Textural classification of R99SAR data as an aid to flood mapping in Coari City, Western Amazon Region, Brazil

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Abstract: This study focuses on improving flood mapping in Coari City, Western Amazon Region, Brazil, by incorporating: (1) results of Unsupervised Semivariogram Textural Classification (USTC) of high-flood season, multi-polarized L-band R99SAR image mosaics as part of the Multi Application Purpose SAR (MAPSAR) Mission; (2) identification of flooded forest and flooded vegetation in different L-band polarizations; these cover types form the most oil-sensitive habitats in the region; (3) analysis of the performance of USTC classification using confusion matrixes related to each multi-frequency (HH, HV and VV) L-band image mosaic; (4) manipulation of covariance and correlation matrixes to extract information about cover types within pairs of multi-polarized image mosaics. The information derived from airborne R99SAR data is easy to interpret and constitutes a useful representation of areas with high oil sensitivity in the Amazon rain forest.

Palavras-chave: R99SAR, MAPSAR, USTC, Amazônia, R99SAR, MAPSAR, USTC, Amazon.

1. Introduction

Synthetic Aperture Radar (SAR) L-band data constitute an invaluable tool to map flood inundation beneath forest canopies. The accurate delineation of the extent of inundation provides important information that can guide management decisions in the event of oil spills in a high sensitivity area such as the Amazon floodplain.

MAPSAR (Multi Application Purpose SAR) is a Brazilian-German initiative to produce a multi-polarized, spaceborne L-band SAR system with high-resolution capability as an aid to assessment and monitoring of natural resources. The objective of the present study is to simulate potential MAPSAR results in the floodplain region near Coari City.

2. Test Site

Petrobras built a pipeline that transports 50 thousands barrels of oil per day from the Urucu oil and gas province to the Solimões Terminal (TESOL) in the vicinities of Coari City. This oil is then shipped to another terminal in Manaus using the fluvial route of the Solimões River. TESOL is located in an area characterized by a flat landscape, in which topographic variations range approximately from 35 to 70 meters. Water level changes between dry and wet seasons usually reach a difference of 14 meters. As a result, the extension of flooding can reach up to 30 kilometers beyond the Solimões River banks at the high flood season, in which flooded forest and flooded vegetation form the most oil-sensitive habitats.

3. Methodology

Data acquisition at Coari City was carried out on 01 June 2006, high-flood season, using the L-band (quad-pol) Synthetic Aperture Radar (SAR) system, known as R99SAR, which is installed onboard the SIPAM (System for the Protection of the Amazon) aircraft. This acquisition is part of the MAPSAR Mission simulation.

The quad-pol L-band airborne R99SAR data were acquired using a NNE-SSW flight path with a swath width of 20 km (distance from nadir varying from 14.63 km in the near range to 34.62 km in the far range) and 6 meters of ground spatial resolution. The incidence angle ranges from 39.57^o (near range) to $70.99\ ^o$ (far range). In order to cover the entire test site initially requested, sixteen strips of data were obtained. The R99SAR data were processed at the SIPAM operational center in Manaus, generating 16-bit images geometrically co-registered and with no radiometric calibration.

Considering the initiative to adapt the acquired R99SAR data to the MAPSAR mission, all the strips were joined together in order to compose a resampled mosaic with approximately 10 meters of spatial resolution. As the incidence angle interval of MAPSAR ranges from 20^o to 45^o, only the interval from 39.57^o to 45^o of each strip was used in this mosaic. This corresponds to an average width of 4 km at the near range of each strip. As a result, SAR image mosaics of LHH, LHV and LVV configurations were composed (**Figures 1, 2, and 3**).

The individual R99SAR image mosaics were processed using the Unsupervised Semivariogram Textural Classifier (USTC). Promising results using this classification approach in the Western Amazon were obtained by Miranda et al. (2005). USTC is a deterministic classifier, which provides the option of combining both textural and radiometric information. Radiometric information is conveyed by the despeckled digital number (DN_{dsp}) value. The speckle noise reduction algorithm to be used is the adaptive Frost filter. Textural information is described by the shape and value of the circular semivariogram function.

