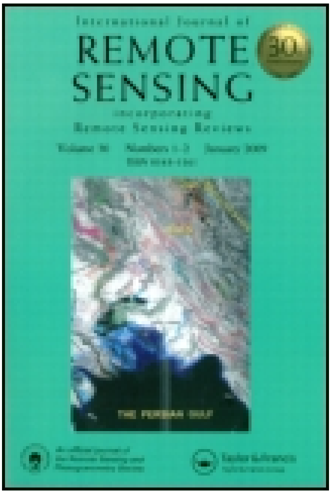

International Journal of Remote Sensing
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tres20

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Published online: 25 Nov 2010.

INT. J. REMOTE SENSING, 2001, VOL. 22, NO. 14, 2661–2673

DMSP-OLS estimation of tropical forest area impacted by surface fires in Roraima, Brazil: 1995 versus 1998

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(*Received 30 July 1999; in final form 18 August 2000*)

Abstract. A procedure has been developed to locate and estimate the area of heavy forest burning based on the frequency of DMSP-OLS (US Air Force Defense Meteorological Satellite Program Operational Linescan System) fire detection from time series of observations across the fire season. A calibration was developed for Roraima, Brazil, using Landsat Thematic Mapper (TM) data acquired near the end of the 1998 burn season and analysed to identify unburnt, partially burnt and heavily burnt forest areas. A fire detection frequency threshold of five nights was used to map heavily burnt forest using the 3 months of DMSP-OLS observations. The threshold of five fire detections, which could occur anytime during the 3-month time period, was selected to constrain errors of commission involving unburnt forest to 10% of the total area for unburnt forest in the calibration area. At this threshold setting the DMSP-OLS estimate of heavily burnt forest area covered 79% of the Landsat measured area. It was found that 77% of the 1998 heavily burnt forest area was outside of the state's protected areas (national parks, reserves, indigenous areas). Two of the protected areas sustained a substantial increase in heavily burnt forest in 1998 relative to 1995 (Reserva Biológica Mucajaí and Parque Indígena Yanomami). The 1998 forest burning in these two areas was concentrated in their eastern-most sections. The core of the Yanomami area did not sustain extensive burning in 1998. Protected areas in the north-eastern section of the state, where forests are mixed with cerrado, had moderate increases in heavily burnt forest in 1998. Other protected areas were largely free of the heavy forest burning, which was concentrated to the west of the state's primary cerrado zone.

International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online © 2001 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160010025961

1. Introduction

During the first 3 months of 1998, drought in Brazil's northern state of Roraima resulted in major fires in tropical forest areas. The extreme fire potential had been predicted by Brazil's Instituto Nacional de Pesquisas Espaciais (INPE). The state has a number of national parks, biological reserves, forest reserves, and indigenous areas that have high priority for conservation (figure 1). Tropical forest is the dominant landcover of the state. There is a large area of cerrado in the north-east quarter of the state. The cerrado is characterized by the presence of widely distributed small trees with shrubs and grass, similar to tropical savanna. Portions of this cerrado area are burnt each year during the dry season, which is typically centred on the December through March time period.

The Roraima fires demonstrated that under severe conditions, fires can move through Amazon tropical forests, causing considerable damage. This possibility raised new relevance to the remote sensing of fires in forests of the Amazon and other tropical areas.

