The large territorial extension of Brazil (8.5 million square kilometers) makes remote sensing technology an important tool for monitoring the Brazilian natural resources. A research history has shown the application of satellite data for studying vegetation cover, primarily in a regional level, using MSS and TM/LANDSAT and more recently HRV/SPOT data. It is well known that the detailed knowledge of the geographic and seasonal patterns of terrestrial vegetation is a necessary factor to understand global climate, biospheric productivity and human impact on the environment. Currently, there are several data collection platforms with sensors of different spatial, spectral, and temporal characteristics which are very useful to study vegetation cover. The AVHRR/NOAA, for instance, having much less spatial detail than LANDSAT sensors but providing daily worldwide data collection shows the great potential for monitoring global vegetation and its dynamic. On the other hand, data provided by LANDSAT and SPOT sensors have been used for regional studies. The objective of this research is to present the potentialities of multi-sensors (AVHRR/NOAA, MSS and TM/LANDSAT and HRV/SPOT) for monitoring vegetation of Brazil. The results of the analysed procedures have shown the potential of multi-sensors for mapping, estimation of biomass, and phenology conditions of the vegetation and the human impact on the environment (deforestation, biomass burning, etc.).
MONITORING VEGETATION OF BRAZIL: POTENTIALITIES OF MULTI-SENSORS APPROACH

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ABSTRACT

The large territorial extension of Brazil (8.5 million square kilometers) makes remote sensing technology an important tool for monitoring the Brazilian natural resources. A research history has shown the application of satellite data for studying vegetation cover, primarily in a regional level, using MSS and TM/LANDSAT and more recently HRV/SPOT data. It is well known that the detailed knowledge of the geographic and seasonal patterns of terrestrial vegetation is a necessary factor to understand global climate, biospheric productivity and human impact on the environment. Currently, there are several data collection platforms with sensors of different spatial, spectral, and temporal characteristics which are very useful to study vegetation cover. The AVHRR/NOAA, for instance, having much less spatial detail than LANDSAT sensors but providing daily worldwide data collection shows the great potential for monitoring global vegetation and its dynamic. On the other hand, data provided by LANDSAT and SPOT sensors have been used for regional studies. The objective of this research is to present the potentialities of multi-sensors (AVHRR/NOAA, MSS and TM/LANDSAT and HRV/SPOT) for monitoring vegetation of Brazil. The results of the analyzed procedures have shown the potential of multi-sensors for mapping, estimation of biomass, and phenology conditions of the vegetation and the human impact on the environment (deforestation, biomass burning, etc.).

INTRODUCTION

The diversity of vegetation types reflects the large dimension of Brazil and the wide range of climatic and ecological conditions. The large territorial extension of Brazil (approximately 8.5 million square kilometers) makes remote sensing technology an important tool for monitoring the Brazilian natural resources.

On July 23, 1972, the National Aeronautics and Space Administration (NASA) launched the first satellite of the Landsat series. It was followed by four satellites and they carried onboard a Multispectral Scanner Subsystem (MSS) with 80 meters of spatial resolution in four different spectral bands. The latter satellites of this series (Landsat-4 and -5) carried onboard in addition to the MSS, a Thematic Mapper (TM) sensor system which provides 30 meters resolution in six different spectral bands (from visible to middle infrared) and 120 meters resolution in a infrared thermal band. The Systeme Probatoire d’Observation de la Terre (SPOT) launched in February 1986 contains the High Resolution Visible (HRV) which provides 20 meters resolution in three different spectral bands (multispectral mode) and 10 meters resolution in a panchromatic band. The data provided by these satellites especially Landsat have been used extensively in studies of vegetation cover, primarily in a regional level.

On October 13, 1978, the National Oceanic and Atmospheric Administration/National Earth Satellite Service (NOAA/NESS) launched TIROS-N the first operational four channel polar orbiting satellite.
This satellite was followed into orbit by NOAA-6, -7, -8, -9, -10, and -11. The AVHRR (Advanced Very High Resolution Radiometer) on these satellites provides 1.1 kilometer resolution coverage in different spectral bands (from visible to thermal infrared). There are a few work done using this kind of data for vegetation studies.

The purpose of this report is to present the potentialities of multisensors (AVHRR/NOAA, MSS and TM/Landsat and/or HRV/SPOT) for monitoring vegetation of Brazil by using the high temporal resolution (daily coverage) of NOAA data and the better spatial and spectral resolution of Landsat and SPOT data. It is well known that the knowledge of global vegetation is an important factor for the environmental planning with the objective to preserve and to use rationally the natural resources for improving the productive system of Brazil.

