Global tropical forest cover change assessment with medium spatial satellite imagery using a systematic sample grid – data, methods and first results

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Abstract. At the Joint Research Centre (JRC) of the European Commission, a methodology has been developed to monitor the pan-tropical forest cover with remote sensing data for the years 1990-2000-2005 in Latin America, Southeast Asia and Africa on the basis of over 4000 sample units sample units with a dimension of 20 km by 20 km located at every full latitude and longitude degree confluence. From the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) instruments, images with low cloud impact from the epochs around the years 1990, 2000 and 2005 were selected and subsets covering the sample units were cut-out, pre-processed, segmented and classified in five different land cover classes in order to build global and regional statistics on tropical forest cover change. The data was validated in three steps, internal correction of wrongly classified objects, external (national or regional) expert validation and internal harmonization of the data. In this paper, the data collection and the workflow of the forest cover change assessment for the epochs 1990 and 2000 is presented. Parts of the results for the Brazilian Amazon have been validated by comparing with interpretations of corresponding samples carried out by the Instituto Nacional de Pesquisas Espaciais (INPE), showing a very high correlation. Further, the figure produced by INPE through the PRODES program on gross deforestation for the years 1990-2000 was compared to the figure calculated on basis of the JRC results for the respective area, where the JRC estimate that was ca. 10% higher than the INPE estimate.

Keywords: tropical forest cover, monitoring, Landsat, object-based classification

1. Introduction

Tropical deforestation contributes approximately to 15% of the world's anthropogenic greenhouse gas emissions (estimates range from 7% to 25%), mainly through carbon dioxide emissions (van der Werf et al. 2009). However, uncertainties in this land use change flux of the global carbon budget are high. In this context, the TREES-3 project at the Joint Research Centre (JRC) of the European commission has developed a method to monitor the tropical forest cover on a global and regional scale with medium resolution satellite data on basis of a systematic sample grid (Eva et al. 2010, Achard et al. 2009), consisting in more than 4000 sample units for the global tropics. The data and statistics derived from the project are a major contribution to the Remote Sensing Survey (RSS) of the Forest Resource Assessment 2010 (FRA2010) carried out by the Food and Agriculture Organization (FAO) of the United Nations (UN) (Ridder 2007, FAO et al. 2009).

2. TREES-3 sampling scheme

At pan-topical level, sampling with medium resolution satellite imagery has been applied successfully (with sample areas from 10 km X 10 km to 50 km X 50 km) (Eva et al 2010). The TREES-3 sampling scheme consists in a 20 km X 20 km sample area at every latitude – longitude confluence point over the countries covered by tropical forest, leading to over 4000 sample units (figure 1). For tropical Latin America and the Caribbean (LAC), the number of sample units is at 1230; thereof Brazil is covered by 707 sample units. The resulting overall sampling rate is 3.4% (Eva et al. 2010). In the context of a collaborative partnership, the scheme was designed together with FAO for their FRA2010 RSS exercise, the FAO being responsible for the forest cover change assessment of the regions outside the pan-tropical belt.