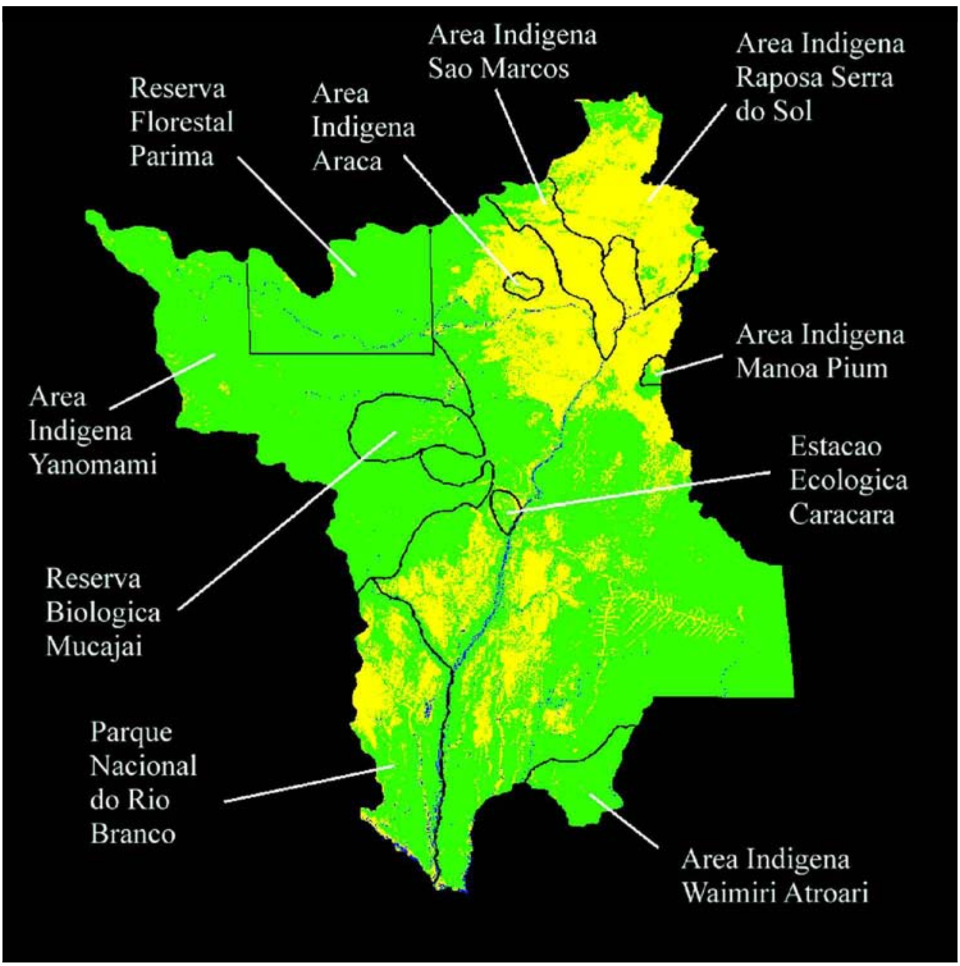

Figure 1. Forest/non-forest land cover for the State of Roraima. Overlain are the outlines of parks, reserves and indigenous areas.

The vast majority of the cleared forest lands in the Amazon region are used for pasture, which is burnt periodically to clear shrub, vine and renewed tree growth to enhance grazing conditions and to reduce the numbers of pests such as rattlesnakes. Forest clearing typically involves the clear cutting of trees and drying for an extended period of time prior to burning. The drying period is a full year in many instances. Under normal circumstances forests are too wet to burn and can be used as fire breaks to control the burning used to clear pasture lands (Uhl and Kauffman 1990, Nepstad *et al.* 1999).

The extreme fire season in Roraima during 1998 was associated with El Niño induced drought. Cochrane and Schulze (1998) and Cochrane *et al.* (1999) provide excellent descriptions of drought-induced fires in tropical forests. The stress induced by prolonged drought causes trees to drop their leaves, creating a dry fuel layer on the forest floor increasing the forest's flammability. Fires typically enter the forest initially from adjacent pasture burning. Surface fires move across the forest floor in thin lines, consuming the dry leaf litter. Most of the burning is restricted to the forest floor and are only able to move into the forest canopy in isolated patches. Unlike fires in other ecosystems, surface fires in tropical forests create new fuel for future fires by drying (but not burning) portions of the canopies, inducing the loss of leaf and stem materials. Trees in tropical forests have thin bark and are not well adapted to fires. Small diameter trees are more readily damaged. However, even larger trees can be impacted if a surface fire moves through an area multiple times. The multiple burn pattern can emerge within a single year or can be carried over into fires in succeeding years.

The description provided by Cochrane and Schulze (1998) and Cochrane *et al.* (1999) indicate that the detection of forest fires in areas like Roraima using coarse resolution meteorological satellite imagery is not a trivial matter. The flames tend to be organized in narrow ribbons, moving 100–150 m per day. The fireline intensity is reported to be generally less than 50 kW m^{-1} and is under a forest canopy. The fires tend to die down at night and restart from burning embers the next day and generally reaching a peak in early afternoon. The forest canopy is left largely intact, with evidence of burning limited to loss in green leaves and occasional consumption of canopies in isolated pockets. This raises questions whether these fires can be detected with satellite imagery having ground resolutions measured in kilometres.

The night-time fire detection capabilities of US Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) have been known since the early 1970s (Croft 1973). However, due to limited access to the digital data, very few studies documenting the OLS fire detection capabilities have been performed. Brazilian Institute for Space Research (INPE) was asked by the Government of Brazil through the Ministry of Science and Technology to perform an assessment of the Roraima fires to answer questions regarding the location and spatial extent of the tropical forest burning. In response to a request from INPE, NOAA processed nightly DMSP-OLS fire products for Roraima from 1 January through the end of March for two years: 1995 and 1998. We report here on the results comparing the fire events from the two years and results obtained with March 1998 Landsat data.

2. Fire detection with DMSP-OLS data

DMSP has operated low light imaging sensors since the early 1970s. However, digital data was not readily available until 1992, when the US Air Force and NOAA established the DMSP digital archive at the NOAA National Geophysical Data Center (NGDC) in Boulder, Colorado. NGDC receives raw DMSP data via an electronic connection to

Air Force Global Weather Central (AFGWC), Offutt Air Force Base, Omaha, Nebraska. The DMSP data arrive at NGDC within 1–2 h after data are initially acquired. It is anticipated that DMSP-OLS will continue to fly until approximately 2010. The night-time low light imaging capabilities of the OLS will be continued under the U.S. National Polar-orbiting Operational Environmental Satellite System (NPOESS).

The DMSP generally operates two satellites in sun-synchronous orbits, one in a dawn–dusk orbit, the other in a day–night orbit. The OLS is an oscillating scan radiometer designed for cloud imaging with two spectral bands (VIS and TIR) and a swath of ~3000 km. The 'VIS' bandpass straddles the visible and near-infrared (VNIR) portion of the spectrum (0.5–0.9 μm). Satellite attitude is stabilized using four gyroscopes (three axis stabilization), a star mapper, Earth limb sensor and a solar detector. The OLS VIS band signal is intensified at night using a photomultiplier tube (PMT), for the detection of moonlit clouds. The low light sensing capabilities of the OLS at night permit the measurement of radiances down to 10^{-9} W cm^{-2} sr^{-1} μm^{-1}. This is more than four orders of magnitude lower than the OLS daytime VIS band or the VNIR bands of other sensors, such as the NOAA AVHRR or the Landsat Thematic Mapper (TM).