LANDSAT MSS AND TM

On July 23, 1972, the first of a new series of unmanned satellites was launched by NASA, using a Thor-Delta launch vehicle, to record data about the Earth's surface and telemeter those data to ground receiving stations. Landsat-2, -3, -4 and -5 were launched in January 1975, March 1978, July 1982, March 1984, respectively.

Landsat-1 and -2 carried three data acquisition systems: (1) a multispectral return beam vidicon (RBV) television system that operated in three spectral passbands designated bands 1 (0.475-0.575 μm), 2 (0.580-0.680 μm) and 3 (0.690-0.830 μm); (2) a multispectral scanner system (MSS) that operated in four spectral passbands designated bands 4 (0.5-0.6 μm), 5 (0.6-0.7 μm), 6 (0.7-0.8 μm) and 7 (0.8-1.1 μm); and (3) a data collection system (DCS). Landsat-3 contained two panchromatic camera (0.505-0.750 μm) RBV system and a MSS with an additional band (band 8) in the thermal infrared region (10.4-12.6 μm).

The Landsat-4 and -5 were launched to improve the data collection system onboard the preceding satellites. In addition to the multispectral scanner system (MSS) a Thematic Mapper (TM) was included onboard the Landsat 4 and -5. This sensor system has more spectral bands and better spatial resolution than MSS. The spectral characteristics of the TM sensor are: 0.45-0.52 μm (band 1), 0.52-0.60 μm (band 2), 0.63-0.69 μm (band 3), 0.76-0.90 μm (band 4), 1.55-1.75 μm (band 5), 10.40-12.50 μm (band 6), and 2.08-2.35 μm (band 7). The spatial resolution is 30 meters except for band 6 (120 meters) and the repetitive coverage is 16 days.

SPOT/HRV

The Systeme Probatoire d'Observation de la Terre (SPOT), a general purpose remote-sensing satellite system, was placed in orbit by the Ariane satellite launcher on February 22, 1986 from the Guiana Space Center in Kourou, French Guiana.

SPOT 1 was inserted into a circular, near polar orbit about 832 km above the earth's surface. During its operational lifetime, it circle earth every 101.46 minutes or roughly 14 times a day. Every 26 days SPOT passes over the same orbit.

The SPOT 1 payload includes two identical High Resolution Visible (HRV) instruments. The instruments are pointable in the across track direction in order to allow rapid access to any point on the globe and the acquisition of stereoscopic image pairs from different satellite passes. The HRVs onboard the SPOT have 60 km swath. The HRV has been designed in order to achieve a multispectral capability with a ground sampling interval of 20 m and a 10 m sampling interval in a "black and
The spectral characteristics of HRV sensor are: 0.50 - 0.59 μm (band 1), 0.61 - 0.68 μm (band 2), and 0.79 - 0.89 μm (band 3) for multispectral mode and 0.51 - 0.73 μm for panchromatic mode.

NOAA/AVHRR

The TIROS-N/NOAA A-H satellites series was introduced with the launch of the protolflight satellite TIROS-N on October 13, 1978. This NASA funded satellite was followed into orbit by NOAA-6 in June 1979, NOAA-7 in June 1981, NOAA-8 in March 1983, NOAA-9 in December 1984, NOAA-10 in September 1986 and NOAA-11 in September 1988 (Needham, 1988). Only NOAA-10 and NOAA-11 are presently in operational mode. The satellite system includes the following instruments package (Kidwell, 1986): (1) AVHRR - Advanced Very High Resolution Radiometer, from which are obtained: HRPT, High Resolution Picture Transmission (High Resolution Direct Readout AVHRR); LAC, Local Area Coverage (High resolution recorded AVHRR); GAC, Global Area Coverage (reduced resolution recorded AVHRR); (2) TOVS - TIROS Operational Vertical Sounder, which includes: MSU, Microwave Sounding Unit; SSU, Stratospheric Sounding Unit; HIRS/2, High Resolution Infrared Radiation Sounder/2.

The TIROS-N satellite series has been designed to operate in a Sun-synchronous orbit at 833 ± 90 km. Two nominal altitudes have been chosen, 833 km and 870 km.

