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Fire behaviour influences the type and amount of greenhouse gas emissions from bushfires

Bushfires, both prescribed and wild, are a major source of non-industrial greenhouse gas emissions in Australia and play a major role in the global carbon cycle. Understanding how such emissions are affected by the behaviour of bushfire is essential to identifying ways to use fire as tool to mitigate emissions and positively influence the carbon cycle.

Bushfire as a greenhouse gas source

Bushfires emit a variety of pollutants to the atmosphere which have impacts on global warming, biogeochemical cycles, ambient air quality and human health. Globally, bushfires contribute approximately 23% of total anthropogenic greenhouse gas equivalent emissions, although there is significant year-to-year variability.

The main greenhouse gas species of interest emitted by bushfires include CO_2, CH_4 and N_2O. Bushfires also emit particulates into the atmosphere that can have a significant impact on climate due to their ability to absorb and scatter light. The majority of the research carried out on greenhouse gas emissions from bushfires has been either conducted in the calm conditions of a stationary laboratory fire or based on the analysis of data collected from the flank and rear of low intensity prescribed fires.

However, the individual fire spread modes around the perimeter of a free-moving bushfire (i.e. heading, flanking and backing) will exhibit very different fire behaviour (such as different rates of spread, flame heights, combustion factors and fireline intensities) which could lead to differences in emissions as a result of the different chemistry involved in combustion of these modes (Sullivan and Ball 2012). That is, a head fire burning with the wind behaves and burns fuel differently compared to a backing fire burning against the wind.

Quantifying effect of fire spread mode on greenhouse gas source

Free-burning experimental fires were conducted in the CSIRO Pyrotron (Sullivan *et al.* 2013), a 25-m-long combustion wind tunnel, to explore the role of fire spread mode on the type and magnitude of greenhouse gas emissions from the combustion of dry eucalypt forest litter, the dominant forest type in Australian temperate forests. Fires were burnt spreading with the wind (heading fire), perpendicular to the wind (flanking fire) and against the wind (backing fire). The amount of greenhouse gas compounds (i.e. CO_2, CH_4, H_2O and N_2O) and CO emitted during each experiment were measured using off-axis integrated cavity- output spectroscopy.

Emissions factors are widely used in biomass burning research to express the amount of a particular species of gas emitted relative to the amount of matter burnt (i.e., kg of gas released per kg of dry fuel consumed). Emissions factors for each gas were calculated from the measurements of each gas species of interest emitted and measurements of fuel consumed.

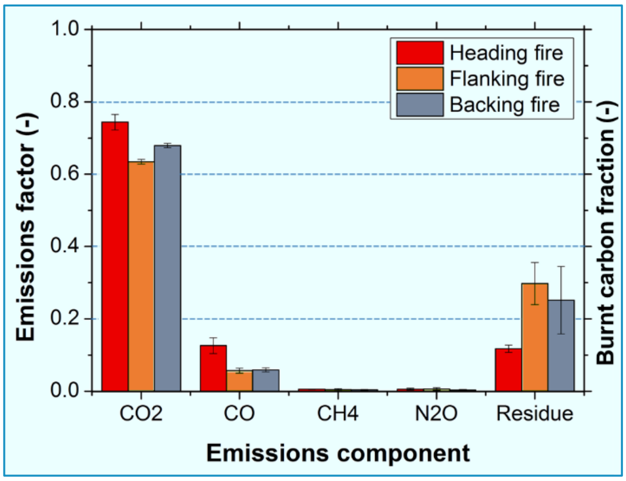

Figure 1. Graph showing emission factors for different green-house gas components by fire spread mode.

Analysis of the results (Fig. 1) shows that most of the carbon was emitted as CO_2, with heading fires emitting 17% more CO_2 than flanking and 9.5% more CO_2 than backing fires. Interestingly about twice as much CO was released by heading fires as flanking or backing fires, a result of the considerable smouldering that occurs following passage of the flaming zone (Fig. 2). Thus combustion phase (i.e. flaming or smouldering) also plays a statistically significant role in emissions, with CO and N_2O emissions increasing during smouldering combustion and CO_2 emissions decreasing.

Perhaps related to this, heading fires had less than half as much carbon remaining in combustion residues after each experiment. No significant differences in emissions factors for CH_4 or N_2O were found as a result of fire spread mode.