There are two spatial resolution modes in which data can be acquired. The full resolution data, having nominal spatial resolution of 0.5 km, is referred to as 'fine'. On board averaging of five by five blocks of fine data produces 'smoothed' data with a nominal spatial resolution of 2.7 km. Most of the data received by NOAA-NGDC is in the smoothed spatial resolution mode.

The potential use of night-time OLS data for the detection of fires was first noted by Croft (1973, 1978, 1979). The first systematic inventory of fires with OLS data was reported by Cahoon *et al.* (1992), who worked with OLS film. More recently, Elvidge *et al.* (1996 and 1997) developed algorithms to identify and geolocate fires and city lights in digital OLS imagery. Time series analysis is used to distinguish persistent nocturnal emissions generated by villages, towns and cities from ephemeral emissions arising from fires.

3. Data sources and preparation

3.1. *Fire products*

DMSP-OLS data was extracted from the archive for each night from the beginning of January to the end of March for 1998 and 1995. The 1995 data was processed to provide a comparison between the extreme fire events of 1998. Meteorological records indicate 1995 was a typical year in terms of precipitation. The data were processed using the OLS algorithms described in Elvidge *et al.* (1996, 1997, 1998) to generate 30 arc second fire and cloud images for each night where data was available in the archive.

3.2. *Land cover*

A 30 m resolution forest/non-forest map of the Amazon, prepared from Landsat Thematic Mapper data by the NASA Landsat Pathfinder project (Chomentowski *et al.* 1994) was used as the primary land cover source. This dataset was assembled using Landsat TM data from the early 1990s. The high resolution coverage was regridded to the 30 arc second grid being used for the DMSP fire products. In locations where there was no land cover data available from the Landsat data, land cover was drawn from the global 1 km Advanced Very High Resolution Radiometer (AVHRR) land cover product prepared by the US Geological Survey, EROS Data Center (Brown *et al.* 1993).

The resulting land cover map is shown in figure 1. Forest is the primary land cover of the state. There is a large cerrado zone in the north-east section of the state, indicated as non-forest. Settlement areas in forest regions, indicated by trellis like road patterns mapped as non-forest, are present to the south of the cerrado zone.

3.3. *Conservation areas*

The outline of parks, reserves, and indigenous areas were manually digitized from a one to million scale map. A total of 10 areas were digitized: Área Indígena Waimiri Atroari, Área Indígena San Marcos, Área Indígena Raposa do Sol, Área Indígena Manoa Pium, Área Indígena Araca, Parque Indígena Yanomami, Parque Nacional do Rio Branco, Estação Ecológica Caracaraí, Reserva Biológica Mucajaí and Reserva Florestal Parimã. The location of the 10 areas are shown on figure 1.

3.4. *Landsat burn analysis*

INPE obtained and analysed low cloud cover Landsat TM data of Path 232 Row 58 acquired for 1997 and on 11 March 1998. The two TM scenes were georeferenced using ground control points extracted from topographic maps. The TM image of 1997 was analysed to establish the locations of intact forests prior to the fire events of 1998. The 1998 data was analysed to identify three classes of forests: unburnt, partially burnt, and heavily burnt.

The analysis of the 1997 TM image was based on the methodology proposed by Shimabukuro *et al.* (1997) for the PRODES (Estimation of Gross Deforestation of Amazônia) project. Bands 3, 4 and 5 were used as input data for a spectral linear mixing model (Shimabukuro and Smith 1991, Shimabukuro *et al.* 1998), generating three fraction images obtained for land surface pixels: green vegetation, soil and shade. The segmented shade fraction image (similarity and area thresholds of 8 and 25, respectively) was submitted to a non-supervised classification process. The result of image segmentation was inspected visually against a TM colour composite (R5 G4 B3) image and it showed good discrimination of forest and non-forest areas. After the segmentation a non-supervised classification was performed using ISOSEG algorithm with a probability threshold of 95%. The end result was classification map indicating areas with forest and non-forest areas. This was again compared against a colour composite image to visually confirm the accuracy of the forest/non-forest discrimination.

The 1998 TM data were processed with the same spectral mixture analysis tools as the 1997 data, identifying the proportion of green vegetation, soil and shade present in each land surface pixel. The analysis proceeded by inspecting the fraction images for the areas determined to be forest in 1997 against colour composites of the 1997 and 1998 scenes. Of the three spectral mixture components the vegetation component was the most sensitive to the detection of areas affected by the fire in the forest areas. Based on this observation, the vegetation fraction image was segmented, using a combination of similarity and area thresholds of 7 and 25, respectively. The segmented image was then classified using a supervised Bhattacharrya algorithm to identify three forest classes: unburnt, heavily burnt and partially burnt. Heavily burnt forests were identified as areas that were mapped as forests in the 1997 data that had lost nearly all of their green vegetation spectral component in the 1998 data. The implication is that these are forest areas where repeated surface fires have resulted in a nearly complete loss of canopy foliage. Unburnt forests were identified as areas mapped as forest in 1997 that retained high proportions of green vegetation in the 1998 data. Partially burnt forests were defined as an intermediate class, between the heavily burnt and unburnt forest classes. The resulting fire intensity classification derived from the Landsat data was aggregated to a 3 arc second grid ($\sim$100 m pixels).

