance to the potential for fire have also been assessed, including the intensity of fronts or the dryness of the air (Hasson et al. 2009; Grose et al. 2014; Tett et al. 2018). All of these studies found an enhancement of the potential fire danger in some regions due to ongoing climate change.

The McArthur Forest Fire Danger Index (FFDI) (McArthur 1967) combines an estimate of fuel dryness and the relevant weather features and is commonly used to describe wildfire danger in Australia (Clarke et al. 2013; Dowdy et al. 2010). Such a combined metric has not been used in an event attribution study before. Recently, a gridded FFDI dataset has been developed using winds from reanalyses

with observed rainfall and temperature for 1950 to the present (Dowdy 2018). Using this new dataset and an established event attribution technique using a seasonal forecast framework (Wang et al. 2016; Hope et al. 2016) we aim to estimate the influence of increasing levels of atmospheric CO₂ on the FFDI in eastern Australia.

THE EVENT. The first two weeks of February 2017 (late austral summer) saw unusually extreme widespread fire danger across central eastern Australia, particularly in northern New South Wales. “Eastern Australia” (east of 141°E, between 20° and 38°S) had the highest average FFDI for the first half of February in the record starting 1950 (Dowdy 2018). During this event the “Sir Ivan” fire burned 55,000 ha (www.abc.net.au/news/2017-08-16/nsw-fires-2017-sir-ivan-fire-recovery/8810284) through central northern New South Wales in fire weather conditions rated as “catastrophic” (FFDI equal to or greater than 100) by fire agencies (Fig. 1a). Intense pyrocumulonimbus was initiated by the fire, leading to subsequent fire ignition by lightning ahead of the main fire front. Extreme wildfire behavior such as this is very rare, with examples including Black Saturday in southeast Australia in 2009, the Fort McMurray fire in Alberta, Canada, in May 2016, and the Waroona fire in January 2016 in Western Australia (Ferguson 2016; Dowdy et al. 2017b). The 12 February 2017 was the highest observed daily estimate of FFDI averaged over eastern Australia for all days in the first two weeks of February. The second highest value was on 7 February 2009, Black Saturday. During this fortnight in 2017 there was no rainfall across most of the region and extremely high daily maximum temperatures (Fig. 1b), and low relative humidity (Fig. 1e).

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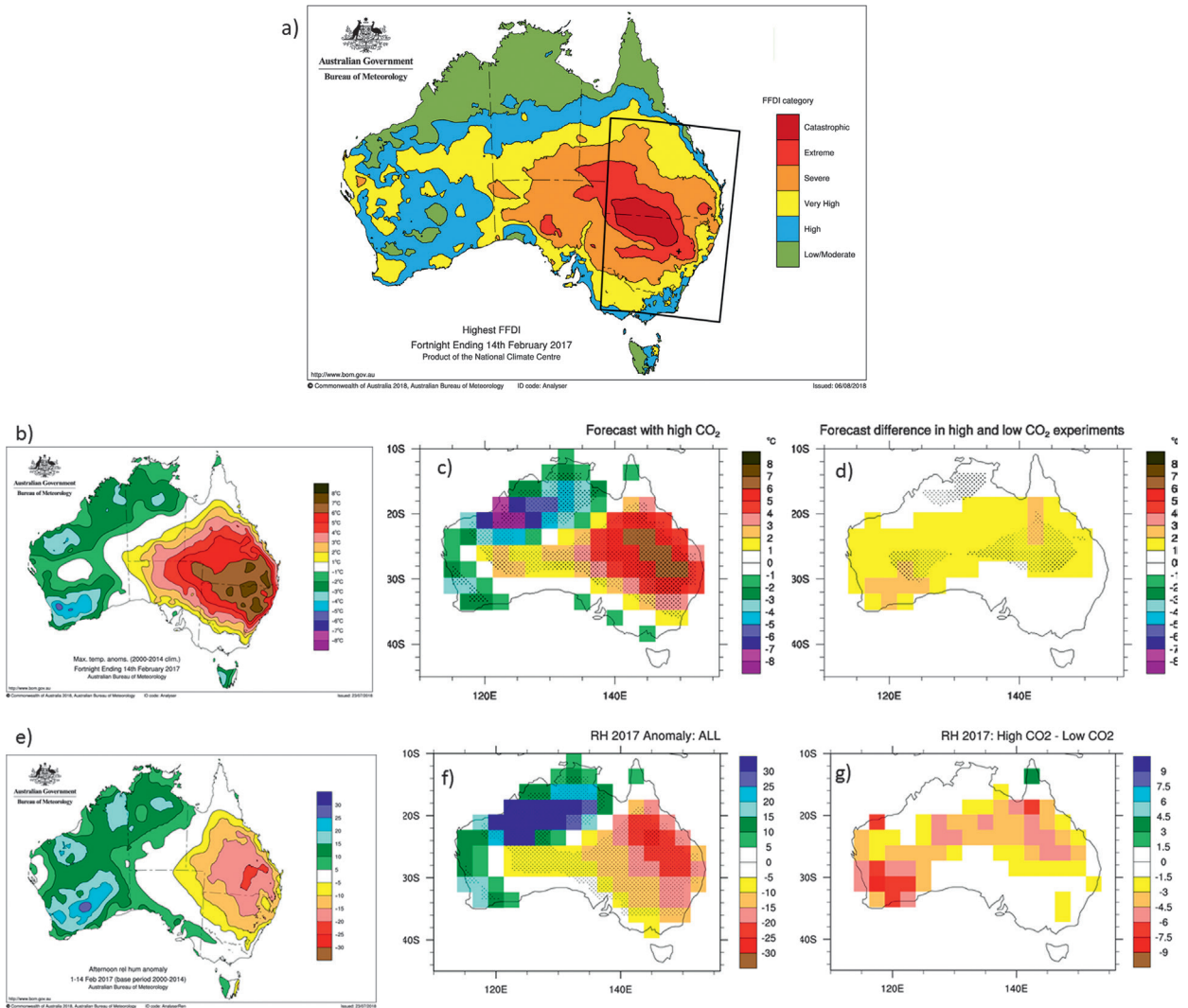


