FIRE MAPPING FOR MANAGERS IN NORTH AUSTRALIAN SAVANNA; AN OBJECT ORIENTATED CLASSIFICATION MODEL FOR MODIS IMAGERY.

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Abstract

Fire is a conspicuous, widespread and frequent disturbance process in the savannas of north Australia. Fire can be a powerful land management tool if understood. Frequent and accurate fire scar mapping can greatly enhance the functionality of fire as a tool by giving managers regular feedback on their management actions, providing burnt area information and updating fire histories.

An object-orientated classification model based on change detection has been constructed for MODIS imagery to delineate fire scars across the Top End of the Northern Territory, with the aim of providing frequent, landscape scale burnt area information to the land manager. In the classification model developed the arithmetic difference in MODIS band 2 between the old image (Time one) and the more recent image (Time two) is a central decision parameter. Segmentation (object generation) weighted heavily towards the Band 2 (NIR) of Image Time 2 was found to be a repeatable and time efficient method of delineating burnt area patches, and created polygons at a scale where misclassification can quickly be resolved in a GIS environment by manual selection. The hierarchical organisation of image objects enabled for study area regionalisation, requisite due to the wide range of spectral response found over such a large region. The spatial concept of distance has proved useful at separating spectrally overlapping cloud and cloud shadow objects from those objects that correspond to fire scars.

The shorter the inter image period, the more effective this method is, as there is less background change or fading of burnt areas. Currently inter-image period for the entire top end is about 7 days, though this varies with image quality and can be more frequent. The outlet of the fire scar maps is the North Australian

Fire Information (NAFI) website, a site dedicated to providing fire information to land managers.

Introduction

Frequent, moderate resolution fire scar maps derived from MODIS imagery are a resource used primarily by land managers for planning and evaluation of landscape burning. The North Australian Fire Information program (NAFI) is an association between Bushfires Council of the Northern Territory, Cape York Peninsula Development Association, Charles Darwin University, Department of Land Information - Western Australia, Kimberley Regional Fire Management Project, Natural Heritage Trust, Sentinel Fire Mapping and the Tropical Savannas Cooperative Research Centre. Currently MODIS/ NOAA Hotspot occurrence and the MODIS derived fire scar maps are posted on a freely accessible website (www.firenorth.org.au) maintained as part of the north Australian fire information cooperative.

During the fire season land managers use these satellite-derived products to determine the fire status of their land. These products play a critical role in the planning and evaluation of landscape strategic burning effort, completing an informal adaptive management cycle. Fire scar maps provide the feedback to the managers burning effort, enhancing the learning process. As the fire season progresses, knowledge of already burnt areas becomes very important in planning future actions. The Moderate resolution and excellent spatial and temporal coverage of MODIS imagery make it superior in many fire history analysis applications (eg Russell-Smith et al. 1997; Edwards et al. 2001), relative to the coarse AVHRR and the infrequence and small extent of the Landsat series.

Unlike hotspot generation, automated fire scar mapping is yet to be operational and so relies on considerable user input. This investigation into object orientated modelling was motivated by the possibility of improve mapping efficiency as well as accuracy and frequency.

The study region covers the northern half of the Northern Territory, Australia (above 18 ° latitude) an area referred to as the Top End (figure 1). Climate of the top end is strongly seasonal the vast majority of rain falling in the summer, wet season period (November- March). Savanna vegetation systems that distinguish this area range with the rainfall gradient from open forest around the north coast to low open woodland and grassland further inland. The important feature of all these savanna landscapes in regard to fire is the highly combustible, continuous grass understorey. Fire occurrence also follows strong seasonality wet season months are highly productive, with rapid growth of the grassy understorey. As vegetation cures and dry, easterly and south easterly prevailing winds arrive, fire intensity and extent increase, with peak fire conditions from mid to late dry season (August to October). Dry season fire patterns contrast greatly with the rare, low intensity, small-scale fire scars during the wet season. The rarity of fires and the extensive cloud cover of the wet season exclude the value of fire mapping. Currently fires are mapped from

April to December, season dependent. Actual fire regimes vary greatly over the top end, a product of different land use and vegetation. Figure 1 illustrates the prominens of fire in the study region.

