UPDATING AN OBJECT-BASED PAN-TROPICAL FOREST COVER CHANGE ASSESSMENT BY AUTOMATIC CHANGE DETECTION AND CLASSIFICATION

R. Beuchle [a], R. Raši, [a,b], C. Bodart [a,c], M. Vollmar [a], R. Seliger [a,d], F. Achard [a]

[a] Joint Research Centre of the EC, Institute for Environment and Sustainability, TP 440, 21027 Ispra (VA), Italy
[b] National Forest Centre, Forest Research Institute, 96092 Zvolen, Slovak Republic
[c] Food and Agricultural Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00100 Rome, Italy
[d] Engineering Ingegneria Informatica SpA, 00185 Rome, Italy

KEY WORDS: Global Forestry**,** Landsat, Object-based Change Detection, Classification, Segmentation, Sampling

ABSTRACT:

The TREES-3 project of the European Commission's Joint Research Centre is producing estimates of tropical forest cover changes during the period 1990 to 2010. Three reference years are considered: 1990, 2000 and 2010. This paper presents the method developed for the automatic processing of year 2010 with the assessment of performance of this method. The processing of imagery of year 2010 includes automatic segmentation, change detection and object spectral classification. The validated maps of forest cover changes for the period 1990-2000 are used as thematic input layer into the segmentation and classification process of the year 2010 images. Object-based change detection (OBCD) technique is applied using Tasselled Cap (TCap) parameters and spectral Euclidian Distances (ED). Objects detected as changed are classified by change vector analysis. The segmentation approach was tested on a subsample of 568 sample units over Brazil. The segmentation results for year 2010 are consistent with segmentation of imagery for the period 1990-2000, the segmentation statistics (number of objects, average objects size, average number of objects per sample site) remain stable between the two approaches. A two-step method of (a) change detection and (b) classification of changed objects was developed on basis of thresholding TCap variance and Euclidian Distance. The approach was tested over 281 sample units in the Brazilian biome of the Amazon, for which validated land cover information for the year 2010 was already available. The resulting overall accuracy of classification for the 281 sample units was 92.2%.

1. INTRODUCTION

The TREES project, based at the EC's Joint Research Centre in Italy, uses optical satellite imagery to provide information on the state of the world's tropical forest resources (Achard *et al.* 2002) and to assess the magnitude of tropical forest cover changes and related carbon emissions for the given time periods (Achard *et al.* 2004). The TREES-3 phase started in 2007 with the objective to produce new estimates of forest cover changes for the periods 1990 to 2000 and 2000 to 2010 at pan-tropical scale from optical satellite imagery (Landsat-TM type). Through this project the JRC was a main partner of the Food and Agricultural Organisation (FAO) for the Remote Sensing Survey (RSS) of its Forest Resource Assessment's 2010 (FRA-2010) (FAO *et al.* 2009, see:
http://www.fao.org/forestry/fra/remotesensingsurvey/en/).

2. STUDY AREA AND DATA

The TREES-3 project uses a regular sample grid covering all countries of the pan-tropical belt (with the exception of Mexico), defined by sample units located at each degree confluence, leading to 4,016 sample units (Figure 1). For each sample unit satellite imagery is acquired and analysed for a 20km x 20km size tile (Figure 2), representing approximately 4 % of the total area of the tropics.

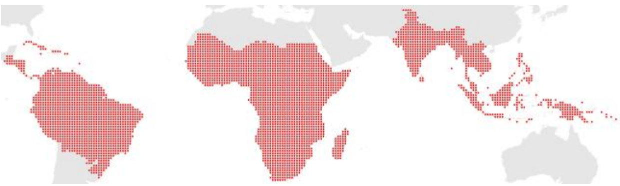

Figure 1. Distribution of the 4,016 pan-tropical TREES-3 sample units

In order to cover the 'epochs' 1990 and 2000, approximately 4,400 Landsat 5 and Landsat 7 scenes, selected as close as possible to years 1990 and 2000, were used to cut out image tiles (Beuchle *et al.* 2011).