FIG. 1. (a) Observed maximum daily FFDI during 1–14 Feb 2017. The box indicates the region that defines the event and over which variables were averaged. The black dot indicates the region of the Sir Ivan fire. (b) Observed Tmax anomaly 1–14 Feb 2017 against a 2000–14 climatology (°C). (c) Forecast Tmax anomaly under current conditions; stippling indicates a significant difference from the 2000–14 mean, given the spread, at 10% level. (d) Current minus low-CO₂ anomaly. Stippling indicates a significant difference in the means, given the ensemble spread, at 10% level. (e)–(g) As in (b)–(d), but for relative humidity (%).

Prior to this period of intense fire risk, antecedent conditions were generally very dry, with many locations in the lowest 10% (decile 1) for accumulated rainfall totals since December. The summer had also been hot; New South Wales experienced its warmest summer on record, 2.56°C above the historical (1961–90) average (Bureau of Meteorology 2017).

There are known associations between large-scale climate drivers, such as ENSO, and fire risk (e.g., Black 2017). ENSO and the Indian Ocean dipole (IOD) were close to neutral during the summer of 2016/17. Indices in the preceding spring were in phases less favorable to summer extreme fire danger (Williams and Karoly 1999; Cai et al. 2009), as the

dipole mode index (www.bom.gov.au/climate/enso/indices.shtml?bookmark=iod) was negative and the Southern Oscillation index (SOI; www.bom.gov.au/climate/enso/soi/) indicated a weak La Niña, both of which are associated with increased rainfall over southeastern Australia (e.g., Risbey et al. 2009). For the subseasonal drivers, the southern annular mode (SAM; <https://legacy.bas.ac.uk/met/gjma/sam.html>) was negative in the preceding spring and the Madden–Julian oscillation was in phases 6 and 7 (www.bom.gov.au/climate/mjo/graphics/rmm.74toRealttime.txt). These phases are linked to dry conditions in central eastern Australia (Marshall et al. 2011; C. Lucas 2018, personal communication). Thus the large-

scale drivers were generally working against high fire danger conditions, although the phase of subseasonal drivers would have encouraged dry conditions.

METHOD. The event is defined as the record-breaking FFDI during 1–14 February 2017 over the east Australian region: east of 141°E, between 20° and 38°S. Below we describe a hybrid scheme used in an effort to assess the influence of increasing levels of atmospheric CO₂ on the intensity of this event.

