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Investigation of vegetation fire plumes using paragliders tracks and micro-scale meteorological model.

Jean-Baptiste Filippi[a], Miguel Cruz[b], Frédéric Bosseur[a], Antoine Girard[c]

[a] *SPE – CNRS UMR 6134, Campus Grossetti, BP52, 20250 Corte.* filippi@univ-corse.fr
[b] *CSIRO Ecosystem Sciences and CSIRO Climate Adaptation Flagship. Black Mountain, Australia*
[c] *Université Stendhal, Grenoble 3, Valence, France*

Abstract
This work presents an interesting and unique analysis of an open air fire plume extrapolated from a large amount of paragliders tracks flying over a sugarcane fire during a world cup super final event in february 2013 Columbia. Vertical speeds of over 20 m/s were observed into a narrow core just over the fire. Simulation of the same event shown the relatively good ability of micro-scale meteorological models to represent quantitatively the velocity fields and behavior.

Keywords*: fire meteorology, fire weather, plume, convection, simulation, modelling, paragliding*

1. Introduction

An understanding of the interaction between a free spreading fire and the surrounding weather system requires knowledge on the dynamics of the buoyant fire plume. Insight into this dynamics, namely how the energy released by the fire sustains this plume can be studied experimentally [clements 2007, Church and snow 1985] and numerically. Nevertheless instrumenting a fire plumes is quite a complex task, particularly due to the nature of the energy source and the height to which instruments would need to be located. Remote sensing has also been used to capture the plume dynamics in large fires, although because the signals can be severely blinded by the amount of large particles in the air it is not clear how certain the remotely sensed data reflects the inside of the plume. In situ measurements may be done using Unmanned Aerial Vehicles (UAV) [clements 2007] but as well are limited by extreme flight conditions caused by flying embers and strong convection
A recent paragliding competition (the 2012 World Cup Super Final held in Roldanillo ,Colombia) offered an unique opportunity to characterize the structure of a buoyant plume above a fire. In this event a large number of paragliding pilots flew into a fire plume developing above a controlled burn in a sugarcane field. Mandatory GPS and variometer instruments carried out by the pilots recorded their detailed movement as they navigated the plume. The pilots can be considered synchronized passive tracers that allow us to reconstruct the plume dynamics and namely inform us on the intensity of the convection within the plume and up to a high altitude.
In our unique study we quantify the energy source of the sugarcane fire, present the 3D dynamics of the plume as characterized by the dataset and compare it with a simulation from coupled fire/atmosphere micro meteorological model in order to (1) verify the relevance of such models for such plumes and (2) see if it may be used to generalise the result.
The first part of the study present the dataset, providing specific insight on sugarcane fuels, and how the flight logs were analysed and convection fields extrapolated. Results are presented in the second part, with first guess analyses of simulation results compared to post-processed tracks.

2. Method

2.1. Fuel source

The fuel complex is a sugar cane plantation prior to harvesting. At this stage the standing crop is approximately 3 m tall and carrying an overall biomass varying between 7.5 and 10 kg/m2. Standing biomass will largely depend on the watering and fertilized regime provided to the standing crop. About 20% of the biomass is dead suspended leaves along the stalk and litter forming a well-aerated fuel layer in the lower 1 – 1.5 m of the stand. This dead biomass is the fuel that will be consumed in pre-harvest burning. It is well accepted that these burns will consume between 1.5 and 2 kg/m2 (Cheney, Sullivan 2008)

The high intensity burning in Fig 1 is indicative of productive sites and varieties, so we can confidently assume a fuel consumption in the high end of the range, i.e., 2 kg/m2. Cheney and Just (1974) suggest flame heights of about 9-11 m (from the ground) in 3 m tall crops with good fuel accumulation. These flame heights are consistent with the ones recorded photographically by several pilots (as per Fig 1). Tabled values for sugarcane heat content vary between 18500 kJ/kg (higher) and 17700 kJ/kg (lower). Considering a fuel load of 2 kg/m2 and an heat content of 18000 kJ/kg it will be appropriate to consider a heat per unit area of 36 MJ/m2. The size of the sugarcane field was 5 ha, corresponding to a total energy released of 1.8 GJ.