4. Results

4.1 DN statistics and semivariogram behavior

The Unsupervised Semivariogram Textural Classifier (USTC) was used to discriminate and map cover types associated to the following scattering mechanisms: (1) predominantly forward scattering (flooded vegetation with low to intermediate values of biomass above water, but also pasture and clear cuts); (2) specular reflection (mostly open water and airstrips); (3) diffuse backscatter (upland forest); (4) double bounce (mostly flooded forest, but also urban areas).

Considering knowledge gained in previous field campaigns in the Coari region, image samples of arbitrary size (11 rows by 11 pixels) were selected as representative of the aforementioned surface cover types. They were used to obtain DN statistics and semivariograms, as well as to verify the performance of the USTC classification by means of the confusion matrix. DN statistics for each surface cover type and for different polarization configurations are shown in **Tables 1, 2, and 3**.

Semivariograms computed for each cover type per polarization configuration are shown in **Figure 4**. Water semivariograms are essentially flat for all polarizations. For flooded vegetation, at LHH and LHV, γ (h) rises up to a lag distance of 4 pixels, then curves into a flat plateau. In LVV configuration, γ (h) rises up to a lag distance of 3 pixels, curves into a flat plateau up to a lag distanced of 7 pixels, and then regularly increases. For upland forest, the semivariogram at LHH presents a regular increase of γ (h). In LHV configuration, γ (h) rises up to a lag distance of 6 pixels, and then steadily decreases. At LVV, γ (h) steadily increases up to a lag distance of 7 pixels, and then reaches a flat plateau. Results for flooded forest indicate that γ (h) increases smoothly and regularly in LHH configuration. At LVV, γ (h) rises up to a lag distance of 3 pixels, then smoothly decreases. At LHV, γ (h) rises up to a lag distance of 3 pixels, then curves into a flat plateau.

Table 1 – DN statistics of 11x11-pixel samples in the L-band, HH polarization

LHH CONFIGURATION				
DN STATISTICS	**FLD. VEG.**	**WATER**	**UPL. FOR.**	**FLD. FOR.**
Median:	106	21	177	243
Mean:	104.0	20.9	174.8	241.6
Variance:	231.0	4.0	462.2	81.0

Table 2 – DN statistics of 11x11-pixel samples in the L-band, HV polarization

LHV CONFIGURATION				
DN STATISTICS	**FLD. VEG.**	**WATER**	**UPL. FOR.**	**FLD. FOR.**
Median:	63	33	136	185
Mean:	62.8	33.3	135.8	183.3
Variance:	70.5	7.8	313.2	256.0

Table 3 – DN statistics of 11x11-pixel samples in the L-band, VV polarization

LVV CONFIGURATION				
DN STATISTICS	**FLD. VEG.**	**WATER**	**UPL. FOR.**	**FLD. FOR.**
Median:	185	20	194	242
Mean:	182.2	20.7	193.8	240.4
Variance:	497.2	4.8	272.2	121.0

4.2 USTC Classification

Semivariograms of different surface cover types for each polarization configuration are clearly distinct (**Figure 4**), justifying the application of USTC to the R99SAR image mosaics. Classification results in the Coari test site for individual LHH, LHV and LVV image mosaics are shown in **Figures 1, 2 and 3**, respectively. Pixels classified as pertaining to specular reflection (blue) outline water bodies, such as the Solimões River, Coari Lake, and a large number of small lakes, as well as the airstrip of the Coari airport. Pixels classified as related to predominantly forward backscatter (cyan) are interpreted as flooded vegetation (macrophyte stands) that mostly surrounds water bodies in the high flood season. In such a climatic context, classified pixels also include the tree tops where only the canopy crown is exposed above water. Furthermore, clear cuts are characterized by DN range and textural signature similar to flooded vegetation. This aspect is better observed at HV and VV polarizations.