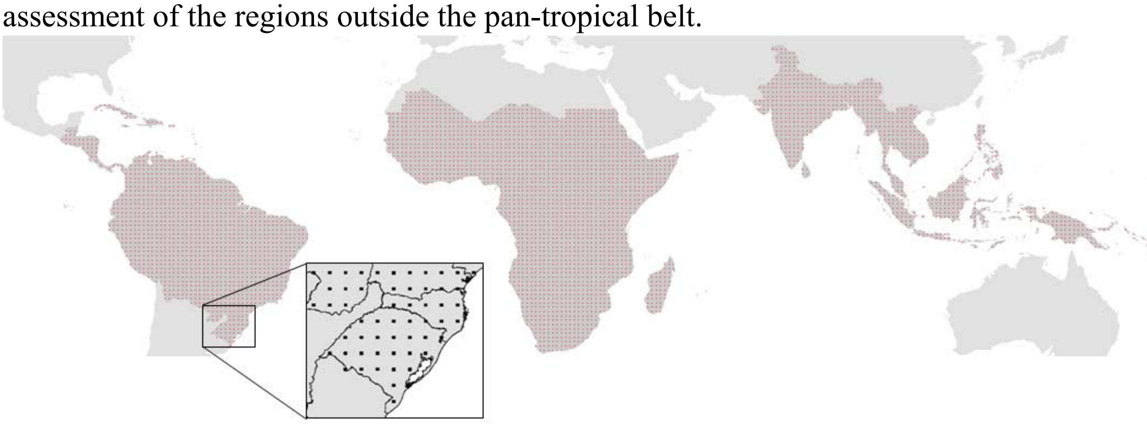
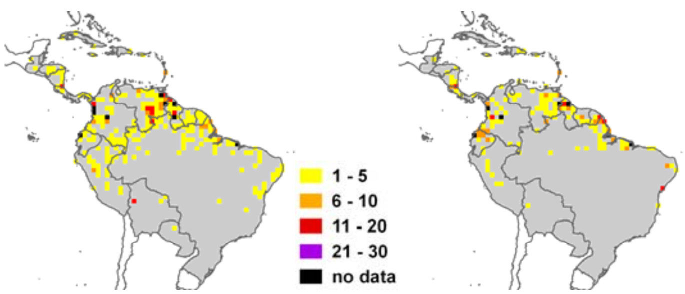


Figure 1: TREES-3 sampling scheme over the global tropics (4016 sample units)

3. Satellite data

The satellite data used within the TREES-3 project for the time periods of 1990 and 2000 is mainly based on the respective Global Land Survey (GLS) archives of Landsat imagery provided by the United States Geological Survey (USGS). Landsat images with the lowest overall cloud cover available for a certain time period were processed to GLS standard, i.e. to a very high geometrical quality (Gutman et al. 2008). Landsat data from the GLS archives was defined as the main input for the FAO FRA2010 RSS exercise (Potapov et al. 2010), however, for some of the areas over the tropics with persistent cloud coverage (Ju and Roy 2008), alternative Landsat for the specific areas of interest (sample units) the could be received from the USGS data portal outside the GLS archives (Beuchle et al. 2011) in order to avoid or at least reduce cloud cover in the GLS data. Figure 2a and 2b show for LAC the remaining cloud cover percentages for the 1990 and 2000 epochs and the amount of alternative data to GLS used for the two epochs. As result of the screening, only 2.4% of the sample images for the year 1990 epoch and 1.6% of the sample images for the year 2000 epoch contain more than 5 % cloud cover (Beuchle et al. 2011).



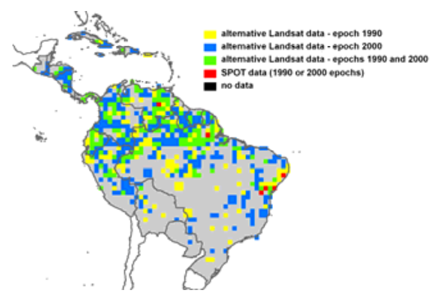


Figure 2a: Cloud cover percentages of the TREES-3 data (LAC) for the 1990 and 2000 epochs

Figure 2b: Alternative data to GLS used for LAC

4. Pre-processing of imagery and object-based classification

4.1 Pre-processing of imagery

The pre-processing chain of the imagery consisted in five steps (Bodart et al. 2010), (i) the geo-location assessment between the images of the 1990 and 2000 epochs for each sample unit, (ii) calibration to top-of-atmosphere (TOA) reflectance of the original digital number (DN) values, (iii) cloud and cloud shadow masking, where necessary, using an automated cloud classifier and solar geometry, (iv) haze correction, when appropriate, on the basis of the method proposed by Lavreau (1991), consisting in the substraction of the fourth component of a tasseled cap transformation and (v) radiometric normalization to reference forest values, where applicable (figure 3). A similar approach has been proposed by Hansen et al. (2008) for the creation of Landsat scene mosaics over the Congo basin.

