# RADAR DETECTION OF MACROPHYTE STANDS USING L BAND AND C BAND DATA

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## ABSTRACT

This paper describes a study performed to assess the suitability of multiband SAR data for discriminating stands of macrophytes with differences in height and density. In this study L band HH JERS-1 SAR and C HH band CCRS SAR 580 data were acquired for the Tucuruí reservoir in March 7, 1994 and April 14, 1992, respectively. In spite of the two year difference in data acquisition, both sets were obtained during the beginning of the rising water season. Therefore it was assumed that differences in the detection of macrophyte stands and dead tree trunks were related to changes in the microwave interaction between macrophyte canopy in the L and C band. The SAR data were georeferenced and resampled to 12 m by 12 m resolution. The SAR data were submitted to digital processing as follows: image filtering, contrast enhancement to produce a multiband composition in which differences in color were related to stand height and density. Aerial photographs were used for selecting macrophyte stand classes and the following image variables obtained: average digital number and standard deviation. The digital data for both L and C band were normalized against the mean digital number obtained for water surface since absolute calibration data were not available. The results show that band C is more sensitive to differences in the macrophyte canopy height and density than L band data.

## 1. INTRODUCTION

Amazon river system is the main source of hydroelectricity for the northern Brazil. Because of that, large areas of forest land have been converted into large reservoirs. Three of them (Tucuruí in Pará state, Balbina in the Amazon state, and Samuel, in the Rondonia state) are responsible for the conversion of over 5 $000^2$ km of forest land into aquatic environments. The environmental problems brought by such transformations in the natural landscape are discussed at length in the literature (Junk and Howard-Willians, 1984, Junk and Mello, 1990; Kelman, 1990; Novo and Tundisi, 1994). The increase in the amount of aquatic vegetation is one of the most widespread environmental impacts of these large tropical reservoirs. The spread of aquatic vegetation brings about the following threatens to the environment: a) spread of endemic diseases; b) deterioration of the water quality; c) increase in the flux of gases to the atmosphere; d) disruption of the geomorphologic and hydrological balance of the local river basin.

Almost nothing is known about reservoir as sources or sinks of the greenhouse gases such as carbon dioxide ($CO_2$) and methane ($CH_4$). 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 (Ruddy and Harris, 1994).

TM/Landsat data have been used to map the distribution of aquatic vegetation in the amazon region (Abdon and Meyer, 1990). Aquatic vegetation biomass changes both seasonally and from year to year according to the nutrient availability, hydrological and hydrodynamic factors, etc. However, cloud cover did not allow the monitoring of these changes along the year, by using optical sensors. On the other hand, synthetic aperture radar (SAR) data are not affected by cloud cover and can provide information on the temporal distribution of the aquatic vegetation stands.

The interaction between the active microwave radiation and the earth surface is affected by two sets of variables: the variables related to the radiation field and the variables related to the target. The variables related to the radiation field are the frequency, the incidence angle and the polarization. The frequency of the incident wave is a key factor in the penetration depth and in the scattering from rough surfaces (Ulaby et al., 1986). The penetration depth varies linearly with $\lambda$ in the radar sensors spectral region. The penetration depth is larger for smaller frequencies. The L-band (24 cm wavelength) signal penetrates deeper than the C-band (5 cm wavelength) signal.

The influence of the incidence angle depends on the frequency of the microwave source. The small wavelengths are more sensitive to changes in the incidence angles. The effect of the incidence angle also depends on the polarization of the microwave source and the canopy features. For crops and shrubs, the L band backscattering is not affected by the incidence angle. According to Holmes (1992) an increase in incidence angle from $0^{\circ}$ to $90^{\circ}$ has little effect on the penetration depth of HH polarized radiation due to its low attenuation in crops. As some groups of macrophytes present crop-like canopies, one can assume that, in the L band, HH polarization, the incidence angle is not a key factor.

Several recent studies (Novo et al. , 1993; Novo et al. , 1995; Costa, 1996; Noernberg, 1995) have reported the use of C band SAR data for mapping different genus of aquatic vegetation in the Tucuruí reservoir. According to the authors airborne C band SAR images provided good discrimination among those genus characterized by differences in height and biomass such as *Salvinia* sp. and *Scirpus* sp.. The discrimination among genus with small differences in height and biomass such as *Salvinia* sp. and *Pistia* sp. was not good even when multipolarization and multiviewing data were used (Costa, 1995).

Results from the SIR-C experiment reported in Hess et al. (1995) suggest that the use of multi-frequency SAR data can improve the discrimination of vegetation in the tropical floodplain. According to the authors, backscattering statistics indicate that both C and L band are necessary for accurate delineation of ground classes, such as flooded forest, macrophyte stands and non-flooded forest.

