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Cover

Monitoring biomass burning in the Brazilian Amazônia

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1. Introduction

Biomass burning ('*queimadas*' in Portuguese) is a traditional/cultural practice among Brazilian farmers for clearing deforested areas, preventing vegetation regrowth, or 'renewing' pastures. The Brazilian Indians already used a similar practice of burning the land to plant cassava. The *queimadas* mostly occur in the domains of the savannah-like vegetation known as '*cerrado*' in central Brazil, and in the Amazonian rainforest. In the *cerrado* they are independent of previous deforestation or slashing, but in the Amazônia they occur mainly in previously deforested areas. Some weeks after the forest has been cut, the dried biomass is burned. The terrain cleared in this way is ready to be sown. The *queimadas* occur annually during the peak of the dry season (mid-August/mid-September), just before the first summer rains. This practice is repeated in the subsequent years in areas already deforested to eliminate large trunks that still remain on the ground and/or to prevent vegetation regrowth.

The region legally defined as the Brazilian Amazônia embraces an area of approximately 5 M km^2, larger than the whole of Western Europe. Based on the analysis of Landsat images, the National Institute for Space Research (INPE) has been monitoring anthropogenic activities associated with the development of agriculture and cattle raising in this huge territory. Estimates of the gross deforestation indicate that by 1999 approximately 570 000 km^2 of forests had been converted into cultivated land, an area nearly equivalent to the sum of the French and Belgium territories. Over this period, the gross deforestation has increased by an annual mean rate of 0.44%. After 1993, this mean reached 0.53%, probably as a consequence of price stabilization promoted by the new Real currency (figure 1).

An increase in the deforestation rate implies an increase in biomass burning and consequently an increase in atmospheric pollution. The *queimadas* produce several atmospheric gases as carbon monoxide (CO), an air pollutant that generates ozone, a greenhouse gas. A global observation of the atmospheric carbon monoxide during the year 2000 was conducted by the United States National Center for Atmospheric Research (NCAR) using the MOPITT (Measurements Of Pollution In The Troposphere) instrument, on board the Terra spacecraft (NASA/GSFC 2002). One

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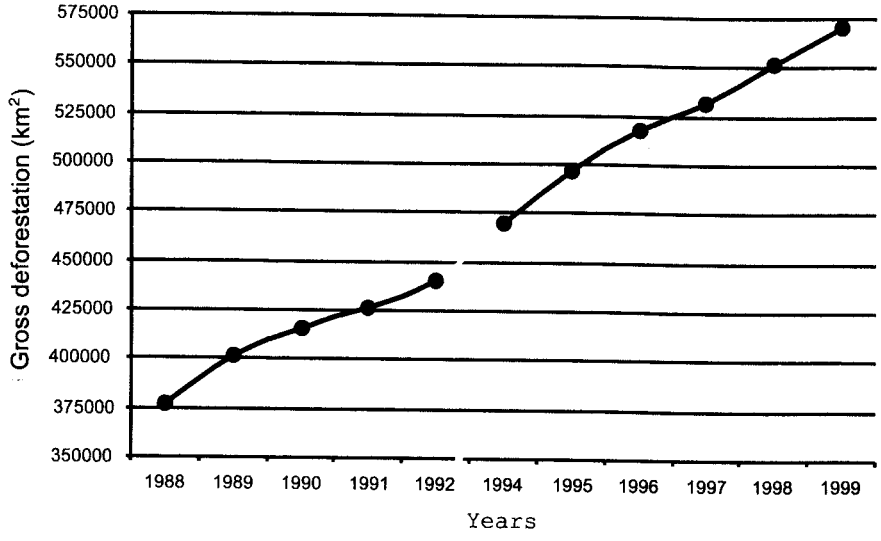

Figure 1. Extent of the gross deforestation (km^2) from 1988 to 1999 (source: INPE 2001).