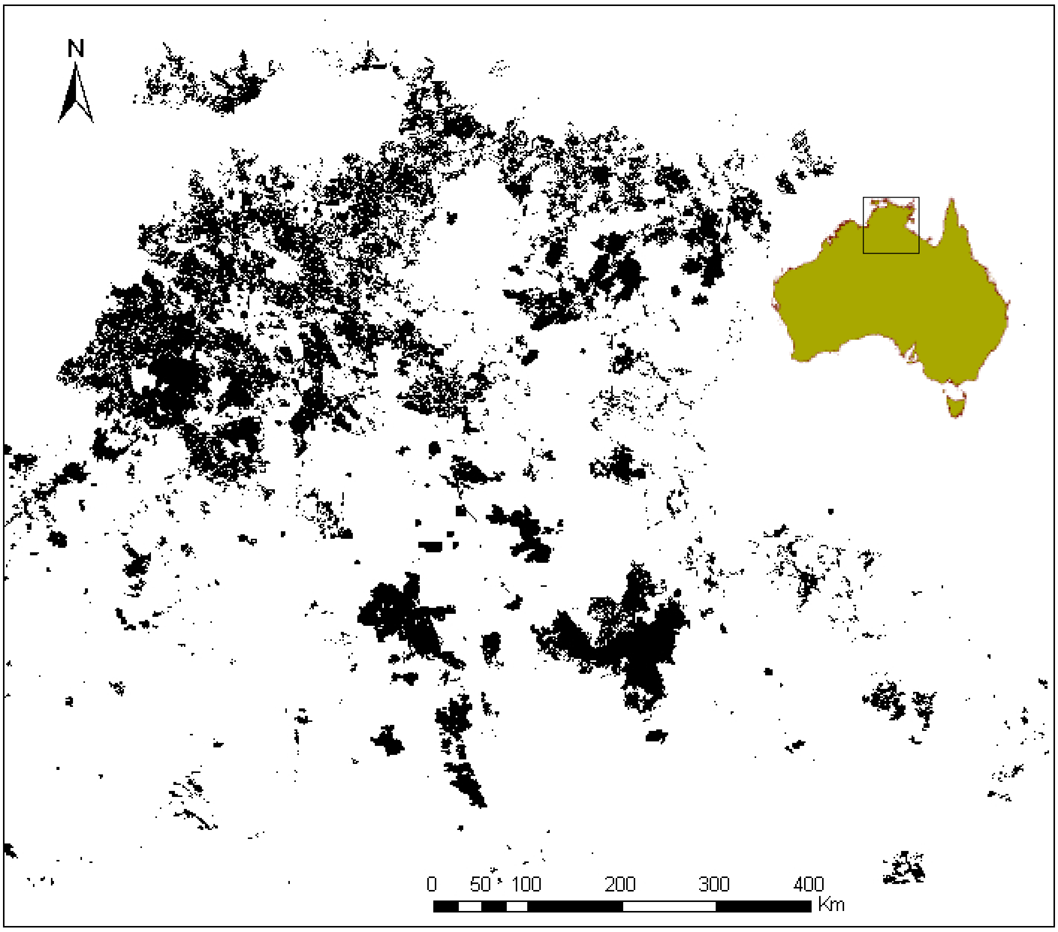

Figure 1: 'Top End' study area, as defined by the presence of combustion of 2003

MODIS data source

MODIS (Moderate Resolution Imaging Spectroradiometer) is the key sensor aboard the satellites Terra (EOS AM-1), launched on 18 December 1999 and Aqua (EOS PM-1), launched on 4 May 2002. MODIS views almost the entire surface of the Earth every day, acquiring data in 36 spectral bands over a 2330 km swath. For the purpose of fire this scar mapping, band 1 and band 2 are used. These bands are red (λ = 620 – 670 μm) and NIR (λ = 841 – 876 μm), both with are resolution of 250 Meters. MODIS images are available almost every day, but the operational mapping only requires updates on a weekly basis, this allows a degree of choice for the most suitable image. The best image will be as cloud free as possible, the morning terra pass typically has less cloud then the afternoon Aqua pass. The difference pair should ideally be of the same path, to avoid azimuth differences (Roy et al. 2002). Images are approximately seven days apart during the fire season, to provide regular updates and ensure that images are close enough together to avoid high degree of background landscape change, such as leaf flush.

Object-orientated image processing

The theoretical basis of object orientated analysis lies in Hierarchical patch dynamics (Burnett and Blaschke 2003). Both the relationship between patches of the same level and the obvious relationships between levels can provide an infinite amount of information about the landscape. It follows that the object for has a much greater capacity to represent a landscape then a pixel and so can be expected to be superior at interpreting the landscape. Advances in image segmentation (Blaschke and Strobl 2001), and the advent of software dedicated to object based processing means that an object-orientated treatment of imagery is a possibility in an operational setting.

Two specific features of an object-orientated approach to fire mapping that confer advantage over the conventional per pixel techniques. Image segmentation partitions an image into informative polygons, much the same way as manual digitization except that the product is repeatable, consistent, requires comparatively little user input and is apparently more informative then a manually digitized version. By partitioning an image into objects, geographical concepts like distance, connectivity, direction and pattern are introduced as image classification tools (Mitri and Gitas 2002), providing a means to deal with the spectral overlap which so often frustrates image analysis.

Methodology

Segmentation

