K&C Final Report – Phase 4

Detecting new deforested areas in the Brazilian Amazon using ALOS-2 PALSAR-2 imageries

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Abstract **—** The primary objective of this regional-scale proposal was to evaluate the accuracy of the ALOS-2 PALSAR-2 ScanSAR based deforestation polygons detected over the Brazilian Amazon by the JICA-JAXA Forest Early Warning System in the Tropics (JJ-FAST). The data analysis was based on the deforestation polygons produced by the JJ-FAST for the Brazilian Amazon (years of 2017 and 2018). A set of 3,172 deforestation polygons was produced in 2017 for the Legal Amazon area. From May to December of 2018, a set of 3,821 polygons was detected. We validated 536 polygons from 2017 using visual interpretation of pairs of Landsat-8 scenes (total of Landsat-8 scenes = 50). We found an accuracy of 38%. Misdetections were mainly related to the land use changes, i.e., deforestation detections over already deforested areas. Visual analysis also detected a significant number of omissions as well. For 2018 data set, accuracy analysis presented similar results, that is, 39% of accuracy. The use of new version of JAXA´s forest/non-forest map that was included in the system in April 2008 as well as the inclusion of new HH, HH/HV, and HH*HV polarized images (only HV polarization was used in 2017) did not improve the accuracy, indicating that the deforestation detection from ScanSAR images is not straightforward. Nevertheless, the JJ-FAST is still an important tool to complement optical-based systems of deforestation detection already developed for the Brazilian Amazon. On the other hand, ALOS-2 StripMap dual-pol and quad-pol images showed promising results to discriminate representative land use and land cover classes from both Amazonia and Cerrado ecosystems.

Index Terms**—**ALOS-2 PALSAR-2, K&C Initiative, Amazonia, ScanSAR, deforestation monitoring, JJ-FAST.

I. INTRODUCTION

Since 2004, near real-time deforestation monitoring over the Brazilian Amazon has been carried out by the National Institute for Space Research (INPE) based on the Real Time Deforestation Detection System (DETER) program. Current DETER-B relies on Resourcesat-1 and Resourcesat-2 AWIFS satellite with the 56-meter spatial resolution and 5-day temporal resolution. The deforestation data from DETER-B have been used by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) for operational, law enforcement purposes. However, the use of orbital optical sensors to detect deforestation in the tropical rainforest region is somewhat constrained because new deforestations are detected only in conditions of free cloud coverage. Regions over dense tropical forests are obscured by clouds approximately 70% of the time. Some areas remain covered for several years. This problem affects critically the time spend by IBAMA´s agents to react against the ongoing deforestation processes.

In 2007, IBAMA became part of the ALOS Kyoto and Carbon (K&C) Initiative, conducting a project to implement an operational system to detect new deforestations that complements the optical systems and thereby supports field law enforcement activities. In 2017, JICA and JAXA launched a fully-automated system of detecting new deforestations over 77 countries with tropical forests, known as JICA-JAXA Forest Early Warning System in the Tropics (JJ-FAST). This system provides polygons of deforestation over the forested areas every 45 days in 1° x 1° regular cells based on the analysis of two consecutive pairs of ScanSAR images.

Because JJ-FAST is a fully-automated system, accuracy analysis for specific ecosystems is required by different users. JAXA´s policy to distribute 50 ALOS-2 PALSAR-2 scenes per year and per approved project, regardless of image acquisition mode, was also a good opportunity to explore, in more detail, the potential of PALSAR-2 images to discriminate representative land use and land cover (LULC) classes from Brazilian Amazon and from tropical savanna (Cerrado).

II. DESCRIPTION OF THE PROJECT

A. *Objectives and relevance to the K&C drivers*

The overall objective of this regional-scale proposal was to evaluate the potential of ALOS-2 ScanSAR mode images over the Brazilian Amazon to detect new deforestations for law enforcement procedures by the agents from Brazilian

Institute of Environment and Renewable Natural Resources (IBAMA). The specific objective of this report was two-fold: a) to validate the accuracy of the deforestation polygons provided by JJ-FAST in 2017 and 2018 over the Brazilian Legal Amazônia; and b) to assess the potential of ALOS-2 PALSAR-2 StripMap images to discriminate LULC classes from the Brazilian Amazon and Cerrado.

The results of this project will greatly contribute for environmental conservation of tropical rainfall forests by reducing clear-cut deforestations and, consequently, reducing CO_2 emission to atmosphere. The achievements of this proposal will complement the well-established but restricted optical monitoring systems of deforestation detections in near real time.

B. *Work approach*

A script in the QGIS software was developed by the IBAMA´s Remote Sensing Center to download polygons detected by the JJ-FAST and to make them available in the shapefile format. As some polygons overlapped each other during the time series processing and analysis of ScanSAR scenes, topological errors were corrected using the ArcGIS 10.1 software. In this project, polygons detected in 2017 (January to December) and 2018 (May to December) were considered.

For each polygon detected in 2017, a pair of colour composites (RGB, bands 4, 5 and 6) of Landsat-8 scenes downloaded from the USGS Earth Explorer platform was visually analysed in the computer screen (Figure 1). The first Landsat-8 scene (Date 1) was the first cloud-free scene available before 45 days of the detection of a deforestation polygon. The second Landsat-8 scene (Date 4) was the first cloud-free scene available after the detection of the same deforestation polygon.

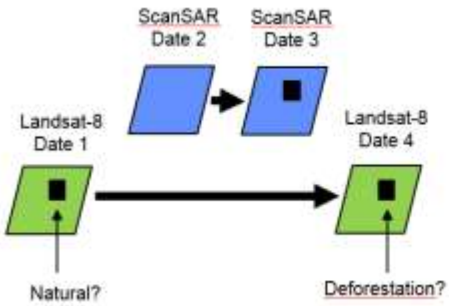


Figure 1: Strategy for visual interpretation of pair of Landsat-8 scenes to validate the accuracy of deforestation polygons provided by the JJ-FAST.