The photos taken by several of the paraglider pilots as they approached the plume suggest an ignition pattern characteristic of sugarcane burning. The ignition method consist of two igniters walking along the longer sides of the field with one of them slightly ahead of the other. If we assume that (1) the igniters are moving at a rate of 1.4 m/s (walking pace) as they light the long edge of the sugar field; (2) as they move along the plot the two fire fronts merge and move along the igniters direction of travel at 1.4 m/s (Fig 1); then we can assume that the fire front is spreading at 1.4 m/s spread rate.

Given the approximately 500 m length of the sugarcane field, the lighters took about 6 minutes (357 s to be more exact) to burn the full 50000 m2 of the sugarcane block. A raw analysis from pilots pictures during the event are in relative agreement with this estimate (between 6 and 8 minutes as fire front position is difficult to locate precisely). Overall the full burn duration is considered to be about 9 minutes, 6 minutes of lightning procedure and 3 more minutes for the full burn out.

From this and the assumption that the fire is spreading at a steady state determined by the igniters pace, it is possible to estimate the energy release rate from the combustion of those fine dead fuels. Considering a burning duration of 40 seconds, and that 50% of the combustion energy is converted to convective heat fluxes, the surface instantaneous heat fluxes for the numerical model is parameterized as 450Kw.m2 for these 40 second. The propagation pattern is force to mimics the actual fire as seen from the photographs, with fires spreading towards the center of the field.

2.2. Tracklogs

The study attempts to leverage the opportunity offered by task 3 of the 2012 paragliding world cup super final that occurred in Roldanillo (near Cali), Columbia the 19th of January 2013, that happened to be at the same time that large sugarcane fields were set to burn before harvest.

More than 120 of the world best competitors were free-flying in this large valley with equatorial climate, all searching for the quickest way to gain altitude in order to reach the finish line first. to be a very effective way to gain altitude, a flock of 80 pilots entered this fire thermal and exited within 10 minutes gaining about 1600 meters in average. This fire thermal was intense enough that some had to deploy their reserve parachute, risking to fall into flames with 20kg of nylon wing and it is since that day forbidden to fly over a fire in the PWC championship rules.

As the format of the competitions requires that tracks must be logged with relatively high frequencies for verification, the resulting dataset may be regarded as a set of relatively well spread and synchronized passive tracers that may inform on the intensity of the convection within the plume and up to a high altitude. The frequency of the tracklogs is in between 5 and 10 seconds, depending on the pilots equipment, all these track points were first compiled into a timed dataset with the computation of the instantaneous vertical velocity for each glider at each point. This vertical velocity was taken as the altitude difference between a point and its next point in time, divided by the duration between those

2 points (5 to 10 seconds). We then subtracted a typical competition glider sink rate (0.7 m/s) to the value.

The second operation required to reconstruct a volume from this dataset in order to interpolate vertical paragliders velocities inside the plume, for that all points within a 120 seconds window were extracted and used to perform a Delaunay triangulation of a volume. Within this volume vertical velocity can then be interpolated as the bilinear interpolate between grid points.

To reconstruct the timely evolution of the plume, the 120 seconds window is moved 10 seconds at a time during the overall burn duration, with a triangulation performed with each window dataset. An animation of this plume rise taken from these tracklogs may be found here: youtube.com/watch?v=Ogsq2yINV6o.

Figure 1 - View of the plume from the sugarcane burn

2.3. Model Set-Up

The coupled simulations were run on a 2.5km×2.5km×3km domain discretized on a 80×80×60 mesh for the atmospheric model simulation (Δx = Δy, 40m, vertical grid up to 5000m, vertical resolution increasing from 20M (ground) to 200m (top)).

Atmospheric conditions were initialized with radio soundings extracted from global model analyses. Simulations were run on a parallel 8 cores computer, with a speedup ration of 0.9 (0.9 seconds of computation for 1 seconds of real time). Mesonh/ForeFire [Filippi *et al* 2010, Filippi *et al* 2013] code was used to perform the computation.