The Landsat analysis was assisted by the review of flight lines of airborne video data acquired by INPE in May of 1998. Interpretation of the airborne video data was complicated by the regrowth of green leaves in many of the tree canopies in forest areas that were heavily burnt. Evidence for the passage of surface fires in the airborne video data frequently had to be implied by subtle losses of green leaf spectral signature and density of burnt openings and burnt canopies in an otherwise intact forest canopy.

4. Analysis and results

The nightly OLS fire and cloud images were analysed with the intention of developing an estimate of the areal extent of tropical forest burning in 1998 relative to 1995. The nightly fire and cloud images were used to make composites of cloud-free fire detections for the first 3 months of 1995 and 1998 (figure 2). A calibration for estimation of the burnt area based on the frequency of fire observations was developed using the Landsat results. This calibration was then applied to the entire state to identify tropical forest areas that had been affected by fire. These results were used to estimate the cumulative area of tropical forest burning for the entire state and each of the parks and reserves in each of the two years.

Because of the long wavelength of the OLS thermal band (10–12 μm) fires are rarely detected in the thermal band data. With the high sensitivity of OLS low light imaging, fires of subpixel size can saturate the visible band data and are yet undetectable in the thermal band. Due to the lack of multispectral information on fire brightness, it is not possible to estimate the active burnt area on a single night. As a result, indirect methods for estimating burnt area from time series of OLS observations have been investigated. A calibration procedure has been developed for identifying the location and estimating the area of forest burning based on the frequency with which fires were detected during a 3-month time period.

The OLS fire pixel count from 1 January through 11 March 1998 was resampled

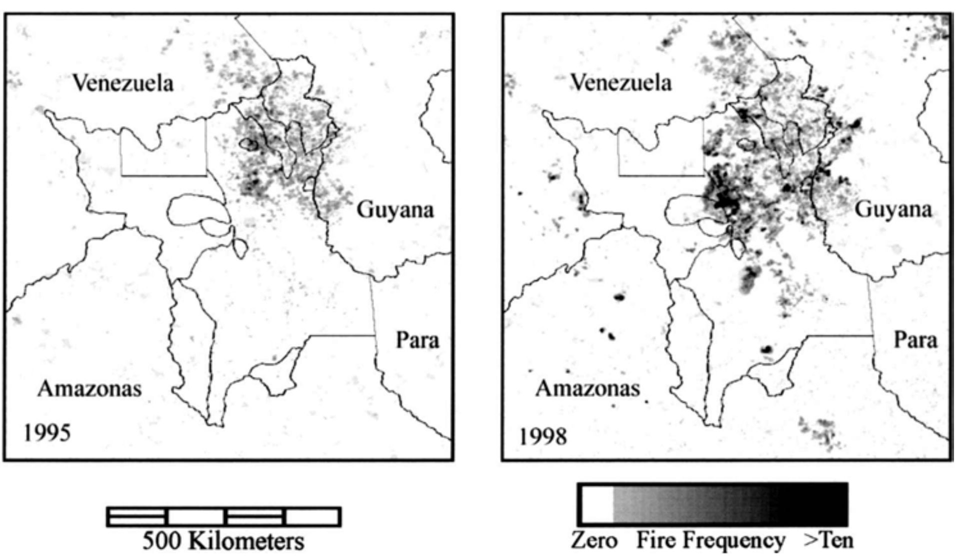

Figure 2. DMSP-OLS fire detection frequency for Roraima during the first 3 months of 1995 and 1998.

to a 3 arc second grid and overlaid this on the Landsat fire intensity classification. A calibration area was selected in the south-west corner of the Landsat scene, covering the core of forest burning observed in the state. Once this overlay was complete the area of the three forest burn classes versus OLS fire detection frequency was plotted. This graph, presented in figure 3, shows the heavily burnt forest class to have higher OLS fire detection frequency than the partially or unburnt forest classes. The curves for partially and unburnt forests show a steady decline as the OLS fire detection frequency increases. For both partially burnt and unburnt forest the area drops approximately by half for each increased step in OLS fire detection frequency. In contrast, the heavily burnt forest area declines gradually as the fire detection frequency moves from one to three. For OLS fire detection frequencies of five to nine the associated area of heavily burnt forests remains at a high and nearly constant level of 145 km^2 before entering a gradual decline from 9 to 18 fire detections.