Table 1 gives the approximate times of the ascending node (Northbound equator crossing) and the descending node (Southbound equator crossing) in local solar time (LST) for the TIROS-N series.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Ascending node</th>
<th>Descending node</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIROS-N</td>
<td>1500</td>
<td>0300</td>
</tr>
<tr>
<td>NOAA-6</td>
<td>1930</td>
<td>0730</td>
</tr>
<tr>
<td>NOAA-7</td>
<td>1430</td>
<td>0230</td>
</tr>
<tr>
<td>NOAA-8</td>
<td>1930</td>
<td>0730</td>
</tr>
<tr>
<td>NOAA-9</td>
<td>1420</td>
<td>0220</td>
</tr>
<tr>
<td>NOAA-1</td>
<td>1930</td>
<td>0730</td>
</tr>
<tr>
<td>NOAA-11</td>
<td>1340</td>
<td>0130</td>
</tr>
</tbody>
</table>

From: Needhan (1988); pp.1333.

The Advanced Very High Resolution Radiometer (AVHRR) has been onboard the TIROS-N/NOAA satellites since 1978. The AVHRR provides data, in the visible, near infrared and thermal infrared of the electromagnetic spectrum (Kidwell, 1986). Table 2 shows the spectral interval, the instantaneous field of view (IFOV) and the ground resolution for the AVHRR channels.
Table 2 - Spectral Intervals, Instantaneous Field of View and the Ground Resolution for AVHRR Channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>Band width (µm)</th>
</tr>
</thead>
</table>
| 1       | 0.58 - 0.68    | (0.55 - 0.90 for TIROS-N)  
| 2       | 0.725 - 1.1    |  
| 3       | 3.55 - 3.93    |  
| 4       | 10.3 - 11.3    |  
| 5       | 11.5 - 12.5    | (channel 4 repeated for NOAA-6, -8, and -10)  
| IFOV  | 1.39 - 1.51 milliradians |  

Ground resolution: 1.1 km (nadir); 2.4 km (max off-angle along track); 6.9 km (max off-angle across track)

REMOTE SENSING OF VEGETATION

Since 1972, when the first satellite of the Landsat series was launched, remote sensing techniques have been used successfully for natural resources survey. In particular, for vegetation studies several works have been developed by the Vegetation Group at the Brazilian Institute for Space Research (INPE). Carvalho et al. (1988) present an overview of the reports concerned with vegetation studies done at INPE. These studies were related generally to mapping, inventory, and assessing the vegetation condition caused by deforestation, fire, diseases, and pollution. For these studies, Landsat MSS and TM and more recently SPOT HRV data have been successfully used to analyze the regional extent and the seasonality of vegetation. However, these kind of data are not well suited for large scale studies. The MSS 80 meters, TM 30 meters and HRV 20 meters ground resolutions produce a large data volume to be analyzed for the whole Brazilian territory. On the other hand, for tropical countries, the 16 day repeat cycle of the current Landsat and the 26 day repeat cycle for large areas of SPOT produce too few cloud-free observations to record vegetation seasonal dynamics.

The AVHRR sensor onboard the NOAA satellite series with a coarse spatial resolution (about 1.1 km) but providing a daily worldwide coverage provides an alternative source of satellite data for vegetation studies in large areas. The works done by Tucker et al., 1985a,b, using AVHRR data have shown the applicability of this kind of information for vegetation studies.

Background

There is a need for consistent, timely, and reliable information sources to facilitate analysis of global vegetation patterns. Remotely sensed spectral measurements may contribute as a major source of information (Goward et al., 1985). Research carried out by several investigators has shown that photosynthetically active "green" vegetation displays a unique spectral reflectance pattern in the visible and near infrared spectral regions when compared to the other Earth surface materials as soil, water, etc. (Figure 1). Note that the vegetation reflectance is low in the visible and high in the near infrared. This green vegetation spectral pattern results from strong absorption of visible light by chlorophyll and other pigments and from scattering determined by leaf structural properties what results in minimal absorption, high transmittance, and high reflectance of light in the near infrared. Several spectral vegetation indices based on
the contrasts in spectral reflectance between green vegetation and background material have been reported in the literature (e.g., Tucker, 1979; Goward et al., 1985). The normalized difference vegetation index (NDVI) is one of these spectral vegetation indices. It is computed as \( \text{NDVI} = \frac{(\text{NIR} - \text{VIS})}{(\text{NIR} + \text{VIS})} \), where, NIR is near infrared spectral measurement and VIS is visible spectral measurements. As can be seen the Landsat, SPOT and NOAA sensors contain bands located in the visible and near infrared region which permit to study vegetation. In addition, AVHRR/NOAA provides information in a thermal infrared region which permit to monitor forest and biomass burning (Matson et al., 1984; Flannigan, 1985; Pereira, 1987).

