SHORT COMMUNICATIONS

Intensive Forest Clearing in Rondonia, Brazil, as Detected by Satellite Remote Sensing

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Imagery from the National Oceanic and Atmospheric Administration satellite's Advanced Very High Resolution Radiometer sensor has been used to identify an area about 100 × 400 km in Rondonia (Brazil) where massive forest clearing or deforestation is occurring. A field study verified the area of the clearing, which is associated with a large colonization program.

Introduction

The tropical forest biome is the most diverse in number of species or in germplasm, is among the most productive in terms of net primary production, contains the greatest biotic carbon reservoir, and remains one of the least well-known aspects of the Earth's surface. Taxonomists have identified one-half million of the several million species that live in this biome (Meyers, 1980). Unfortunately, clearing of tropical forests threatens extinction of species on a scale probably unprecedented in the Earth's recent history. The Amazon Basin of South America makes up about 66% of the area of the remaining tropical forests. Within the greater Amazon Basin attention has focused upon the Brazilian portion because it is the largest political unit. Tropical forests in the Brazilian Amazon Basin cover 5,000,000 km^2, of which about half is tropical moist forests and half, tropical seasonal forests (Fearnside, 1982).

The extent and rate of forest clearing in the Amazon Basin are the subjects of continuing controversy. Estimates of the cumulative area cleared range from about 72,000 km^2 for the total Amazon Basin through 1978 (Tardin et al., 1978; 1979; 1980) to 260,000 km^2 for the rain forest portion of the Amazon through 1979 (Meyers, 1980; Sioli, 1980). The rate of forest clearing in the total Amazon Basin has been estimated to be as low as 10,000 km^2/year and as high as 100,000 km^2/year (Meyers, 1980; Muthoo, 1977). The lack of any systematic data on the subject has hampered discussion of what many scientists feel to be a major ecological crisis with serious biological, climatic, and political ramifications. One possible means of collecting these data is satellite remote sensing.

Heretofore, the majority of satellite remote-sensing studies of the terrestrial surface have used the Landsat satellites. The Landsat multispectral scanner (MSS) with its four reflective channels, 18-day repeat cycle, 80-m spatial resolution, and 185-km image swath has been used to monitor tropical forests (Williams and Miller, 1979). However, certain features

0034-4257/84/$3.00

of the Landsat MSS are not well suited for accurate assessment of forest clearing. There is difficulty, for example, in distinguishing regrowing cleared areas from undisturbed tropical forests. This difficulty results from the spectral configuration of the Landsat MSS and the sensitivity of this sensor system to green leaf biomass and *not* total standing biomass (Tucker et al., 1981). Thus, a regrowing cleared area with a dry leaf biomass of 400 g/m^2 and a total dry biomass of 1000 g/m^2 can be spectrally identical in the Landsat MSS bands to a virgin tropical forest with a dry leaf biomass of 400 g/m^2 and a total dry biomass of 40,000 g/m^2. This criticism has been raised by Fearnside (1982) in reference to Landsat MSS assessments of Amazon clearing by INPE, the Brazilian National Institute for Space Research (Tardin et al., 1978; 1979; 1980). We now report on a study, covering part of the southern Amazon Basin, that has used data from the advanced very high resolution radiometer (AVHRR) on the National Oceanic and Atmospheric Administration's seventh satellite in the TIROS-N series of near-polar-orbiting, sunsynchronous environmental satellites (NOAA-7).

Approach

NOAA-7 has a mean orbital period of 9.2 days, overpass times of 0230/1430 h local solar time, 1024 quantizing levels, a ±56° field of view, an image swath of about 2700 km, and spatial resolution at nadir of 1.1 km. The AVHRR has five spectral channels: 0.55–0.68 μm (channel 1); 0.73–1.1 μm (channel 2); 3.5–3.9 μm (channel 3); 10.5–11.5 μm (chananel 4); and 11.5–12.5 μm (channel 5) (Kidwell, 1979). The first two AVHRR channels are spectrally similar to Landsat MSS channels 5 and 7, respectively, and both instruments are thus able to monitor the green leaf biomass of plant canopies (Tucker et al., 1981). For vegetated targets, channel 1 is sensitive to *in situ* chlorophyll while channel 2 is sensitive to the green leaf biomass (Tucker, 1978). Channel 3 is sensitive to a combination of reflected and emitted radiation while channels 4 and 5 are sensitive to only emitted or thermal radiation from the target (Matson and Dozier, 1981; Weinreb and Hill, 1980). The outstanding characteristic of data from the NOAA satellites is high frequency of observation; nearly worldwide AVHRR imagery is available daily. In practice, however, more useful data for a given target can be obtained 2–3 days out of every 9 because of the difficulties in using data with extreme look angles.

