TREES-3 - Forest cover change assessment for tropical South and Central America based on a systematic sampling of medium resolution satellite imagery– data, methods and first results for year 2010

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Abstract.
The TREES-3 project of the European Commission's Joint Research Centre has monitored tropical forest cover change with medium to high resolution satellite imagery for the reference years 1990, 2000 and 2010 on basis of a regular grid of 10 km x 10 km samples located at every full degree confluence, giving a total of 1230 sample sites for tropical South and Central America and the Caribbean. For the years 1990 and 2000, imagery from the Landsat sensors covered 99% of all sample sites, and for the year 2010, 86% of all sample, a further 13% of the sample sites are covered by imagery from other sensors, leaving 1% of the sample sites not covered due to the lack of good quality (cloud-free) images. All satellite images are pre-processed, including a check for geo-location, conversion to top-of-atmosphere reflectance, atmospheric correction (haze-correction and masking of cloud and cloud shadow) and normalized by a pseudo-invariant feature approach on basis of dense evergreen humid forest areas. Land cover maps are produced for each sample site and for each reference year with the following classes: tree cover, tree cover mosaic, other wooded land, other land and water. The first estimates of forest cover change between the years 1990 and 2010 have been produced by extrapolation of 175 samples to the study area of the Brazilian Cerrado biome. The resulting yearly deforestation rates for the Cerrado for the periods 1990-2000 and 2000-2010 were 0.6% and 1.0% respectively.

keywords: remote sensing, object-based image analysis, tropical forest, land cover change, Landsat

1. Introduction

Since more than 20 years, the TREES project of the European Commission's Joint Research Centre (JRC) has been monitoring the globe's tropical forests by means of remote sensing with the goal of reducing the uncertainties in measuring both forest changes and the ensuing emissions from such changes (Achard et al. 2002, Eva et al. 2012). In 2007 the TREES-3 project was launched, monitoring extent and areas of change of tropical forests from for the period 1990-2010 with medium to high resolution satellite imagery acquired for a regular sampling grid (Figure 1). A sample site of 10 km x 10 km at each full latitude and longitude confluence, leads to altogether more than 4000 sample sites in South and Central America and the Caribbean, sub-Saharan Africa and South and Southeast Asia (Beuchle et al. 2011), covering ca. 1 % of the total area. It is designed to produce tropical forest cover and forest cover change statistics and, in combination with biomass information, estimates on

carbon emissions and removals at regional and global scale. The outcome of the TREES-3 project was a major contribution to the global Forest Resource Assessment's Remote Sensing Survey 2010 (FRA-RSS-2010) carried out by the Food and Agricultural Organization (FAO) (FAO and JRC 2012).

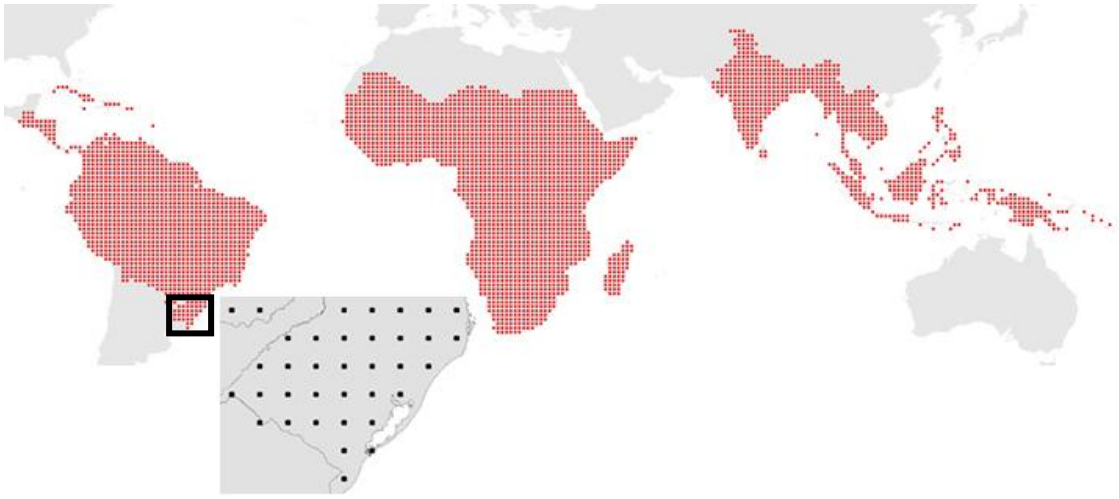

Figure 1: TREES-3 sampling scheme with detail (covering the Brazilian states of Rio Grande do Sul and Santa Catarina)