Segmentation aims to partition a pixel image into non-overlapping homogeneous objects to create meaningful regions (Pal et al. 2000). The landscape patch has been used a theoretical justification of the image object (Burnett and Blaschke 2003). There is a huge number of possible solutions to image segmentation (Blaschke and Stroble 2001) the method that is chosen must produce objects which are homogeneous in the most informative way and at the correct scale.

The landscape cover measured here is burn area. Burnt area landscape patches have relatively hard boundaries, defined simply as the presence or absence of the combustion process having occurred there. For this mapping exercise, to create the most meaningful objects is to create image objects that best represent burnt area patches, at a suitable scale. In the case of fire scar mapping using temporal difference, the NIR bands and the most recent image (image 2) become most important. Band weighting should reflect this importance when trialling different segmentations. The creation of multiple levels with different scale parameters combined with the scale parameter assessment tool can be used to determine which scale parameter is most informative, but at the same time no smaller then necessary. For the purpose of delineating fire patches from MODIS Bands 1 and 2, a segmentation defined by the following parameters was chosen as the most informative or meaningful.

Relative importance of bands

T2 NIR: T1 NIR: T2 Red: T1 Red	= 8: 4: 1: 1
Scale parameter	= 30
Colour: Shape ratio	= 8:2
Compactness: Smoothness ratio	= 1:9

Band Weight is decided by two criterion.

1. NIR (band 2) is spectrally more sensitive to fire scars.
2. Image Time 2 is weighted higher then image time 1 so that objects closely resemble the current landscape, but image 1 is still included so that historic objects (especially cloud) are considered and so that new fire scars may be delineated from old ones.

Class hierarchy (classification model)

The primary means of fire scar object identification for this model is Change detection. This approach uses the high degree of spectral change from the unburnt landscape to burnt landscape to distinguish those scars that have occurred in the time period bounded by two images. Change detection avoids some of the spectral overlap reported as problematic for the mapping of burnt areas, as with water and shaded areas, because these features are spectrally stable. A difference function calculated for band 2 (expressed as: image time 1 – image time 2), enables the clear delineation of new fire scars, however there are a number of other dynamic classes that can still spectrally overlap with fire fresh scars. Particularly problematic is the presence of cloud in either image or the shadow they cast. With a resolution of 250 m Sub pixel misregistration can also cause problems (Roy 2000), as the objects on the boundaries of very dark and very light landscapes register as a change. Coastal environments also exhibit change; the twice-daily tidal cycle often causes a negative change for inundated areas.