A set of 50 scenes was considered in this approach (22% of total number of Landsat scenes necessary to cover the entire Legal Amazonia, i.e., 229) (Figure 2). In this set of scenes, a total of 536 deforestation polygons were included.

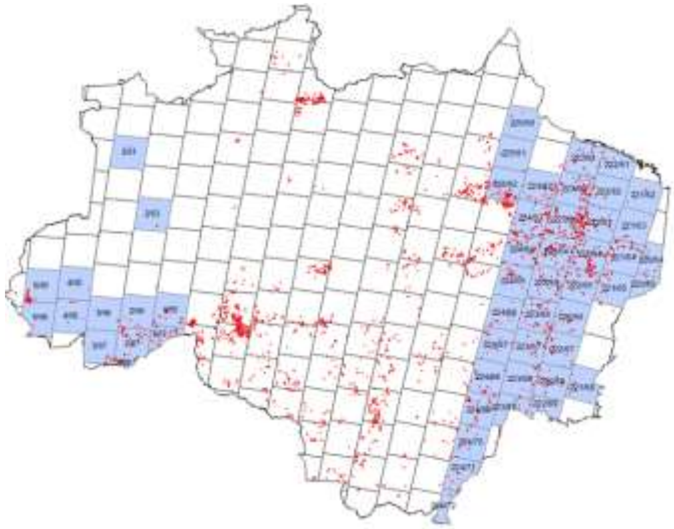


Figure 2: Path/rows of Landsat-8 scenes considered in this study to evaluate the accuracy of JJ-FAST to detect deforestation over the Legal Amazônia.

The same pairs of Landsat-8 scenes analysed to estimate the accuracy of JJ-FAST were used to estimate the omission errors. In this case, eight Landsat-8 path/rows were considered (Figure 3).

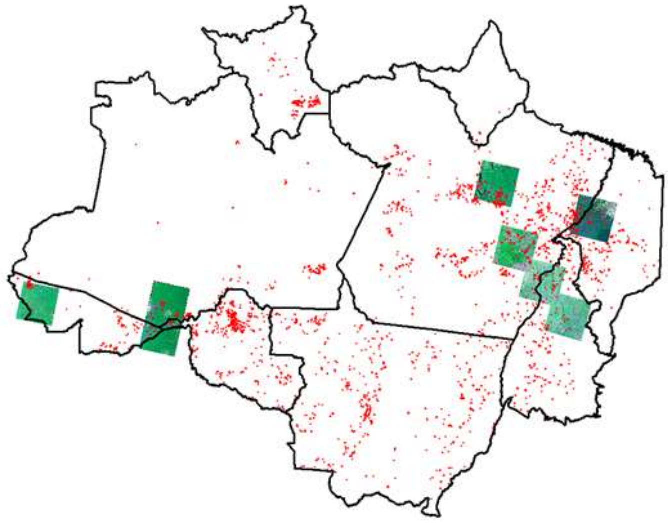


Figure 3: Path/rows of Landsat-8 scenes considered in this study to evaluate the omission errors of JJ-FAST to detect deforestation in 2017 over the Brazilian Legal Amazônia.

The accuracy of JJ-FAST polygons detected in 2018 in the Brazilian Legal Amazon (Figure 4) was analysed based on the time series of full resolution Sentinel-2A optical images available in the Sentinel Hub EO Browser. This browser allows the users to upload polygons in kml format and select the satellite (Landsat, Sentinel, Envisat, Proba-V, MODIS) and criteria such as time range and cloud coverage to inspect your area of interest. For each of nine states covering the Brazilian Legal Amazon, 30% of deforestation polygons from May to December of 2018 were selected randomly for validation purposes (Table 1).

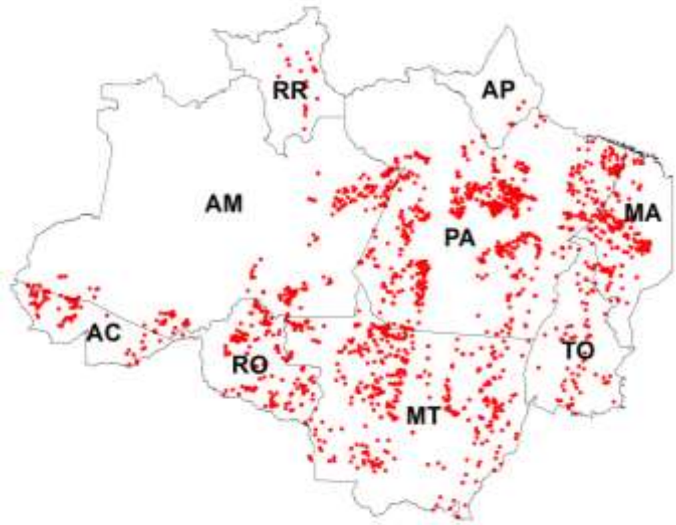


Figure 4: Deforestation polygons detected by the JJ-FAST in 2018 in the Brazilian Legal Amazon (total of 3821 polygons). State names: AC = Acre; AM = Amazonas; AP = Amapá; MA = Maranhão; MT = Mato Grosso; PA = Pará; RO = Rondônia; and RR = Roraima.

Table 1: Number of polygons detected by JJ-FAST from May 1st to December 31st, 2018 in each state of the Brazilian Legal Amazon and corresponding number of randomly selected samples for validation purposes.

State	Number of polygons	Number of randomly selected samples for validation
Acre	115	35
Amazonas	390	117
Amapá	18	5
Maranhão	248	74
Mato Grosso	1252	376
Pará	1325	398
Rondônia	325	98
Roraima	25	8
Tocantins	123	37
TOTAL	**3821**	**1146**

Field surveys were conducted in November, 2017 in Rondônia State (municipality of Porto Velho and Ariquemes) and in February, 2018 in Mato Grosso State (municipality of Juína) to characterize the field conditions of different deforestation polygons detected by the JJ-FAST. Two scientists from Tokyo Denki University (Dr. Manabu Watanabe and Dr. Christian Koyama) participated in these field surveys.