2. Methodology

2.1 Data

While for the first two epochs of the TREES-3 study the coverage for South and Central America and the Caribbean using imagery from Landsat 4, Landsat 5 ('year 1990 epoch') and Landsat 7 ('year 2000 epoch') was almost complete, imagery for the 'year 2010 epoch' suffered from the failure of Landsat 7's scan line correction.

Good quality 2010 imagery from the Landsat 5 sensor could be used for many areas in the Southern and Central part of tropical South America. However, due to the lack of an on-board recording facility, the number of recorded Landsat 5 images remains relatively small in comparison to Landsat 7, as the sensor depends fully on the recording capacity of the various Landsat receiving stations. In consequence, the number of good quality Landsat imagery for the areas with persistent cloud cover, namely for Central America, Ecuador, the Colombian Chaco, Northeast Venezuela, Guyana and the Brazilian Northeast coast is low.

In order to fill the resulting data gaps for the year 2010 epoch, alternative satellite data from four different sensors were identified and acquired (Figure 2) through the TropForest project from the European Space Agency (ESA), namely data from the RapidEye, AVNIR-2, Kompsat-2 and Deimos-1 sensors (Table 1).

sensor	Landsat (5 or 7)	RapidEye	AVNIR-2	Kompsat-2	Deimos-1	No Data
sample sites covered 2010 (sum 1230)	1064	100	44	8	7	7
percentage of sample sites covered 2010	86,5%	8,1 %	3,6 %	0,6%	0,6%	0,6%
number of multi-spectral bands	6	5	4	3	3	n/a
ground resolution (multispectral bands)	30 m x 30 m	5 m x 5 m	10 m x 10 m	4 m x 4 m	22 m x 22 m	n/a
swath width	185 km	77 km	70 km	15 km	600 km	n/a

Table 1: satellite imagery used for the year 2010 epoch

Figure 2: TREES-3 sources of satellite imagery for the year 2010 epoch for tropical South and Central America and the Caribbean

2.2 Pre-processing and Segmentation of Year 2010 Imagery

The pre-processing of the Landsat, ALOS AVNIR-2 and Deimos-1 imagery for the year 2010 was carried out using the same process used for images from the epochs of the years 1990 and 2000. This consisted of geometric correction (where necessary), conversion to top-of atmosphere reflectance, cloud and cloud shadow masking, haze correction and image radiometric normalization (Bodart et al. 2011). The pre-processing chain is currently adapted to RapidEye and Kompsat-2 data.

The segmentation process (with eCognition software) applied a Minimum Mapping Unit (MMU) of 5 ha. A thematic layer produced by dissolving adjacent objects with the same change trajectory between the years 1990 and 2000 was used as input in order to avoid sliver polygons due to small geometric inconsistencies between images of different acquisition dates (Raši et al. 2012).

2.3 Change Detection and Classification of Change of Year 2010 Imagery

In order to create land cover information based on 2010 imagery an automatic process of object-based change detection and classification of change was designed for Landsat images and the process adapted for AVNIR-2 data (Raši et al. 2012, Vollmar et al. 2012). The resulting land cover information produced by the process is then checked and corrected, if necessary, by visual interpretation. A specifically designed software tool is used for this step (Simonetti et al. 2011).

