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Characterizing the surface heterogeneity of fire effects using multi-temporal reflective wavelength data

D. P. ROY*† and T. LANDMANN‡
†Department of Geography, University of Maryland, College Park, and NASA Goddard, Space Flight Center, Code 614.5 (B32), Greenbelt, MD 20771, USA
‡CSIR Environmentek, P.O. Box 395, Pretoria, South Africa

The relationship between changes observed in multi-temporal remotely sensed data and disturbance processes are increasingly being studied in support of various land process modelling and management decision applications. The possibility of mapping both the location and degree of change and retrieving information concerning the disturbance process are primary goals. This paper studies changes in reflective wavelength data caused by the action of fire. We consider the heterogeneity of fire effects in terms of the fraction of the observation that burned (f) and the combustion completeness (cc). A spectral mixture model and field and satellite observations of prescribed fires are used to examine the relationship between change in reflectance, and cc and f. The prescribed fires were lit in different South African savannah types during the SAFARI 2000 dry season campaign. Implications for the development of methods to retrieve cc and f, and for the development of methods to map the spatial extent of fire-affected areas with known detection capabilities are discussed.

1. Introduction

Satellite remote sensing provides the only practical means of monitoring biomass burning over large areas. In the last decade, various methodologies have been proposed to map the spatial extent of biomass burning using remotely sensed data (e.g. Kasischke and French 1995, Eva and Lambin 1998a, Barbosa *et al.* 1999, Fraser *et al.* 2000, Roy *et al.* 2002). Although these methods have provided useful information, their detection capabilities remain unclear, particularly with respect to the heterogeneity of the fire-affected area. To first order, the heterogeneity of fire-affected areas may be considered in terms of the spatial distribution of the burned components and the combustion completeness. The combustion completeness is a commonly used term and is defined as the fraction of fuel exposed to the fire which actually burns (Scholes *et al.* 1996, Shea *et al.* 1996). These parameters are important for understanding the effect of fire on vegetation structure and ecosystem processes (Knapp and Seastedt 1986, Trollope and Tainton 1986). They are important for estimating the amount of biomass burned and so for estimating trace gas and particulate emissions required to understand release of carbon and greenhouse gasses to the atmosphere (Levine 1996).

*Corresponding author. Email: droy@kratmos.gsfc.nasa.gov

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9. Conclusions

The field and satellite observations and modelling results described in this paper demonstrate that both the combustion completeness (*cc*) and the fraction of the observation area that burns (*f*) influence the change in reflectance that occurs after the passage of fire. Consequently, methodologies that use change in reflectance to retrieve *f* or *cc*, or related fire properties, may not work reliably without prior knowledge of one of these two parameters. In addition, the results demonstrate that the change in reflectance observed for fires with the same product of *cc* and *f* will depend on the pre-fire reflectance. Further, the action of certain high-temperature fires is to deposit highly reflective white ash that may increase rather than decrease the reflectance after a fire (Stronach and McNaughton 1989), and so bias methodologies that expect a drop in reflectance associated with burning. As pre-fire reflectance, fire temperature, *cc* and *f* vary as a function of many factors, empirical relationships made between ground observations of these parameters and changes in reflectance may only be applicable in a local context, for example, for fire monitoring and management of protected areas (e.g. Biggs 2002) and local post-fire ecosystem rehabilitation studies (e.g. Miller and Yool 2002). Techniques used to classify satellite data into broadly defined fire severity classes (e.g. unburned, lightly burned, and severely burned) may be insensitive to these effects.

The findings described here imply that algorithms developed to make spatially explicit maps of fire-affected areas have variable detection capabilities. Algorithms may detect burns with different degrees of heterogeneity as the pre-fire reflectance changes (e.g. due to vegetation phenology), as the combustion completeness changes (e.g. due to the seasonally controlled amount of fuel moisture), and as the degree of spatial fragmentation of the burned surface changes. We recognize that detection variability may always be present, especially when classification approaches are used. However, this observation has implications for the utility of such data, and implies that their accuracy should be validated by examination of regions that include representative variations of *cc*, *f* and pre-fire reflectance.

The model presented in this paper is simple and is probably not representative of most fire-affected surfaces, such as, for example, certain forested ecosystems where spectral differences between burned and unburned vegetation are low, and the canopy structure introduces strong directional reflectance effects. The modelling results imply, however, that methods to map fire-affected areas may be less sensitive to noise, and provide less variable detection capabilities with respect to *f* and *cc*, by thresholding absolute changes in reflectance, rather than thresholding relative changes in reflectance, or thesholding ratio type spectral band indices such as that examined in this study. Finally, we note that the product of *f* and *cc* is related to the change in reflectance, and that this product multiplied with the fuel load ($g\,m^{-2}$) provides an estimate of the biomass burned (g) in a satellite observation. Retrieval of this information by remote sensing would provide a major advance over anecdotal estimates of combustion completeness and assumptions that the entire satellite observation area burned that have been previously used for emissions estimation (e.g. Scholes *et al.* 1996, Barbosa *et al.* 1999). The use of well-calibrated, atmospherically corrected, cloud-screened, reflectance data, combined with less empirical mapping approaches, based for example upon inverting bi-directional reflectance models against surface reflectance measurements (Roy *et al.* 2002), may possibly allow the development of algorithms with known detection limits defined with respect to *f* and *cc* and the retrieval of the product of *f* and *cc*. Further work is required in these respects.