According to Rosenqvist (1995) L band backscatter was sensitive to changes in rice growth, reaching the highest backscatter as the plants grow to their full length of about 100 cm. There was around 8 dB difference in the rice backscatter from the beginning of the growing season to the period of maximum growth.

This paper describes a study performed to assess the suitability of multiband SAR data (L band and C band ) for discriminating among stands of macrophytes with differences in height and density in a Amazon reservoir. In this study, although the SAR data had been acquired at different incidence angles ( 35° and 76° for the L and C band respectively) , it was hypothesized that by combining L and C wavebands one could separate macrophyte stands according to the canopy height and density.

## 2. THE STUDY SITE

Tucuruí reservoir was selected as test site because it has been subjected to a series of studies since 1988 (Abdon and Meyer, 1990). Tucuruí is the first large reservoir in operation in the Amazon region. It is located 300 km south Belém, limited by the coordinates of 3° 43' S/ 49° 12' W and 5° 15' S/ 50°00'W in the Tocantins river basin (Figure 1).

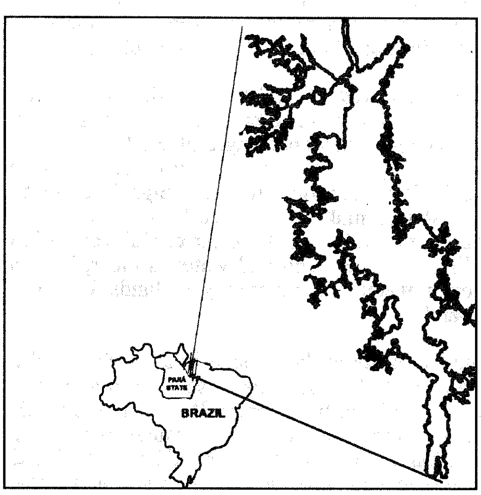


Figure 1 - The study site location

At the maximum height (72 m) the reservoir surface is estimated in 2 700 km $^2$. The water level can reach 68 meters in normally dry years and even 58 meters in the extremely dry years.

The study area includes a wide variety of aquatic vegetation. The annual rise and fall of the reservoir's water level imposes a constant change in the area occupied by the different aquatic plant genus along the year. Some groups of aquatic vegetation, however, are dominant in the reservoir: a) the free-floating such as *Eichhornia* sp., *Salvinia* sp. and *Pistia* sp.; b) the emergent such as the *Typha* sp.; c) the floating leafed such as *Scirpus* sp.

## 3. REMOTE SENSING DATA

The data used in this study are the following:

- airborne C-band SAR wide mode image acquired during the SAREX 92 mission in Brazil. The images were processed in the Canadian Centre for Remote Sensing (CCRS) being submitted to slant to ground range correction and antenna pattern correction.
- color aerial photography at the scale of 1:10 000 taken concurrently to the SAREX 92 mission.
- orbital L band JERS-1 data (P397/R308 and P395/R307).
- georeferenced Thematic Mapper/Landsat digital images

Table 1 presents the main features of the SAR data used in this study.

Table 1 - SAR data used in the study

| SAR data | Date | Pixel Spacing | Incidence Angle |
|---|---|---|---|
| C Band | April, 14 1992 | 15 m x 6.9m | ~ 76 ° |
| L Band | March, 7 1994 | 12.5 m x 12.5 m | ~ 35 ° |

In spite of the two year difference in data acquisition, both sets were obtained during the beginning of the rising water season. Previous studies in the area have shown that the main variable affecting the spread of macrophytes in the reservoir is the water level. Therefore, the differences in the backscatter from 1992 to 1995 data set can be assumed to be more related to changes in the wavelength than in target variables. Figure 2 shows the changes in water level in April 1992 and March, 1995.

## 4. ANCILLARY DATA

During the SAREX 92 mission ground conditions were documented by aerial, boat and ground survey. The following information was collected during boat survey for several macrophyte stands: GPS coordinates, dominant genus, qualitative information such as stand density, homogeneity and height of the aquatic vegetation stands. These information helped to produce a reference map based on the color aerial photography visual interpretation. This map was taken to the ground in the following year and the final reference map produced (Novo et al. , 1996)

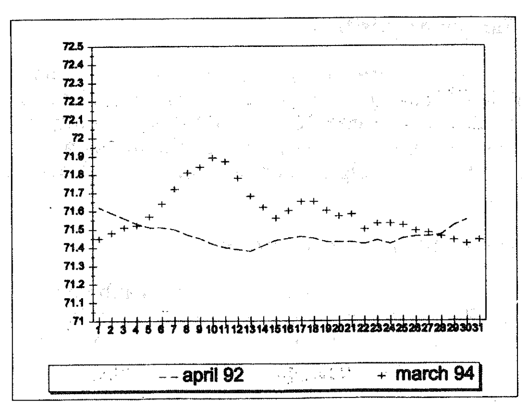


Figure 2 - Reservoir water level during the SAR data acquisition.