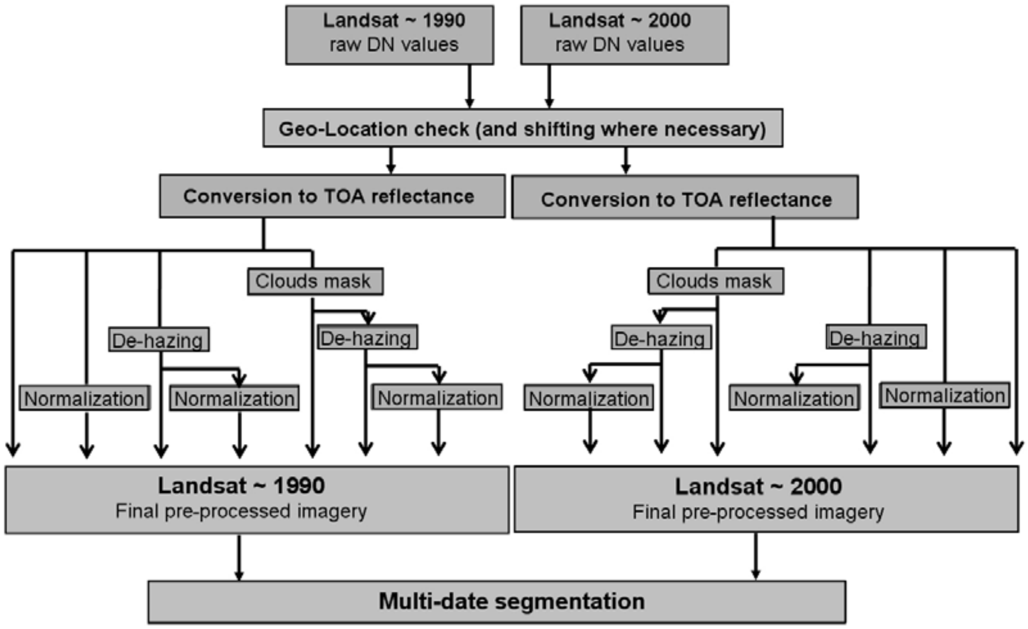


Figure 3: pre-processing steps of the TREES-3 imagery

4.2 Image segmentation and object-based classification

Image segmentation is the process of partitioning an image into groups of pixels that are spectrally similar and spatially adjacent, by minimizing the within-object variability compared to the between-object variability. On this basis a multi-date image segmentation of each image pair was applied with Definiens software (Baatz and Schape 2000, Meinel and Neubert, 2004). A two-step segmentation approach was chosen. The first step consisted in creating a large number of small segments ("level 1") for each sample unit as a basis for segment (or object) classification, the small segments covering less area and thus comprising more 'pure' landscape units in terms of land cover (Bodart et al. 2009). In the process of segmentation, statistics for each segment were collected like segment mean and standard deviation of each of the considered Landsat bands (i.e. band 3, 4 and 5), then they were classified with membership functions (Definiens 2007) on basis of a global collection of spectral signatures for the Landsat bands 3, 4 and 5. The target classes were defined as follows: tree cover, tree cover mosaic, other wooded land, other land cover, water, cloud and no data (see table 1 for detailed description).

'TREE COVER'	• 70% or more of a mapping unit is covered by a continuous layer of trees, the tree canopy can be closed or open • the tree layer density is at least 10% or more, • tree height is ≥ 5m
'TREE COVER MOSAIC'	• the tree layer in a mapping unit is discontinuous • the tree layer covers 30% to 70% of the mapping unit • tree density ≥ 10% • tree height ≥ 5 m (as required for the definition of 'Tree Cover')

'OTHER WOODED LAND'	• a mapping unit is covered to 70% or more of by a layer of shrubs, tree re-growth, or mixed vegetation with a mainly woody component (including village complexes) • the height of the layer is mainly < 5 m
OTHER LAND COVER	• land cover other than tree cover or other wooded land, including e.g. herbaceous cover, non-woody agricultural crops and mosaics, bare soils, built-up or urban areas • a potential trees cover component covers less than 30% of a mapping unit and/or tree density is less than 10%
WATER	• inland and sea water
CLOUDS	• cloud and cloud shadow
NO DATA	

Table 1: Description of TREES-3 land cover classes

The second step consists in an aggregation of the segments ("level 2") created in step one in order to achieve the defined minimum mapping unit of 5 ha. The aggregated segments were then classified on the basis of the proportions of the classified small segments within each "level 2" segment.