In this project, we also analyzed the capability of the target decomposition techniques and the polarimetric ratios applied to the ALOS/PALSAR-2 satellite images to discriminate the LULC classes in the Tapajós National Forest (TNF) region, Pará State. Three full polarimetric ALOS/PALSAR-2, single look complex (SLC) scenes were selected to generate the coherence [T3] and the covariance [C3] matrices to derive the Cloude-Pottier and the Freeman-Durden target decomposition attributes. The images were processed by the Cloude-Pottier polarimetric decomposition techniques to extract the entropy (H), anisotropy (A) and alpha angle (α) attributes, as well as by the Freeman-Durden decomposition target model to obtain the surface scattering, double bounce and volumetric attributes.

From the radiometrically calibrated images, we generated the backscatter coefficients, the cross polarized ratio (RC; HV/HH), the parallel polarized ratio (RP; VV/HH) and the Radar Forest Degradation Index (RFDI). The images resulting from these polarimetric attributes were processed by the Maximum Likelihood (MAXVER) classifier coupled with the Iterated Conditional Modes (ICM) contextual algorithm.

We also proposed a a workflow for LULC classification of ALOS-2 StripMap images over the Brazilian tropical savanna (Cerrado) biome (quad-pol, pixel size of 6 m, ascending orbit, incidence angle of 27.8º, and 1.1 processing level). The study area is located in the eastern Goiás State and in the northeastern Federal District of Brazil, which is a representative area of Cerrado in terms of the major LULC classes found in this biome (Figure 5). The following LULC classes were considered: forestlands; shrublands; grasslands; reforestations; croplands; pasturelands; bare soils/straws; urban areas; and water reservoirs. The proposed methodological approach combined polarimetric attributes, image segmentation, and machine learning procedures. A set of 125 attributes was generated using polarimetric ALOS-2 StripMap-2 images, including the van Zyl, Freeman-Durden, Yamaguchi, and Cloude-Pottier target decomposition components, incoherent polarimetric parameters (biomass indices and polarization ratios), and amplitude, HH-, HV-, VH-, and VV-polarized images. These attributes were classified using the Naive Bayes (NB), DT J48 (decision tree), Random Forest (RF), Multilayer Perceptron (MLP), and Support Vector Machine (SVM) algorithms.

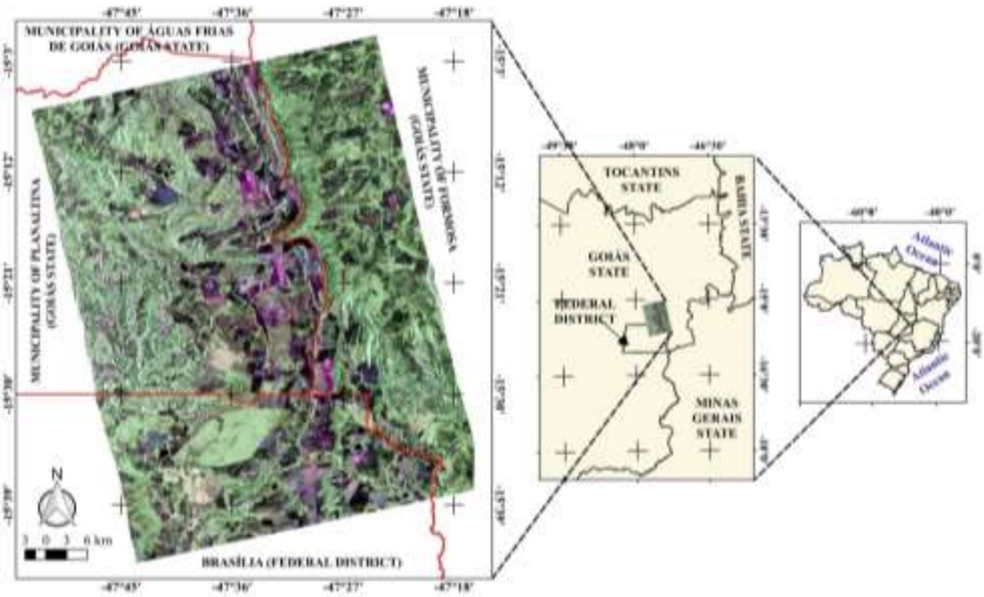


Figure 5: Study area located within the borders of the Federal District of Brazil and the municipalities of Planaltina and Formosa, Goiás State. The image corresponds to the RGB color composite of HH, HV, and VV polarizations from the ALOS-2/PALSAR-2 image (overpass: May 14, 2016).

III. Results and Summary

JJ-FAST deforestation polygons from 2017

A total of 3,172 polygons were detected by the JJ-FAST in 2017 over the Legal Amazônia (Figure 6). Pará (982 polygons), Mato Grosso (672 polygons) and Rondônia (476 polygons) were the states that presented the highest number of polygons. These states belong to the arc of deforestation, located in the southern part of the Brazilian Legal Amazon, where most of the deforestations are also detected by the INPE´s optical-based systems. They are also the states where IBAMA concentrates most of its actions to prevent and to combat illegal deforestations.

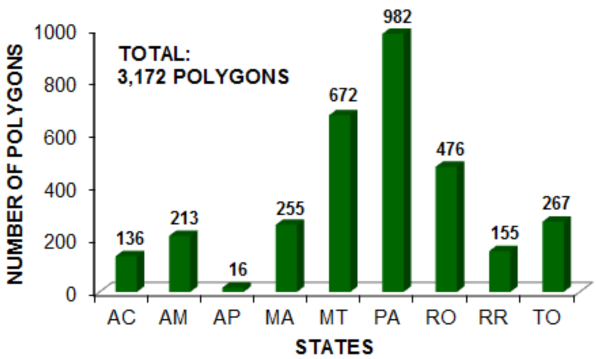


Figure 6: Total number of deforestation polygons detected by the JJ-FAST in 2017 over the states of Legal Amazônia.