Figure 3 demonstrates the potential for estimating the area of heavily burnt forest based on OLS fire detection frequency. A calibration was developed to classify pixels as heavily burnt forests if their landcover was mapped as forest and their OLS fire detection frequency during a 3-month period exceeded a specified value. Knowing the total area of heavily burnt forest in the calibration area it would be possible to select a fire frequency threshold that results in a burnt area estimate that closely matches the burnt area derived from the Landsat data. But would there be a correspondence in the identification of specific areas impacted by surface fires between the two systems? That is to say, can the OLS burn frequency be used as a classifier

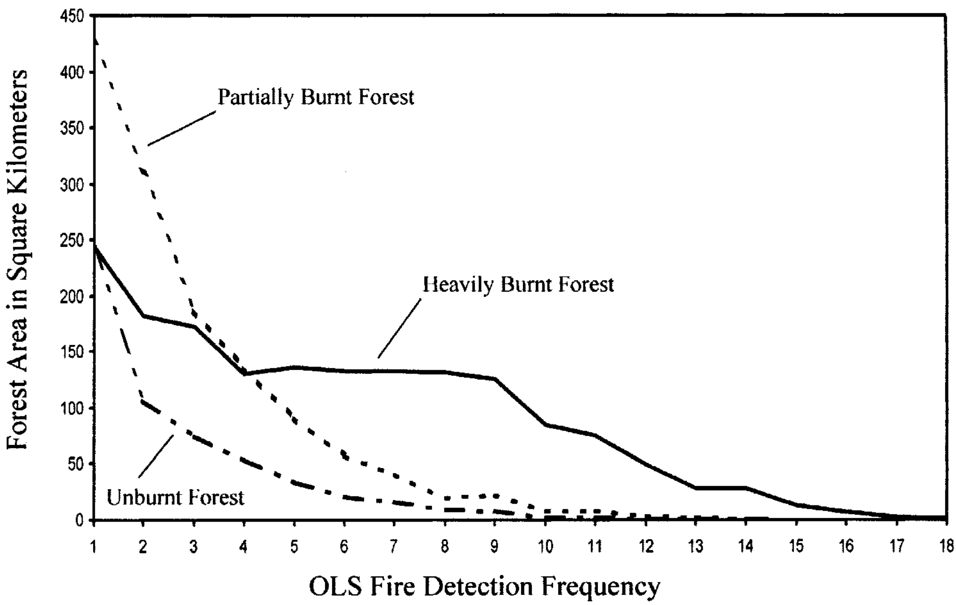

Figure 3. Area of heavily, partially and unburnt forest from 1998 Landsat TM analysis for each OLS fire detection frequency level. Data was generated in a calibration area using OLS fire detection frequency data from 1 January to 11 March 1998 that was coregistered to the 11 March 1998 Landsat TM forest burning classification. The calibration area is in the south-west corner of the Landsat scene which covers the core of the forest burning observable in the scene.

to distinguish between tropical forest areas that were free of surface fire during a burn season and locations where surface fires passed?

As can be seen in figure 3, any threshold that detects a large percentage of the heavily burnt forest area will also detect partially burnt and unburnt forest areas (errors of commission). Setting an OLS fire detection frequency threshold requires the balancing of the correct identification of heavily burnt forest against the errors of omission and commission that would be present at any fixed threshold. It was agreed that detection of partially burnt forest, while not desirable, was not as deleterious as the detection of unburnt forest based on OLS fire detection frequency.

The effect of the frequency threshold on the identification of heavily burnt forests was explored by overlaying images of the Landsat heavily burnt forest class and 10 threshold classes of OLS fire detection frequency in forest areas (figure 4). The 10 OLS cumulative fire detection frequency classes are defined as the set of pixels which had fire frequencies equal to or exceeding the specified number. The images were generated by assigning the heavily burnt forest class to cyan (blue plus green) and the OLS fire detection cumulative frequency class to red. Where the two coincide, the image area is white, indicating the correct identification of heavily burnt forest. Where the OLS fire detection frequency class does not coincide with heavily burnt forest, the image shows red (errors of commission). Where the heavily burnt forest class does not coincide with the OLS fire detection frequency class, the image shows cyan (errors of omission). The first image in the series (upper left) shows the class of reference grid pixels that had one or more OLS fire detections in 1998 up to 11 March. This image shows a core of white in the upper left corner, but large areas of red

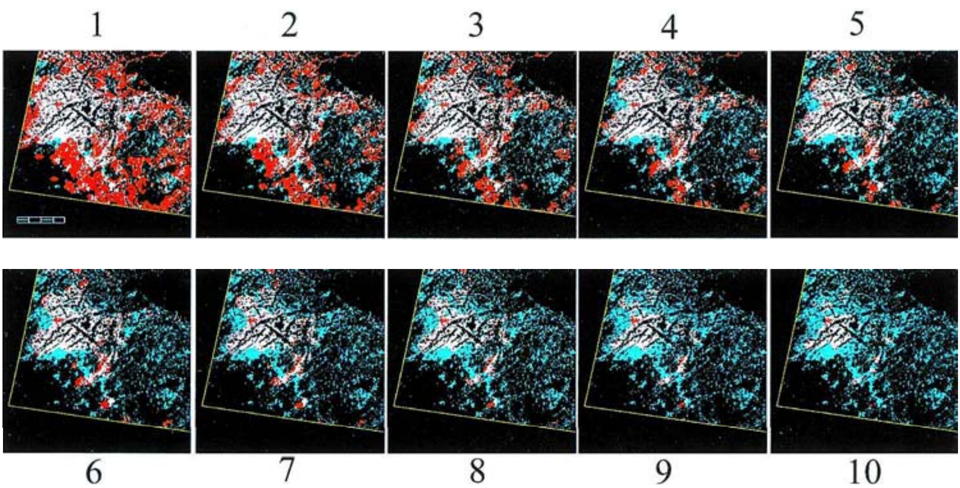

Figure 4. The effect of the frequency threshold on the identification of heavily burnt forest is demonstrated by overlaying images of the Landsat-derived heavily burnt forest class and 10 threshold classes of OLS fire detection frequency in forest areas. The OLS fire frequency classes are defined as the set of pixels which had fire frequencies equal to or exceeding the threshold value. The images were generated by assigning the heavily burnt forest class to cyan (blue plus green) and the OLS fire detection cumulative frequency class to red. Heavily burnt forest areas that were correctly identified by an OLS fire frequency class are white. Red areas are either partially or unburnt forest areas covered by the OLS fire frequency class. Cyan areas are heavily burnt forests that were not covered by the OLS fire frequency class.