The equation for the FFDI is as follows:

$$\text{FFDI} = 1.2753 \times \exp[0.987 \times \ln(\text{DF}) + 0.0338 \times \text{Tmax} + 0.0234 \times V - 0.0345 \times \text{RH}],$$

where Tmax is the daily maximum temperature (°C); RH is the afternoon (3 p.m.) relative humidity (%) calculated from the mixing ratio, mean sea level pressure, and temperature; and *V* is the afternoon (3 p.m.) 10-m wind speed (km h⁻¹) for each day of the first two weeks of February 2017. The drought factor (DF) represents a temporally accumulated antecedent soil moisture deficit derived from temperature and rainfall data from 20 days prior to the targeted fire danger period (Keetch and Byram 1968; Finkele et al. 2006).

The seasonal forecast attribution method of Wang et al. (2016) is used to assess the Tmax, RH, and wind during the first two weeks of February in the current and a low-CO₂ environment.

The seasonal forecast model, the Predictive Ocean Atmosphere Model for Australia version 2 (POAMA-2), was until recently the operational seasonal forecast system of the Australian Bureau of Meteorology. Using an observation-based DF means that the forecast can be initialized at shorter lead time (no need for the 20-day lead-in to calculate DF), and thus the forecasts are more likely to better reflect the weather associated with the event.

Eleven-member ensemble forecasts were initialized on 26 January with realistic atmosphere (including observed 2017 atmospheric CO₂ concentration of ~406 ppm), ocean, and land conditions, and verified for 1–14 February 2017. A second, low-CO₂, 11-member ensemble forecast was initialized with the same initial conditions, but from which the influence of the last 57 years of CO₂ increase was removed from the temperature and salinity through the full depth of the ocean (Fig. ES2 in the online supplemental material shows the sea surface temperature anomaly). Anomalies of change in the atmospheric temperature and humidity and also land surface temperature and soil moisture were also removed prior to initializa-

tion, following Wang et al. (2016). Atmospheric CO₂ was set to 1960 values (315 ppm). The very deep ocean might contain information from other anthropogenic forcing aside from CO₂; however, given the short lead time of the forecast used in this study, the CO₂ change will be the dominant factor.

The same forecast method was applied to create 11-member ensemble forecasts for the years 2000–14 to represent the climatology of the current climate. Atmospheric CO₂ was set to each year's value. The low-CO₂ climatology was created with starts from the same dates in 2000–14, but with the modifications used in the 2017 experiment to capture a low-CO₂ climate. CO₂ was set to 315 ppm.

For the calculation of the FFDI we developed a hybrid approach using observations to estimate the DF in the setup of a subseasonal forecast of the event. A hybrid approach was required because the forecast was good at the short lead time used, but lengthening the lead time to more than 20 days prior to the event to allow the calculation of the DF resulted in a poor forecast with this system.

The DF is calculated from observed [Australian Water Availability Project (AWAP); Jones et al. 2009] rainfall and temperature for the 20 days prior to the event and throughout the event. To account for the influence from increasing levels of atmospheric CO₂ on the DF, we apply a simple shift in the temperature data. Climate change has been shown to influence upward trends in southeast Australian daily maximum temperature (Tmax) (Karoly and Braganza 2005) and extreme heat events (Black and Karoly 2016). Observed Tmax trends since 1960 show an upward trend (Fig. ES1a), and, to account for natural variability, we choose a conservative estimate of 1°C to remove from the temperature in the low-CO₂ calculation of the FFDI. No change is applied to the precipitation as it is unclear on the direction of change in summer rainfall due to CO₂ increase (CSIRO and Bureau of Meteorology 2015), although there is a slight drying trend since 1960 (Fig. ES1b).

RESULTS. The POAMA2 forecast captured the hot and dry conditions well. For 1–14 February, the extreme heat across eastern Australia was well forecast in the current climate, with significant differences from the 2000–14 climatology at 10% level (Fig. 1c). The low-CO₂ Tmax was also well forecast when compared to the low-CO₂ climatology. Using the forecast attribution system, it was significantly warmer in the northern part of the region in the current climate compared to the same event in a low-CO₂ “1960” climate, but there was little change in the southern part of the region.