Figure 4 - Semivariograms of R99SAR 11x11-pixel samples obtained from the (A) LHH, (B) LHV and (C) LVV image mosaics. Areas interpreted as upland forest (green) are characterized by diffuse backscatter. This surface cover type is spatially dominant in all three polarizations. Flooded forest is characterized by the double bounce mechanism (yellow), which occurs in areas of alluvial influence. This mechanism is better observed in the LHH configuration, although LVV is capable of mapping some double bounce. Such an effect is not observed in the LHV configuration.

Table 4 – Confusion matrix (LHH) for USTC classification

CLASS (HH) \ % PIXELS	WATER	FLOODED VEGETATION	UPLAND FOREST	FLOODED FOREST
WATER	100	0	0	0
FLOODED VEGETATION	0	90.9	9.1	0
UPLAND FOREST	0	0	100	0
FLOODED FOREST	0	0	0	100

Table 5 – Confusion matrix (LHV) for USTC classification

CLASS (HV) \ % PIXELS	WATER	FLOODED VEGETATION	UPLAND FOREST	FLOODED FOREST
WATER	100	0	0	0
FLOODED VEGETATION	0	100	0	0
UPLAND FOREST	0	0	100	0
FLOODED FOREST	0	0	98.3	1.7

Table 6 – Confusion matrix (LVV) for USTC classification

CLASS (VV) \ % PIXELS	WATER	FLOODED VEGETATION	UPLAND FOREST	FLOODED FOREST
WATER	100	0	0	0
FLOODED VEGETATION	0	0	100	0
UPLAND FOREST	0	0	100	0
FLOODED FOREST	0	0	0	100

Confusion matrixes for the 11x11-pixel samples used in USTC classification of LHH, LHV and LVV image mosaics are shown in **Tables 4, 5 and 6**, respectively. The LHH configuration presents the best classification results, where only 9.1% of flooded vegetation is misclassified as upland forest.

Regarding the LHV image mosaic, the confusion matrix highlighted that 98.3% of flooded forest is misclassified as upland forest. This result can be explained by visual inspection of semivariograms in **Figure 4B**, in which both surface cover types present similar behavior. Furthermore, the double bounce mechanism characteristic of flooded forest is not observed. The confusion matrix for the LVV image mosaic shows that pixels in the flooded vegetation sample are completely misclassified as upland forest.

4.3 Analysis of covariance and correlation matrixes

The analysis of covariance and correlation matrixes enables the interpreter to choose pairs of images that best highlight surface cover types. Such an approach was applied to the multi-polarized L-band R99SAR image mosaics (**Table 7**). Results demonstrate that LHH and LVV present the best correlation, while the least correlated pair is LHH and LHV.