3. Results

Figure 2 presents the reconstructed wind field when the fire was approximately towards the end of the burn and much gliders present, we can see areas in excess of 20 m.s vertical speed. Obviously vertical velocity may be extrapolated only where data is present, but with 80 tracers, this field is composed of about 4800 real points. It is possible to observe a relatively narrow convection core (about 200 meters) rising with some negative velocities area its outer edges of this core.

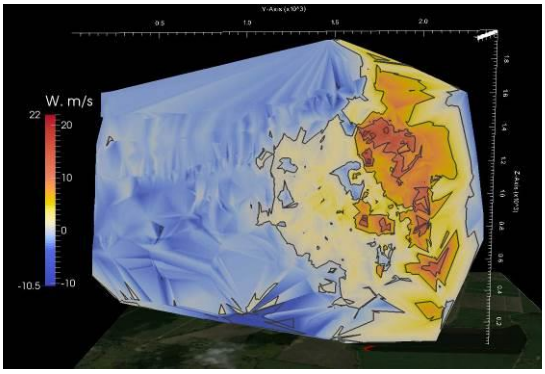

Figure 2 - View of reconstructed plume

The very basic idealized simulations that were performed are presented in figure 3. It might be observed that overall a similar (although obviously much more smooth) vertical velocity pattern is formed. These results shows in particular a nice accordance between the maximum vertical rate, and as well a 200m wide convective core and a plume that rises at about the same height (although no glider went higher than +2000m, so higher than that, no data is there for comparison). The vertical downdrafts is less intense in the simulation, but still present and at the outer edge of the main core.

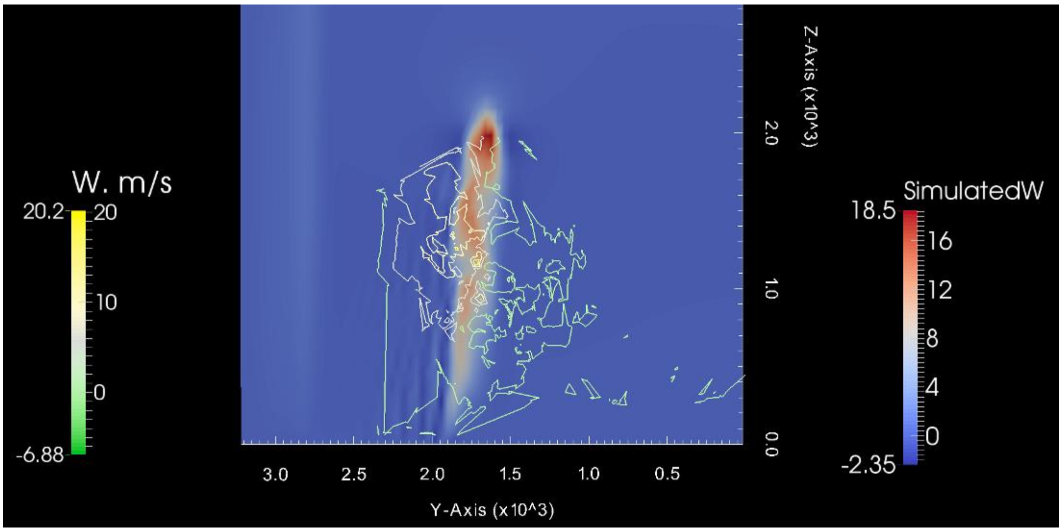

Figure 3. Simulated plume (red/blue vertical wind velocity) and approximately synchronized isolines of the estimated vertical paragliders velocities (-5,0,5,10,15,20 m/s). Time = Ignition + 340s.

4. Conclusion

This work presented an interesting and unique analysis of an open air fire plume extrapolated from a large amount of paragliders tracks. Vertical speeds of over 20 m/s were observed into a narrow core just over the fire. Simulation of the same event shown the relatively good ability of microscale meteorological models to represent quantitatively the velocity fields and behaviour even with very crude parameterisation consequence of the lack of field data.

5. Acknownlegements

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