For the epoch 2010, the number of good quality available Landsat TM scenes covering the TREES-3 sample sites is more than 1,750 scenes (imagery acquired within the period 2009–2011). This number is lower than for the previous epochs due to failure of the scan line correction of Landsat 7 satellite in 2003 and the reduced acquisition capacity for Landsat 5 data due to the lack of on-board recording facility (Goward *et al.* 2006). From these 1,750 Landsat 5 TM scenes, good quality (i.e. cloud-free) imagery for the epoch 2010 is available for approximately 3,000 out of the circa 4000 tropical sample sites. For most of the remaining sample sites imagery from other sensors, such as ALOS-AVNIR-2, Deimos-DMC or RapidEye, has been identified and partly acquired.

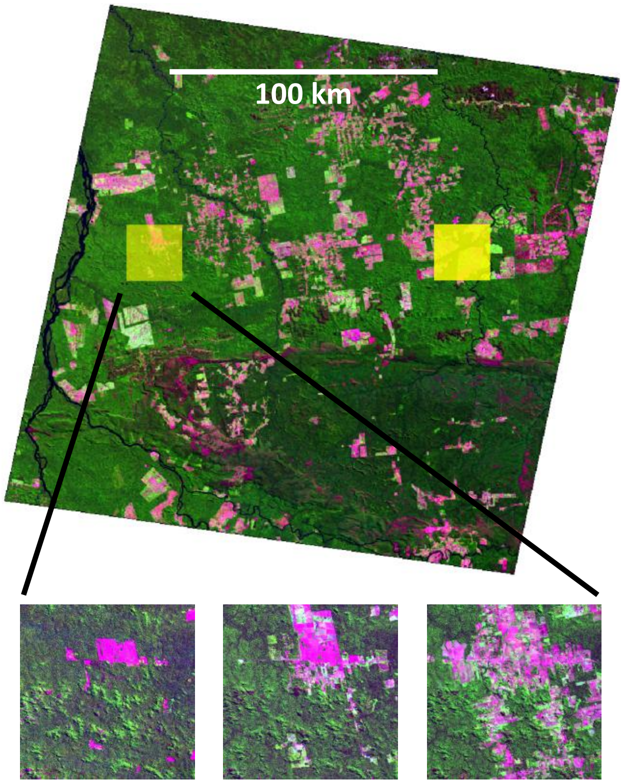

Figure 2. Top: example of the distribution of two sample sites (yellow tiles, size 20km x 20km) within a Landsat 7 TM scene (Path-Row 228-67) of year 2000. Bottom row: imagery over 20km x 20km tile for sample site 10˚South / 58˚West for year 1990 (left), year 2000 (centre) and year 2010 (right)

The image tiles were pre-processed, including geometrical adjustment, calibration (conversion to top of atmosphere reflectance), pseudo-invariant feature normalization, de-hazing, and cloud & cloud shadow mask production (Bodart *et al.* 2011). Multi-temporal image segmentation with a Minimum Mapping Unit (MMU) of 5 ha was applied, followed by a separate supervised land cover classification of the obtained objects for each date. The supervised classification was based on membership functions derived from a collection of representative training areas distributed across the tropics (Raši *et al.* 2011a). The supervised classifications of epochs 1990 and 2000 were then interactively validated and corrected by regional or national experts (Simonetti *et al.* 2011, Eva *et al.* 2012).

The classes used in the project are:

(1) Tree Cover (TC): tree height above 5 m, canopy density over 10%, object tree cover portion above 70%
(2) Tree Cover Mosaic (TCM): as above, object tree cover portion between 30% and 70%
(3) Other Wooded Land (OWL): plants with wooden stem, height between 0.5 and 5m, object OWL portion at least 50%, (including e.g. coffee and tea plantations)
(4) Other Land (OL): bare soil, built-up areas, all agricultural areas (excluding e.g. tea or coffee plantations)
(5) Water (WA)
(6) Cloud and Shadow (CS)
(7) No data (ND)

The resulting validated maps of period 1990-2000 are used as input for the process of updating the forest cover for the year 2010 through object-based image analysis (OBIA) of new imagery acquired for epoch 2010. This analysis includes two automated steps, change detection and classification of objects detected as changed.