The land cover classes applied are ‘tree cover’, ‘tree cover mosaic’, ‘other wooded land’, ‘other land cover’ and ‘water’ (Table 2), additional classes are ‘cloud and cloud shadow’ and ‘no data’.

tree cover	tree height > 5 m, tree layer density > 10%, continuous layer of trees covers > 70 % of mapping unit (object)
tree cover mosaic	tree height > 5 m, tree layer density > 10%, discontinuous layer of trees covers between 30% and 70 % of mapping unit (object)

other wooded land	mapping unit (object) is covered with > 50% of a layer of shrubs, tree re-growth or mixed vegetation with a mainly woody component
other land	land cover other than tree cover or other wooded land, including herbaceous cover, non-woody agricultural crops, bare soils, built-up areas
water	see and inland water

Table 2: TREES-3 land cover classes with definitions

2.4 Validated Land Cover Statistics and their Extrapolation

From 1230 sample sites covering tropical South America, Central America and the Caribbean, for 15 sample sites images are missing in either one or more of the epochs due to persistent cloud cover. For each of the remaining 1215 sample sites, good quality imagery and validated land cover maps exist for the three epochs (Figure 3).

The specific segmentation and classification process ensures that trajectories of land cover exist for all the sample site's objects over the three epochs.

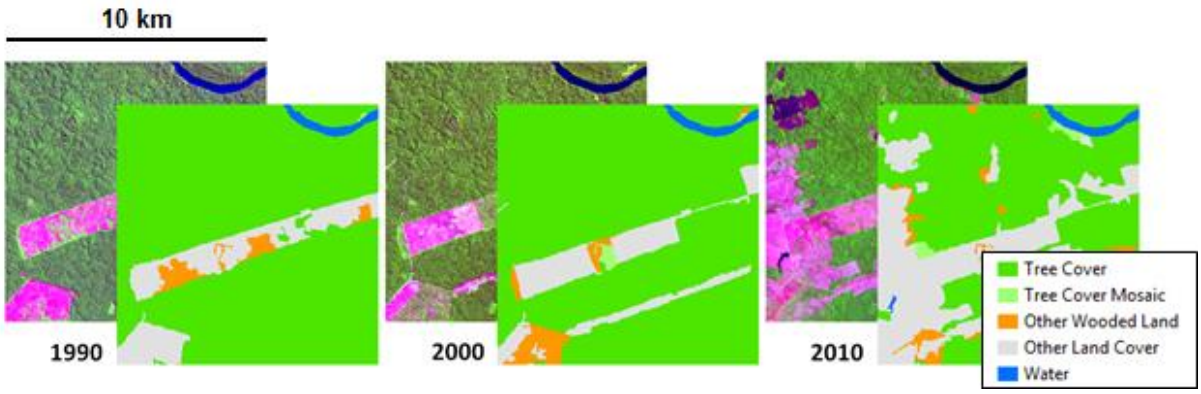

Figure 3: TREES-3 satellite imagery (three epochs) and corresponding validated land cover information (example Lat/Lon -9/-62 in Northern Rondônia)

For the extrapolation of the sample site's land cover change matrices to the study area with the Horvitz-Thompson Direct Expansion Estimator (Särndal et al. 1992), the following assumptions were made or steps were undertaken (Eva et al. 2012):

(i) A sample site is selected for a study zone if the sample center point falls within this study zone. A sample site may contain a portion of sea or area outside the study zone

(ii) Linear adjustment to the baseline dates of 30 June of the years 1990, 2000 and 2010 respectively, assuming that the land cover changes have linear trends during the given period

(iii) Area proportions are calculated for each sample site in relation to total visible land area, i.e. excluding cloudy cover and sea. It means that areas of cloud and cloud shadow within a sample site are considered as unbiased data loss

(iv) Application of a local average from the neighboring sample sites as surrogate results for missing sample sites (because of low quality imagery due to cloud cover)

(v) 'Calibration' (offsetting) of year 2000–2010 change matrix to the year 1990–2000 change matrix in order to correct potential small inconsistencies in year 2000 due to temporal linear adjustments

(vi) Sample sites with a portion of sea (or with a portion of land outside the study region) are weighted as other sample sites (without sea and or fully within study zone) as compensation for sample sites which center point falls outside the study zone but with a portion of area within the study zone

(vii) Weighting of the sample sites according to their latitude (cosinus(lat)) in order to account for the resulting higher spatial sampling frequency away from the equator

3. Results and Discussion

3.1 Land Cover and Land Cover Change

The Southern border of the Amazon rainforest is the most dynamic area in terms of land cover change related to deforestation (Morton et al. 2006). The results of the TREES-3 land cover and land cover change assessment of the years 1990-2010 are shown in Figure 4 along the southern border of the "Tropical Rainforest" ecozone as defined by FAO (FAO 2001). The buffer area in Brazil (Fig. 4: shown in white) contains eight Brazilian federal states, namely Pará, Amapá, Maranhão, Tocantins, Goiás, Mato Grosso, Mato Grosso do Sul, Rondônia, and the Brazilian Federal District. Bolivia and Paraguay (both in light orange) were added to the area, both countries have also high deforestation rates during our study period (Aide et al. 2012).