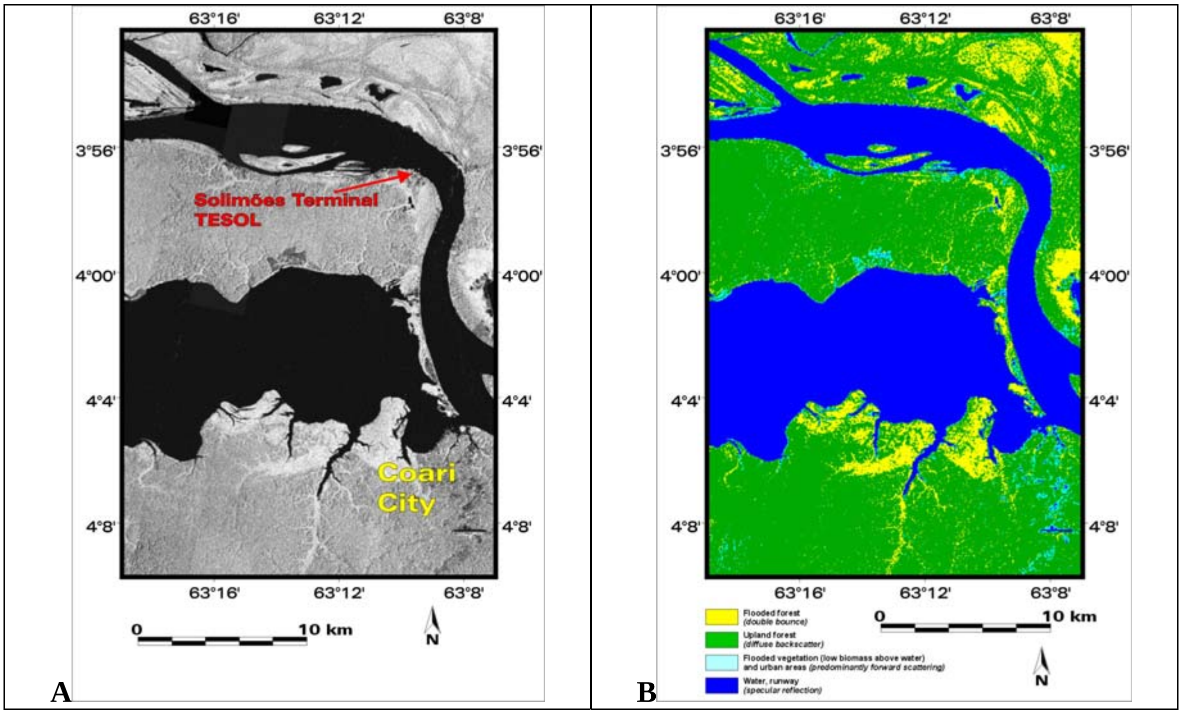

Figure 1 – R99SAR original LHH image mosaic (A), and corresponding USTC classification result (B). Pixels are labeled as: water (blue) = 34.8%; flooded vegetation (cyan) = 2.4%; upland forest (green) = 54.1%; flooded forest (yellow) = 8.7%.