3. METHODS

The digital processing steps of image segmentation, change detection and classification of changed objects for the imagery of epoch 2010 were carried out with Trimble eCognition 8.7 software (Baatz and Schäpe 2000).

3.1 Segmentation

The segmentation of the combined 1990/2000 imagery avoided potential sliver polygons by applying multi-temporal segmentation (Desclée *et al.* 2006), and by using a minimum mapping unit of 5ha through the process (Raši *et al.* 2011a). In order to avoid sliver polygons when combining the segmentation of imagery of year 2010 with objects from the 1990/2000 segmentation, the result of the validated maps of the period 1990/2000 is used as thematic input layer for the segmentation process of the image of year 2010.
This thematic layer is created by dissolving adjacent segments with the same land cover labels, i.e. the same change trajectory, for the two epochs 1990 and 2000 (Figure 3). The segments of this layer are used as “super-objects” for the segmentation of the year 2010 imagery. This layer is also used as thematic information in the subsequent change detection and classification steps to automatically label the new objects from the year 2010, using year 2000 classification as most recent thematic information.

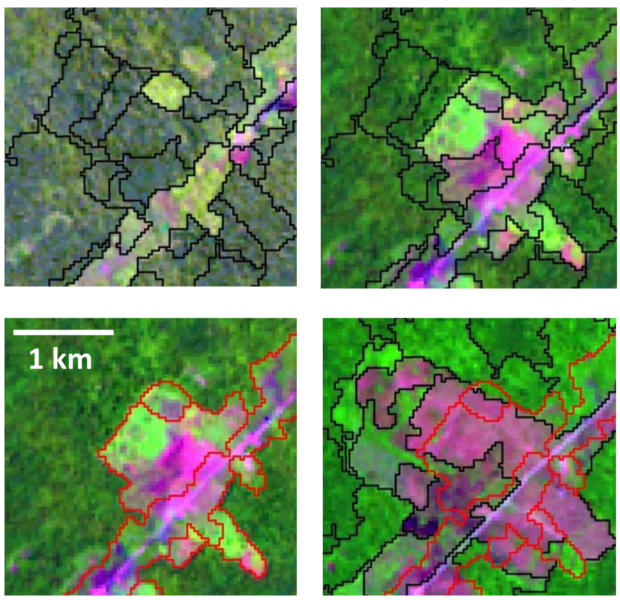

Figure 3. UL: Example of multi-temporal segmentation for the period 1990/2000 displayed on the image of year 1990; UR: the same segmentation on the image of year 2000; LL: dissolved segments with same change trajectory 1990/2000 (red) over the image of year 2000; LR: dissolved segments 1990/2000 (red) integrated in the segmentation of year 2010 over the image of year 2010

For each object produced through this process (the segmentation of 2010 imagery, combined with the thematic layer from the period 1990/2000), the land cover class information from the years 1990 and 2000 is available in the new object-related database, i.e. in the final output the class information of each object is available for the 3 epochs 1990, 2000 and 2010.

3.2 Change detection

Due to the large range of forest cover types and seasonal conditions between sample sites spread over the tropics, an automatic approach was designed with consideration of tile-related image characteristics of the years 2000 and 2010 during the change detection and classification steps.

We have tested various methods and parameters for change detection and we found that good results can be obtained using Tasseled Cap (TCap) approach and spectral Euclidian distances (ED) (Raši *et al.* 2011b). In order to detect unchanged objects, thresholding of the first two TCap components (brightness, greenness) and ED derived from TM channels 3, 4 and 5 was used sequentially:

a) for each object the differences between the TCap components from the year 2000 and from the year 2010 were compared to the TCap variance for all objects with the same land cover class in the year 2000 within the same sample unit.

b) for each object remaining unclassified comparing its TCap components from the year 2010 image to the range of the TCap mean values from all segments belonging to the object's corresponding class from the year 2000 image within the same sample unit.

c) for each object still remaining unclassified using the ED of Landsat bands 3,4 and 5

Thresholds on TCap variance (a,b) and the length of the ED (c) are applied for these three subsequent steps. If the values for a given object lie within one of these (corresponding) thresholds, the object is classified as unchanged and the object's land cover class from the year 2000 is used for the year 2010. All objects remaining unclassified are considered as 'changed' between year 2000 and year 2010.