Decision Principals and Model parameters.

Where Fx is the model parameter and Xmin is the lower threshold and Xmax the upper threshold. T1 is image time 1 and T2 is image time 2.

Class: Cloud T1, Cloud T2

Decision principal: Cloud is easy to distinguish spectrally (cloud shadow is not) as it highly reflective and dynamic.

Parameters: Cloud T1

(Mean Band 2, T1)	Fx > Xmin
(Mean Band 2, T2)	Xmin < Fx < Xmax
(Mean Band1, T1 – Band 1, T2)	Fx > Xmin
Cloud T2	
(Mean Band 2, T1)	Fx < Xmax
(Mean Band 2, T2)	Fx > Xmin

(Mean Band1, T1 – Band 1, T2)   Fx < Xmax

Class: Water
Decision principal: water objects are spectrally distinct in the NIR spectrum and stable over time.
Parameters: (Mean Band 2, T1)   Fx < Xmax
(Mean Band 2, T2)   Fx < Xmax
Or
= Region “non combustible”

Class: Possibly Burnt
Decision principal: Potentially burnt areas will exhibit a high degree of positive spectral change between time 1 and time 2
Parameters: (Mean Band2, T1 –Band 2, T2)   Xmin < Fx < Xmax
(Mean Band 2, T1)   Fx > Xmin
(Mean Band 2, T2)   Fx < Xmax
Not cloud T1
Not water

Class: Burnt
Decision principals: several classes may be confused with burnt areas (water edges and cloud shadow T2).
The intertidal zone is adjacent to the sea.
Cloud shadow is spatially associated with cloud.
Parameters: NOT (distance to cloud T2)   < 2500 m
NOT (distance to water)   < 1500 m
AND
= Possibly burnt

Regionalisation

The hierarchical organisation of object-orientated classification is conducive to regionalisation. Image subsets, and masking can all be achieved with a region layer, where all image objects must belong to one of the regions. The study area is large by any standards exhibiting considerable variation in spectral behaviour. Although the model structure is robust, parameter thresholds need to be set specifically for different regions for each classification. A masking region was created to eliminate areas where fire does not occur, including the ocean, intertidal zone and inland waters.

Model structure

Figure 2 shows how the model parameters fit together to make the ultimate decision. After the classification model has been applied to the imagery a manual classification in eCognition is used to correct false negative classification results. The fire scar feature polygons (raster) are then exported as a shape file. By displaying the fire scars over the enhanced imagery in a GIS, false positive classification results can be deleted quite efficiently.