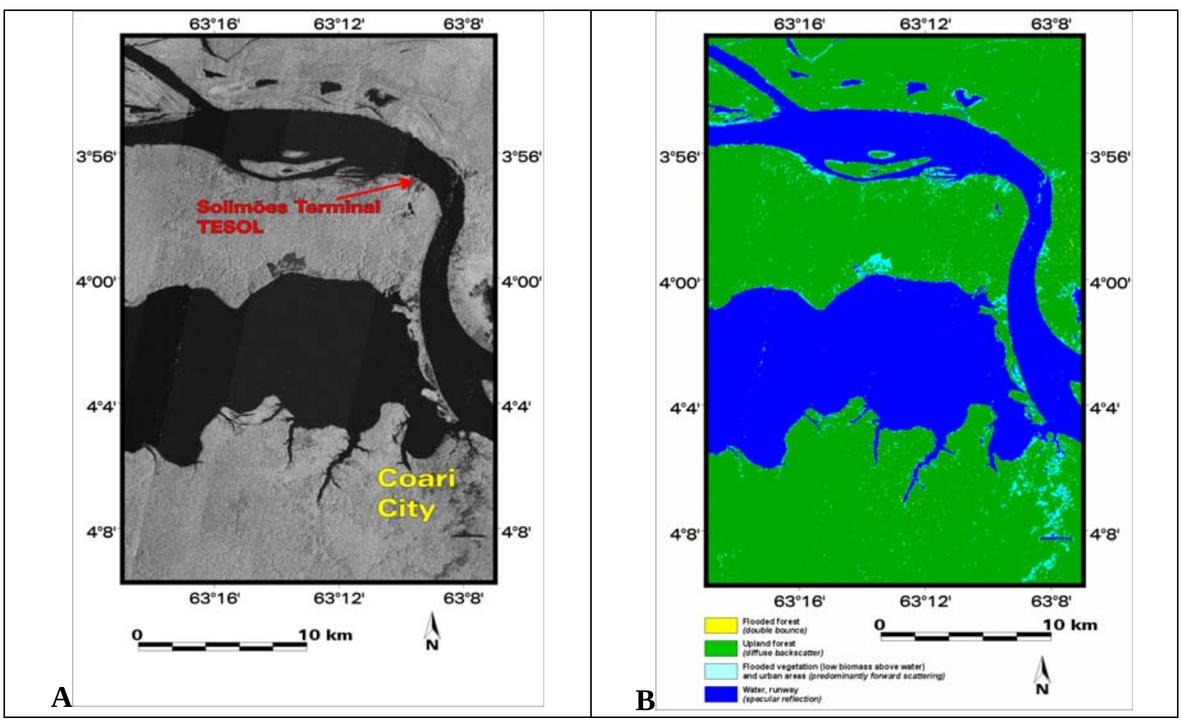

Figure 2 – R99SAR original LHV image mosaic (A), and corresponding USTC classification result (B). Pixels are labeled as: water (blue) = 34.6%; flooded vegetation (cyan) = 3.2%; upland forest (green) = 62.1%; flooded forest (yellow) = 0.1%.

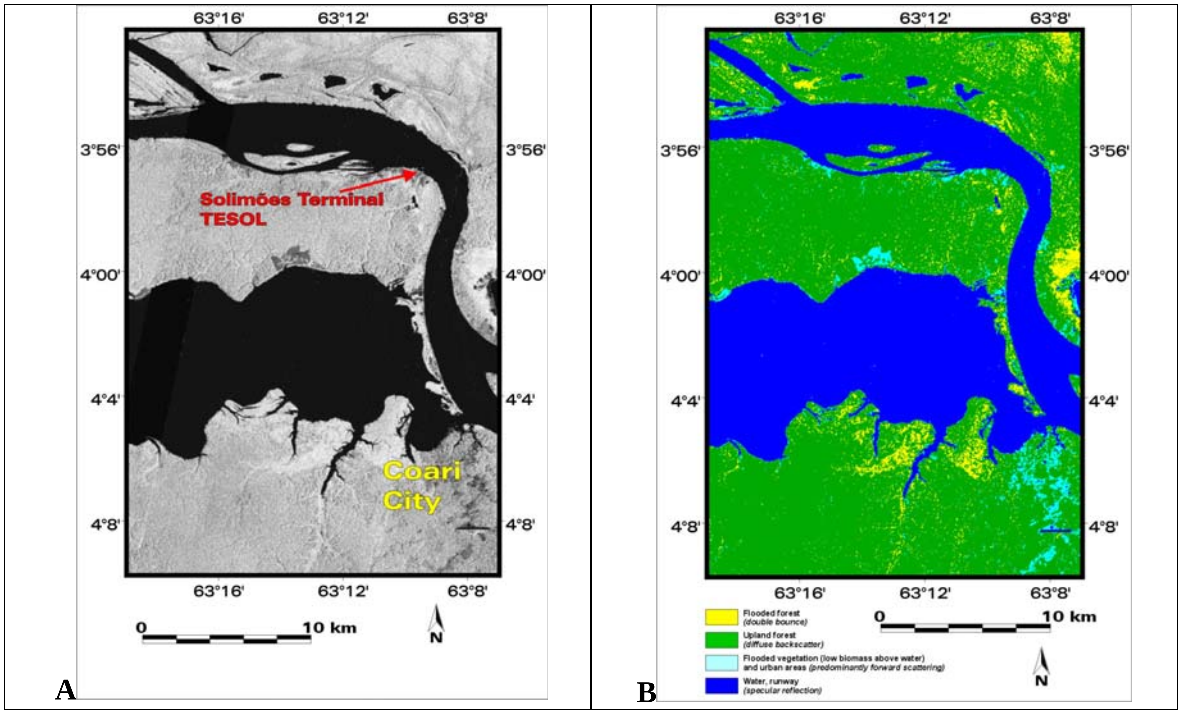

Figure 3 – R99SAR original LVV image mosaic (A), and corresponding USTC classification result (B). Pixels are labeled as: water (blue) = 35.2%; flooded vegetation (cyan) = 3.0%; upland forest (green) = 57.8%; flooded forest (yellow) = 4.1%.