The sequential approach considers two types of variability expected to occur in objects without real land cover change. The first type of variability is due to potential spectral differences of individual components within the object. It is related to the composition of pixels within the object (e.g. a "TCM" object can change its proportion of tree cover from 2000 to 2010) and can be defined as land cover class variability around a mean spectral value. The second type of variability is due to spectral changes for a given land cover class and can be defined as a spectral temporal variability around the land cover class mean spectral value. The land cover class spectral variability is calculated independently for each sample unit using the year 2000 validated classification. The Euclidean spectral distance is a simple parameter describing the spectral distance of the same object at two dates in a multi-dimensional spectral space (Landsat bands 3,4,5).

3.3 Classification of changed objects

For objects identified as unchanged by the change detection process, land cover labels from the year 2000 were used as year 2010 labels. The objects identified as changed were classified through a supervised classification based on a modified vector analysis of the first two TCap components. For this purpose the difference and variance of first two TCap components for each land cover class change trajectory was calculated using imagery and validated LC classification from the year 2000. The classification of the year 2010 change objects was done by comparing direction and value of the change vector in the two dimensional space of TCap components to the change vectors calculated for hypothetical LC change trajectories from the year 2000. The decision rule was based on the highest probability of change vector value and direction similarity. The exceptions are applied for the land cover classes "Water" and "Other Land". The labels of these two classes were directly copied from the year 2000 classification as (i) we assumed that large water bodies are relatively stable and that the temporary change of small water bodies was not of interest in this study and (ii) there is a low occurrence of OL conversion to OWL or TC in a 10 year period. In addition, we wanted to avoid wrong assignment of change for these areas due to the high variability of vegetation by e.g. various agriculture processes or different phenological stages of crops.

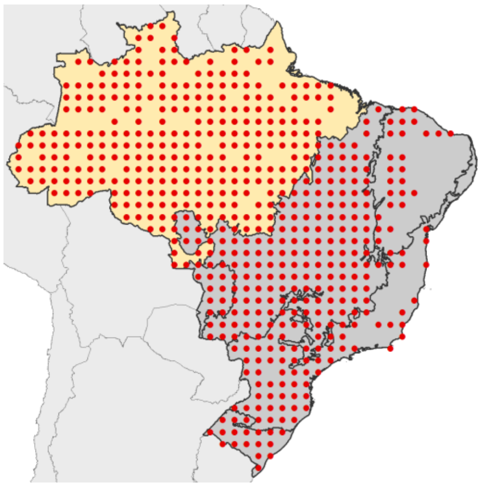

Figure 4. Distribution of the 568 sample units (SU) in Brazil used for assessment of segmentation consistency (red dots) and of the sub-sample of 281 SU used for assessment of change detection and classification of changed objects over the Amazon biome (red dots in yellow area)

4. RESULTS

We processed 568 sample units located in Brazil (Figure 4), covering a total of approx. 227,000 km^2. For these units imagery of year 2010 was processed through the steps of segmentation, change detection, classification of changed objects and production of land cover information for year 2010. For these SUs the consistency of the segmentation process was assessed.

For a sub-sample of 281 SUs located in the Amazon biome of Brazil (Figure 4) an expert validation of the results of year 2010 land cover has been carried out.

This validated sub-sample was used to assess the quality of the automatic change detection and classification process. In the future this assessment will be extended to the other biomes of Brazil (Eva *et al.* 2004, Bitencourt *et al.* 2007), namely the biomes of (i) Pantanal, Cerrado and Caatinga and (ii) Mata Atlântica and Pampa (IBGE 2004).

4.1 Segmentation

For the segmentation process the goal was to maintain the consistency of the segmentation approach for the 2010 imagery, i.e. to avoid significant change of the mean of object sizes, number of objects in respect to the multi-temporal segmentation with images from the year 1990 and year 2000 periods.

