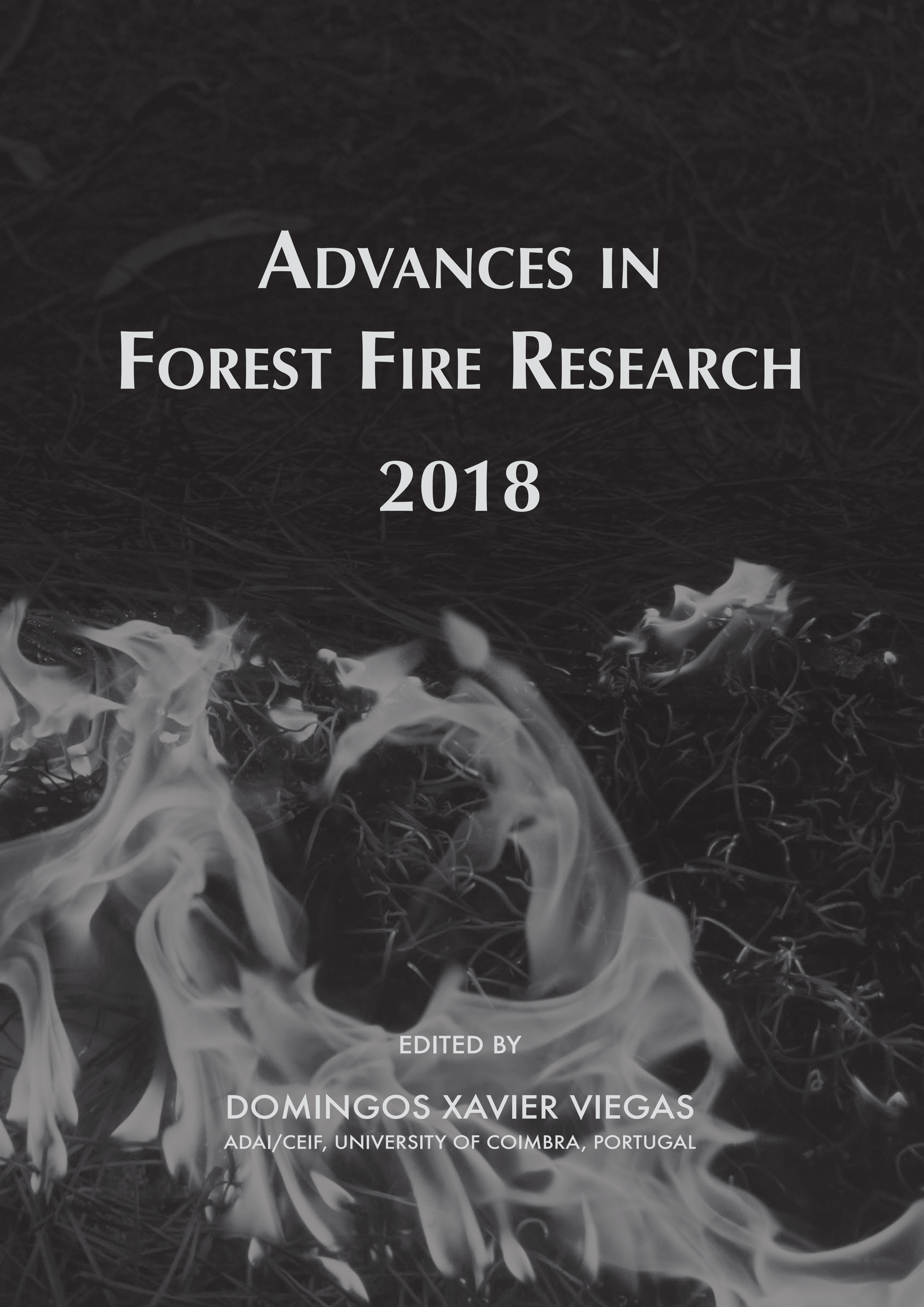

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Short contribution – Fire Management

New Zealand prescribed fire experiments to test convective heat transfer in wildland fires

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Abstract

The physics of bushfires has traditionally been studied through intensive modelling that requires numerous assumptions of combustion and heat transfer adapted from established structure-fire engineering relations. Renewed emphasis in experimental research has caused rethinking of some of the most basic concepts in wildland fuel particle ignition and flame spread. These findings suggest new possibilities for advancing bushfire behaviour science. Laboratory and field experiments conducted by the U.S. Forest Service's Missoula Fire Sciences Lab reveal the source of convective heating in spreading fires derives from fire-induced vorticity which forces flames downward and ahead of the combustion zone in intermittent contact with fuel particles. New laboratory techniques capture the intermittency and suggest it has predictable average frequencies familiar in studies of buoyant instabilities. Dependent only on buoyancy, these scaling relations have shown promise at field scales. A project being led by Scion's Rural Fire Research Group in New Zealand aims to test this hypothesis that heat-driven buoyancy (convection) creates a series of peaks and troughs in the flame front that drive fire spread and scale with flame size and wind speed. The theory is being tested through a series of heavily-instrumented fire experiments at sites in a range of fuel types, starting in uniform crop stubble fuels (February 2018), moving to more complex scrub fuels (2018/19) and then to wilding pine forest fuels (2019/20).