Table 7 – Covariance (A) and correlation (B) matrixes of the R99SAR image mosaics

(A) COVARIANCE MATRIX			
	HH	HV	VV
HH	6109.21		
HV	4257.20	3310.94	
VV	6275.12	4583.54	6926.38

(B) CORRELATION MATRIX			
	HH	HV	VV
HH	1.0000		
HV	0.9466	1.0000	
VV	0.9646	0.9571	1.0000

In order to improve overall results of the USTC classification, the least correlated pair of **Table 7B** (LHH and LHV) was jointly processed (**Figure 5**). Results of LHH+LHV USTC classification constituted an improvement in the delineation of some surface cover types (mostly flooded vegetation and clear cuts).

The confusion matrix for LHH+LHV USTC classification is shown in **Table 8**, where 100% of pixels are correctly classified for water, upland forest and flooded forest. A limited misclassification is observed for flooded vegetation (1.7% of pixels is misclassified as upland forest). The confusion matrix of **Table 8** presents better results if compared with the ones corresponding to the individual mosaics (**Tables 4, 5, and 6**).

5. Conclusions

R99SAR data were successfully processed in order to generate co-registered, uncalibrated multi-polarized image mosaics (LHH, LHV, and LVV). Calculated semivariograms from selected sample sites presented distinct signatures, thus justifying the use of the USTC classifier. The observation of confusion matrixes for classification results demonstrated that the LHH configuration yielded the best results for the individual mosaics.

