Combined analysis of SAR C and TM/Landsat data in the assessment of aquatic vegetation changes in the Tucuruí reservoir, Pará State, Brazilian Amazon

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Abstract-- The objective of this study is to assess the changes in the aquatic vegetation in two different water levels of the Tucuruí reservoir. During the SAREX 92 mission, for the first time, remote sensing data from the rising water stage became available for the entire reservoir. SAR -C data obtained over the entire reservoir in the wide mode were processed into a mosaic by the Canadian Centre for Remote Sensing. This mosaic was used to map the areas occupied by different stands of aquatic vegetation in April 1992. TM/Landsat color composite (band 3,4 and 5) acquired in June 1992 was used to map the stands during the high water stage. The results showed that differences between SAR and TM data prevented the accurate assessment of the changes in the area occupied by aquatic vegetation.

INTRODUCTION

The Amazon river basin, in Brazil, has a hydroelectric potential of 100 000 MW. To exploit this potential, 63 hydroelectric plants shall be built in Amazonia, potentially flooding around 100 000 km^2 [1]. Three of them, Balbina, Tucuruí and Samuel are already operating, and are responsible for the conversion of about 5500 km^2 of the Amazon forest into aquatic and wetland environment.

Reservoir construction worldwide is turning the attention to its role as source of greenhouse gases [2,3,4]. Almost nothing, however, is known about reservoir as sources or sinks of the greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4). Measurements of reservoir methane flux in northern Quebec (Canada) showed that it is affected by several environmental variables such as age of the lake, temperature and amount of biomass available for decomposition[4]. Reported data for floodplain environment shows that the methane fluxes from floating mats can be in average ten times larger than the fluxes measured in open water [5]. A better assessment of the role of the reservoirs as source of methane to the atmosphere, however, is still dependent on the knowledge of the area occupied by the macrophyte stands [1].

Remote sensing data can improve the estimates of methane flux from the reservoirs by providing the information on the extent of the different habitats along time. TM/Landsat data have been used to map the macrophyte distribution in the amazon reservoir. The main constraint to the use of optical remote sensing to monitor the macrophyte infestation is the lack of seasonal data.[6,7,8,9,10]

Macrophyte biomass changes both seasonally and from year to year according to the nutrient availability [11, 12]. Ground observations since 1987 [13] have shown that the macrophyte community in the Tucuruí reservoir changes along the year. During the high water the dominant specie is *Scirpus cubenses* which is replaced during the low water stage by rooted macrophytes such as *Tipha Dominguenses* [13]. Synthetic aperture radar (SAR) data can provide information of the temporal distribution of the macrophyte stands.

During the South American Experiment (SAREX 92) SAR data were obtained over the Tucuruí reservoir. Campaign details are reported in [14, 15]. Results showed that Nadir polarimetric SAR C allowed the discrimination of at least two large classes of macrophytes in the Tucuruí reservoir: the grass-like species such as *Scirpus, sp.*, *Tipha, sp* and the forbes such as the *Eicchornia crassipes*, *Salvinea auriculata*, etc. when using the HH Nadir mode data [13,16]. Variables such as stand density and height affected the accuracy of specie discrimination [16]. Theoretical and empirical models, however, have already demonstrated the sensitivity of radar backscatter to changes in biomass for agricultural fields [17].

This paper reports the results of a study assessing the suitability of using SAR and TM/Landsat data acquired in different dates to monitor changes in the area covered by aquatic vegetation as a contribution for a better estimation of the carbon budget in the Tucuruí reservoir.

0-7803-2567-2/95 $4.00

THEORETICAL BACKGROUND

The spectral behavior of the aquatic vegetation in the visible and near-infrared spectrum is very similar to the land vegetation. The grass-like species such as *Scirpus, sp.* and *Typha, sp.* have very high infrared reflectance and can be easily detected in the TM/Landsat images [7]. Forbes like *Salvinea auriculata, Pistia stratiotes* have distinctive spectral response characterized by a decrease in the infrared reflectance. As the biomass and stand cover density decreases, the effect of the water on its spectral behavior increases.

The interaction between the active microwave radiation and the earth surface is affect by two sets of variables: the variables related to the radiation field and the variables related to the target. The frequency of the incident wave is a key factor in the penetration depth and in the scattering from rough surfaces. The penetration depth is larger for smaller frequencies[18]. The radar backscatter is also dependent on the angle of the incident wave. At small angles, the backscatter provides information on the topography. At large angles, the return signal provides information about the small scale features. The radar backscatter is affected by the polarization of the incident wave.

The main target variables affecting the radar backscatter are the surface roughness and the surface moisture [18]. If the surface is rough, the energy is reradiated in all directions. The amount of energy scattered is a function of the surface roughness relative to the wavelength of the incident radiation. The penetration depth for a given wavelength is inversely proportional to the moisture content of the surface.

No observational or theoretical investigations of the microwave backscattering properties of aquatic vegetation are available at present [16]. One can assume that σ^o will be affected by: a) the size of the plant components relative to the illuminating wavelength (5.6 cm in this case); b) the geometric arrangement of the components; c) the plant biomass; d) the reflectance properties of the plant substrate [13]. Because of its high dielectric constant, water is very reflective at microwave frequencies. If the plant canopy is open or thin enough to allow microwaves to penetrate a double bounce scattering mechanism will be important and may result in an increased backscatter in relation to that of similar plants growing in a soil substrate [19].