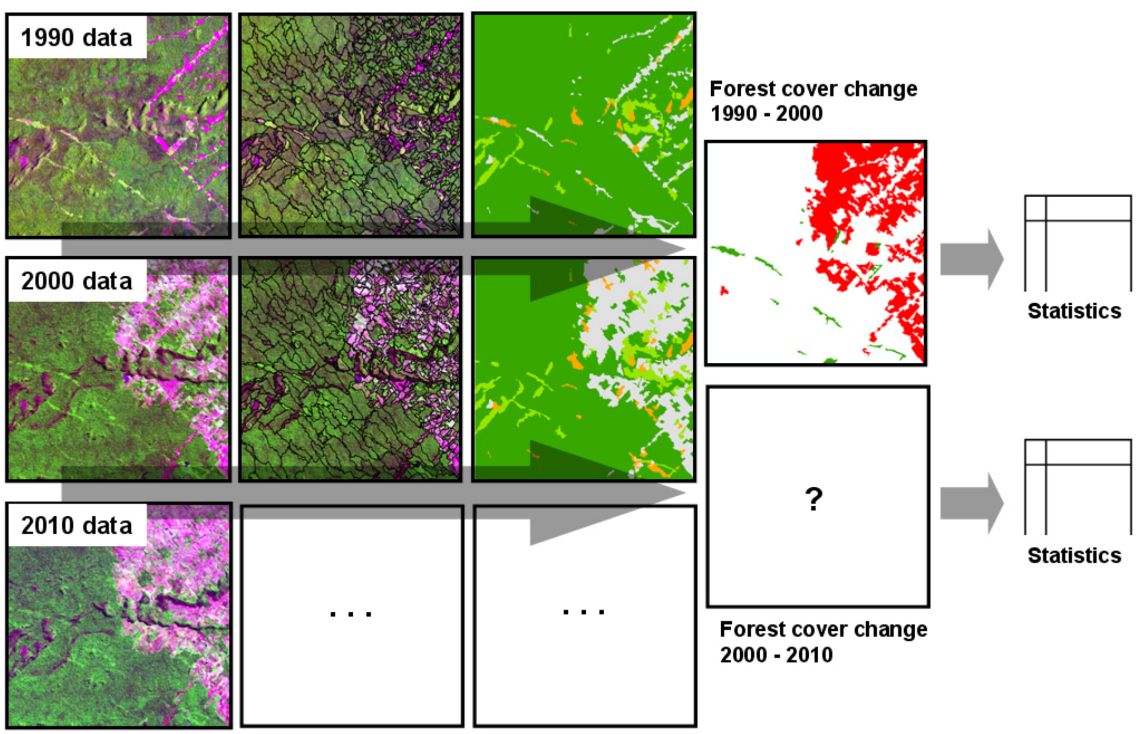


Figure 4: Workflow from pre-processed Landsat imagery, segmentation, classification, forest cover change map and statistics – example of the sample unit at the coordinate 11° S; 63° W