Keywords: Convective Heat Transfer, Prescribed Fire, Remote Sensing

1. Introduction

The physics of bushfires has traditionally been studied through intensive modelling that requires numerous assumptions of combustion and heat transfer (Sullivan 2009) adapted from established structure-fire engineering relations. Renewed emphasis in experimental research has caused rethinking of some of the most basic concepts in wildland fuel particle ignition and flame spread. These findings suggest new possibilities for advancing bushfire behaviour science.

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2. Instrumentation and Preliminary Results

Nine plots were established in Darfield, New Zealand to measure atmospheric turbulence structure and scales, heat transfer, and flame characteristics on spreading line-fires in cereal crops (Figure 1b). Loading and particle sizes were measured in the fields of wheat, barley, and triticale. Fires were ignited with drip torches from multiple line segments along the upwind edge to allow a linear flame zone to develop (Figure 1b).

Experimental design focussed on measuring a cascade of spatial and temporal scales starting from the fuel bed, through the flame and up to a few hundred meters in the atmosphere. Air turbulence and temperature characteristics as the fire passed were measured by a 10 meter tower near the center of each plot with sonic anemometers at 2m, 5m, and 10m along with array of 20 thermocouples installed at intervals along the vertical pole (Figure 2a). A 30m sonic anemometer tower was setup outside the fire perimeter to measure the near-surface atmospheric background turbulence structure. Instruments to measure heat fluxes and flame behaviors were installed at intervals along 30 meter lines oriented parallel with the anticipated wind direction. These instrument packages consisted of a heat flux package with tri-directional differential pressure disks to measure air and flame velocity (see paper by Grumstrup et al. this volume), two fine wire thermocouples (bead 5e-5m) for gas temperature variations and , and a wide angle radiometer (Figure 2b). Frequency and distance of forward flame bursts were measured using 4.8m horizontal arrays of 32 fine-wire thermocouples at intervals of 0.15m; thermocouples were elevated to the height of the fuel particles (~.2-.4m) and the array oriented parallel to the fire spread direction (Figure 2c). Changes in atmospheric pressure (hydrostatic) were measured using a pressure transducer with the orifice flush with a steel plate positioned on the ground (Fgiure 2d). This package also measured flame residence time with a flame ionization probe that records changes in electrical conductivity from ioniziation when immersed by flame

Figure 1 - A) Aerial image of experimental burn plots in ceral crops in Darfield, New Zealand. B) Linear flame zone spreading from simultateous ignitions along a fire break.

Finally, a series of in-fire cameras were installed to record passage of flame zones (60 frames per second) through the instrument arrays (Figure 2e). All of these instrument packages used a custombuilt 8-channel data logger (Figure 2f) recording at 50Hz which synchronized time-stamps and sensor location with an on-board GPS unit.

Figure 2 - Pictures of field instrumentation a) 10m tower with sonic anemomenters and vertical array of fine-wire thermocouples, b) heat flux sensor with tri-directional velocity disks, radiometer, and thermocouples, c) horizontal array of fine-wire thermocouples, d) hydrostatic pressure and flame ionization detector, e) in-fire video cameras, and f) custom 8-channel data logger with GPS

Remote sensing was accomplished with a variety of tools. A LIDAR unit with 18m resolution was used to scan horizontal and vertical swaths of wind velocity, while a SODAR was continuously measuring the velocity boundary layer up to 300m AGL. Three high-speed longwave infrared cameras were mounted on a 23m portable lift recorded oblique video of fire spread as well as pre-fire, post-fire thermal features of the airflow across the fields. A fixed-wing unmanned aerial vehicle (UAV) flying pre-programmed traverses was used to capture changes in atmospheric turbulence before, during and after the fires. Aerial video was recorded from two UAVs flying overhead as well as obliquely to the experimental plots. High-speed thermal video was recorded of the fires from a ground-based camera (FLIR 6811) at 480fps and standard video (240 fps, 700fps) from multiple angles.

3. Preliminary Findings

All fires occurred with 10m winds of approximately 6 to 10 m s^{-1}. With different fuel species (wheat, barley, triticale), wind, and fuel moisture, fire rate of spread among plots varied from about 40 m min^{-1} to over 100 m min^{-1} with flame lengths of approximately 1m to 5m. Forecasted wind direction was accurate to within about 10 degrees and used to orient directionally-dependent instruments (thermocouple arrays, heat flux packages) with the expected spread direction. Preliminary observations and examination of the data suggest these field-scale stubble fires were consistent with laboratory results that convective heating plays the crucial role in heating fuel particles to ignition in wind-driven wildland flame spread. In-fire video (Figure 3a) revealed intermittent flame bursts contacting fuel particles 1 to 5 meters forward of the ignition interface. No pyrolysis products were visible ahead of the flame zone before flame contacts occurred. Coherency of the flame burst parcels was evidenced from synchronous spikes in temperature among thermocouples extending in a line forward of the flame zone (Figure 3c). Flame residence time was approximately 10 seconds as estimated from video as well as the ionization detectors (Figure 3d).