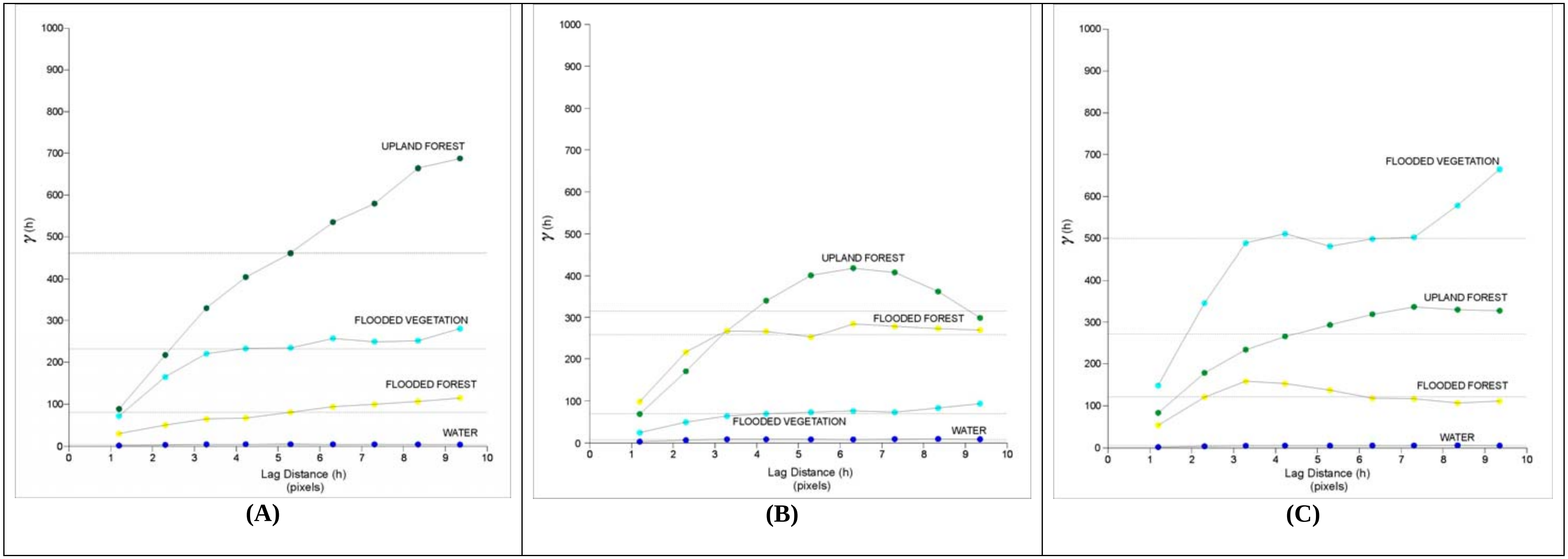

Figure 4 - Semivariograms of R99SAR 11x11-pixel samples obtained from the (A) LHH, (B) LHV and (C) LVV image mosaics

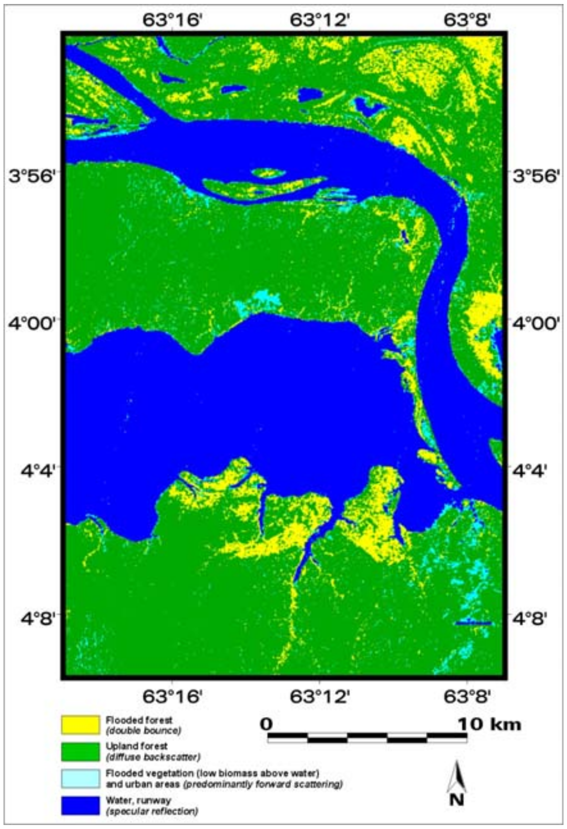

Figure 5 – USTC classification result of LHH+LHV image mosaics. Pixels are labeled as: water (blue) = 34.7%; flooded vegetation (cyan) = 3.2%; upland forest (green) = 54.7 %; flooded forest (yellow) = 7.4%

Table 8 – Confusion matrix (LHH+LHV) for USTC classification

CLASS (HH+HV) \ % PIXELS	WATER	FLOODED VEGETATION	UPLAND FOREST	FLOODED FOREST
WATER	100	0	0	0
FLOODED VEGETATION	0	98.3	1.7	0
UPLAND FOREST	0	0	100	0
FLOODED FOREST	0	0	0	100

In order to further improve the proposed approach, the least correlated mosaics (LHH and LHV) were jointly processed. The resulting confusion matrix presented better results if compared with the ones corresponding to the individual mosaics. Therefore, it has been demonstrated that information derived from R99SAR data is easy to interpret and constitutes a useful representation of areas with high oil sensitivity in the Amazon rain forest.

6. Reference

Miranda, F.P., Beisl, C.H., Forsberg, B.R., Arruda, W., Pedroso, E.C. Application of seasonal JERS-1 SAR full resolution image mosaics for identification of oil spill sensitivity in Western Amazonia, Brazil. In: I Congresso Internacional do Piatam: Ambiente, Homem, Gás e Petróleo. **Anais do 1º Congresso Piatam: Ambiente, Homem, Gás e Petróleo**, Manaus, 2005, p. 153.