The observed relative humidity was low during this period across most of the region of interest (Fig. 1e), and it was also well forecast (Fig. 1f). The event in the current climate had lower RH than in a low-CO₂ climate in the north of the region. While the RH difference in the current minus low-CO₂ climate is large, the difference is not significant at the 10% level across the 11-member ensemble. Aspects of the wider circulation were less well forecast, but local westerly winds were evident in both the observed anomalies for the 2-week period and the forecasts, bringing dry inland air to the region of extreme FFDI (not shown).

Using the hybrid method to estimate the FFDI, the pattern is well forecast in the current climate (Fig. 2a) and reflects the observed interannual variability (Fig. ES3a). Early February 2017 had the highest FFDI anomaly compared to the climatology (Fig. ES3a). The very dry conditions captured by the observed rainfall component of the DF contributed to the high value of FFDI in 2017. The estimate of 2017 FFDI calculated with cooler temperatures and forecast in a low-CO₂ climate also reflects the observed anomaly pattern. The differences between the two estimates are small (Fig. ES3b), with strong overlap between the ensemble members.

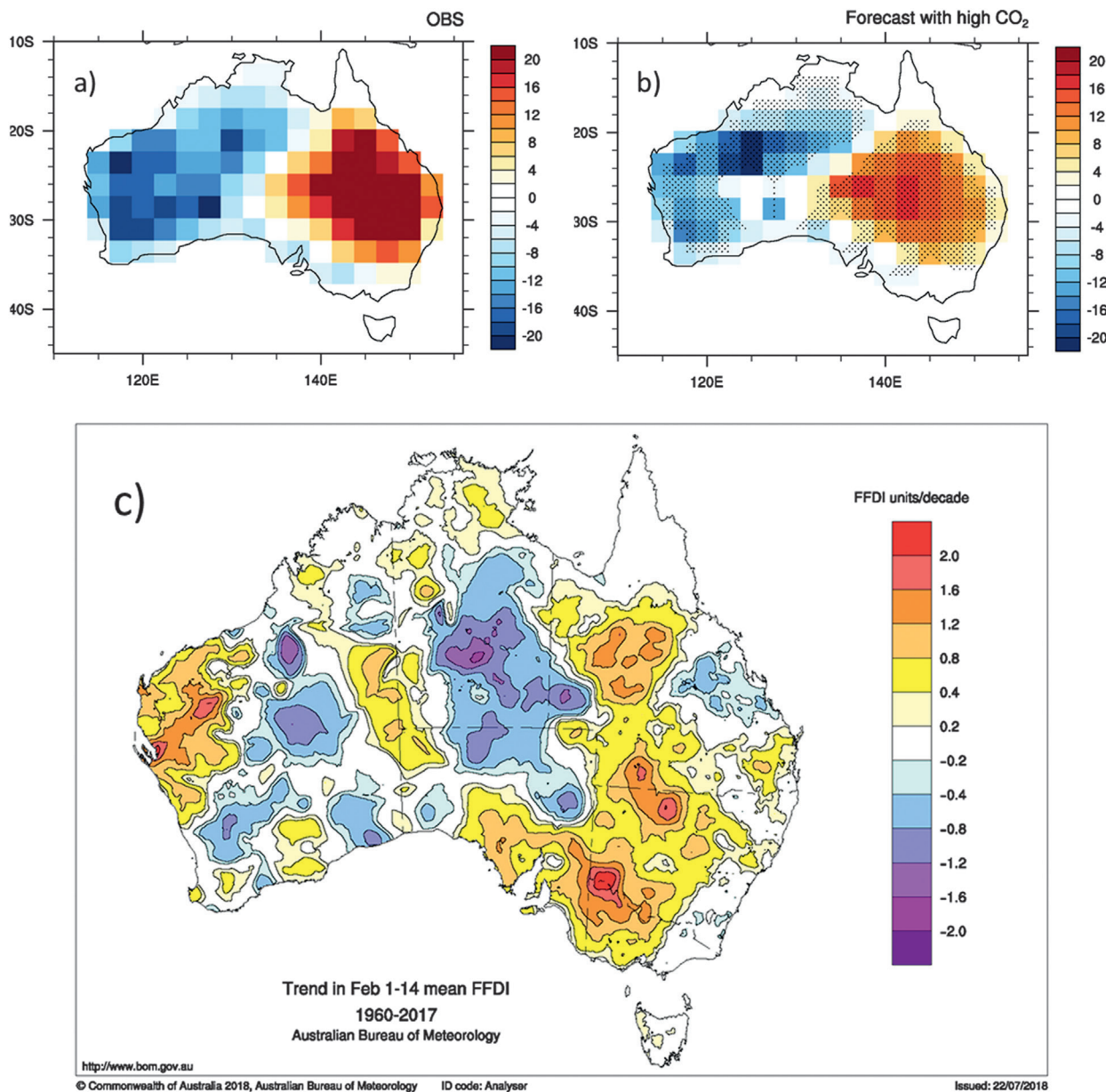


FIG. 2. (a) Observed averaged daily FFDI 1–14 Feb 2017 anomaly [Dowdy (2018) dataset; FFDI units] against a 2000–14 climatology. (b) Hybrid observed–POAMA forecast anomaly of the same event. (c) The observed linear trend 1960–2017 in observed estimated daily average FFDI (FFDI units per decade) for 1–14 Feb.

DISCUSSION. This extreme event occurred on the background of an upward trend in FFDI from 1960 to 2017 in the region (Fig. 2c). This might suggest that ongoing climate change is causing an increase in the potential for extreme fire danger in eastern Australia. However, observed trends can be influenced by other factors, including natural variability. In 2017, some measures of natural variability (ENSO and IOD) were not favoring high fire danger conditions, although the subseasonal drivers were.

Trends in some components of the FFDI metric have been attributed to increasing CO₂—notably Tmax (e.g., Williams et al. 2001). Our seasonal forecast experiments indicate that CO₂ caused an increase in Tmax in the north of the region during this particular event. Thus we can have some confidence that increasing Tmax enhanced FFDI values in the north of the region.

