Detection and mapping of burnt areas and active fires in tropical woodland ecosystems with the VEGETATION sensor: the SMOKO-FRACTAL case study over Northern Australia

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Abstract. The SMOKO-FRACTAL field campaign was conducted during the 1999 dry season in Australia (Northern Territory). The objective of the experiment was to collect ground and satellite data to develop and test methodologies for burnt area detection from low resolution satellite imageries in a tropical woodland ecosystem. In this work we present burnt area maps derived from VEGETATION and AVHRR images. The methodology applied is based on classification rules extracted from decision trees. In order to map burnt areas, classification rules were directly implemented in the case of VGT images. A different approach was used with the AVHRR images for which classification rules and active fire positions were used in a seed-growing algorithm. The accuracy of the results was evaluated using high resolution Landsat-TM images. Active fire detection was also performed using daytime and nighttime VGT images and results were compared to active fire positions provided by the World Fire Web System.

Introduction

The SMOKO-FRACTAL field campaign was conducted in Kakadu National Park, Northern Territory, Australia in June 1999. It was organized in the framework of a scientific collaboration between the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Centre National d’Etudes Spatiales (CNES), the Technical University of Lisbon (TUL) and the Space Applications Institute (SAI) of the European Commission Joint Research Centre (JRC). The short-term objective of the experiment was to collect data to develop and test burnt area detection algorithms using low resolution satellite images (SPOT-VEGETATION and NOAA-AVHRR) in the tropical woodland ecosystem in a long-term perspective of mapping burnt areas using the same sensors at a global level. The burnt area product will also contribute to the quantitative assessment of carbon and CO₂ budget, as well as to studies related to emissions of other greenhouse gases and aerosols globally. This type of information is of key importance in the context of the Kyoto Protocol to the Framework Convention on Climate Change (FCCC) and Biodiversity and Desertification Conventions.

The experimental site (figure 1) covers an area of about 300,000 km² (129°-134° E, 11°-16° S) where tropical woodland savannah is the predominant ecosystem. There is a marked wet and dry season (November-March and April-October respectively) and vegetation fires are extensive and frequent during the dry season (Graetz et al. 1992, Russell-Smith et al. 1997). During the field campaign ground and satellite data were collected. The ground data concern the extension of the main burns (collected using a portable Global Position System instrument and helicopter surveys), characteristics of the vegetation cover (species, tree density, height and crown characteristics for the commonest species) and fire behaviour (smouldering or flaming fires). The satellite data set is composed of imageries acquired by low resolution orbital (SPOT-VGT, NOAA-AVHRR-HRPT, ERS-ATSR) and geostationary (GMS-VISSR) systems, high resolution SAR (ERS-SAR, Radarsat) and optical (SPOT-HRV, Landsat-TM) systems. In this work we focused on the use of VGT and AVHRR images for burnt area mapping. High resolution Landsat-TM images were used to evaluate the accuracy of the results. An algorithm was also developed to extract active fires from VGT daytime and nighttime images. Among the ground data we used the information concerning position and extension of the main burns in order to extract their spectral signature. The analysis of spectral behaviour of burnt areas in different vegetation cover types was used as a basis for the development of the burnt detection algorithm. This part of the work is not presented in this paper. In this paper we present the characteristics of the remotely sensed data set (section 1), the methodology applied to detect burnt areas from VGT and AVHRR (section 2)
and active fires from VGT (section 3) imageries. In section 4 we draw some conclusions and underline which could be the future developments for a multi-satellite approach to fire monitoring.

1. The remotely sensed data set
Time series acquired by the VGT sensor (S1 product) are composed of daily images of ground reflectance from May, 15th to July, 15th 1999. A limited data set of nighttime images was also made available by CNES. The NOAA-AVHRR data set is composed of daily Top Of Atmosphere reflectance (afternoon pass) for the period May, 19th to June, 14th 1999. Temporal compositing was applied to daily VGT and AVHRR images to reduce noise due to cloud cover and atmospheric effects, and to stabilise the variability produced by daily changes in illumination and viewing geometry. Among the high resolution images available, we used two Landsat-TM scenes (105/69 and 105/70) from the 9th of June 1999.

2. Burnt area mapping from VGT and AVHRR

2.1 Mapping burnt area from VGT
Ten day composites were produced from daily images with a minimum near infrared (NIR) criterion. In order to minimise the risk of selecting cloud shadows the simple minimum value technique was adjusted with a condition that looks at the temporal trend in the NIR reflectance in each pixel during the compositing period. The steps of the temporal compositing can be summarised as follows:
a) During a ten day period the four days with the lower values in NIR are selected.
b) The lowest value is kept as potential “best composite day”. From the remaining three days the mean and range are computed.
c) The potential “best composite day” is confirmed only if it is contained in the interval mean ± range. If it is not, the second lowest value of the four values chosen in a) is selected.