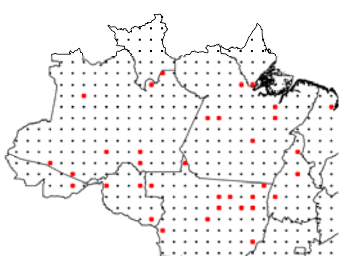
5. Validation

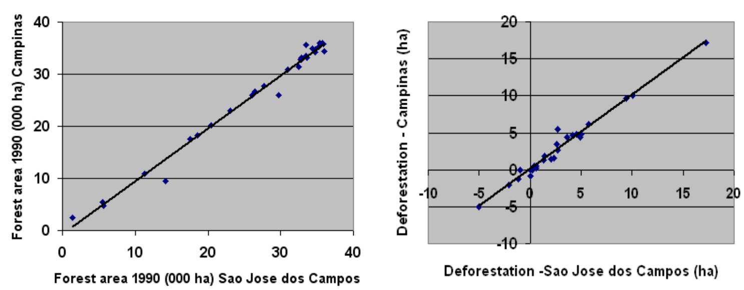
After the classification of the segments, the data went into an internal validation step, i.e. the classification results are checked in order to correct obvious classification errors before giving the data out to the external expert validation. Therefore the classified sample units (together with the Landsat imagery) with a centroid falling within a specific country border, were delivered to the national or regional expert of the respective country or region in order to check and if necessary correct remaining interpretation errors. For the whole tropics, more than 20 workshops have been carried out, either on-site at Ispra (Italy) or in the countries or regions concerned. Examples of institutions involved are EMBRAPA Satellite Monitoring at Campinas (Brazil), the Ministry of Forestry of Indonesia or the Observatory for Central African Forests (OFAC). The last validation step consisted in the harmonization of the results, in order to ensure that the interpretations of the different national experts were carried out in a similar manner.

6. Evaluation of the results for the Brazilian Amazon

6.1 Evaluation of the results on the Brazilian sample units carried out by EMBRAPA Satellite Monitoring

For 35 sample units distributed over the Amazon basin an evaluation of the interpretation by experts from EMBRAPA Satellite Monitoring was carried out by comparing the results to interpretations carried out by experts from INPE. The results show a very good correspondence between the two interpretations (Figure 5a and 5b)





Forest area (1990)
y = 1.017x - 847.2 R2 = 0 9861

Deforestation 1990-2000
v = 1.0078x + 105.55 R2 = 0.9777

Figure 5a: selection of 35 sample units over the Amazon Basin for interpretation comparison

Figure 5b: results of the interpretation comparison EMBRAPA – INPE of the 35 selected sample units

6.2 Comparison of figures on gross deforestation by INPE

We compared our results to those provided annually by INPE, the Brazilian National Space Agency. INPE's figure for the annual average gross deforestation between 1990 and 2000 for the legal Amazon is 16 700 sq km (INPE 2009). For the same area we have a slightly (10%) higher figure of 18 400 sq km per year. The reasons for this difference can be attributed to a combination of sampling error, differences in interpretation methods and definitions. However, it has to be mentioned that the sampling is not designed for the production of national or sub-regional deforestation statistics, but for regional, continental or global ones.

7. Conclusions and outlook

A robust and cost-effective method of pan-tropical forest cover change assessment was developed using a systematic sample grid, repeatable and consistent across space and time. For areas with persistent cloud cover, screening and ordering alternative datasets to GLS data reduced the loss of data due to clouds considerably. Segmentation and object-based classification proved to be an overall efficient approach, even if the classification for some of the datasets needed a considerable amount of improvement; however, this is not surprising in view of the global approach of the classification.

High correspondence was measured between interpretations of selected sites within the Brazilian part of the Amazon Basin carried out by independent experts. While not specifically designed to measure area change for the Legal Amazon, where deforestation is highly concentrated in the southeastern corner, our estimates are within 10% of the official statistics, which are obtained by a wall-to-wall survey.

A consistency test is planned as soon as the land cover interpretations from all sample units are finalized (spring 2011), where a subset of the interpreted objects will be re-interpreted by independent experts. In the following, satellite data from the 2010 epoch will be integrated into the workflow (see figure 5). The process will be adapted to the new set of satellite data from different sensors to Landsat, namely ALOS AVNIR-2, KOMPSAT-2 MSC, DMC Deimos-1, that will be provided through the TropForest program by the European Space Agency.

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