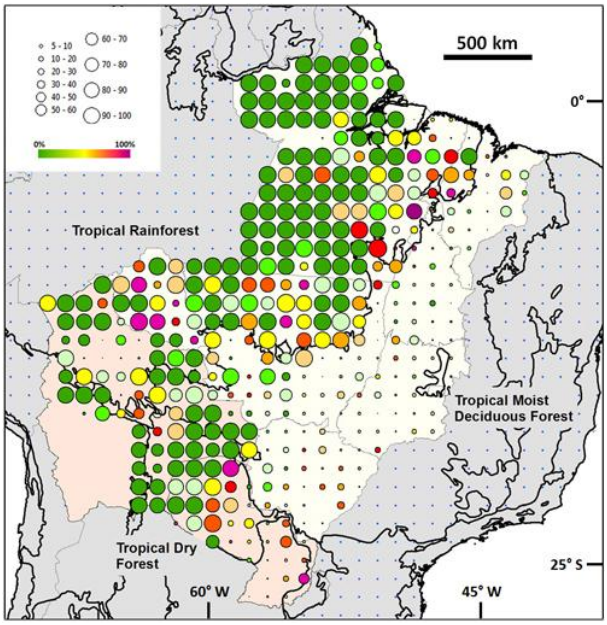

Figure 4a: Forest cover 1990 for each sample site in (in km²) with the percentage of deforested area thereof between 1990 and 2010. The size of the circles indicates the area of forest cover (in km²) in 1990, the colours show the percentage of the forest cover cleared between 1990 and 2010 (relative to year 1990).

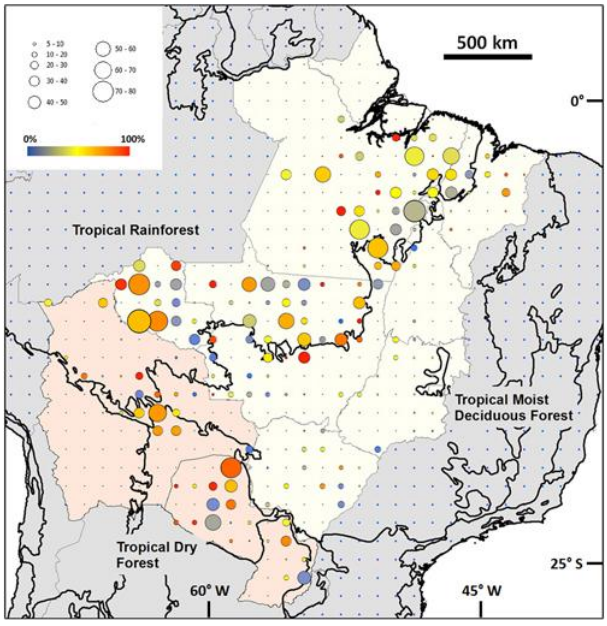

Figure 4b: Gross deforestation (in km²) 1990 – 2010 and the proportion of forest clearance for the second decade (year 2000 – 2010). The size of the circles indicates the area of forest cleared between 1990 and 2000; the colours show the proportion of the clearance during the period 2000 – 2010 with respect to the overall clearance (1990-2010).

Figure 4a shows that the sample sites with the highest percentages of loss of the year 1990 forest cover are found in southeastern Pará (82%), Rondônia (77%) and Central Paraguay (72%). It shows also that in some areas the a considerable amount of forest had been cleared

before the year 1990, for example in Central and Southern Rondônia, in Northern Mato Grosso and in Western Pará.

