MODELLING THE IMPACT OF WILDFIRE ON SPECTRAL REFLECTANCE

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1. INTRODUCTION

Measurement of the occurrence of wildfires from spaceborne remote sensing instruments has been widely studied in recent decades. Thermal observations have obvious advantages in detecting fires, the main practical issues being sampling frequency and detection thresholds. Routine monitoring of wildfires from optical and thermal moderate resolution data is also now possible, as exemplified by the MODIS fire products [1][2]. Inference of the occurrence of wildfire from optical data is in many ways more complex than from thermal data, in that an algorithm must generally seek for evidence that there has been a fire rather than directly observing the fire itself. The method of [2][3] achieves this by modelling day-to-day variations in spectral BRF due to angular influences and looking for sudden changes in the signal that may be due to other factors (such as wildfires in this context). In many ways, we can view the *detection* of wildfire from such data as essentially a solved problem, and the research focus can shift to one of *characterization* of the fire regime. [4] review methods used to characterize the fire regime and post-fire effects. The most common method of remotely-sensed assessment of fire severity is based on the Normalised Burn Ratio (NBR) or dNBR, the change in NBR between pre- and post-fire imagery, although several studies suggest that (d)NBR may be rather far from optimal as an optimal remote indicator of post-fire effects. There are several challenges associated with characterizing the fire regime. These include: (i) the need for information to be relevant to that required by those interested in e.g. pyrogenic emissions from wildfires, forest managers, fire ecologists and other relevant parties; (ii) at the same time the information should be accessible (in part or all) from remote sensing data, ideally for some reasonable time period so that temporal dynamics can be studied; (iii) the derived information should be robust and ideally be provided with error characteristics. These requirements are not always easy to balance. The 'index' approach, such as (d)NBR in essence attempts to define a measure that is easily characterized from remote sensing data and related in some general sense to wildfire impacts. This has been used to produce e.g. 'burn severity' classifications [4] or related to composite ground-based measures of fire impact [5]. An alternative to relating remote sensing data indices to composite fire severity indices is to attempt to model the impact of fire in a radiative transfer model. This has been achieved by various authors in recent years [6][7][8]. The emphasis in earlier studies has been sensitivity analyses. It is commonly found that canopy cover, LAI and canopy water content are factors that have major influences on remote signals. More recently, attempts have been made to 'invert' the radiative transfer models [7][8] although the aim of such inversions has still been to estimate some composite burn severity measure, rather than (as in more traditional radiative transfer modeling inversion approaches) to attempt to separate out the various biophysical paramaters and their dynamics. This is understandable in many respects: first, a detailed quantification of 'all' (controlling) canopy biophsyical may not be required by the application; second, it is a far from trivial matter to attempt to unambiguously characterize these terms: in many applications where such 'full' model inversion is attempted, a relatively simple set of assumptions regarding canopy structure is used, but in many fire-affected environments multiple canopy layers (each with their own LAI and other biophysical parameters) must generally be considered. [1] highlight the issue of ground fires, where the 'burn' signal may be either fully or partially obscured by a canopy overstory, particularly in regions with high LAI or tree cover. [6] show that the discrimination between spectral reflectance before and after fire at visible and near infrared wavelengths to be a function of time since fire, tree cover/LAI and viewing and illumination geometries for miombo woodland, but their results suggest that the 'burn signal' from understory fires is detectable even for high/moderate canopy covers (up to 60% cover examined). [9] suggest that crown and ground fires may be distinguishable in thermal data due to the different intensities of the fire regimes, suggesting (as yet generally unexploited) complimentarity between optical and thermal measures.

2. PROPOSED MODELS

Whilst the modeling approach of [7] and [8] attempts to relate the remote sensing signal to a composite measure of fire severity, we believe a more fruitful approach may be one that explicitly attempts to separate out a 'ground' signal from a 'crown' signal. We believe this should be quite feasible from moderate spatial resolution data such as those used in the MODIS fire-affected area algrithm. Whilst [6] does explicitly model BRF effects on signals, there is no real attempt in this or the work of [7] and [8] to *exploit* this domain of information. The method of [2] on the other hand takes direct account of BRF effects in fitting a semi-empirical model (that used for the MODIS BRDF/albedo product). Whilst this model is very capable of describing BRF effects in the signal, allowing for effective distinction of 'burn' signals, the model used is not appropriate for estimating biophysical parameters.

We first define a 'complex geometric' model of fire impact, using 3D models of vegetation structure and Monte Carlo ray tracing techniques [10][11] where explicit models are defined for pre- and post-fire for experimental plots measured in October/November 2008 in Kruger National Park, South Africa. These models are used to test our ability to model fire impacts (at least for savanna fires via comparisons with spaceborne, airborne and ground radiometry) and provide a wider set of simulations to test potential 'inversion' models. Next, we define a simple model appropriate for a single ground layer of vegetation (e.g. grass). At present, this is a linear mixture model based on that of [12], modelling post-fire reflectance as a proportion of pre-fire reflectance and a spectral burn signal (currently a two-parameter empirical function). This has proved capable of modeling both white ash and black char signals as well as dealing with exposed soil. This is a useful first-pass model in its own right, providing information on the proportion of a pixel affected by fire and potentially combustion completeness. Although it takes no direct account of tree cover, it can be readily embedded in a fuller radiative transfer model as a description of the lower boundary. A first attempt at this has been achieved using a 2-stream model of spectral albedo [13] although we are also exploring separating the crown and ground signal using models that more directly describe the BRF. Whilst we are only currently testing the model under Southern African conditions, the general approach of the model should be more widely applicable.

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