Segmentation approach	Overall number of objects	Overall average object area	Average number of objects per sample site
1990/2000	622595	36.52 ha	1096
2010	618034	36.78 ha	1087

Table 1. Comparison of segmentation statistics of 1990/2000 and 2010 approaches

Table 1 shows very small differences for the overall number of objects, for the overall average size and for the average number of objects for the 568 sample units in Brazil. The distributions of number of objects vs. object size are very similar for the two segmentation approaches (Figure 5).

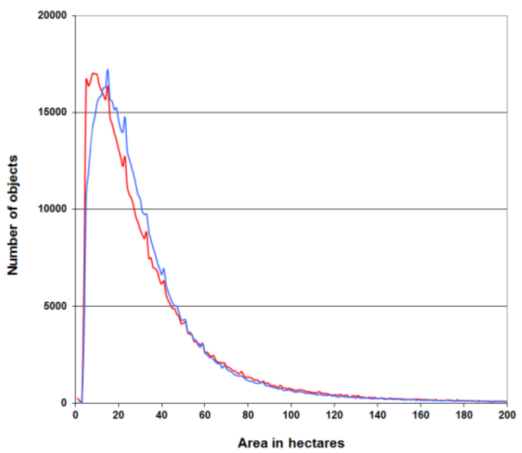

Figure 5. Distribution curves of the number of objects vs. object sizes (in ha) for the segmentation of year 1990 / 2000 images (blue) and for the segmentation of year 2010 (red)

4.2 Change detection

The change detection algorithm for the subset of 281 SU in the Amazon biome resulted in an overall percentage of correct assignment of change/no-change at 93.7% (Table 2). By aggregating the land cover classes to the main class groups relevant for deforestation estimates, i.e. Tree Cover (TC and TCM), Other Land (OWL, OL, WA) and No Data (CS and ND), the correct class assignment reaches 95.61% (Table 3).

The overall percentage of objects with (validated) land cover change is 13.4% for the 281 sample units, thus a good detection of objects without land cover change has a main impact on overall classification accuracy. Applying our change detection approach, the commission and omission errors of the NoChange class were low, meaning that the change detection worked well. The commission error is very small (2.25% for non-aggregated or 1.56% for aggregated classes) while the omission error of NoChange class is higher (5.41%. resp. 3.34%); however, objects wrongly detected as changed entered the classification step and there had the chance to be correctly classified.

	No Change	Change	Total	Com.E. %	Om.E. %	O.A. %
No Change	212193	4887	217080	2.25	5.14	-
Change	11487	29665	41152	27.91	14.14	
Total	223680	34552	258232	-	-	93.66
Total %	86.62	13.38	100.00	-	-	-

Table 2. Summary statistics showing the number of objects with land cover change / no-change and description of automatic change/no-change detection for the sub-sample of 281 SU. Rows – automated classification, columns – validated results

	No Change	Change	Total	Com.E. %	Om.E. %	O.A. %
No Change	225053	3568	228621	1.56	3.34	-
Change	7768	21843	29611	26.23	14.04	-
Total	232821	25411	258232	-	-	95.61
Total %	90.16	9.84	100	-	-	-

Table 3. Summary statistics showing the number of objects with land cover change/no-change and description of automatic change/no-change detection for the sub-sample of 281 SU (aggregated classes Tree Cover, Other Land, No Data). Rows – automated classification, columns – validated results

4.3 Classification

The percentage of correct detection of objects with land cover change is lower compared to objects without land cover change (Tables 2 and 3). Mainly the commission error is high; however a high commission error is in line with our concept of two phase-classification for the 2010 imagery; first change detection and copy of LC labels for unchanged objects and then classification of objects detected as changed. The quality of classification of changed objects depends on comparability of class change trajectories in the space of Tasselled Cap components in imagery from the year 2000 compared to the trajectories for each object between years 2000 and 2010. The results of LC classification for the objects detected as changed show a classification accuracy of 62.9% (Table 4) for the subset of 281 SUs in the Brazilian Amazon biome. After aggregation to the main classes (TC/TCM – OWL – OL/WA – CS/ND), the overall accuracy is 69.7%.

The overall classification accuracy for the 281 SU in the Brazilian biome of Amazon shows a percentage of 92.2% (Table 5). If the main classes are aggregated (TC/TCM – OWL – OL/WA – CS/ND), the percentage is at 93.6 %.