Figure 7 shows the accuracy of the JJ-FAST deforestation detection. We found a global accuracy of 38%. Most of the misdetection was due to the deforestation detected over the already deforested areas (44% of polygons). This indicate potential problem in the forest/non-forest map used by JAXA to eliminate detections corresponding to land use changes or over the early-stage secondary vegetation. In order to increase the overall accuracy, the use of a mask of deforestation, for instance, the INPE´s shapefiles of annual deforestation produced by the PRODES project is a good possibility.

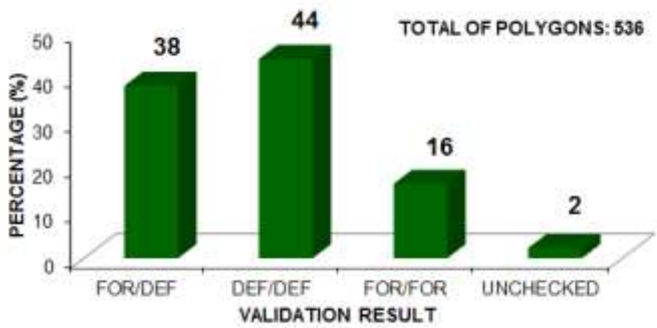
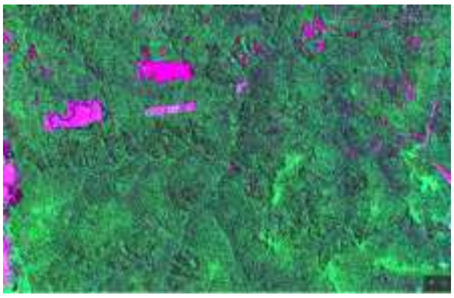


Figure 7: Percentage of correct and wrong deforestation detection by the JJ-FAST in 2017 over the Legal Amazônia.

Regarding the omission errors, we found a total of 187 deforestated areas that was not detected by the JJ-FAST within the eight scenes randomly selected (Figure 8).



(a)

(b)

Figure 8: Example of omission errors of JJ-FAST in detecting deforestation over the Brazilian Legal Amazon in 2017 (red circles). The images correspond to the Landsat-8 scenes (path/row: 001/66) from September 18, 2016 (a) and June 17, 2017 (b). Blue line corresponds to a polygon detected by the JJ-FAST in May 8, 2017.

JJ-FAST deforestation polygons from 2018

A total of 3,821 polygons were detected by the JJ-FAST from May to December, 2018 (Figure 9). Again, the states of Pará and Mato Grosso, with 1,325 and 1,252 polygons, presented the highest number of polygons. The Amazonas State, traditionally with low rates of deforestation, according to the Landsat-based Inpe´s PRODES project, presented a relatively high number of deforestations, especially in the borders of states of Acre and Pará.

Figure 10 shows the deforestation polygons detected per month (from May to December, 2018). The detection was especially high in the wet season (November and December). This agrees with the fact that deforestation in the Brazilian Amazon is more intense in the wet season. During the dry season, fire activities to burn trunks and branches left over in the terrain are dominant.

The accuracy for the 2018 data set was **39%**, similar to that found for 2017 data set. Figure 11 shows the accuracies found per state. Tocantins State presented the highest accuracy (78%) while the states of Amapá and Roraima presented the lowest accuracies (20%). Almost half of deforestation misdetection (49%) was related to detection in areas already deforested (Figure 12). A significant number of misdetection (24%) was also related to detection of areas already deforested that was burned during the dry season. The other misdetections were associated with seasonal changes in forestlands (forest/seasonal forest), removal of dead branches and shrubs (deforestation/bare soil), changes in the levels of surface water in floodplains (floodplain/floodplain), seasonal changes in shrublands (savanna/savanna) or forestlands (seasonal forest/seasonal forest or forest/forest).

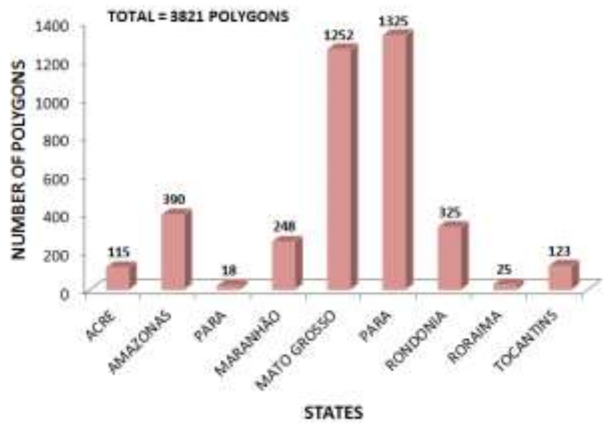


Figure 9: Number of polygons detected by the JJ-FAST in 2018 in the Brazilian Legal Amazonia per state.

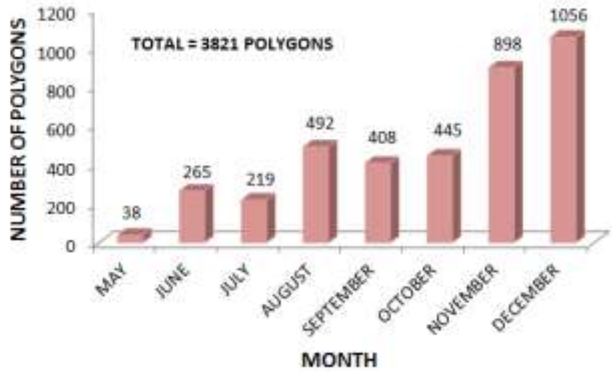


Figure 10: Number of polygons detected by the JJ-FAST in 2018 in the Brazilian Legal Amazonia per month.

Figure 11: Accuracy of deforestation detection by JJ-FAST per state.