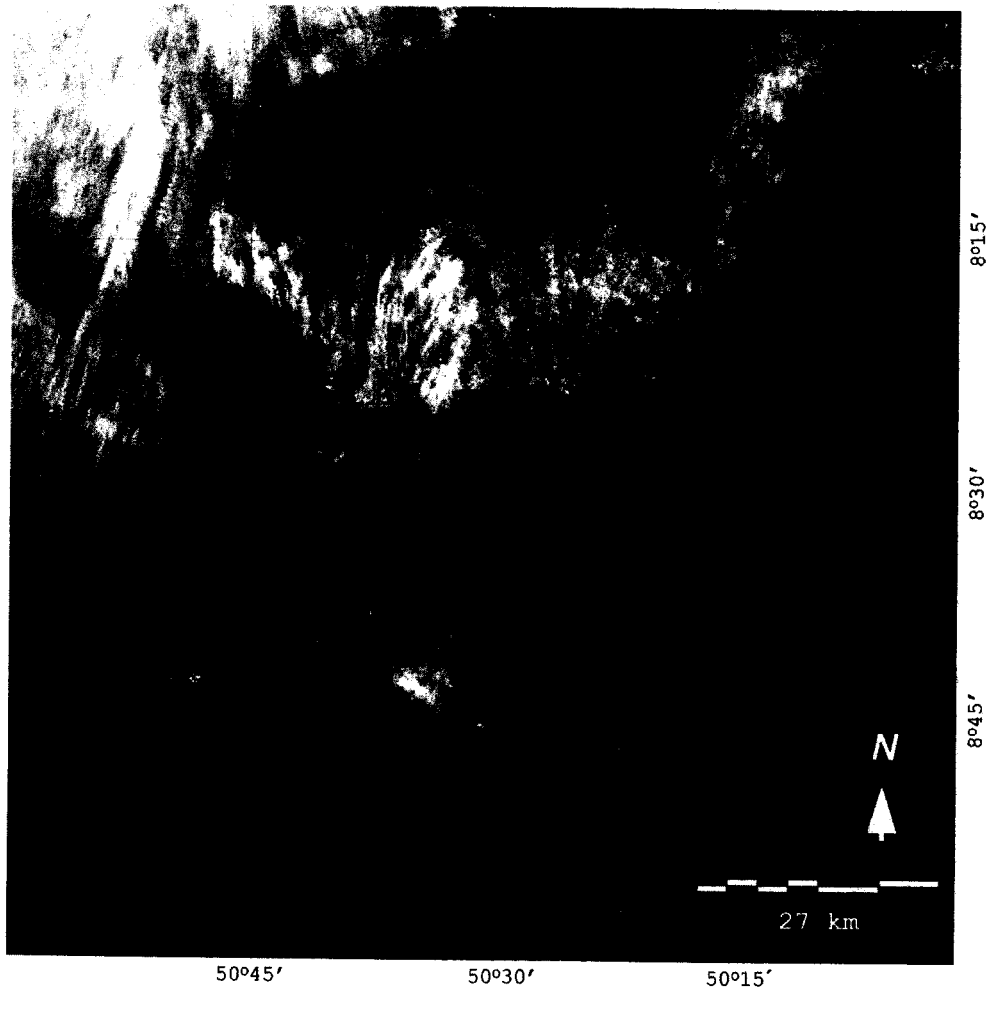

Figure 2. During the period of the fires in the Amazônia, the sky is covered by a thick, greyish layer of smoke, as indicated by Landsat TM band 1, acquired on 15 August 1994.

of the world largest plumes of carbon monoxide emitted from biomass burning was identified over the Amazônia during September/October. The concentration of carbon monoxide from about 220 to about 390 parts per billion was approximately 8 times higher compared with areas with low concentration. The impact of the *queimadas* goes beyond the destruction of the vegetation and atmospheric pollution. They affect the local ecological balance by wiping out small animals like insects, birds, snakes, etc.

During the period of the *queimadas* in the Amazônia, the sky in the region remains obscured by a thick, greyish layer of smoke. The littered sky sometimes results in airports having to cancel flights due to the poor visibility caused by a pall of smoke, as indicated in the Landsat Thematic Mapper (TM) band 1 (figure 2 and cover).

2. *Queimadas* in Landsat TM images

Landsat TM images acquired during the dry season in the Amazônia generally show a number of fire scars in cultivated lands, as in the colour composite (TM5 (R)+TM4 (G)+TM1 (B)) acquired on 15 August 1994 (figure 3). This area of approximately 11 084 km^2, between 50°–51° W and 8°–9° S, is located on the border