We obtained NOAA-7 AVHRR data at 9-day intervals from May to September 1982 over the general area of long. 50°W–65°W between lat. 15°S and 5°N, with particular emphasis on the state of Rondonia, Brazil. Rondonia has been reported to be experiencing the most rapid rate of forest clearing in the Amazon Basin (Table 1). One image from 9 July 1982 that was largely cloud-free over Rondonia was processed on the NASA/Goddard Sensor Evaluation Branch's Hewlett-Packard 1000 image processing computer system. Data from all five AVHRR channels were mapped to a Mercator projection.

Results and Discussion

Inspection of the channel 3 image indicated a series of linear features of higher spectral return radiating from highway

TABLE 1 Clearing in the Amazon Basin

State or Territory[a]	Total (km²)	Observed Cummulative Cleared Areas (km²)		Rate of Increase, 1975–1978(%)
		1975	1978	
Amapa	139,068	153	171	12
Para	1,227,530	8,654	22,445	159
Roraima	243,004	55	144	162
Maranhao	257,451	2,905	7,334	152
Goias	285,793	3,307	10,289	211
Acre	152,589	1,166	2,465	111
Rondonia	230,104	1,217	4,185	244
Mato Grosso	881,001	10,124	28,255	179
Amazonas	1,558,987	780	1,786	129
Total	4,975,527	28,361	77,074	

Source: Tardin et al. (1978; 1979; 1980) as cited by Fearnside (1982).
[a]States not totally within the Legal Amazon included are: Goias north of lat. 13°S and Maranhao west of long. 44°W.

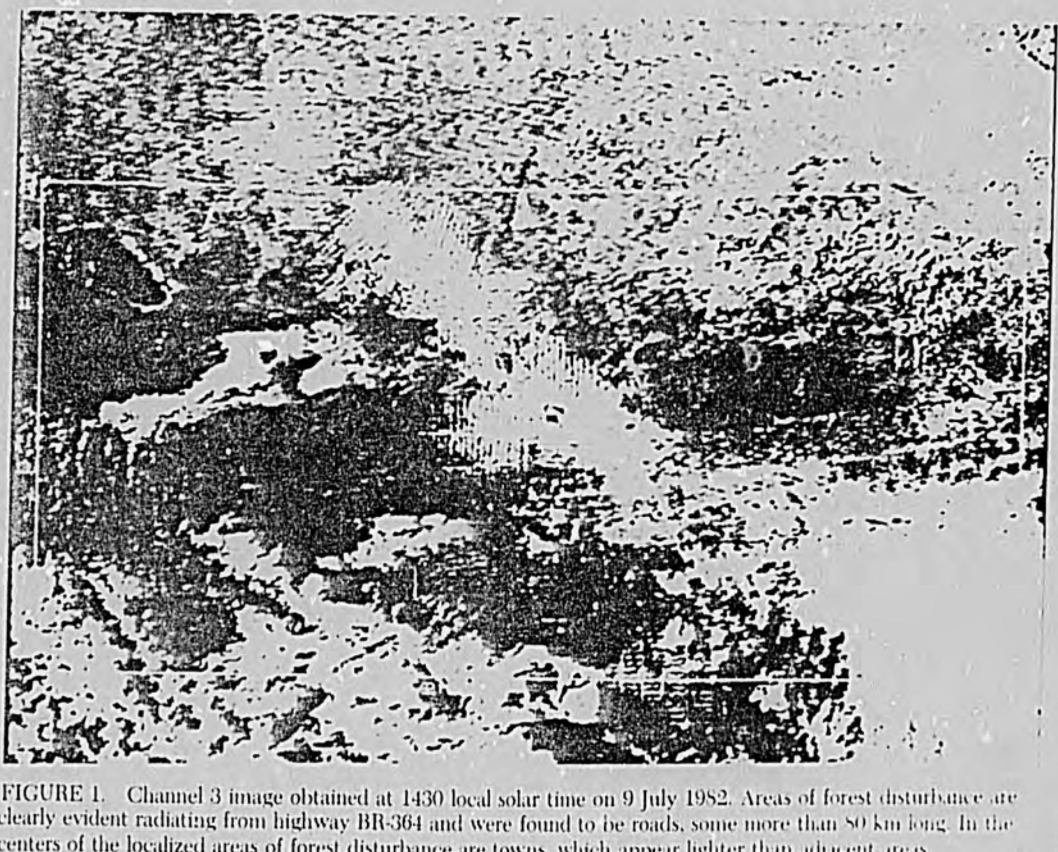

FIGURE 1. Channel 3 image obtained at 1430 local solar time on 9 July 1982. Areas of forest disturbance are clearly evident radiating from highway BR-364 and were found to be roads, some more than 80 km long. In the centers of the localized areas of forest disturbance are towns, which appear lighter than adjacent areas.