![Figure 1: The responses of vegetation, soil and water in the electromagnetic spectrum.](image)

Prospective of Multisensors Approach
Based on the spatial, spectral and temporal characteristics of the Landsat, SPOT and NOAA sensors presented in the preceding sections, some preliminary investigations using this data for vegetation studies are discussed here.

Brazil has a diversity of vegetation types distributed in large areas defining regions as Amazonia, "Cerrado" (Savanna), "Caatinga", "Pantanal", etc. The multisensors approach using remote sensors with coarse spatial resolution but high temporal resolution and sensors with fine spatial resolution and low temporal resolution appears as a potential tool for studying Brazilian vegetation types.

This paper is concerned primarily with the AVHRR data since the use of Landsat MSS and TM for vegetation studies has been frequently reported in the literature.

In the Amazon region, there are some works done utilizing AVHRR for a global vegetation analysis using vegetation index imagery (Justice et al., 1985). Also, the deforestation and fire detection in Amazon has been studied using thermal channel of the AVHRR sensor (Pereira, 1987; Setzer et al., 1988). Nelson et al., (1987) showed the usefulness of
multisensors approach for monitoring deforestation in Mato Grosso state using AVHRR-LAC thermal data and Landsat MSS and TM spectral data to estimate the rate of forest clearing and total area cleared in the whole state.

Figure 2 shows a vegetation index imagery composed from 01 to 08 July, 1988. In this figure there are sampled windows showing the (1) Amazon forest, (2) "cerrado", (3) "pantanal" and (4) an agricultural region in the south of Brazil. The vegetation index profile for these samples is showed in Figure 3.

Every year large areas of vegetation area are burned in different parts of the country causing damage even in the preserved areas as national parks. An investigation was carried out in the Emas National Park located in the southeast of Goias state between 52o 30' and 53o 10' west longitude and 17o 50' and 18o 15' south latitude (Figure 4). This park has its area totally burned in August 1988. In this investigation it was used AVHRR (bands 1, 2, and 3) and TM (bands 3, 4, and 5) data for monitoring the biomass burning. It was analyzed two TM images, one obtained before the fire (July 29, 1988), another obtained on August 14, 1988, and three AVHRR images obtained between this period. Figure 5 shows TM 4 imagery of July 29, which was used to map the undisturbed vegetation cover in this area. Figure 6 shows AVHRR channel 3 obtained on August 5, 1988 showing fire points. These images showed how the fire occurred in the area. Then, Figure 7 shows TM 4 imagery of August 14, 1988, which permit to map and evaluate the burned area. From the imagery analysis, half of the Emas National Park had been destroyed by the fire.

Figure 2: The vegetation index imagery composed by 01 to 08 July, 1988.
Figure 3: The vegetation index profile.

Figure 4: Localization of Emas National Park.
Figure 5: TM 4 imagery of July 29, 1988 showing the undisturbed vegetation in the Emas National Park.

Figure 6: AVHRR channel 3 imagery obtained on August 05, 1988, showing the fire points.

Figure 7: TM 4 imagery of August 14, 1988, showing the burned areas in the Emas National Park.
PROPOSED RESEARCH

The Vegetation Group of INPE has proposed two projects using AVHRR data for a global approach and TM and/or HRV data for a detailed study on selected areas. These projects are: (1) The study of “cerrado” vegetation region through vegetation indices obtained from multisensors data; and (2) Monitoring of Amazonian vegetation.

CONCLUSION

Initial investigations have shown the multisensors approach using AVHRR/NOAA, TM/Landsat for vegetation monitoring. The AVHRR data is very useful to detect deforestation, forest fire and vegetation phenological change due to its global coverage and daily temporal resolution. On the other hand, the fine resolution data like TM and HRV have been showed very useful for detailed study, principally for area estimation. The future remote sensing programs as Eos (Earth observing system) and CBERS (China-Brazil Earth Resource Satellite) which will be carrying onboard sensors with coarse and fine spatial resolution and several temporal resolutions encourage all those involved in vegetation studies to become acquainted with the multisensors approach.

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