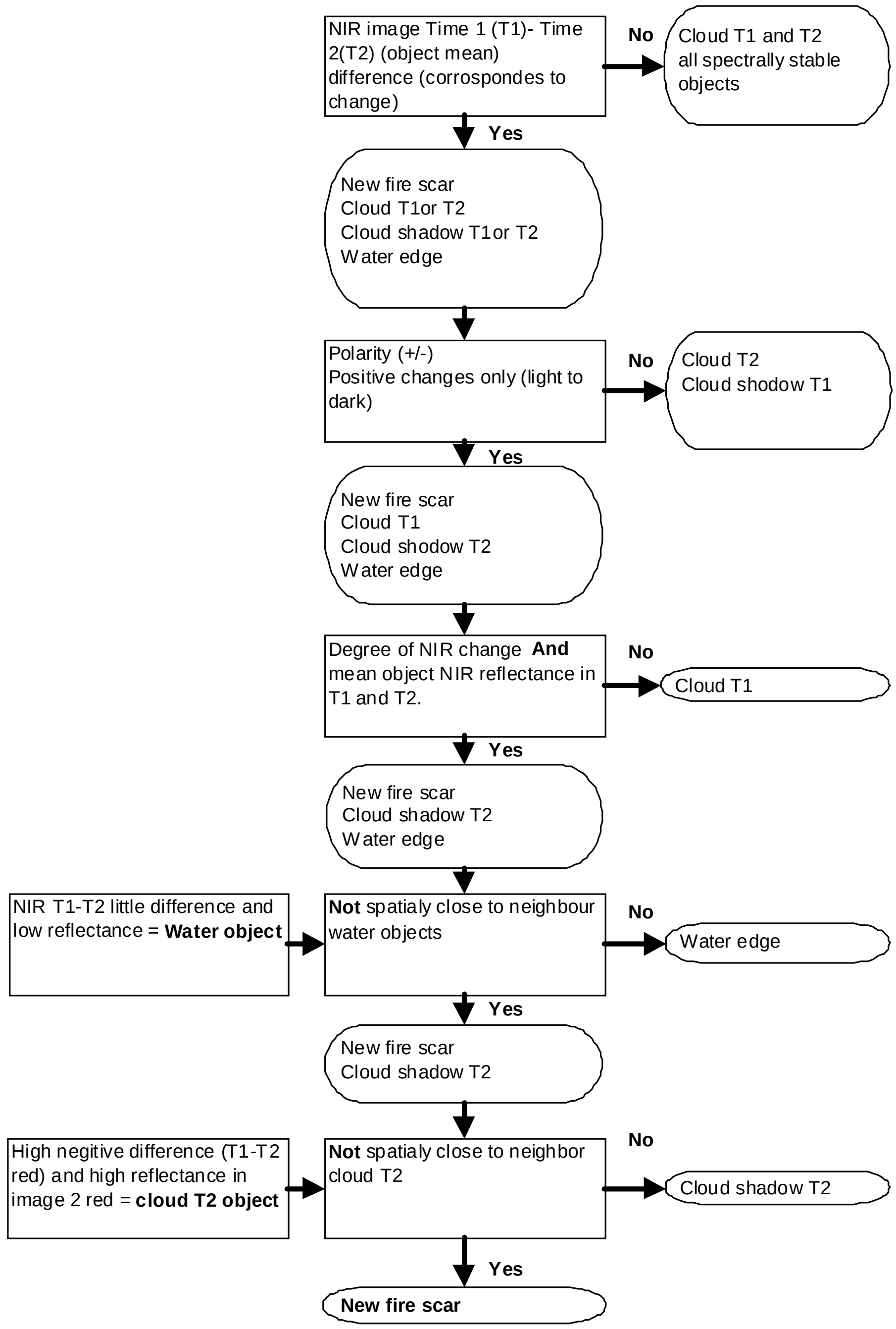

Figure 2 Model structure, illustrating class elimination across decision nodes

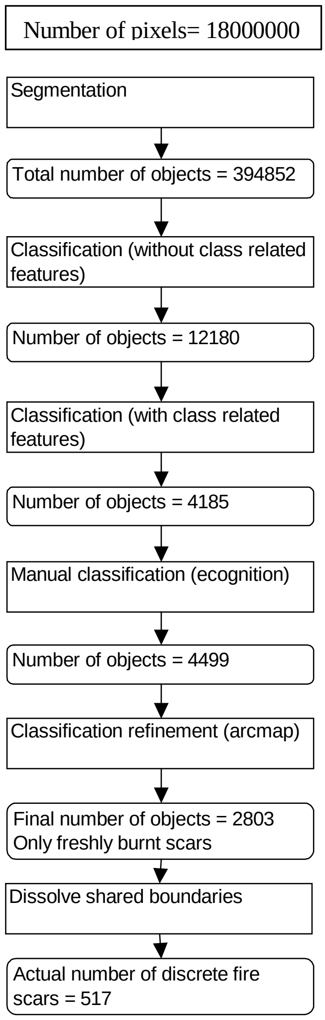

Figure 3. The progressive elimination of objects in the classification process. From the 18 million pixels to the 517 discrete fire scars. Example from terra orbits 19946 and 20150, covering the period 18/9/2003-2/10/2003