extending to other parts of the calibration area. The series of images show the area of red decreasing rapidly as the fire detection frequency used to define the class is stepped to higher levels. The core of white also decreases, but less rapidly. The trade-off for lowered errors of commission is higher errors of omission, indicated by the increase in cyan pixels as the image series progresses to the lower right-hand corner.

The selection of the OLS fire detection frequency threshold was made by constraining errors of commission involving unburnt forests to 10% or less of the total area of unburnt forest in the calibration area, which covers the core of the 1998 forest burning. The cumulative area for each of the three forest fire classes versus OLS fire frequency class is shown in figure 5. By applying the selection criteria to the data in figure 5, an OLS fire detection frequency of five was selected as the heavily burnt forest classification threshold. At this threshold 8.7% of the unburnt forest area and 11.5% of the partially burnt forest area are detected as errors of commission in the calibration area. The area of heavily burnt forest correctly identified with this threshold is 47.7% of the total. The estimated area of heavily burnt forest observed with an OLS fire detection frequency threshold is the sum of the detected areas for the three forest classes. With the selected threshold of five, the estimated area of heavily burnt forest in the calibration area is 1299 km^2 (948 from heavily burnt forest, 254 from partially burnt forest, and 97 from unburnt forest). This is 79% of the actual area of heavily burnt forest in the calibration area, as mapped with Landsat data.

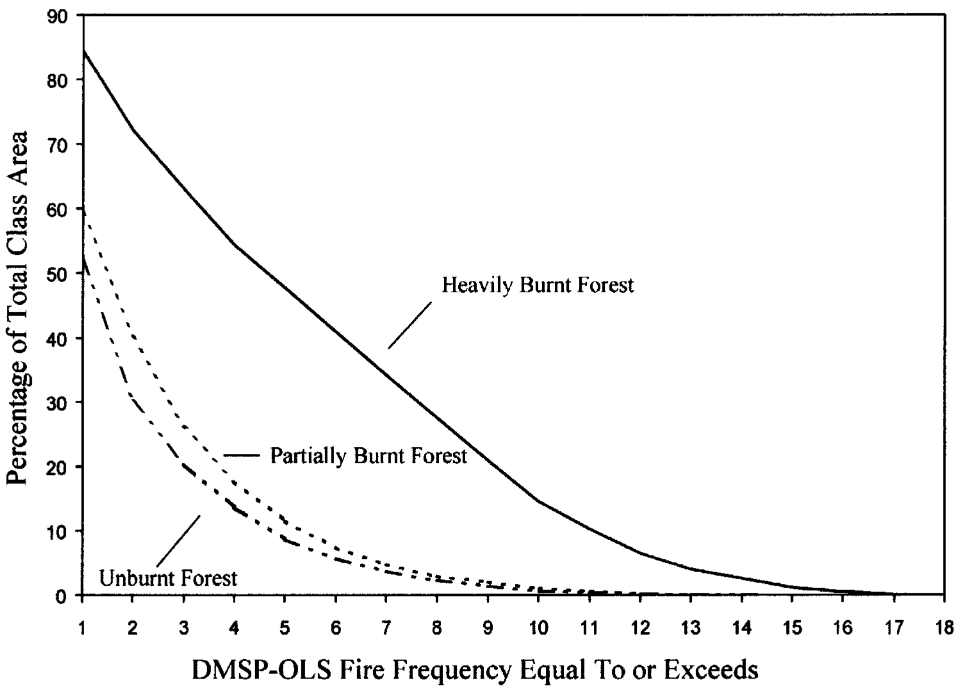

Figure 5. Plot showing the cumulative area of unburnt, partially burnt and heavily burnt forests covered by each of the DMSP-OLS fire frequency classes. In order to satisfy the requirement that the area of unburnt forest errors of commission be 10% or less of the total area of unburnt forest, a fire frequency threshold of five was selected for the identification of heavily burnt forest.

Having developed a calibration between the Landsat and OLS fire detection frequency capable of locating and estimating the cumulative area of heavily burnt forests with a minimal detection of partially burnt and unburnt forests, this was then applied to the entire state for 1995 and 1998 by identifying all forest areas where fires were detected in the OLS grid five or more times. The OLS fire frequency derived image maps of heavily burnt tropical forest for 1995 and 1998 are shown in figure 6. In 1995 the heavily burnt forest area was quite small (425 km^2) and was concentrated in settlement areas. There was a 20-fold increase in the extent of heavily burnt forest in 1998, with an estimated area of 9038 km^2. The 1998 forest burning was primarily concentrated along the fringes of the cerrado zone, with the greatest extension to the west of the cerrado zone located in the north-eastern part of the state.