	Validated (281 SU Amazon biome)									
Classif.	TC	TCM	OWL	OL	WA	CS	ND	U	Total	C.E.
TC	1022	295	218	335	73	10	8		1961	52.12
TCM	2352	1169	380	631	82	5	2		4621	25.30
OWL	2324	1079	3693	1978	31				9105	40.56
OL	1107	524	1443	19403	136	6	1		22620	85.78
WA	21	5	12	27	338				401	84.29
CS	1431	19	18	34	8	186			1696	10.97
ND							62		62	100.00
U	374	13	43	223	14	13	1	3	684	0.44
Total	8631	3104	5807	22631	684	220	64	3	41152	
O.E.	11.84	37.66	63.60	85.74	49.42	84.55	96.88	100	**O.A.**	**62.88**

Table 4. Change matrix of the classification of changed objects (U = 'Unclassified')

	Validated (281 SU Amazon biome)									
Classif.	TC	TCM	OWL	OL	WA	CS	ND	U	Total	C.E.
TC	151884	730	546	1212	73	104	8		154557	1.73
TCM	2581	3961	462	824	82	7	2		7919	49.98
OWL	2562	1374	9792	2552	31				16311	39.97
OL	1337	712	2323	66361	182	10	1		70924	6.43
WA	21	5	14	91	5760				5891	2.22
CS	1435	24	19	145	10	203			1836	88.94
ND							81		81	0.00
U	374	13	43	228	14	13	1	25	711	96.48
Total	160194	6819	13199	71413	6152	337	93	25	258232	
O.E.	5.19	41.91	25.81	7.07	6.37	39.76	12.90	0.00	**O.A.**	**92.19**

Table 5. Change matrix of the overall classification (U = 'Unclassified')

5. DISCUSSION

The use of super-objects of the year 1990/2000 (i.e. adjacent objects with the same land cover for both years are dissolved) has proved to be a good solution for the segmentation of the year 2010 imagery. In addition, the use of the year 2000 land cover label for each 2010 object provides a priori information for the year 2010 change detection and classification steps. It also gives the possibility to trace back each object's land cover at the two previous time steps. At the same time the use of the year 1990/2000 outlines, together with the implementation of a minimum mapping unit of 5 ha for year 2010 avoids the creation of sliver polygons. The overall segmentation statistics for the year 2010 segmentation show that this segmentation is consistent with the multi-temporal segmentation obtained for period 1990/2000. However, our segmentation approach still needs to be tested when other satellite imagery.

The automatic change detection algorithm leads to an overall accuracy of 92.2% when comparing to a subset of 281 validated sample units the 281 sample units. Considering that the overall percentage of changed objects for this subset is 13.4%, it demonstrates that the automatic change detection and classification allows correct identification of more than 42% of the changes.

The main remaining errors are due to the wrong assignment of the class 'Other wooded land' (OWL). This can be explained by the difficulty in separating tree cover from shrub cover (i.e. 'Other wooded land') with class definitions based on plant height (max. 5 m for the class OWL).

This low accuracy has also to be related to the large amount of sample units which have been considered with imagery acquired under different atmospheric conditions. For images strongly contaminated by haze the process does not work in a satisfactory way.

Future development will consist in the extension of the assessment of change detection and classification of changed objects to areas outside the Amazon biome and to adapt the existing processing chain to other types of satellite data which are needed in order to cover areas where there are no acceptable Landsat images for the year 2010.

ACKNOWLEDGEMENTS

The authors would like to thank Evaristo de Miranda from the Brazilian Gabinete de Segurança Institucional (GSI), Claudio Spadotto, Wilson Holler and Osvaldo Oshiro from EMBRAPA GTE (Gestão Territorial Estratégica), both at Campinas (SP), Brazil and Silvia Carboni from the JRC for their excellent contribution during the validation phase of the TREES-3 sample sites over Brazil.

REFERENCES

Achard, F., Eva, H.D., Stibig, H.-J., Mayaux, P., Gallego, J., Richards, T. & Malingreau, J.P. (2002). Determination of deforestation rates of the world's humid tropical forests. *Science*, 297, pp. 999–1002.