Results

Classification of an image with regard only to the object characters (i.e. without class related features) identifies all the fire scar objects and any other feature that can be confused with them. The example of image 20150 from the terra platform (figure 3) shows a yield of 12180 objects classified this way. Following on from this, classification with class related features removes 8000 objects. Manual classification subsequently adds 314 fire scar objects, these were either removed from the fire scar class by the “distance to” rules, which aimed to remove non fire scar features or are fire scar objects that did not conform to the rule base because they were obscured by cloud. Further manual classification in the GIS environment removes any non-fire scar objects that were not removed by any of the class related membership functions. Most of the 1696 objects removed in this way were attributable to either cloud shadow or the intertidal zone. The final number of discrete fire polygons in this instance was 515.

Application of the model over the 2003 and 2004 fire season found it to be structurally sound, though parameter thresholds required change between subsequent images. Feed back from land managers about the fire scar product has been positive (Jacklyn 2004; A. Edwards pers. Comm.) Results of an accuracy assessment against ground truth and Landsat fire mapping are presented by A. Edwards (this conference)

Discussion

This object-orientated model has been developed to the minimum required to produce suitable products, there are a number of obvious future developments. Further development of multiscale organisation to give regional context to fire scar objects may prove a solution for more automated future mapping models, were many regions with uniform fire scar signature could be used to increase decision specificity. MODIS bands 1 and 2 are used exclusively in the model because of their higher spatial resolution (250 m). Band 2, a NIR band has proven most informative in this modelling exercise. MODIS bands 5 and 6 have been found to be good predictors of burnt surfaces (Sa et al. 2003) and the Normalised burn ratio (NBR) (band 5 –band 7) / (band 5 + band 7) has proven useful for delineating burnt areas (Key and Benson 2002) and may be applicable in this model framework. Although these bands are 500m resolution, they need not be factored in with image segmentation, instead they would offer a new decision making dimension for the model rule base. The possibility of using the fire scar shape characters as an additional decision tool was briefly investigated. But found to be largely unworkable at the resolution of MODIS imagery. Shape character was found to be useful for eliminating the products of misregistration as they are typically long and skinny (high length to width ratio), however this rule eliminated many of the true fire scars and was abandoned.

Multi temporal imagery is widely used for landscape change detection and is particularly suited to burnt area mapping (Roy *et al.* 2002). The success of this approach lies in the extreme spectral changes brought about by combustion, where high absorbance from ash and low reflectance from scorched vegetation combine to cause low reflectance in NIR bands. For operational fire mapping Image acquisition times are close enough together so that background spectral change is generally not significant. However, anomalous rainfall during the transition periods either side of the dry season caused very rapid fading of fire scars, and poor classification results. Unlike uni temporal classification, change detection confines fire scars to the discrete period between the two images, making the product well suited to updating the burnt area database. Similarly repeat burns can be detected more accurately and past burns can be ignored.

Changes required to parameter thresholds can be attributed to annual model evolution, atmospheric variation and path differences. Parameters thresholds need to be adapted slightly as the season progresses due to underlying spectral trends. The eCognition modelling environment provides many useful tools to quickly identify the thresholds that require changed and are simple to manipulate. The modified class hierarchy can then be retained and applied to the images of the same period next year. The temporal range over which change is detected is very significant for model application and classification accuracy. Using the assumption that within the annual cycle, landscape reflectance tends to be more similar with shorter temporal range. For fire scar identification using change detection in the top end there are two processes that must be considered when choosing the temporal interval. Gradual landscape changes that effect spectral reflectance such as vegetation greening or curing and water body drying mean that the further apart images are, the greater the background change from which fire scars must be distinguished. The other consideration when identifying scars with change detection is fading; as ash is lost from the ground surface and new foliage re-sprouts the fire scars become less distinct from the surrounding unburnt vegetation (Roy et al. 2002; Sa et al. 2003).