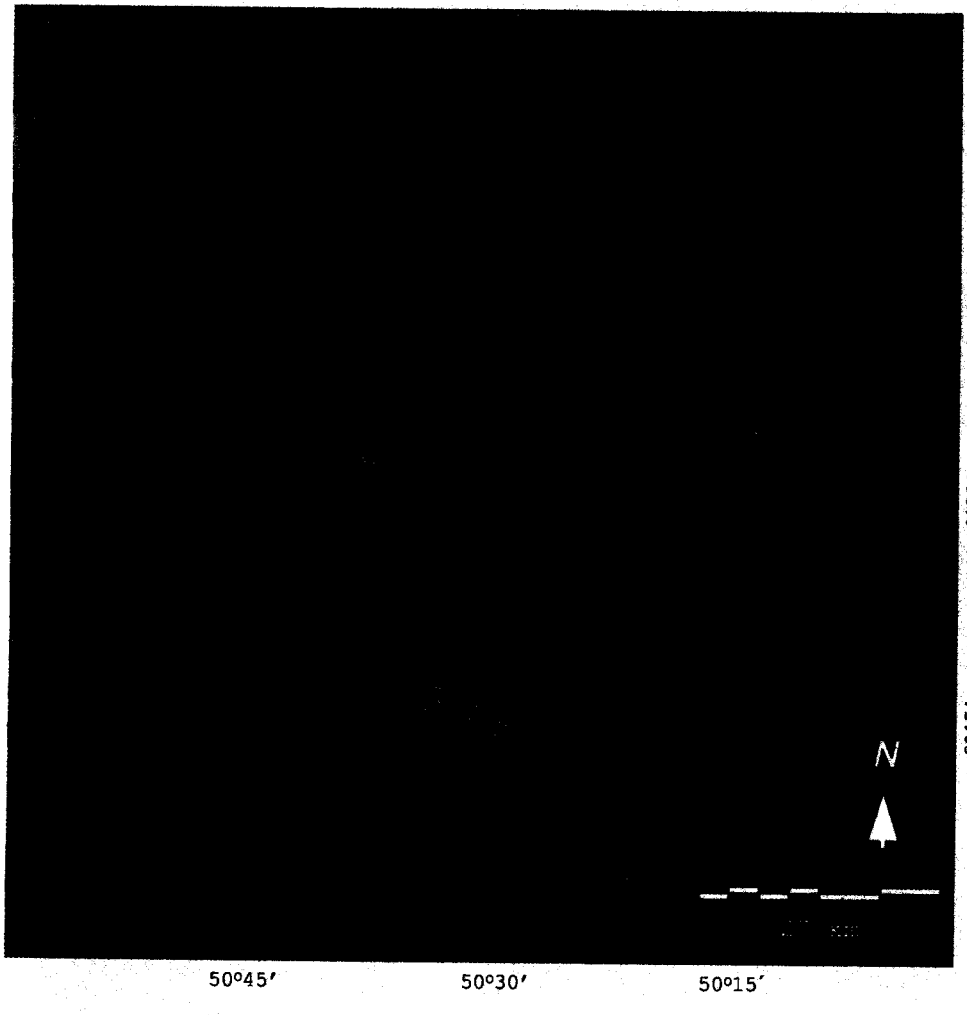

Figure 3. Landsat TM colour composite acquired on 15 August 1994. Tropical rainforest appears as hues of green, cultivated lands as hues of magenta, and *queimadas* as dark shades. Circles indicate fire fronts in cultivated lands (yellow) and in the domain of the rainforest (red).

of the states of Mato Grosso and Pará, one of the most critical regions of *queimadas* in the Amazônia. In the colour composite, tropical rainforest (hues of green) occupy approximately 7169 km^2, cultivated lands (hues of magenta) approximately 3915 km^2, and burned areas (dark shades), approximately 745 km^2. Smoke plumes and saturated pixels in TM bands 5, 6 and 7 allow us to distinguish between fire scar areas and fire fronts. Eighteen fire fronts were identified in figure 3 (yellow circles), which are mostly restricted to previously clear-cut areas. Only in one place does fire seem to invade the domain of the rainforest (red circle).

The comparison of figure 3 with figures 4 and 5 help us to verify the dynamic of the burning activity in the region. Landsat TM band 4 acquired on 30 July 1994 (figure 4) shows few fire scars (arrows), comprising approximately 41 km^2. Figure 5 shows Landsat TM band 4 acquired on 2 October 1994 in the initial stage of the fire scar regeneration after the first summer rains. This scene indicates that practically all the cultivated lands were burned over a period of approximately 2 months. The *queimadas* were favoured by the climate dryness during the period when these images were acquired. The total precipitation in the region over 1994 was 1718 mm, with only 37 mm from May to August and 78 mm in September.

