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From organic matter to pyrogenic char to ash: the role of smouldering combustion in wildfires

G. Rein (1), R. Hadden (1,2), and C. Zarccone (3)

(1) School of Engineering, University of Edinburgh, United Kingdom (reingu@gmail.com), (2) Now at Faculty of Engineering, University of Western Ontario, Canada, (3) Dept. of Agro-Environmental Sciences, Chemistry and Plant Protection, University of Foggia, Foggia, Italy

Smouldering combustion of natural organic layers like peatlands leads to the largest fires on Earth and posses a possible positive feedback mechanism to climate change. Smouldering wildlfires propagate slowly during several months consuming organic matter and threatening to release ancient carbon stored deep in the soil. Recent figures at the global scale estimate that on average, greenhouse gas emissions from smouldering peat is annually equivalent to ∼15% of man-made emissions.
In-depth spread over thick peat layers consumes biomass in the order of ∼100 kg/m̂2, this is 50 to 100 times larger than flaming fires. Because smouldering combustion involves both the production and consumption of pyrogenic char, it has become a topic of global interest linked to ecosystem perturbations, carbon sequestration and climate change.

In this presentation, we investigate experimentally the chemical reactions and fate of organic matter during smouldering. Vertical and horizontal samples of peat (∼100 g) are ignited on one side and a smouldering front is allow to freely propagate. We track the spread rate, mass loss rate, and the evolution of peat, char and ash mass fractions.

We observed a heterogeneous kinetic scheme of three reactions: competing peat pyrolysis and peat oxidation, and subsequent char oxidation. The measurements show that char species is formed by the simultaneous pyrolysis and oxidation reactions, which initially results in net char production and later become net char consumption. Most of the energy for combustion propagation is released during char consumption.

The carbon balance shows that the fraction of carbon in char is approximately 1.5 times higher than the virgin dry peat (70 vs. 51%). This results in a carbon density of the char approximately twice that of the peat (133 vs. 77 kg-C/m̂3). Meanwhile, the carbon content of the ash is approximately half that of peat (27%, 10 kg-C/m̂3). The rest of the carbon is emitted mostly as carbon dioxide and carbon monoxide, but also as methane and PAH (traces). The chemical analysis of the solid residue shows it is a mixture of ash and char with a strong increases of pH and higher C/H and C/N ratios relative to the virgin peat. As the intensity of the fire increases (via increasing oxygen concentration above 21%), the fraction of residual char rapidly decreases to zero.

These laboratory results allow translation to the field-scale of carbon budgets and the fate of the organic matter following smouldering wildfires. Also, the chemical analysis presented here helps paleofire reconstructions of peat cores, and illuminates the role of wildfires in pyrogenic char.