Application of this model is relatively time efficient, class related feature rules tend to be computationally intensive directly proportional to the number of classified features. Operator time demands are also relative to the amount of cloud and fire present on the image, owing to the amount of manual classification needed, though are generally less then method previously used.

The relevance of these model products to managers is only as good as their communication. The NAFI website is an easily accessible outlet for fire information. With continual growth in remote internet access rates (Australian bureau of statistics 2004), internet is becoming a realistic outlet for information to land managers. High-speed connections are still uncommon in remote areas so NAFI has compact ‘quick look’ options, a map viewer options allows users with faster connections to explore the data and customise settings and layers. The most recent addition to NAFI is a map service that provides users with data, which they can use in their own GIS. Uptake of the NAFI by managers appears to be strong, satisfying most managers needs (Jacklyn 2004)

Conclusion

The potential of pixel based image processing to map fire scars has been near fully exploited. The object based classification model developed here has demonstrated an alternative and successful method to per-pixel classification, encouraging the realization that there is far more untapped potential in this method. The model that was constructed was relatively robust, efficient and provided a product suitable for operational fire information.

REFERENCES

Anon., 2003, Breakthrough websites track fire by satellite. *Savanna Links*, 26:2.

Australian bureau of statistics., 2004, Proportion of households with access to the Internet by type of household, income and broad region. Australian bureau of statistics.

Blaschke, T., and Strobl, J., 2001, What's wrong with pixels? Some recent developments interfacing remote sensing and GIS. Geo-Informations-Systeme 14 (6): 12-17

Burnett, C., and Blaschke, T., 2003, A multi-scale segmentation / object relationship modelling methodology for landscape analysis. *Ecological Modelling* 168(3): 233-249

Edwards, A., Hauser, P., Anderson, M., McCartney, J., Armstrong, M., Thackway, R., Allan, G., Hempel, C., and Russell-Smith, J., 2001, A tale of two parks: contemporary fire regimes of Litchfield and Nitmiluk National Parks, monsoonal northern Australia. *International Journal of Wildland Fire* 10 (1): 79-89

Key, C.H., and Benson, N.C., 2002, Measuring and Remote sensing of burn severity. In J.L. Coffelt and R.K. Livingston, U.S. *Geological Survey Wildland Fire Workshop*, Los Alamos, NM October 31-November 3, 2000. USGS Open-File Report 02-11. 55.

Mitri, G.H., and Gitas, I.Z., 2002, The development of an object oriented classification model for operational burned area mapping on the Mediterranean island of Thasos using LANDSAT TM images. *Forest fire research and wildland fire safety*, Viegas (ed). Millpress, Rotterdam.

Pal, S.K., Ghosh, A., and Uma Shankar, B., 2000, Segmentation of remotely sensed images with fuzzy thresholding, and quantitative evaluation. *International Journal of Remote Sensing,* 21 (11): 2269-2300

Roy, D., 2000, The impact of misregistration upon composited wide field of view satellite data and implications for change detection, *IEEE Transactions on Geoscience and Remote Sensing*, 38:2017-2032.

Roy, D.P., Lewis, P.E., Justice, C.O., 2002, Burned area mapping useing multi temporal moderate spatial resolution data- a bi-directional reflectance model-based expectation approach. *Remote sensing of the environment* 83: 263-286.

Russell-Smith, J., Ryan, P.G., and Durieu, R., 1997, A LANDSAT MSS- derived fire history of Kakadu National Park, monsoonal northern Australia, 1980-94: seasonal extent, frequency and patchiness. *Journal of Applied Ecology*, 34: 748-756.

Stroppianna, D., Gregoire, J.M., and Pereira, J.M.C., 2003, The use of SPOT VEGETATION data in a classification tree approach for burnt are mapping in Australian savanna. *International Journal of remote sensing*, 24(10): 2131-2151.

Jacklyn, P., 2004, Website links the remote manger. *Savanna Links*, 27: 5.