Figure 4b shows that for the sample site in the state of Pará mentioned above, 71% of the deforested area was cleared between 1990 and 2000, thus resulting in 29% for the following decade. Other sample sites in Pará with high deforestation figures show a more constant process, with proportions of 40% – 60% of the overall deforestation for year 2000 - 2010. Deforested areas in the eastern part of the state of Rondônia tend to have been deforested mainly in the first decade (year 1990-2000), whereas many sample sites in western and northern Rondônia have higher percentages of deforestation in the second decade.

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3.2 Extrapolation of Sample Statistics over the Area of the Brazilian Cerrado

The area of the Brazilian biome of the Cerrado (IBGE 2004), with an area of approximately 205 million hectares, is covered by woodlands, savannas, grasslands, and gallery and dry forests. It is the second largest of Brazil's major biomes, after Amazonia (Klink and Machado 2005). The rate of land cover change in the Cerrado is thought to be very high (Brannstrom et al. 2008, Sano et al. 2010), with a predominant change of forest and natural savanna to agricultural areas. The area of the biome taken into consideration (Figure 5) contains 175 sample units with land cover change information over the period 1990-2010.

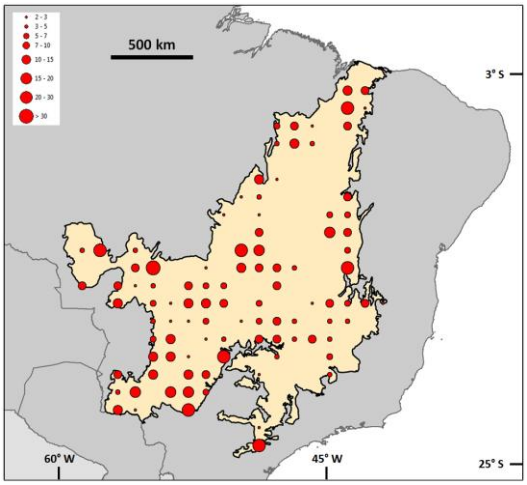

Figure 5: Area of the Brazilian Cerrado (light yellow) with areas of gross loss of forest for the years 1990–2010 (red dots, in km²)

Land Cover 1990	**Area (1000 ha)**	**S.E.**
Tree Cover	44,030	3,021
Tree Cover Mosaic	12,622	805
Other Wooded Land	75,708	3,365
Land Cover 2000	**Area (1000 ha)**	**S.E.**
Tree Cover	41,274	2,907
Tree Cover Mosaic	12,132	757
Other Wooded Land	71,837	3,304
Land Cover 2010	**Area (1000 ha)**	**S.E.**
Tree Cover	36,823	2,541
Tree Cover Mosaic	11,757	768
Other Wooded Land	69,460	3,205

Table 3: Total areas (in 1000 ha) for three land cover classes for the Brazilian Cerrado biome - years 1990, 2000 and 2010

In the Cerrado, the areas of all three land cover classes defined by woody vegetation are decreasing during both decades (Table 3). While the net loss of tree cover is higher in the second decade (2000-2010), the net loss of other wooded land was higher in the first decade (1990-2000). The area of tree cover mosaics has seen a stable decrease in both decades. While FAO reports Brazilian yearly national deforestation rates of approximately 0.5% for both decades (FAO 2010); our calculated yearly deforestation rates for the Cerrado area are higher, approximately 0.6% for the period 1990-2000 and 1.0% for the period 2000-2010.

4. Conclusions

The method developed has proved to be valid for estimation of land cover and land cover change (Eva et al. 2010, Eva et al. 2012) on regional, continental and global scale. For year 2010 the amount of available Landsat imagery decreased due to the failure of the scan line

correction of Landsat 7. In difference to the year 1990 and 2000 imagery, the usage of data from other satellite sensors has increased; however, the adaption of our Landsat image processing chain to other sensors is feasible (Vollmar et al. 2012). When combined with reliable regional or global biomass information, the TREES-3 land cover and land cover change information leads to a valid estimation of global tropical carbon emissions and removals. An accuracy assessment will be carried out for the results of year 2010 in complement to previous assessment of results for period 1990-2000 reported in Eva et al. 2012. This study has confirmed earlier work by Klink and Machado (2005) on the high rates of deforestation in the Cerrado, where agricultural expansion is a main driver.

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