## 5. METHODS

### 5.1 -L-band SAR data pre-processing

Each JERS-1 scene was submitted to a spatial filtering for speckle removal. Previous studies (Shi and Fung, 1994) recommend the use of adaptive filters because they smooth the image without removing edges and sharp features. In this study a spatial filter based on Lopes et al. (1990) algorithm and known as FGAMMA filter was used. The algorithm assumes a gamma distribution for the image and performs spatial filtering on each individual pixel using the digital number in a square window surrounding each pixel. In this study a 3 by 3 pixels window was used and provided a good result.

After the speckle removal, the JERS-1 scenes were mosaicked and then geometrically corrected using TM/Landsat image as reference. This image had ben previously ortho-rectified using the method developed by Toutin (1995). For further discussion on this subject refers to Costa (1995).

The geometrically corrected image was resampled to a resolution of 12 m by 12 m using the 8 point Sin (x)/x method as suggested by Shlien (1977). This algorithm determines the digital number from the weighted average of 64 closest pixels to the specified input coordinates and assigns the value to the output coordinates. The resulting image is sharper than that obtained by bilinear interpolation.

### 5.2 C-band SAR data pre-processing

The antenna pattern correction applied to the mosaic produced by the Canadian Centre for Remote Sensing was not sufficient to remove the range effect on the surface backscatter. To eliminate this effect, a correction factor was applied to the data as follows:

- selection of a homogenous 50 lines swath along the range direction;
- computation of a average correction factor applied to every pixel along the range direction.

This procedure also accounted for most of the image speckle what prevented further filtering.

The next step was to register the C-band SAR image onto the L-band SAR image using the same resampling algorithm to produce a 12m by 12 m pixel image.

### 5.3 - Sample Acquisition

The sample acquisition of the different targets was done using visual interpretation of aerial photographs and the Landsat image. Masks were created to sample areas corresponding to the classes of interest in each image. The masks were used to compute the mean digital number, the standard deviation of each class.

### 5.4 - Digital number normalization

Because of the uncertainty of the absolute calibration of the C-Band SAR data available (Costa, 1995), it was decided to use the digital number for both data set. The data were converted submitted to a normalization.

For the normalization procedure, it was assumed that: a) for a calm open water surface the backscatter from both wavebands should be low and equal; b) calm open water would present the lowest digital numbers in both images; c) the ratio between the average digital number of open water at C band and L band would provide a normalization factor which would allow a quantitative analyses of the macrophyte backscattering properties.

### 5.5 - Generation of SAR multiband composition

A series of contrast stretch functions (linear, equal and root) were tested to produce multiband color composites using the L and C band images. With aid of ground information it was selected the best combination of color and contrast to maximize the visual discrimination among the macrophyte genus and the visual discrimination between the terrestrial and the aquatic ecosystem.

## 6. RESULTS

### 6.1 - Multiband Composition

Figure 3 shows : a) the multiband composition of L band image displayed as red (R) and C band image displayed as cyan (B and G), both submitted to linear contrast stretch; b) the C band and L band images submitted to linear contrast stretch; c) L band image submitted to squared root contrast stretch.

The most obvious difference between the SAR images is the low return from the macrophyte stands displayed in the L band. As seen in figure 2, the reservoir water level was 71.50 in March 7 and 71.65 in April 15. This difference in water level (15 cm) is not sufficient to affect the area covered by macrophytes. Therefore, the differences in the return can be explained by the larger L band penetration depth which exceeds the aquatic plant canopy height (1m in average). As a result most of the radiation interacts directly with the water surface being reflected in the forward direction. At C band, the penetration depth is smaller allowing for multiple scattering within the canopy and a stronger backscatter.

The multiband composition clearly shows the area covered by macrophyte stands in cyan in the lower reach of the Pucuruí inlet. Towards upstream, where the macrophyte stands are thicker, an increase in L band backscatter can be observed.

The limit between the terrestrial and the aquatic environment is more evident in the multiband composition than it is in the individual bands. The low incidence angle of the C band casts long shadows which prevent setting a precise boundary between land and water. Besides that, the high backscatter from the thicker stands makes it difficult to set the limit between the aquatic vegetation and the terrestrial vegetation. In L band, the limit between land and water is clear, but the limit between open water and macrophyte stands is not as evident as in C band.