The estimated area of heavily burnt forest for parks, reserves and indigenous areas for 1995 and 1998 are presented in figure 7. No heavy forest burning was observed in either year the Parque Nacional do Rio Branco and the Área Indígena Waimiri Atroari. For five of the areas (Reserva Florestal Parimã, Parque Indígena Yanomami, Reserva Biológica Mucajaí, Área Indígena Manoa Pium and Estação Ecológica Caracaraí) there was little or no heavy forest burning in 1995 but some level of heavy forest burning in 1998. For three of these areas (Reserva Florestal Parimã, Área Indígena Manoa Pium and Estação Ecológica Caracaraí) the increase appears to have been minor. The most substantial increase in heavy forest burning in 1998 relative to 1995 occurred in the Parque Indígena Yanomami and the Reserva Biológica Mucajaí. In examining figure 6 it can be seen that the increased burning was concentrated in the eastern portion of these two areas. The indigenous areas in the north-eastern part of the state, where tropical forests are mixed with cerrado (Área Indígena Araca, Área Indígena San Marcos and Área Indígena Raposa do Sol) all sustained an increase in heavy forest burning in 1998 relative to 1995. These three areas appear to be prone to sustain some level of forest burning each year due to the mixture of forest with cerrado. On a statewide basis the fires in both years were concentrated outside of the state's parks, reserves and indigenous areas. In 1998, 77% of the heavy forest burning was outside of the protected areas. During 1995 63% of the heavy forest burning was outside of the protected areas.

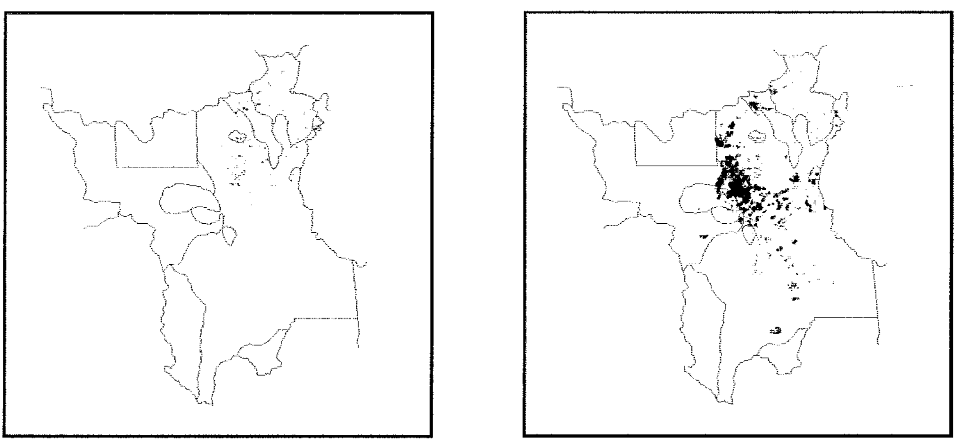

Figure 6. Distribution of heavily burnt forest in Roraima from 1995 and 1998 based on a DMSP-OLS fire detection frequency of five or greater during the January through March time period.

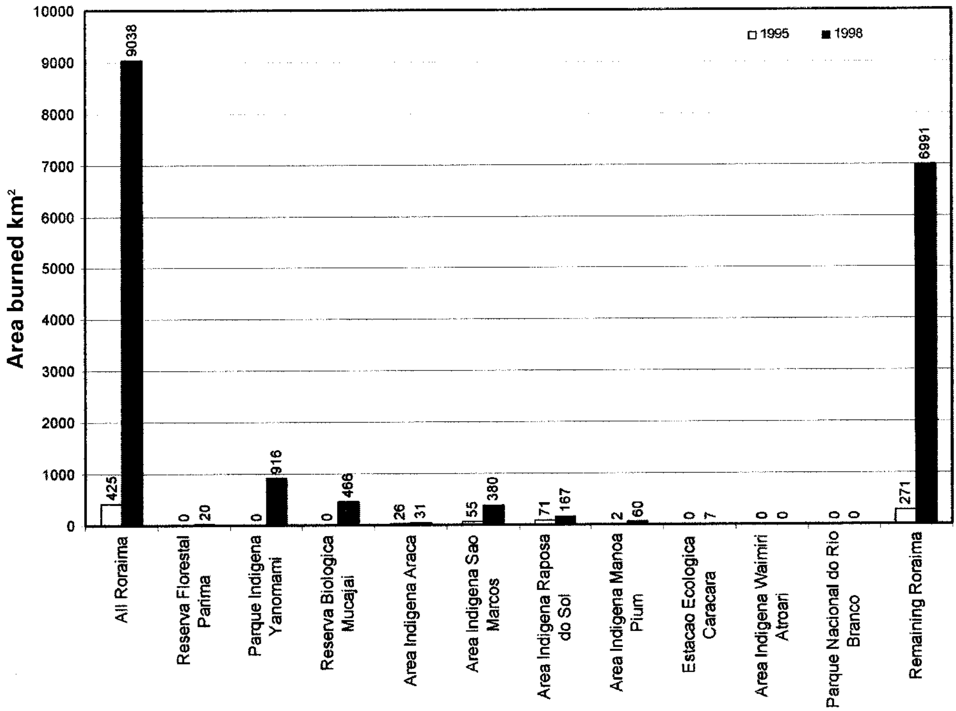

Figure 7. DMSP-OLS estimated area of heavy forest burning statewide and for each of the protected areas during 1995 and 1998.

