

Radiative Transfer Modelling for the characterisation of natural burnt surfaces

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Executive Summary

Fire is arguably the most important and widespread agent of ecosystem disturbance worldwide. It affects the Carbon cycle, is a control on ecosystem structure, and can potentially impact humans both directly and indirectly.

There is a long history of using Earth Observation (EO) data in monitoring wildfires that has led to the development of operational products measuring fire occurrence. These tend to use thermal and/or optical observations to denote an area as being affected by fire if, for instance, the thermal signature is high or the reflectance in near infrared (NIR) or middle infrared (MIR) follows the patterns expected of fire impacts. In recent years, more refined information from time series of thermal observations has allowed the calculation of Fire Radiative Energy that can be related to Carbon release due to fire.

Various researchers have attempted to characterise fire 'severity' from optical data — usually focusing on a change in a normalised 'burn ratio' (Δ NBR) from satellite measurements in the NIR and MIR. Such measures have been criticised because: (i) they have no direct physical meaning (they require local calibration for interpretation); (ii) they do not make full use of available spectral information; and (iii) they can be far from optimally related to fire impacts.

An additional consideration is that high temporal resolution observations help in monitoring several types of wildfire. But this tends to imply the use of moderate spatial resolution data. This in turn generally implies that the observations will be taken under varying viewing and/or illumination geometries. While it is well known that satellite reflectance varies as a function of such geometries ('BRDF effects') and there are several quite straightforward methods for taking these into account, studies involving Δ NBR tend to ignore such effects. Further, if moderate or coarse spatial resolution optical data are to be used to monitor fires, the sum of pixels identified as 'fire affected' will over-report the area affected if fire only affects a proportion of the area viewed. While this will be somewhat mitigated by reporting algorithms missing some small fires it leads to a rather uncontrolled strategy for estimating 'burned area'. In addition, the proportion of a pixel affected and/or the impact of the fire within that area will strongly condition the detectability of a fire and is therefore important information to carry through to further uses of the derived information.

This study develops and applies radiative transfer models of wildfires' impact on vegetation to refine the information derived from optical EO data regarding fires. The study's central theme is the development of a method to estimate the product of the fractional area of a pixel affected by a fire (f) and a radiometric definition of combustion completeness (cc). The derived product is termed *fcc*. Such a measure overcomes many of the issues raised above and would be an extremely useful addition to 'burned area' mapping algorithms. It could also potentially be integrated into detection algorithms, although that feature is not explored in great depth in this study.

The algorithm for *fcc* proposed here follows from considering a linear spectral mixture model:

Reflectance_{pre-fire} – Reflectance_{post-fire} = fcc (Reflectance_{pre-fire} – Reflectance_{burn})



fcc can be calculated by measuring the pre- and post-fire reflectance (Reflectance_{pre-fire} and Reflectance_{post-fire} respectively) and characterising the 'burn reflectance' (Reflectance_{burn}) at several wavebands, under the same viewing and illumination geometries. While more complicated formulations might be considered, the linear statement is particularly appropriate for considering sub-pixel area affected. Since this model relates the change in reflectance to *fcc*, it does not require explicit treatment of those spectral components not directly related to the fire impact. The key to using this simple model lies in defining a generic spectral model of 'burn reflectance'. This is achieved by assuming the impact of wildfire to be the translation of a pre-fire spectral signal to some combination of char, ash and/or exposed (dry) soil. A two-parameter (linear) model capable of achieving this is defined and tested in this study. In Figure 1, an example of fitting the proposed model to observed char and ash spectra demonstrates its suitability.



Figure 1: Modelling char and ash spectra using the proposed two-parameter model for hyperspectral data (p. 84 in final report).

Since the imaging geometries need to be the same for pre- and post-fire signatures, BRDF modelling must form the backbone of any algorithm exploiting the model. Well-developed practical solutions are presented and demonstrated for dealing with these issues. The algorithm is tested using a range of data types and modelling studies, and demonstrated using moderate spatial resolution satellite data. The radiative transfer modelling details the importance of multi-layer canopy effects in fire impact modelling and shows that such effects can sometimes complicate the interpretation of *fcc*. For example, if the fire impacts are limited to a vegetation understorey, the derived parameter takes on an effective value, involving a modulation by the proportion of viewed and sunlit understorey relative to the total sunlit proportion of the pixel viewed in a particular angular configuration. This 'blocking factor' is inevitable when using optical data to explain the 'fire signal', but has rather interesting angular signatures that offer some potential for differentiating between fires that affect the whole canopy (all layers) and those that affect only an understorey.





Figure 2: 3D modelling of wildfire impact developed in this study. Pre- and post-burn simulated scenes.



Figure 3: Spatial distribution of the retrieved value of *fcc* for southern Africa, August 2004 from MODIS (AQUA and TERRA) surface reflectance data.

Significant additional aspects of this study have been: (i) the development of a 3D optical radiative transfer model of fire impact (see Figure 2); (ii) new measurements of Fire Radiative Energy (FRE), combusted fuel, and emission factors from savannah fires; (iii) the application of the *fcc* algorithm described above to MODIS (see Figure 3) and CHRIS-PROBA data; (iv) an initial comparison between combusted biomass estimated using *fcc* and FRE; (iv) a set of recommendations relating to further research directions and the application of the models developed to ESA and related sensors.

