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Changes in fire and carbon dynamics for projected future climates in the south eastern Australian high country

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Abstract

There is mounting evidence that warmer and drier climates will result in an increase in fire activity. Lower fuel moistures result in an increase in fuel availability, and hence a greater probability of fire ignition success, with fires potentially burning for extended periods and at higher intensities. At present, the implications of these anticipated changes in fire regimes for carbon dynamics in Australian ecosystems are unclear. This study attempts to address this by combining the carbon dynamics model FullCAM and the landscape fire regime simulator FIRESCAPE to investigate the relative effects of projected climate changes on fire and carbon dynamics in the south eastern Australian high country. Three climate scenarios were simulated, representing the present climate and two projections for the year 2070. To encompass the range of climate change scenarios, both projected changes are based on anticipated global populations peaking mid-century, with one projection resulting from the use of fossil intensive technologies (A1FI), and the other projection resulting from the use of clean and resource-efficient technologies (B1). The 2 million hectare study landscape predominantly contains a diversity of native forest communities, with some areas containing native and pasture grasses, shrub communities and *Pinus radiata* plantations.

Simulations using the FIRESCAPE / FullCAM hybrid model indicate that both fire regimes and carbon dynamics are sensitive to projected changes in climate, with the greatest deviances evident for the warmest and driest climate (A1FI). In simulations, the fire incidence, fire areas and fire intensities all increased as the climate became warmer and drier. Declines in carbon stocks were also evident across the landscape as shorter inter-fire intervals in all vegetation communities resulted in younger stand ages and hence reduced biomasses. Simulated carbon emissions increased for warmer and drier climates, reflecting the associated increase in fire activity. This study provides useful insights into changes in fire and carbon dynamics for the high country of south eastern Australia resulting from increased fire activity during warmer and drier climates.

Keywords: *fire regimes, carbon, FIRESCAPE, FullCAM*

1. Introduction

Australia is one of the most flammable continents, with fire considered an integral part of all Australian ecosystems (Gill 1981). South east Australia is no exception, with periodic episodes of extreme fire weather (e.g. 1939, 1983, 2003, 2009) resulting in large high intensity fires that negatively impact on people and property and affect ecosystem and carbon dynamics. As fire is the main disturbance regime in Australian forests, it is important to understand the impact of changing climates on fire and carbon dynamics.

Mounting evidence suggests that projected shifts to warmer and drier climates in south eastern Australia (CSIRO and Australian Bureau of Meteorology 2007) will result in increased fire activity, with consequential reductions in inter-fire intervals (Beer and Williams 1995; Williams *et al.* 2001; Cary 2002; Hennessey *et al.* 2005; Pitman *et al.* 2007). In support of these predictions there is evidence of an associated increase in fire activity in recent decades in the northern boreal forests during a period when the climate has become warmer and drier (e.g. Amiro et al 2001; Pausas 2004; Xiao and Zhuang 2007).

Post-fire carbon trajectories in vegetation differ depending on fire frequency, fire severity and regeneration rates. Fire intensity determines the amount of carbon emitted as a result of combustion, and the amount of fire-killed material that will decompose post-fire. Predicted increases in fire activity with warmer and drier climates are likely to result in the loss of potentially significant amounts of carbon. Understanding these dynamics is important given the significance of forests in the global carbon cycle. However, interactions between fire and carbon dynamics with climate change are relatively poorly understood, particularly in Australian ecosystems, with uncertainty remaining as to the quantitative effects of climate on fire and carbon dynamics.

In this study we investigate the implications of a projected warming and drying climate in the high country of south eastern Australia on fire and carbon dynamics, by merging the carbon accounting model *FullCAM* and the landscape fire regime simulator *FIRESCAPE*, both of which have been parameterised for that landscape.

2. Method

In our study a new simulation model was developed to investigate fire and carbon dynamics in the south eastern Australian high country. This model combined the existing carbon accounting model *FullCAM* (Richards and Brack 2004; Richards and Evans 2004; Brack *et al.* 2006; Waterworth *et al.* 2007) and the landscape fire regime simulator *FIRESCAPE* (Cary and Banks 1999; Cary 2002; McCarthy and Cary 2002; Keane *et al.* 2003, 2004; Cary *et al.* 2006; King *et al.* 2006, 2008), both of which have been independently developed for use in south eastern Australia. The 2 million hectare study landscape (Fig. 1) contains a diversity of native *Eucalyptus* forest communities (63.4% of area), *Pinus radiata* (D. Don) plantation forests (2.8%), shrublands (1.1%), and both native and introduced pasture grass communities (32.7%). Fire and carbon dynamics were modelled at a one hectare resolution. Fires were propagated across the landscape using fire behaviour algorithms specific to each vegetation community (grassland - Noble *et al.* 1980, Cheney and Sullivan 1997; shrubland - Catchpole *et al.* 1998; native forests and pine plantations – McArthur 1967; Noble *et al.* 1980). Significant spatial and temporal variations in historical weather parameters were apparent across the study region, and these were captured using outputs from the *ANUSPLIN* model (Kesteven and Hutchinson 1996).