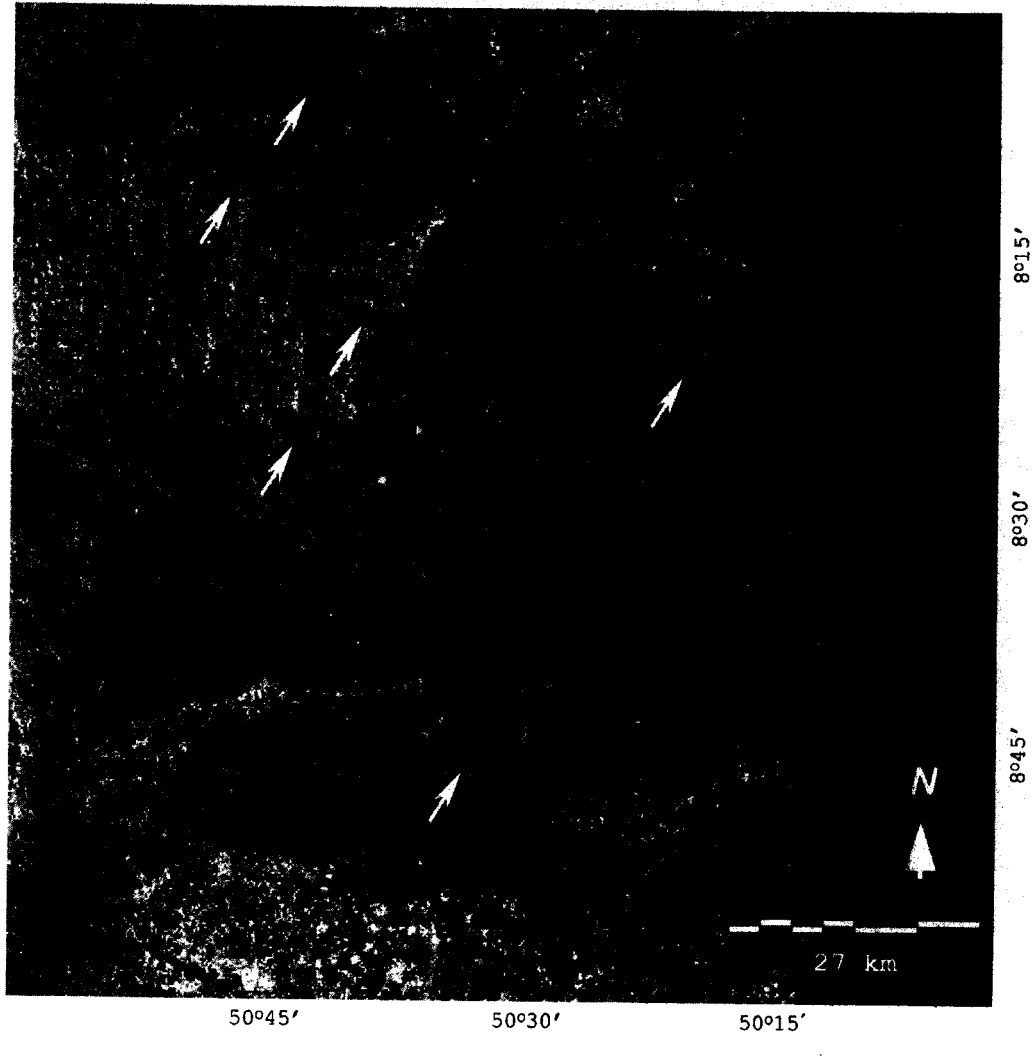

Figure 4. Landsat TM band 4 acquired on 30 July 1994 with the few fire scars (~41 km^2) indicated in dark shades (arrows).