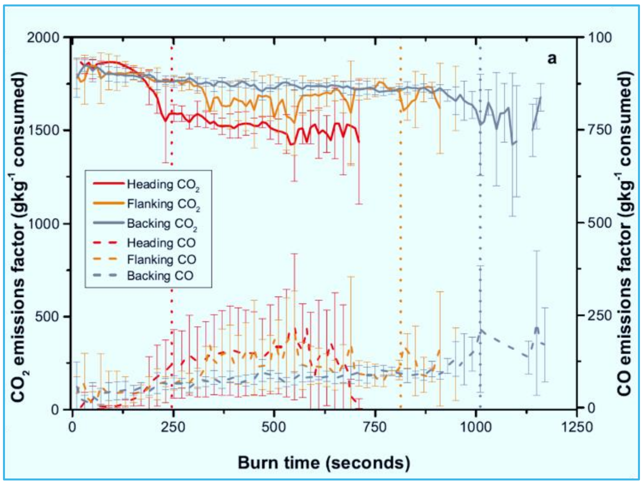

Figure 2. Time-resolved emissions factors for CO_2 (solid lines) and CO (dashed lines) over the life of each experiment with dotted vertical lines identifying the end of flaming combustion for each fire spread mode.

Management implications

The results from this study have a number of implications for the management of fuel hazard through prescribed burning and the calculation of Australia's national carbon accounting from bushfires. The primary implication for land management is that prescribed fire practices could be used to mitigate greenhouse gas emissions from forests by modification of ignition methods to favour spread by flanking or backing fire over heading fire.

Applying prescribed fire in such a way as to preferentially burn fuel with a low intensity backing fire will reduce the total amount of CO_2-equivalent emissions by 12% compared to a hotter heading fire and increase the amount of carbon remaining on the ground post-fire by 220%. If fuel is preferentially burnt by a flanking fire it will reduce CO_2-equivalent emissions by 25% and increase carbon post-fire residue by 250%. While it is generally not possible to operationally limit fire behaviour to a single fire spread mode, and the choice of mode may be limited by operational requirements in many situations, variations in lighting pattern can be used to judicially influence the overall outcomes of a burn.

Applying non-heading fires during prescribed burning operations can also reduce CO emissions, which are implicated in respiratory health effects. Further research is required to quantify emissions of different fire spread modes under variable burning conditions.

Flaws in calculations of global greenhouse gas emissions from bushfires

Estimating carbon emissions from bushfires relies on a carbon mass balance technique that has evolved with two different interpretations around the world. All estimates of global bushfire emissions use an approach based on 'consumed biomass', in which it is assumed that all vegetation that is burnt is emitted to the atmosphere. This is an approximation to the more accurate 'burnt carbon' approach, in which the amount of carbon remaining on the ground after the fire must be taken into account.

Applying the 'consumed biomass' approach to emissions from bushfires, as most formal reporting methods do, leads to over-estimations of annual carbon emitted to the atmosphere globally by 4.0% (or 100 million tonnes) compared with the 'burnt carbon' approach. All bushfire emissions studies should use the 'burnt carbon' approach to quantify this carbon, which is not emitted to the atmosphere, and quantify the role of this burnt carbon as a sink in the global carbon cycle.

Further reading

Surawski NC, Sullivan AL, Meyer CP, Roxburgh SH, Polglase PJ (2015) Greenhouse gas emissions from laboratory-scale fires in wildland fuels depend on fire spread mode and phase of combustion. *Atmospheric Chemistry and Physics* 15, 5259–5273.

Surawski NC, Sullivan AL, Roxburgh SH, Meyer CP, Polglase PJ (2016) Incorrect interpretation of carbon mass balance biases global vegetation fire emission estimates. *Nature Communications* 7, Article number: 11536.

References

Sullivan AL, Ball R (2012) Thermal decomposition and combustion chemistry of cellulosic biomass. *Atmospheric Environment* 47, 133–141.

Sullivan AL, Knight IK, Hurley R, Webber C (2013) A contraction-less, low-turbulence wind tunnel for the study of free-burning fires. *Experimental Thermal and Fluid Science* 44, 264–274.

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