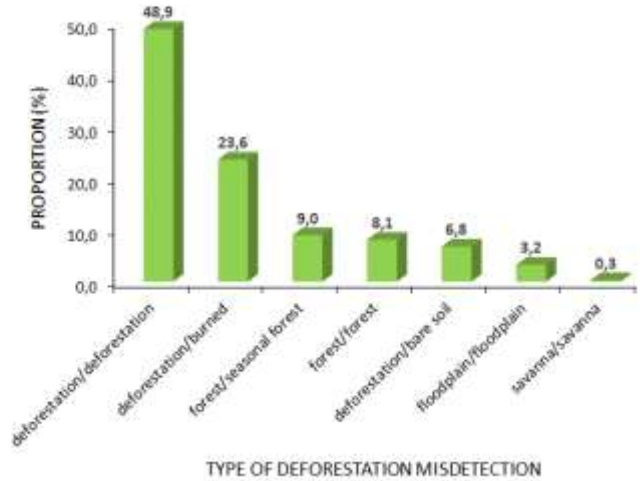


Figure 12: Types of deforestation misdetection related to the JJ-FAST system.

Field inspection

Field inspection showed that there is no single pattern of deforestation in the Legal Amazônia. In fact, deforestation in the Brazilian Amazon is a process. First, the biggest trees are cut by chainsaw and a number of trunks, branches and leaves are left over in the terrain (Figure 13a). This makes the backscattering in the L-band SAR images quite high. As the vegetation becomes dry, landowners usually make fire to clear the terrain (Figure 13b). In the final process of deforestation, tractors clean the terrain and the soil surface is almost completely bare (Figure 13c). In the last two cases, radar backscattered signals are much lower than that from the first case.

Nevertheless, in the field campaign conducted in February, 2018, deforestations detected in the ALOS-2 ScanSAR images were able to be confirmed in the field. Figures 14 and 15 shows the time series of ALOS-2 ScanSAR images obtained in January 19, February 2, and February 16 of 2018 in the HH and HV polarizations and in the municipality of Juína, Mato Grosso State. We can notice a clear increase in the area of deforestation in the HH polarization throughout the time series. The field inspection on February 26 showed an ongoing activity of deforestation, as shown by the Unmanned Aerial Vehicle and field photos.

Amazon LULC mapping from StripMap mode images

The classifications derived from the target decomposition attributes, mainly from the Cloude-Pottier technique (Figure 16), with a Kappa index of 0.75, presented a significant higher performance than those derived from the RC ratio, RP ratio, and RFDI. The attributes derived from Cloude-Pottier decomposition technique showed good potential to discriminate between the natural forest classes and less or no vegetation covered classes in the Tapajós National Forest region. However, the potential to distinguish ecological succession classes, utilizing H and α attributes was not so good.

The H attribute showed high mean values for the forest classes in different successional stages, indicating that the different scattering mechanisms contributed similarly the backscattering process. The A attribute showed higher sensitivity to discriminate the thematic classes considered in this study, presenting higher variability in the radiometric responses compared with H and α attributes. A attribute still presented high potential among the Cloude-Pottier decomposition attributes to discriminate degraded forests, mainly the forestlands affected by fire that occurred over the study area.

(a)

(b)

(c)

Figure 13: Different field conditions of deforestation in the Brazilian Amazon: trunks and branches are left over in the terrain (a), ongoing burning activity (b) and dominant bare soil (c).

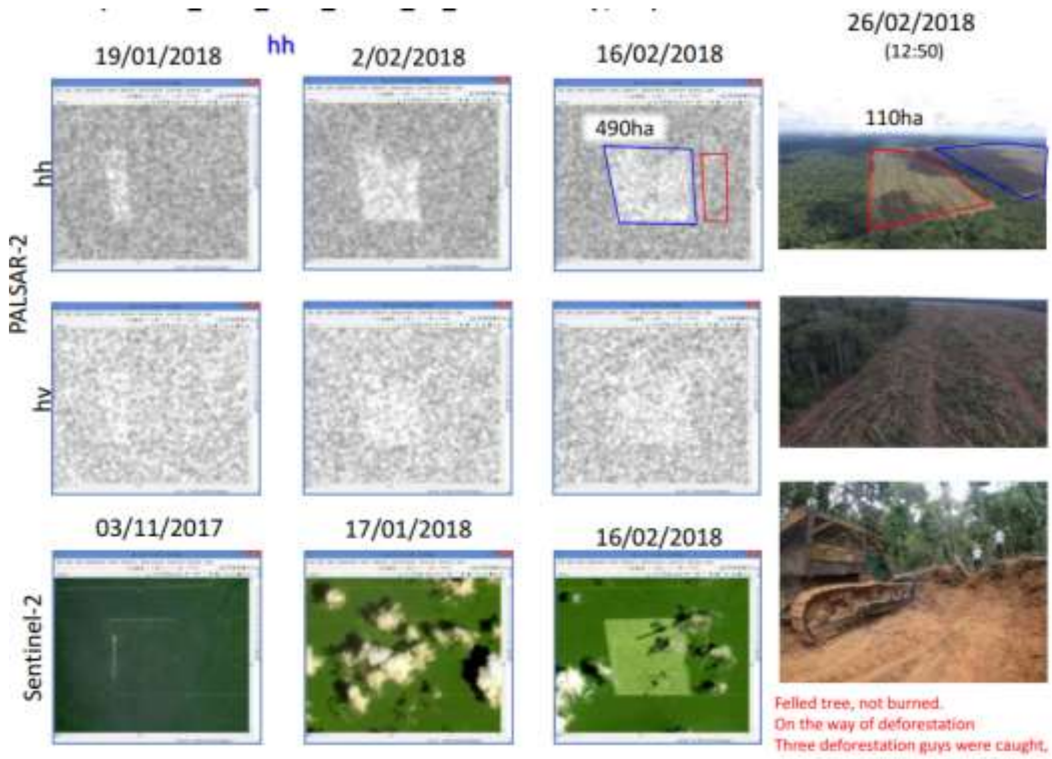


Figure 14: Example of deforestation detected by JJ-FAST in February, 2018 in the municipality of Juína, Mato Grosso State.