The Global Environment Monitoring Index (GEMI) (Pinty and Verstraete, 1992) was computed from the red and NIR bands. The methodology used to map burnt area is based on classification trees (Breiman et al. 1984) and it is summarised by the following steps:
1. Choice of the number of classes (burnt, unburnt and clouds).
2. Extraction of a training data set by visual inspection of the daily images.
3. Choice of the predictor variables (NIR and SWIR bands and the GEMI index, in this case).
4. Output: a decision tree (set of binary decisions). Each decision involves a predictor variable and a threshold value.
5. A classification rule can be extracted as a set of consecutive binary decisions and the algorithm built from the set of rules.

In order to build the decision tree we used to Classification And Regression Trees software (Salford Sytems, San Diego, CA 1997). The following conditions summarise the classification rules for VGT data. A pixel is classified as burnt if one of the three tests is satisfied.

(1)  \( \text{NIR} \leq 0.170 \) and \( \text{SWIR} > 0.120 \) and \( \text{GEMI} \leq 0.437 \)
(2)  \( \text{NIR} \leq 0.170 \) and \( \text{SWIR} > 0.171 \) and \( \text{GEMI} \leq 0.437 \)
(3)  \( \text{NIR} \leq 0.195 \) and \( \text{NIR} > 0.170 \) and \( \text{SWIR} > 0.217 \) and \( \text{GEMI} \leq 0.451 \)

Figure 2 presents the burnt area map derived from the VGT composite image June 1–10 1999.
### 2.2 Mapping burnt area from AVHRR

Nine day composites were derived from daily AVHRR images with a two steps compositing criterion: within the compositing period the four days with the lower channel 2 are selected and, among these dates, the day with the highest brightness temperature in channel 4 is chosen. This compositing criterion showed to perform well in minimising the risk of selecting cloud shadows (Pereira 1999). Although temporal compositing reduces noise from cloud cover, a cloud detection algorithm was applied before the compositing (Saunders and Kriebel 1998, Stowe et al. 1991). A pixel is flagged as cloud if:

i. $\rho_1 > 44\%$ and $B_{T4} < 293K$

OR

ii. $0.9 < \frac{\rho_2}{\rho_1} < 1.1$ and $B_{T4} < 293K$

OR

iii. $B_{T4} < 294K$

Active fire maps were derived from daily images by applying a contextual algorithm (Flasse and Ceccato 1996).

In order to map burnt areas the methodology described in section 2.1 provided the classification rules, which were applied in a seed-growing technique using the information on active fire positions. The rule extracted for the burnt class in based on the values in channel 2 (TOA reflectance) and channel 3 (brightness temperature). A pixel is classified as burnt if it satisfies the following condition:

$\rho_2 \leq 0.12$ and $B_{T3} > 305K$

The seed-growing algorithm is an iterative procedure. At a first step the condition is tested for the eight pixels surrounding a pixel labeled as active fire (seed). Those pixels that satisfy the condition are classified as burnt and they constitute the seeds for the next iteration. The process stops when the number of pixels classified as burnt in two consecutive iterations is constant. Figure 3 the results obtained from the AVHRR composite image June 5–13 1999.

### 2.3 Accuracy of the results

The accuracy of the results was evaluated using two Landsat-TM frames (June, 9th 1999) that were geo-located with ground control points and digital topographic maps (scale 1:250,000). Burnt areas were visually extracted from the TM images. Thirty validation windows (14 km by 14 km) were randomly extracted in the study area. The percentage of area classified as burnt in each window was calculated for burnt area maps derived from VGT, AVHRR, and TM images. The scatter plots (VGT vs. TM and AVHRR vs. TM) qualitatively show the accuracy of the results (figure 4).

The graphs show that classifications derived from both VGT and AVHRR tend to overestimate the area burnt. The rate of overestimation increases with the proportion of the window that is burnt. Yet results derived from VGT are more accurate especially for lower percentages (less than 30%). Two interesting cases can be pointed out. The first one is a misclassification in the burnt area map derived from VGT images. Visual inspection of VGT and AVHRR spectral bands showed that this burnt area is clearly visible only in AVHRR channels 3, 4 and 5. Neither in AVHRR channel 1 and 2 nor in VGT NIR and SWIR bands the window’s burnt portion can be distinguished against the unburnt vegetation. Probably a fire burnt only the grass layer and did not affect the upper tree layer. The second point, that is present in both the graphs, corresponds to a case where the same area classified as burnt in VGT and AVHRR is not present in the TM interpretation. This specific case shows the limitation of the visual interpretation performed on the Landsat-TM data.
3. Active fire detection from VGT
The feasibility of detecting active fires from VGT images was tested and the results evaluated by the comparison with the active fire maps provided by the World Fire Web System (section 3.2) (http://www.gvm.sai.jrc.it) (Grégoire and Pinnock, 2000).