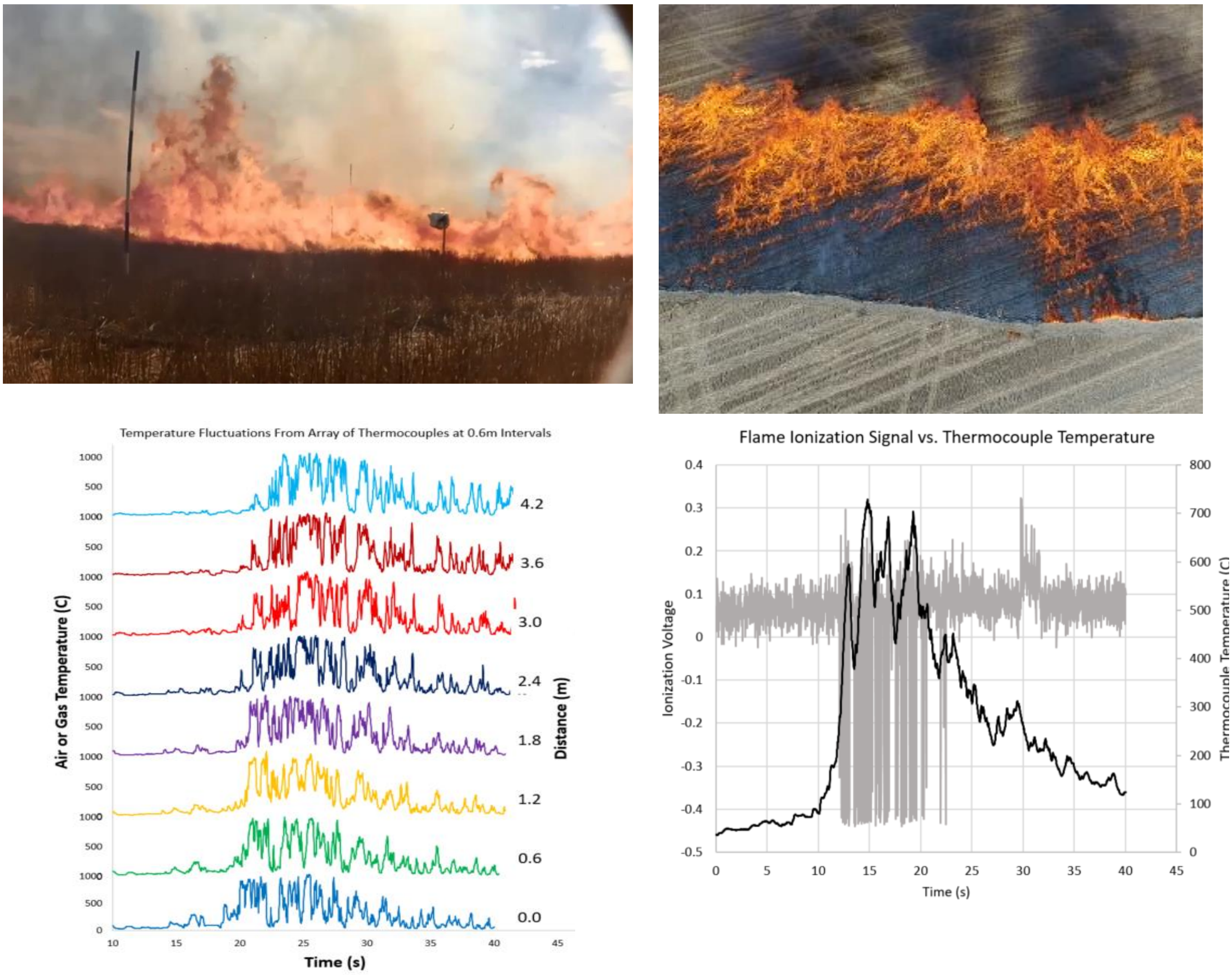

Figure 3 - Still image from in-fire video camera (a) and UAV (b) showing peak-and-trough flame structure consistent with buoyant instabilities of the flame zone. (c) Coherency of temperature data from 4.8m long thermocouple array for plot DD2 (spread rate ~ 100m min^{-1}), (d) example of flame residence time estimated at about 10s from plot EE3 shown relative to medium-fine 1e-4m diameter thermocouple temperature.

4. Future Work

Full analysis of all data will be required to convective heating characteristics associated with these stubble fires. Future field research will entail application of these experimental methods to gorse shrub fuel types and to crown fire in conifer forests to test scaling of heat transfer in fires with larger flames.

5. References

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