Achard, F., Eva, H.D., Mayaux, P., Stibig, H.-J. & Belward, A. (2004). Improved estimates of net carbon emissions from land cover change in the tropics for the 1990s, *Global Biogeochemical. Cycles*, 18, GB2008, doi:10.1029/2003GB002142.

Baatz, M. & Schäpe A. (2000). Multiresolution Segmentation: an optimization approach for high quality multi-scale image segmentation. In J. Strobl, T. Blaschke & G. Griesebner (Eds), *Angewandte Geographische Informationsverarbeitung*, XII (pp.12-23). Heidelberg: Wichmann-Verlag.

Beuchle, R., Eva, H.D., Stibig, H.-J., Bodart, C., Brink, A., Mayaux, P., Johansson, D., Achard, F. & Belward A. (2011). A satellite dataset for tropical forest area change assessment. *International Journal of Remote Sensing*, 32:22, 7009-7031.

Bitencourt, M., de Mesquita Jr, H., Kuntschik, G., da Rocha, H., Furley, P. (2007), Cerrado vegetation study using optical and radar remote sensing: two Brazilian case studies. *Canadian Journal of Remote Sensing*, 2007, Vol. 33, No. 6 : pp. 468-480.

Bodart, C., Eva, H.D., Beuchle, R., Raši, R., Simonetti, D., Stibig, H.-J., Brink A., Lindquist, E., & Achard, F. (2011). Pre-processing of a sample of multi-scene and multi-date Landsat imagery used to monitor forest cover changes over the tropics. *ISPRS Journal of Photogrammetry and Remote Sensing*, 66(5), 555–563.

Desclée, B., Bogaert, P. & Defourny, P. (2006). Forest change detection by statistical object-based method. *Remote Sensing of Environment*, 102 (1-2), pp. 1-11.

Eva, H.D., Belward A., De Miranda, E., Di Bella, C., Gond, V., Huber, O., Jones, S., Sgrenzaroli, M., & Fritz, S. (2004). A land cover map of South America. *Global Change Biology*. 10, 732–745.

Eva, H.D., Achard, F., Beuchle, R., De Miranda, E., Carboni, S., Seliger, R., Vollmar, M., Holler, W., Oshiro, O., Barrena, V. & Gallego, J. (2012). Forest cover changes in tropical South and Central America from 1990 to 2005 and related carbon emissions and removals, *Remote Sensing*, Submitted

FAO, JRC, SDSU & UCL (2009): The 2010 Global Forest Resources Assessment Remote Sensing Survey: an outline of the objectives, data, methods and approach. *Forest Resources Assessment Working Paper 155*. Published by FAO with FRA RSS partners, Rome, 2009. http://www.fao.org/docrep/012/k7023e/k7023e00.pdf

Instituto Brasileiro de Geografia e Estatística IBGE (2004). Mapa de Biomas do Brasil; 2004; Available online: http://www.ibge.gov.br. (accessed on 21 February 2011).

Goward, S., Arvidson, N, T., Williams, D., Faundeen, J., Irons, J. & Franks, S. (2006), Historical record of Landsat global coverage: mission operations, NSLRSDA, and international cooperator stations. *Photogrammetric Engineering & Remote Sensing*, 72, pp. 1155-1169.

Raši, R., Bodart, C., Stibig, H.-J., Eva, H.D., Beuchle, R., Carboni, S., Simonetti, D. & Achard, F. (2011a). An automated approach for segmenting and classifying a large sample of multi-date Landsat imagery for pan-tropical forest monitoring. *Remote Sensing of Environment*. 115(22), 3659-3669.

Raši, R., Kissiyar, O. & Vollmar, M. (2011b). Land cover change detection thresholds for Landsat data samples. 2011 6th International Workshop on the Analysis of Multi-Temporal Remote Sensing Images, Trento, Italy, 12.-14. July 2011, *Multi-Temp 2011 - Proceedings* , art. no. 6005084, pp. 205-208.

Simonetti, D., Beuchle, R. & Eva, H.D. (2011). User Manual for the JRC Land Cover/Use Change Validation Tool, *EUR 24683 EN*, Luxembourg: Publications Office of the European Union, 2011.