TABLE 2 Mean Digital Counts (Possible Range: 0–1,023) for Virgin Forest and Disturbed Areas from 9 July 1982 Image from Rondonia.[a]

			Digital Counts		
			Disturbed Areas		
Spectral Channel	Wavelength Interval (μm)	Virgin Forest (188 pixels)	Ouro Preto (457 pixels)	Ji-Parana (135 pixels)	Colorado (257 pixels)
1	0.55–0.68	28 (0.88)	39 (2.73)	46 (5.94)	37 (3.22)
2	0.73–1.1	91 (1.59)	97 (3.51)	96 (3.87)	88 (1.94)
3	3.5–3.9	820 (2.39)	850 (12.23)	886 (22.58)	861 (23.87)
4	10.5–11.5	811 (1.31)	822 (5.67)	846 (11.33)	826 (10.97)
5	11.5–12.5	805 (1.82)	810 (4.78)	833 (10.[illegible])	812 (9.09)

[a]The means, pixel sample number, and variances (in parentheses) are also given. Note the greatest contrast in channel 3.

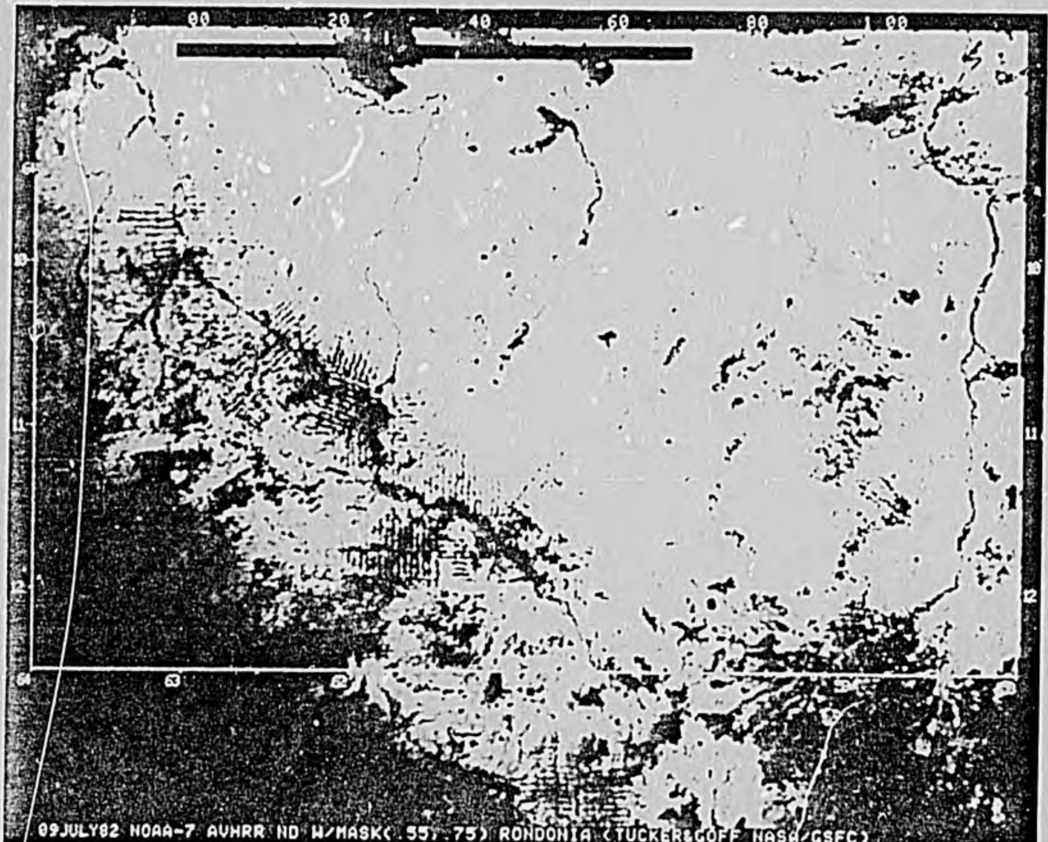

FIGURE 2. Display of normalized difference calculated as [(0.73–1.1 μm) – (0.55–0.68 μm)]/[(0.73–1.1 μm) + (0.55–0.68 μm)] from the 9 July 1982, data obtained at 1430 h local solar time over Rondonia. The normalized difference is directly correlated to the green leaf density or green leaf biomass. The white color represents high green leaf biomass areas and the dark areas no green leaf biomass (i.e., clouds, water, and cleared areas. This image has been stretched to maximize the contrast for the normalized difference between the deforested and adjacent forested areas (See also Fig. 1).