Three climates were simulated – one depicting the historical climate, and two depicting warmer and drier projections for the climate for 2070 (CSIRO and Bureau of Meteorology 2007). Both projected changes used the 50th percentile values for changes in climate variables for Canberra (CSIRO and Australian Bureau of Meteorology 2007), and are based on anticipated global populations peaking mid-century, with one assuming use of clean and resource-efficient technologies (B1), and the other assuming continued use of fossil intensive technologies (A1FI) (Table 1). In all simulations, the frequency of lightning strikes remained constant, as did the vegetation communities at each locality. Climatic influences on vegetation growth, including CO_2 fertilisation, heat and water stress, were not simulated due to the uncertainty regarding their combined effects.

Figure 1 - (A) Location of the study landscape in the south eastern Australian mainland high country. (B) Digital elevation map for the study landscape.

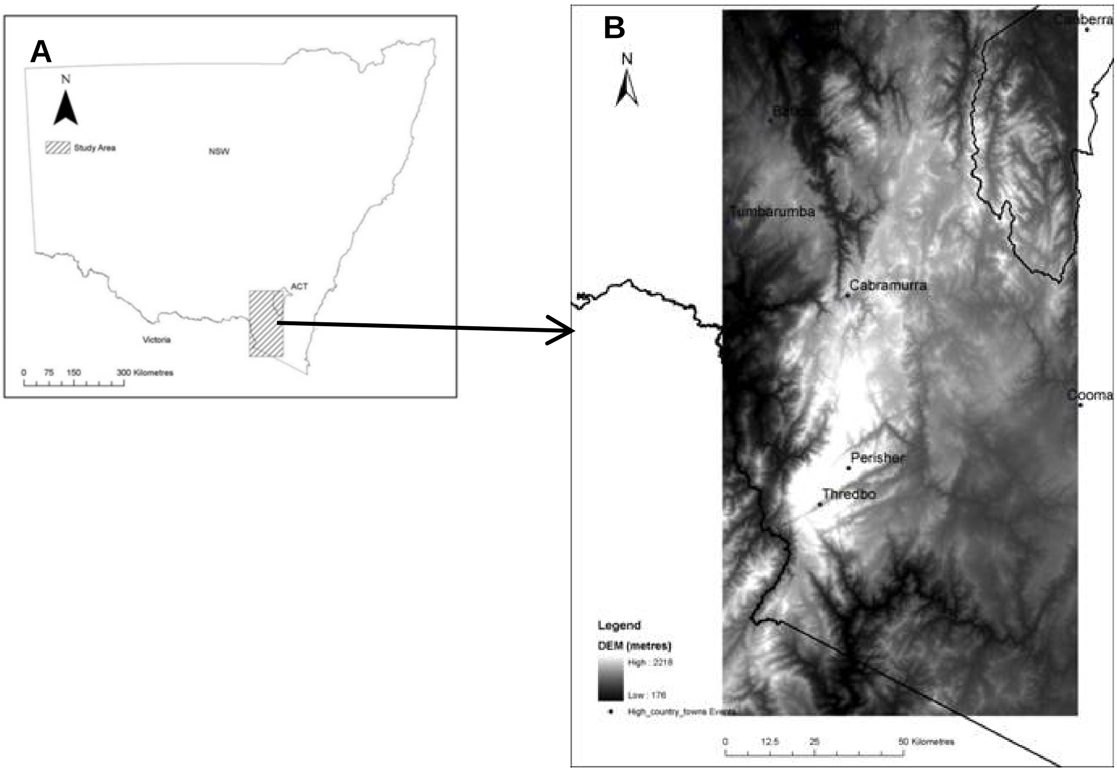


Table 1 – Projected climate changes for Canberra, Australia for 2070 (50th percentile values from the Climate Change in Australia: Technical Report 2007, Appendix B (CSIRO and Australian Bureau of Meteorology 2007))