3.1 Methodology
The algorithm used to detect active fires was elaborated empirically and it is based on a local contrast distinction technique for the daytime data set and on a simple thresholding for the nighttime images. The algorithm used with daytime images is based on the value of the NDVI, the Normalised Difference Water Index (NDWI; Gao 1996) and the reflectance in the SWIR band. NDWI was computed using Eq. 2.

\[
\text{NDWI} = (\rho_{\text{NIR}} - \rho_{\text{SWIR}}) / (\rho_{\text{NIR}} + \rho_{\text{SWIR}}) \quad \text{(Eq. 2)}
\]

The algorithm works on a pixel basis. First the average SWIR reflectance in a window 45 by 45 pixels was computed. Then the SWIR reflectance was subtracted to the average image to highlight those pixels contrasting against the background. A threshold (-1 to -0.06) was applied to the difference image to extract pixels identified as active fires. To confirm this first identification a second threshold (0.6 to 1) was applied on the image NDVI-NDWI. The inspection of nighttime images confirmed that the features clearly visible in the SWIR band were active fires. A simple thresholding on the SWIR band allowed the extraction of active fires.

3.2 Evaluation of the results
Active fires detected from VGT images were overlaid to those provided by the World Fire Web network. Figure 5 shows the good spatial correspondence between active fires detected with nighttime VGT images and active fires detected using daytime AVHRR images. The area burnt by the fire is also clearly visible. VGT sensor has some potentialities for active fire detection even if the number of fires detected was only a small fraction of those detected with AVHRR.

4. Conclusions and perspectives
The methodology applied to derive burnt area maps from VGT and AVHRR images performed quite well in terms of overall accuracy. Results obtained from both systems show an overestimation of the area burnt. Yet results were more accurate for VGT images probably due to the better geometry of the sensor, compared to AVHRR. This characteristic is also very important when temporal compositing is applied. From a spectral point of view, the presence of a SWIR band in the VGT sensor might be useful for burnt area mapping in this type of ecosystem (tropical woodland savannah) even though the burnt signal in this band is not as persistent in time as in the NIR band. The usefulness of the SWIR band is strongly dependent on the vegetation cover type and on the age of the burnt area. The accuracy assessment also underlined the importance of the information brought by AVHRR channels 3, 4 and 5. Hence the lack of a thermal channel is the main drawback for the use of VGT data for burnt area mapping. Results obtained from AVHRR images using the seed-growing technique confirmed the importance of the information on active fire positions as a guide in burnt area mapping. The presence of a detected active fire can help in mapping small burnt areas and in avoiding commission errors in those cases where the burnt signal is not easily separable from the unburnt one.

The methodology applied to detect active fires from VGT images performed quite well. Fires cannot be extracted by simple threshold from the daytime images, but rather by taking advantage of their local contrast. On the contrary a simple thresholding on the SWIR band can be applied with the nighttime images. Nevertheless due to the small size of the study area it is difficult to draw conclusions on the accuracy in term of fire count.
This work highlighted some advantages and drawbacks of both VGT and AVHRR sensors for burnt area mapping purposes. As a perspective, a multi-satellite approach might combine the unique and positive aspects of each sensor and the detection of both active fires and burnt areas. Active fires, as detected by the World Fire Web network based on NOAA-AVHRR, could be used to guide burnt area mapping from SPOT-VEGETATION imagery. An improved procedure for geo-location of the active fires is being developed to make this approach feasible. From an operational point of view, the CTIV could consider the systematic production of VGT composite images using the criterion tested in this study.
REFERENCES


**Figure 1.** Vegetation map derived from the Atlas of Australian Resources (Australian Surveying and Land Information Group, Department of Administration Services, Canberra 1990) representing the spatial distribution of the present vegetation in the study area.
Figure 2. Burnt area map derived for the composite VGT image for the period June 1st-10th 1999.
Figure 3. Burnt area map derived for the composite AVHRR image for the period June 5-13, 1999.
Figure 4. Scatter plots that qualitatively show the accuracy of the burnt area maps derived from AVHRR (panel a) and VGT (panel b) imagery using visual interpretation of Landsat-TM as reference. Data a) Scatter plots that qualitatively show the accuracy of the burnt area maps derived from AVHRR (panel a) and VGT (panel b) imagery using visual interpretation of Landsat-TM as reference.
Figure 5. Active fires detected using VGT nighttime images from the 15th of June 1999, AVHRR daytime images from the 15th and 16th of June 1999, and AVHRR nighttime images from the 15th of June 1999 and VGT.