RH is also found to be lower for this event in the current climate than in the low-CO₂ climate in the north of the region, and thus the air was drier, although the spread across the forecast ensemble members was large. The wind was generally from the west in both the observations and forecasts, which would bring dry continental air toward the region. However, there was also large spread across the members and the timing and location of particular weather events. The magnitude of the (uncorrected) hybrid estimate of FFDI is smaller than the estimate from observations (Fig. ES3), and this is probably due to shortcomings in representing finescale features of the wind variation. Wind is difficult to include in metrics of fire danger, even for those built on observations (Lucas 2010; Clarke et al. 2013).

In developing a hybrid method to estimate the FFDI, we make assumptions about how temperature and rainfall have changed due to increasing levels of atmospheric CO₂. The change in temperature is reasonably clear, but the summer precipitation change can vary widely under future levels of CO₂ increase (CSIRO and Bureau of Meteorology 2015) and there have been no clear attribution studies of the February trends to date. The forecast precipitation from this experiment was drier through most of the region in the current climate compared to the low-CO₂ climate. Ideally, we would draw the DF from the forecast itself, if there was skill at 20 days lead time. This system did not have skill at that lead time for this event.

This preliminary study of attributing the record high fire risk fortnight to CO₂ change has produced some indication that increasing atmospheric CO₂ led to higher temperatures and reduced RH. Those factors would lead to enhanced fire danger. A full sensitivity

analysis of the importance of each component to the resultant FFDI would strengthen any statement that we might make using this system.

POAMA2, as part of the seasonal forecast attribution framework used here, has limitations in simulating the wind associated with this event, and has limited skill at lead times long enough to calculate the DF directly. A higher-resolution system forced with sea surface boundary conditions, weather@home for example (Black et al. 2016), might better represent the lead-in time required for the DF and the event itself (e.g., Black 2017). However, the ability to forecast the actual event in question is a major strength of an initialized system, particularly in an operational context. Some modeling groups already issue seasonal forecasts of fire risk indices (<https://cefa.dri.edu/CFS/fwi.php>). In Australia, a new operational seasonal forecast model with finer resolution has been shown to have skill in forecasting FFDI (Dowdy et al. 2017a). As forecast skill at longer lead time improves, the full FFDI can be calculated directly from model output, removing the need for a hybrid approach, and attribution statements could be made for extreme fire danger for every event that is well forecast.

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