	Temperature (°C)		Rainfall (%)		Wind speed (%)		Relative Humidity (%)	
	B1	A1FI	B1	A1FI	B1	A1FI	B1	A1FI
Summer	+ 1.7	+ 3.2	+ 0.0	+ 1.0	+ 2.0	+ 4.0	- 0.8	- 1.6
Autumn	+ 1.5	+ 3.0	- 3.0	- 6.0	- 4.0	- 8.0	- 0.8	- 1.6
Winter	+ 1.3	+ 2.5	- 9.0	- 16.0	- 1.0	- 1.0	- 0.8	- 1.6
Spring	+ 1.7	+ 3.3	- 10.0	-19.0	- 2.0	- 3.0	- 0.8	- 1.6

Simulations were performed for 30 years, and included spatial weather data derived from ANUSPLIN for the period 1975-2005.Single factor ANOVA analysis was used to compare fire outputs (incidence, areas, and fire intensities) and carbon outputs (emissions – from both decomposition and fire activity; and stocks - total above ground, below ground and debris carbon pools) between simulated climates. Daily Forest Fire Danger Index (FFDI) values were calculated for each pixel and averaged spatially and annually to determine the mean annual summed FFDI for the entire study landscape under each of the three projected climates

(Beer and Williams 1995). A comparison was made between mean annual summed FFDI values and mean annual areas burned.

3. Results and Discussion

3.1 Fire dynamics

There were significant increases in the mean annual areas burned between the present climate and warmer and drier climates, while a significant increase in fire incidence occurred only between the present and A1FI climates ($F > F_{crit} = 5.318$; $P < 0.05$) (Fig. 2). A positive relationship is evident between mean annual summed FFDI (a measure of fire weather) and the mean annual area burned (Fig. 3). These findings are consistent with results in other fire-prone, forested areas in south eastern Australia (e.g. Beer and Williams 1995; Williams *et al.* 2001; Cary 2002; Hennessey *et al.* 2005; Pitman *et al.* 2007) and around the world (e.g. Stocks *et al.* 1998; Amiro *et al.* 2001; Flannigan *et al.* 2005; Tymstra *et al.* 2007), and reflect an increase in the opportunities for ignition, and diminished opportunities for fires to be extinguished either naturally or by humans during warmer and drier climates.

Figure 2 - Mean incidence of unplanned fires (diamonds) and mean annual area burned by unplanned fires (bars) for each climate projection (P = present; B1; A1FI) for three hundred year simulation periods. Standard error bars are shown.

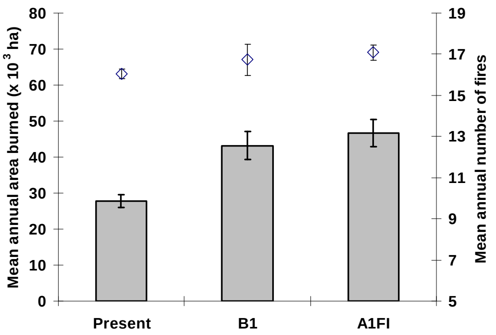
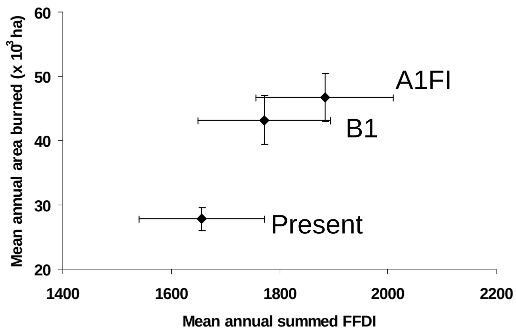
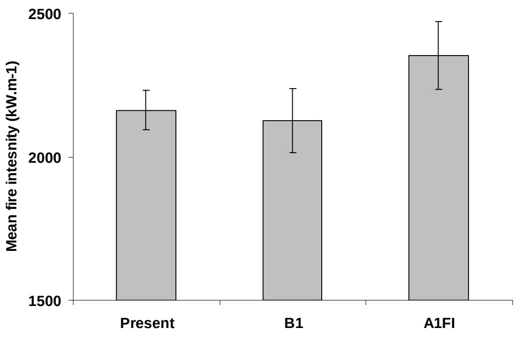


Figure 3 – The relationship between the mean annual summed FFDI and the mean annual area burned (x10^3 hectares) for the range of climate projections (Present; B1; A1FI). Standard error bars for the mean annual area burned by unplanned fires and the mean annual summed FFDI are shown.