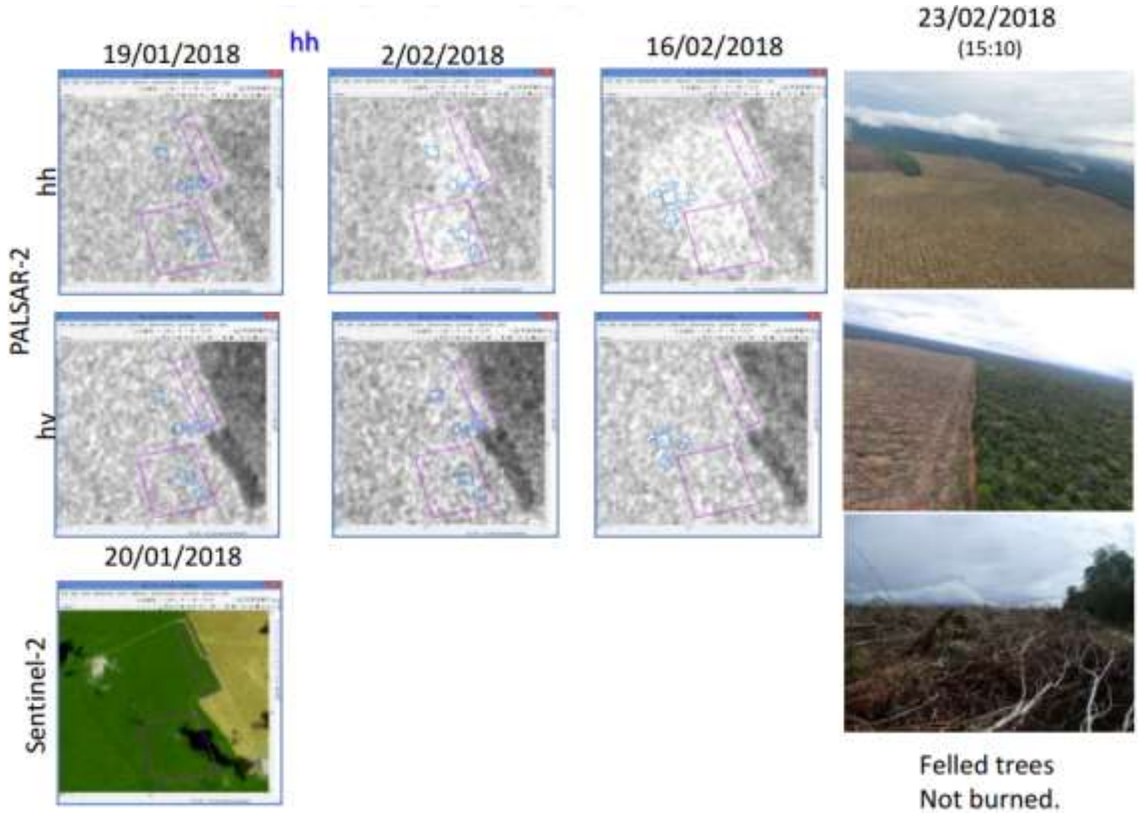


Figure 15: Another example of deforestation detected by JJ-FAST in February, 2018 in the municipality of Juína, Mato Grosso State.

Cerrado LULC mapping from StripMap mode images

Figure 17 presents the classification results obtained by the NB, DT J48, RF, MLP, and SVM classifiers. The NB classifier overestimated the urban areas, probably due to the presence of hilly terrain in the surrounding areas. The effects of layover and foreshortening on the ALOS-2 images from the study area probably generated some confusion in identifying urban areas. The DT J48 presented a more accurate identification of urban areas.

Two groups of classifiers were identified. The first group, which obtained the best results, was comprised by the RF, MLP, and SVM algorithms, which presented statistically similar Kappa indices. The second group, which had less accurate performances, was composed of the NB and DT J48 classifiers, which also presented statistically similar Kappa indices. The RF classifier outperformed DT J48, which agrees with the results found in the literature. DT J48, although more complex, did not present more accurate results in comparison with those obtained by the NB classifier.

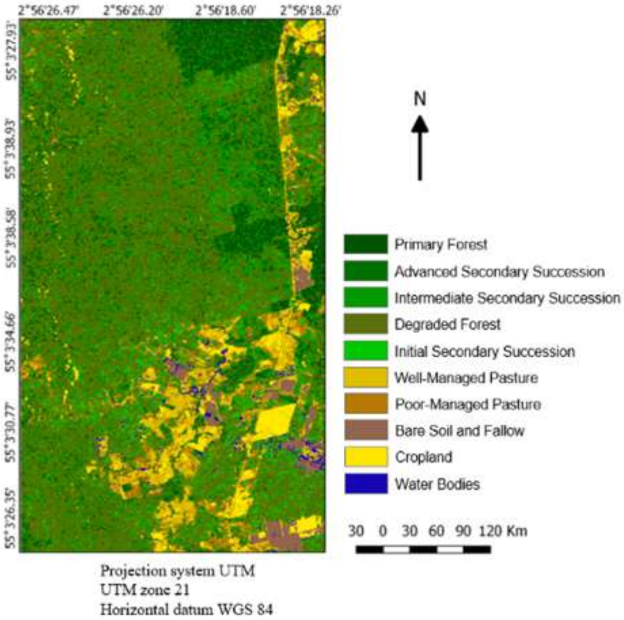


Figure 16: Spatial distribution of LULC classes derived from the Cloude-Pottier decomposition technique using ALOS/PALSAR-2 image.

As for the polarimetric attributes, we verified that the decompositions were important in the identification and classification of LULC classes. Volumetric scattering components (van Zyl, Freeman-Durden, and Yamaguchi theorems) were used in the DT J48 classification. These components are related to the structure of the vegetation canopy. However, a more detailed study should be performed to understand the mechanisms and types of scattering that prevailed in the scene.

IV. CONCLUSIONS

1. The JJ-FAST overall accuracy was rather low in both 2017 and 2018 data sets, regardless of the introduction of a more accurate forest/non-forest map and the use of HH, HV, HH*HV, and HH/HV images instead of only HV polarization, as done for the 2017 data set.

2. Detecting deforestation in the Brazilian Amazon is not a straightforward task since field conditions during the satellite overpass can change significantly depending on the time interval between the beginning of deforestation and the satellite overpass.