BR-364 in Rondonia between the towns of Ariquemes in the north and Pimenta Bueno to the south. Additional linear areas of higher spectral return were apparent Vilhena near the Bolivian border (Fig. 1). We interpreted these features to be a large-scale, systematic forest disturbance because of their regularity and close association with highway BR-364. Digital count differences between virgin forests and the areas of forest disturbance were found to average 46 counts for channel 3, 20 counts for channel 4, 13 counts for channels 1 and 5, and 3 counts for channel 2 (Table 2). The physical reason for the high sensitivity of channel 3 to the forest disturbance is not well understood. However, we suggest that it is related to the sensor's unique response to emitted and reflected energy. The linear forest-disturbance features were apparent in some areas but not in others when the normalized-difference measure for green leaf density was calculated as [(0.73–1.1 μm) − (0.55–0.68 μm)]/[(0.73 + 1.1 μm) + (0.55–0.68 μm)] and displayed (Fig. 2).

A field verification mission was undertaken in September 1982. Site visits were made at numerous locations along highway BR-364 between Porto Velho and Pimenta Bueno, where the linear forest-disturbance features were found to be forest-clearing swaths some more than 80 km long, about 4 km apart, and ~600–800 m wide (Fig. 3). The large-scale primary forest disturbance apparent in Fig. 1 is a government-planned colonization project in which immigrants to Rondonia are sold 100-ha (500- × 2000-m) lots of forest to use for agriculture or pasture. Each lot has about 500 m of road frontage. Clearing on a lot begins nearest the access road, then gradually moves away as the farmer clears more land to

FIGURE 3. Photograph taken in one of the cleared areas apparent in Fig. 1. These areas are approximately 600–800 m wide and can extend upwards of 80 km in length.

maintain or increase agricultural production and to reach soil not yet depleted of nutrients (World Bank, 1981). Currently, the colonization project comprises wide areas of agriculture and pasture adjacent to the access roads, with relatively narrow strips of primary forest between. This pattern accounts for the light and dark parallel lines apparent in the grids of Fig. 1.

Economical crop production on a given lot is usually limited to 1–4 years because of plant diseases, decreasing soil fertility, and the prohibitively high cost of chemical fertilizers (Wambeke, 1978). This land obsolescence is compensated for by clearing more of the primary forest. The rate of forest clearing is increasing as new settlers arrive and new colonization projects are begun to accommodate them. The paving of highway BR-364, under funding by the World Bank and due for completion sometime in 1984, is expected to facilitate immigration and enlarge the markets for the agricultural and forest products, thereby increasing the pressure for forest clearing.

Estimates of forest clearing in Rondonia are few. Inspection of the 1972–1973 radar imagery for Rondonia at a scale of 1:250,000 showed only minor and scattered forest disturbance along BR-364 (RADAMBRAZIL, 1978; Tucker et al., 1983). More recent (11 November 1981) radar imagery from the space shuttle Columbia imaging radar indicated an area of forest-clearing roads adjacent to the Rio Guapare at about long. 62°10′W, lat. 12°30′S (Tucker et al., 1983). Estimates of primary forest clearing for Rondonia in 1975 and 1978 indicated that 1200 km^2 and 4200 km^2, respectively, had been cleared, an increase of 3000 km^2 in the 3 years (Table 1). After a series of classifications, our data of 9 July 1982 indicated that as a most conservative estimate about 9200 km^2 was cleared in the areas adjacent to BR-364. We conclude that previous estimates of the cumulative forest clearing in Rondonia have been conservative and that forest clearing is accelerating along BR-364 and will probably increase further with the paving of this highway.

This area in Rondonia presents an ideal opportunity for testing remote-sensing techniques for monitoring tropical forest clearing. We believe that a combination of coarse-resolution off-nadir viewing satellites for large area survey, finer spatial resolution sensor systems for more detailed studies, and radar systems would offer a logical multilevel link to the "ground truth" data necessary for accurately assessing tropical forest clearing. It is only by collection of these data that the rate of tropical deforestation can be accurately determined.

We thank G. Woodwell, T. Stone, D. Williams, and J. Otterman for suggestions on the manuscript.

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6

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Received 7 April 1983; revised 19 July 1983