For the warmest and driest climate (A1FI) the proportion of the total area burned at higher intensities increased in simulations (Fig. 4). Further, for these climates, a greater proportion of vegetation can potentially burn earlier in the fire season, reflecting the increased availability of sufficiently dry fuels at this time (data not shown). The 3 - 14% increase in mean fire intensity observed for the A1FI climate is similar to the finding of Cary (2002) who noted a 7–25% increase in average fire intensity with a doubling of atmospheric CO_2.

Figure 4 – Mean fire intensity ($kW.m^{-1}$) for each climate projection.



In our study, climate induced changes to vegetation dynamics were not simulated due to uncertainty regarding the combined effects of CO_2 fertilisation, heat and water stress. Further, predicted potential increases in lightning occurrence were not simulated. Inclusion of a positive CO_2 fertilisation effect and / or more lightning ignitions in our study would have resulted in more rapid re-accumulation of fuels post-fire, and an increased probability of their ignition, exacerbating the simulated changes in fire activity.

Figure 5 - The mean annual carbon emitted from both decomposition and fire activity (t $C.ha^{-1}.yr^{-1}$) for the range of climate projections (Present; B1; A1FI).

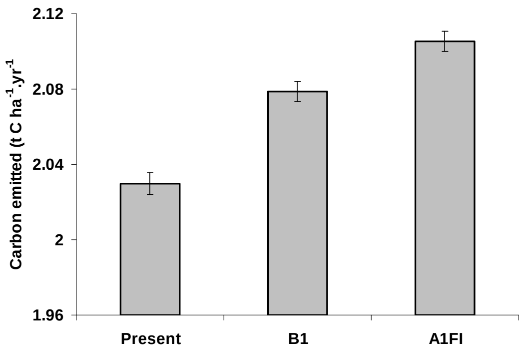
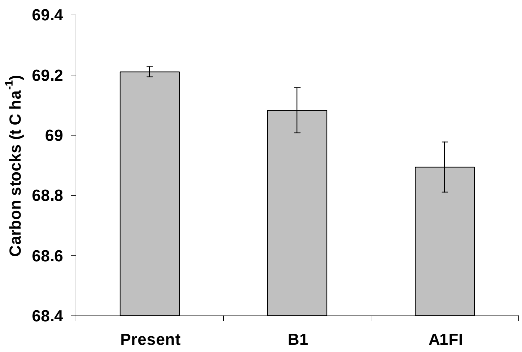


Figure 6 - The mean carbon stocks from the total above ground, below ground, debris and soil carbon pools ($t.ha^{-1}$) for the range of climate projections (Present; B1; A1FI).



3.2 Carbon dynamics

With simulated warmer and drier climates carbon emissions increased by approximately 2.4% (B1) to 3.7% (A1FI) (Fig. 5), carbon sequestration rates declined by approximately 4.1% (B1 and A1FI) (not shown), and carbon stocks declined by 0.19% (B1) to 0.46% (A1FI) (Fig. 6). Simulated carbon emissions were positively correlated to the extent of fire activity, with greatest emissions occurring with the greatest fire activity, this being consistent with the positive relationship between fire activity and carbon emissions observed in other studies (e.g. Andreae and Merlot 2001; Kasischke *et al.* 2005). The observed reduction in carbon stocks is also consistent with other studies (e.g. Harmon and Marks 2002; Gough *et al.* 2007; Irvine *et al.* 2007), and is primarily due to the increased fire activity and consequential reductions in inter-fire intervals with warmer and drier climates. As climates warmed and dried, the amount of carbon sequestered also declined to reflect the reduced amount of biomass present (carbon stocks). Net carbon balances (sequestration – emissions) remained positive for all simulations, but declined with warmer and drier climates. If carbon stocks continue to decline with prolonged increases in fire activity, then future carbon emissions may also decline to reflect further declines in biomass available for burning.

4. Conclusion

Our results for the high country in south eastern Australia suggest that fire activity will increase as climates become warmer and drier. Specifically, warmer and drier climates increased the availability of fuels and rates of fire spread, resulting in a greater number of larger, higher intensity fires. Fire incidence, area burned and average fire intensity all increased, and consequently the interval between fires decreased. In simulations, carbon emissions were proportional to the extent of fire activity, with the greatest amount of emissions occurring for the warmest and driest climate (A1FI). A decline in biomass (carbon stocks) was observed with this increase in fire activity. If increased fire activity were maintained for longer periods than those simulated, there is the potential for continued declines in biomass (carbon stocks), and possibly future reductions in carbon emissions associated with the reduction in the amount of biomass available for burning.

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