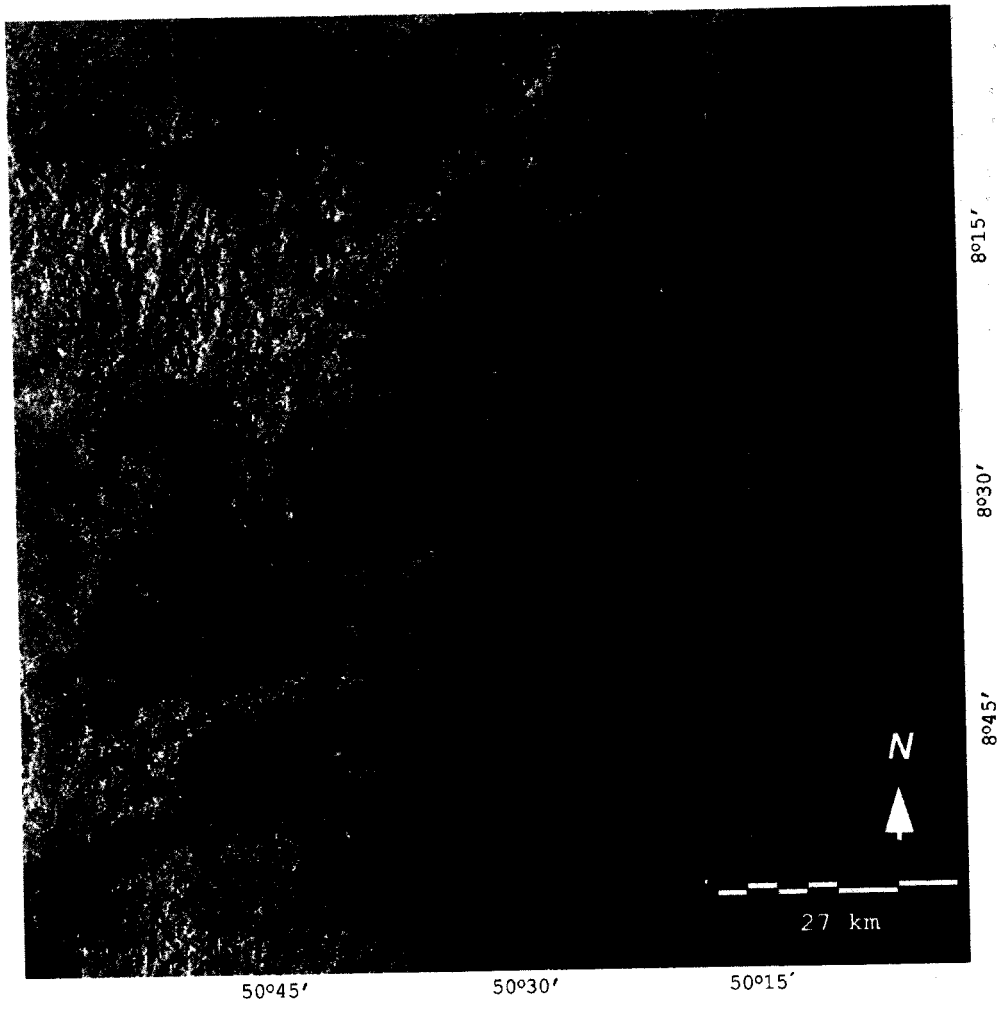

Figure 5. Landsat TM band 4 acquired on 2 October 1994 after the first summer rains. The scene indicates that practically all of the cultivated lands in this area ($\sim$3915 km^2) were burned during a period of approximately 2 months.

3. An operational system for monitoring biomass burning at Amazonian scale

Orbital remote sensing is the only effective means of surveillance for a large-scale operational programme for *queimadas* monitoring. Setzer *et al.* (1994) stressed the limitations in using the data from the Landsat TM and NOAA AVHRR (National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer) satellites on an operational basis to detect, map and monitor forest and grassland fires at an Amazonian scale. Landsat TM images provide a precise estimation of burned areas, but the low revisiting capability combined with frequent cloud cover restrict their use. Additionally, it would require a long time for mosaicing a great number of scenes. The daily coverage of the NOAA AVHRR system enables real-time operation for fire spot detection, but its low spatial resolution limits the estimation of the extent of the burned areas. Due to similar reasons, systems like MODIS (Moderate-resolution Imaging Spectroradiometer) and MISR (Multi-angle Imaging Spectro-Radiometer), on board the Terra spacecraft, do not produce adequate results.

An operational programme for detecting, mapping and monitoring *queimadas* at an Amazonian scale would not require a sophisticated orbital remote sensing payload. Such a system could be configured with an approximately 1500 km swath,

a 1–2-day revisiting capability, an approximately 250 m nominal resolution at nadir, and four spectral bands: green (0.55 μm), red (0.66 μm), near-infrared (0.80 μm), and middle infrared/thermal (3.75 μm) in a 12-bit quantization. Visible/near-infrared colour composites would provide synoptic views to calculate the extention of the burned areas, whereas the thermal band would detect the fire spots at a daytime/night-time frequency.

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