3. Target decomposition technique of ALOS-2 PALSAR-2 StripMap mode images showed promising results to discriminate representative LULC classes from the Brazilian Amazon and Cerrado.

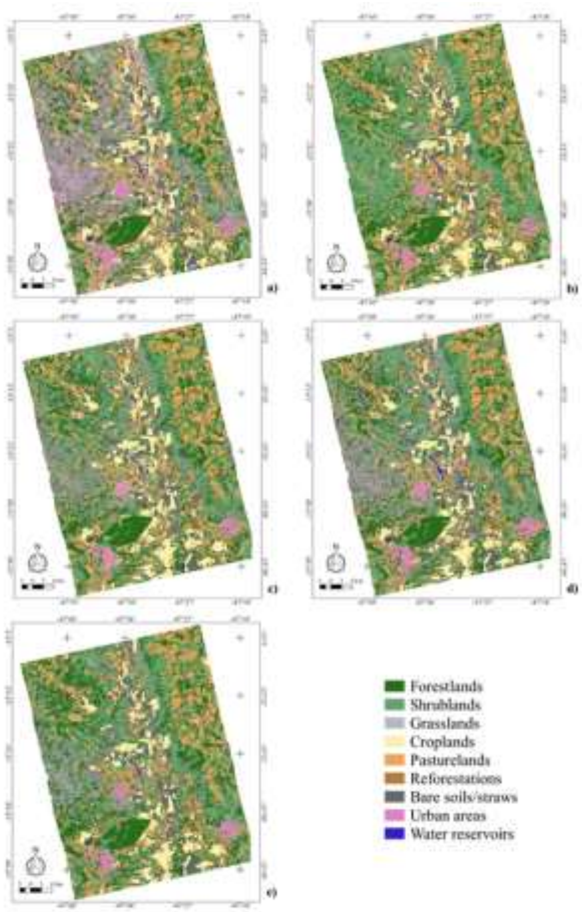


Figure 17: Classification results obtained with NB (a), DT J48 (b), RF (c), MLP (d), and SVM (e) algorithms and nine LULC classes.

V. PUBLICATIONS

We have submitted the following papers in scientific journals and symposia related to the KC Phase 4:

Camargo, F.F.; Sano, E.E.; Mura, J.C.; Almeida, C.A.; Almeida, T. A comparative assessment of machine learning techniques for land use and land cover classification of the Brazilian tropical savanna using ALOS-2/PALSAR-2 polarimetric images. Remote Sensing, v. 11, 1600, 16 p., 2019.

Camargo, F.F.; Sano, E.E.; Almeida, C.; Mura, J.C. Data mining techniques applied to ALOS-2/PALSAR-2 satellite imagery for land use and land cover classification (submitted to the Expert Systems with Applications journal).

Wiederkehr, N.; Santos, J.R.; Gama, F.; Sano, E.E. Analysis of the target decomposition techniques attributes and polarimetric ratios to discriminate land use and land cover classes of the Tapajós region (in press, Boletim de Ciências Geodésicas).

Camargo, F.F.; Sano, E.E.; Mura, J.C.; Almeida, C.M.; Almeida, T. Comparative assessment of machine learning techniques for land use/land cover classification in the Brazilian savanna using ALOS-2/PALSAR-2 polarimetric images (accepted to be presented in IGARSS 2019).

Camargo, F.F.; Sano, E.E.; Almeida, C.M.; Mura, J.C. Data mining techniques applied to ALOS-2/PALSAR-2 satellite imagery for land use and land cover classification (presented at the Brazilian Remote Sensing Symposium, Santos, SP, 14-17 April 2019).