5. Conclusion

A methodology has been developed to locate and estimate the area of heavy forest burning based on the frequency of DMSP-OLS fire detection from a time series of observations across the fire season. This calibration was developed using Landsat TM data acquired near the end of the 1998 burn season and analysed to identify unburnt, partially burnt and heavily burnt forest areas. A fire frequency threshold of five nights or greater was used to map heavily burnt forest using the 3 months of DMSP-OLS fire observations from 1995 and 1998. The threshold of five fire detections was selected to constrain errors of commission involving unburnt forest to 10% of the total area for unburnt forest in the calibration area. Recognizing that the fire frequency associated with heavy forest burning varies with forest type and species composition, we have set the threshold high to avoid overestimation of burn area. For the calibration area, centred on an area of intense forest burning in 1998, the method underestimates the area of heavy forest burning by 21%.

Based on DMSP-OLS fire frequency we estimate the area of heavily burnt forest in Roraima during 1998 to be 9038 km^2. This represents a 20-fold increase over the estimate of heavily burnt forest in the state for the year 1995. The DMSP estimate of heavily burnt forest area is 77% of the statewide estimates made by INPE using Landsat and airborne video data (11 730 km^2). The Instituto Nacional de Pesquisas da Amazônia (INPA) estimated the area of heavily burnt forest in Roraima for 1998 to be 13 000 km^2 based on airborne missions and intensive field work. The DMSP-OLS estimate is intentionally set to yield conservative estimates of forest burn area to avoid overestimation.

It was found that 77% of the 1998 heavily burnt forest area was outside of the state's protected areas (national parks, reserves, indigenous areas). Two of the protected areas sustained a substantial increase in heavily burnt forest in 1998 relative to 1995 (Reserva Biológica Mucajaí and Parque Indígena Yanomami). The 1998 forest burning in these two areas was concentrated in their eastern-most sections. The core of the Yanomami area did not sustain extensive burning in 1998. Protected areas in the north-eastern quarter of the state, where forests are mixed with cerrado, experienced moderate increases in heavily burnt forest in 1998. Other protected areas were largely free of the heavy forest burning, which was concentrated to the west of the Roraima's primary cerrado zone.

Errors of commission for unburnt forest being identified as heavily burnt amounted to 8.7% of the TM identified unburnt forest in the calibration area. When our DMSP fire frequency procedure was applied to the entire state, large areas of forest were identified with very low fire frequencies. For instance, only 0.2% of the combined 45 370 km^2 of forest in the Reserva Forestal Parimã, Área Indígena Araracá, Mandapium, Waimiri Atroari and Parque Nacional do Rio Branco were identified as heavily burnt in 1998 based on DMSP fire frequency. This suggests that the 8.7% error of commission for unburnt forest in the calibration area is a substantial overestimation of the techniques errors when applied across large regions.

The primary factor contributing to the misidentification of unburnt forest as heavily burnt in the calibration area is the large disparity in the size of the OLS and Landsat TM pixel footprints on the Earth's surface. The OLS pixel footprints are approximately 1000 times larger than the TM pixels. Because OLS is capable of detecting fires which are much smaller than the pixel size, there is an in-built tendency to overestimate burn area. Based on this argument errors of commission on the order of 5–10% can be expected when fire activity is high.

Despite these uncertainties, direct comparison of OLS fire detection frequency in early 1998 with a map of burnt forest from Landsat TM data reveals a substantial level of agreement. At the scale of a Landsat scene there is a close correspondence between the cumulative area estimates of the area for unburnt, partially burnt, and heavily burnt tropical forest from Landsat multispectral data and OLS fire frequency. When used as a classifier, OLS fire frequency produces forest burn classes that have a general correspondence to Landsat results. The Landsat classes tend to be fragmented while the OLS classes tend to be more contiguous. This can be partially explained by the different spatial resolution of the two sensors. Another factor which probably contributed to the fragmented versus continuous nature of the classification results may be explained by the differences in the observations made by the two systems. The OLS is making a direct observation of the radiant energy emitted from the fires with more than 80 nights of observations contributing to the fire frequency results. The Landsat classification is based on the spectral evidence of the fire impacts, expressed primarily as a decline in the green vegetation spectral signature of tropical forest canopies.

Our results indicate that the DMSP-OLS is capable of detecting surface fires at night in tropical forests. These surface fires rarely move in to the upper levels of the forest canopy and as a result much of the radiant energy from the fires is absorbed by the canopy and forest structural elements. Only a fraction of the fire's total radiance is transmitted up through the canopy towards space. Because of the obscuration of the fires by the forest canopy, the satellite detection of surface fires in tropical forests is a challenging observation. The detection of the surface fires with OLS data demonstrates the value of DMSP data for fire detection in tropical forests. This is particularly significant because night-time fires are those that are out of control and most likely to persist over many days.

Acknowledgment

The authors appreciate the DMSP program office and the US Air Force Weather Agency for providing NOAA-NGDC with DMSP data used in this research. This research was sponsored in part by the US Agency for International Development. The views and opinions expressed are solely the author's and do not necessarily represent those of the US Department of State.

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