In figure 3 c one can observe the L band image submitted to square root contrast stretch. In this case, the macrophyte stands are enhanced and can be mapped. It indicates that, the L band is perhaps more sensitive to the stands height and density than the C band. The combination of both wavebands can highlight differences in stand density, biomass and dossel structure as seen in more detail in figure 4.

The differences in waveband sensitivity of canopy height and density can be better observed in the graphic of figure 5. The first striking feature is that, as expected from the theory, the normalized digital number (DN) for the Forest class is much higher in L band than in C band. These results are in agreement with the backscatter statistics provided by Dobson et al. (1995). Using data from the SIR-C/X- SAR experiment in which L band and C band data were acquired under equal image parameters (look angle, pixel spacing and number of looks) for boreal forest. The authors related total dry biomass to image backscatter. For a constant biomass of 10 kg $m^{-2}$ , the average backscatter for L band was around -8 dB, whereas for C band, the average value was around -10 dB.

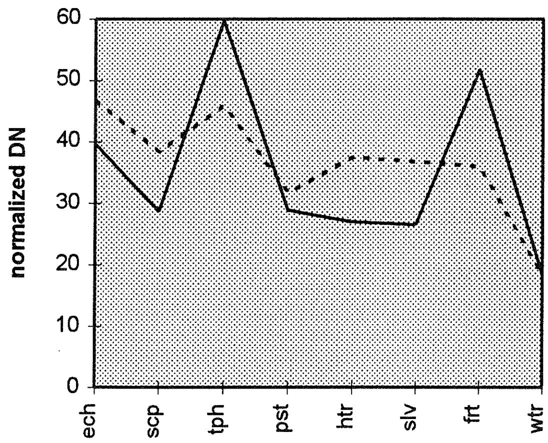


Figure 5 - Normalized digital number of the various ground classes (ech - eichhornia; scp- scirpus; tph - typha; pst- pistia; htr -heterogeneous; slv -salvinia; frt - forest; wtr -water). Dotted line - C band; Continuous Line - L band.

The average DN for the macrophyte stands, on the other hand, are much higher in the C band than in the L band, except for the *Typha* sp. stands. The higher L band DN values observed in the *Typha* sp stands are related to the larger biomass and height of this genus when compared to the others present in the reservoir. The *Ttypha* sp. genus is characterized by 1 to 2 meter vertically oriented grass-like leaves organized in very dense tufts. It is interesting to observe that the *Typha* average DN is even higher than that of the Forest, what suggests the contribution of double bounce scattering between the tufts and the underlying water. The same behavior can be observed in the C band.

In order to qualitatively explore the relationship between the classes biophysical parameters and the DN in the L and C band, table 2 was organized.

In table 2 the ground classes where ranked according biomass and height, and the SAR bands according to DN value. The following can be observed: a) L band is more sensitive to the canopy background than to biophysical parameters since the forest biomass and height is much larger than the *typha* 's. L band is not sensitive to changes in biomass among the macrophyte genus grouping together *pistia* and *scirpus* which have an average of 100 cm difference in height; b) C band also does not respond to changes in biomass and height, but much more to canopy structure. The six different types of macrophyte stands were better discriminated in the C band.

Table 2 - Ranking of macrophyte biophysical features

| Ground Class | Biomass and height ranking | L band DN ranking | C band DN ranking |
|---|---|---|---|
| Forest | 1 | 2 | 5 |
| *Typha* sp. | 2 | 1 | 2 |
| *Scirpus* sp. | 3 | 4 | 3 |
| *Eichhornia* sp | 4 | 3 | 1 |
| Heterogeneous | 5 | 5 | 4 |
| *Pistia* sp. | 6 | 4 | 6 |
| *Salvinia* sp. | 7 | 5 | 5 |

*Eichhornia* sp. shows the first and the second higher DN in the L and C band, respectively. *Eichhornia* sp. is densely distributed reaching a height of 30 cm. It has randomly oriented cup-shaped leaves 10 to 15 cm large. As a consequence of this dossel structure, volume scattering seems to be the primary scattering mechanism being responsible for the high DN values in both bands. *Pistia* sp. and *Salvinia* sp. show the lowest DN in both bands. They have small leaves and they do not grow more than 10 cm off the water surface. Though in both bands they behave as smooth surfaces acting as quasi-specular reflectors.

## 7. CONCLUSIONS

This study led to the following conclusions: 1) L band is not as good as C band for discriminating among the macrophyte genus; 2) L band C composition is very useful for setting the limits between open water and aquatic vegetation and aquatic system and terrestrial system; 3 ) multiband composition allows to separate the macrophyte stands according to their structural features rather than their biophysical features.

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