STUDY AREA

Tucuruí reservoir is located 300 km south Belem, limited by the coordinates of 3° 43' S, 49° 12' W and 5° 15' S 50°00'W. At the maximum height (72 m) the reservoir surface is estimated in 2 400 km ^{2}. The water level can reach 68 meters in normally dry years and even 58 meters in the extremely dry years. Five major species of aquatic vegetation can be found in Tucuruí reservoir. They can be classified as free-floating such as *Eichornia crassipes, Salvinea auriculata,* and *Pistia stratiotes;* emergent such as the *Typha;* floating leafed such as *Scirpus.*

METHOD

The data for this research is described in table 1. The CCRS SAR 580 mosaic was acquired in April, 1992 at the end of the water level raising period when the reservoir quickly jumps from 69.8 m to 71.4 m. The TM/Landsat image was obtained in June 1992, when the water level had already been kept around 72 meters for two months, providing an environment suitable for the aquatic vegetation growth [20].

The first step in the image interpretation was to define the mapping units for both products. The availability of aerial color photography at the scale 1:10 000 and ground photography obtained concurrently to the SAREX 92 mission helped to define the classes to be identified in the SAR C mosaic. The 1:1000 000 SAR transparency was enlarged to the scale 1:250 000 with the help of an optical magnifier. The magnification to the 1:250 000 made it difficult to detect differences in aquatic vegetation genera, but one could classify the macrophyte stands according to the cover density. The maps obtained by visual interpretation of the remote sensing products were digitized and the area covered by each class determined.

RESULTS

The analyses of the interpretation key produced for each remote sensing data reveals the first difference between optical and active microwave data. TM/Landsat data provided more information for discriminating the different genera of macrophytes occurring in the area. Differences in color in the TM composition could be related to differences in the frequency of a given specie or genera on the ground SAR images, changes in the film density in the transparency could be related to the density of the macrophyte stands (percentage of ground cover). Samples collected on the ground [21] in mixed stands of *Eicchornia,sp.* and *Paspalum, sp.* suggest that the percent of water surface coverage can be related to the stand biomass. [22]. The second difference was the sensitivity to low density stands of aquatic vegetation. The finer spatial resolution of SAR data make it possible to detected small stands of macrophyte whereas the coarser TM resolution makes it impossible to map the areas where aquatic vegetation is less dense.

There is also difference in the area mapped as "dead tree trunks" in the SAR and TM data. This class could not be separated from the aquatic vegetation stands in this TM composition. The SAR image, on the other hand, allowed the detection of large areas of dead tree trunks.

The area covered by each class be observed in tables 2 and 3. They show that the percentage of area covered by macrophytes during April 1992 computed with SAR data is larger than the area computed with TM data. Clearly those differences are not related to the decrease in the macrophyte infestation from April to June but to the differences in the detectability of low density macrophyte stands in this TM color composition. The total area covered by aquatic vegetation estimated with TM data represents 10 % of the reservoir surface area, whereas the area of the high density of aquatic macrophytes estimated with SAR data is 11.03 %. It suggests that the TM data was able to detect the high density stands, overlooking the stands of average density and stands with dead aquatic vegetation and dead tree trunks. The area covered by macrophytes in April 92 is around 25 %. There are, therefore, at least 15 % of area covered by macrophytes which were not detected by the TM data, assuming that from April to June there was not a spread in the aquatic vegetation infestation. Similar results were obtained elsewhere [16] when using SAR -C data acquired at the Nadir Mode.

CONCLUSIONS

The results of this study allowed the following conclusions: 1) the differences in the interaction between the aquatic vegetation and the electromagnetic radiation in the microwave and optical regions make it difficult to create an interpretation key suitable for both remote sensing products: TM/Landsat and SAR; 2) SAR - C data proved to be more sensitive to average and low density stands of aquatic vegetation. 3) TM/ Landsat data allowed the detection of aquatic vegetation stands characterized by high percentage of ground cover; 4) TM images presented the highest ability to discriminate macrophyte genera but. it underestimates the total area of macrophytes; 5) during the rising water period (April) the percentage of the reservoir covered by all classes of aquatic vegetation is 25 % or around 600 km^2.

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AKNOWLEDGMENTS

The authors acknowledge the Canadian Centre for Remote Sensing for providing the SAR data and the Canadian International Development Agency (CIDA) for supporting this research. M.L. S. Silva thanks the CNPq for providing research fellowship

Table 1 - Remote sensing data used in the study

DATA	DATE	PRODUCT	OBSERVATIONS
TM/Landsat	June, 1992	Color composite bands 3R,4G,5B	Scale 1:250 000
CCRS SAR 580	April, 1992	Black and white transparency C band, HH polarization	Scale 1:1000 000, Wide mode; around 60 degree incidence angle

Table 2 - Area occupied by each mapping unit based on the interpretation of the TM/Landsat data acquired in June, 1992.

Mapping Unit	Area(km^2)	(%)
Salvinea, sp	069.99	2.88
Scirpus, sp.	129.80	5.34
Mixed aquatic vegetation	44.14	1.81

Table 3- Area occupied by each mapping unit based on the interpretation of the SAR-C data acquired in April, 1992.

Mapping Unit	Area (km^2)	(%)
High density of aquatic vegetation	268.21	11.03
Average density of aquatic vegetation	190.39	07.83
Aquatic vegetation and dead tree trunks	160.69	06.61
Dead tree trunks	131.07	05.39