ACKNOWLEDGEMENTS

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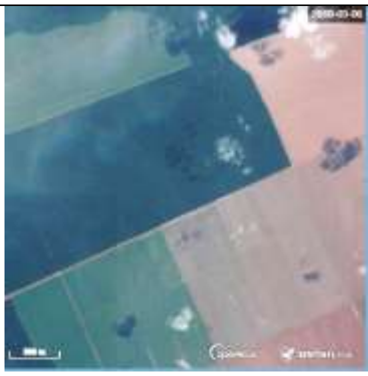
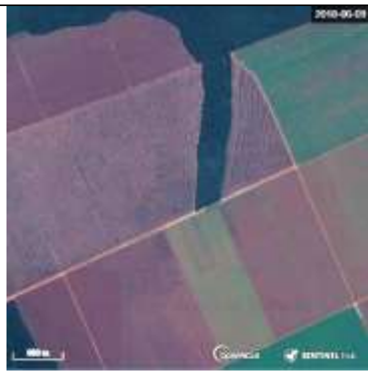
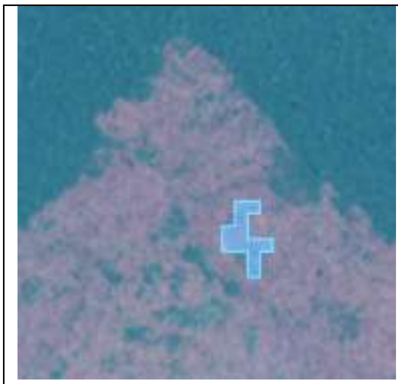
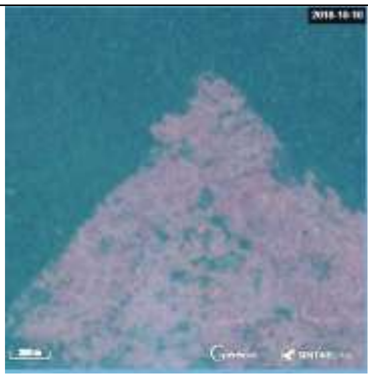
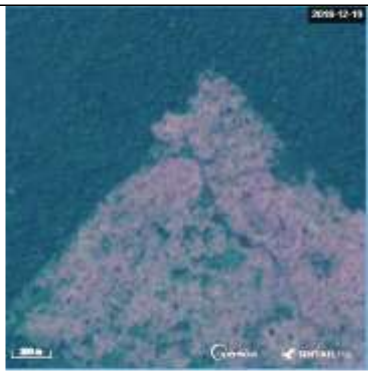
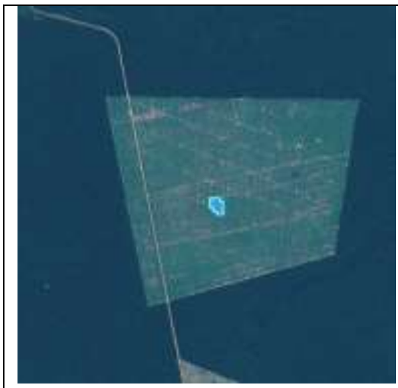
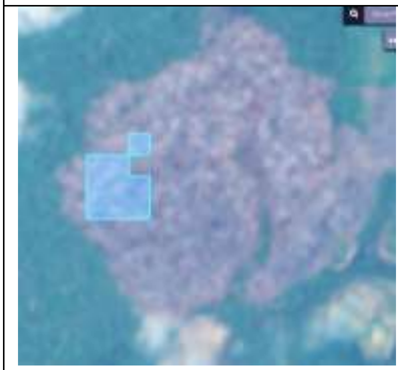
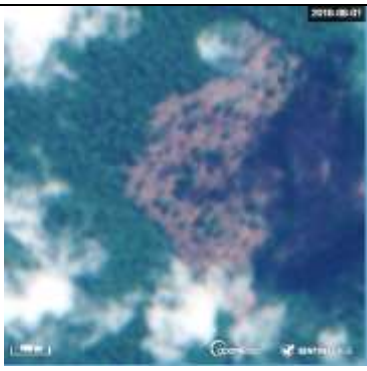
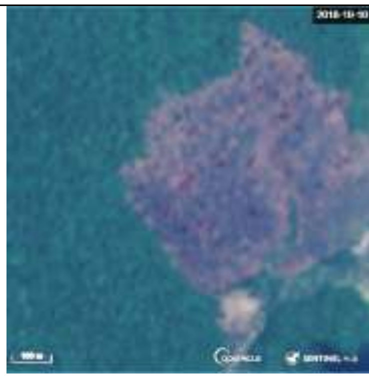
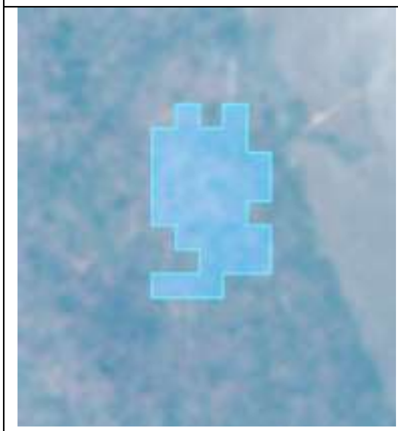
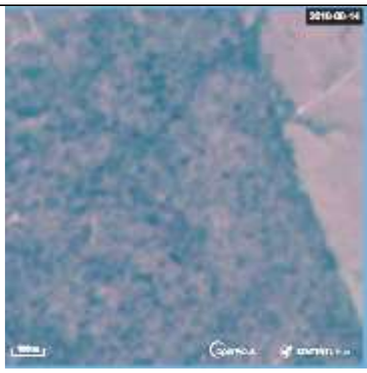
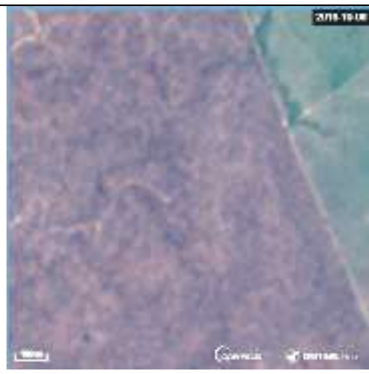
APPENDIX 1 – EXAMPLES OF POLYGONS DETECTED CORRECTLY

 JJ-FAST deforestation polygon over Tocantins State in 2018/11/07	 Sentinel-2 overpass in 2018/09/15 showing forest	 Sentinel-2 overpass in 2018/11/19 showing deforestation
 JJ-FAST deforestation polygon over Mato Grosso State in 2018/06/08	 Sentinel-2 overpass in 2018/03/06 showing forest	 Sentinel-2 overpass in 2018/06/09 showing deforestation
 JJ-FAST deforestation polygon over Amazonas State in 2018/11/14	 Sentinel-2 overpass in 2018/09/17 showing forest	 Sentinel-2 overpass in 2018/11/11 showing deforestation

APPENDIX 2 – EXAMPLES OF POLYGONS DETECTED UNCORRECTLY

 JJ-FAST misdetected deforestation polygon over Amazonas State in 2018/12/22	 Sentinel-2 overpass in 2018/10/10 showing deforestation	 Sentinel-2 overpass in 2018/12/19 showing deforestation
 JJ-FAST misdetected deforestation polygon over Maranhão State in 2018/06/11	 Sentinel-2 overpass in 2018/02/27 showing deforestation	 Sentinel-2 overpass in 2018/06/12 showing deforestation
 JJ-FAST misdetected deforestation polygon over Mato Grosso State in 2018/08/16	 Sentinel-2 overpass in 2018/06/18 showing deforestation	 Sentinel-2 overpass in 2018/08/12 showing deforestation

 JJ-FAST misdetected deforestation polygon over Mato Grosso State in 2018/08/16	 Sentinel-2 overpass in 2018/06/18 showing deforestation	 Sentinel-2 overpass in 2018/08/12 showing burned area
 JJ-FAST misdetected deforestation polygon over Amazonas State in 2018/10/03	 Sentinel-2 overpass in 2018/08/01 showing deforestation	 Sentinel-2 overpass in 2018/10/10 showing burned area
 JJ-FAST misdetected deforestation polygon over Rondônia State in 2018/10/13	 Sentinel-2 overpass in 2018/08/14 showing deforestation	 Sentinel-2 overpass in 2018/10/08 showing burned area