Tropical Forest Mapping Using Single Date TerraSAR-X High Resolution Spotlight Data

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Abstract – The survival of many tropical forest areas worldwide is critically endangered. To prevent further damage up to date land cover information is crucial. Only the remote sensing technology allows for a robust, area-wide monitoring of these vast forested areas. It is widely accepted that currently only microwave remote sensing provides the means for an almost weather independent monitoring of frequently cloudy regions. Consequently, high resolution TerraSAR-X images have been investigated to support the United Nations present global Remote Sensing Survey inside the tropics. Nested within their global sample schema, 350 single date TerraSAR-X images have been automatically processed to different spatial resolutions. Also various texture measures have been analyzed. This helped to find the most useful input data combinations for an object-based land cover classification. Based on visual comparison with available high-resolution optical imagery the first semi-automated classification results are promising.

Keywords: tropical forest mapping, texture, TerraSAR-X

1. INTRODUCTION

Without doubt, the world's tropical forests represent a precious and often highly vulnerable ecosystem. The huge biodiversity of these ecosystems represents a unique value to entire humankind. Of course the biodiversity of itself is not the only valuable function of tropical forests. These forests protect the soil from being washed away by the enormous precipitation rates throughout the tropics. The massive evapotranspiration rates help to stabilize the temperature to moderate values, thereby a lot of energy is captured and transformed into latent heat, which is then transported further away for the benefit of other subtropical regions. According to recent studies, undisturbed tropical rainforests have been acting as a carbon sink over the last decades. This is, because of the enormous net primary production of tropical rain-forest trees (e.g. Baker et al., 2004, Phillips et al., 2008). Hence, despite the large scale permanent land cover conversion throughout the tropical belt, the net carbon release could be balanced (e.g. Phillips et al., 2008, le Quéré et al., 2009). However, under a scenario of an increasing global temperature it is not yet clear if tropical rainforest will continue to be a carbon sink or if they could possibly turn into an additional source of carbondioxid (Lewis, 2006).

Besides the undisputable ecological benefits of tropical forests, they also possess a large economic worth. The market for tropical wood has certainly created a lot of employment opportunities for all countries in the tropical belt. Tropical ecotourism is no longer just a vision. It has become reality in quite a lot of tropical countries and it generates a considerable income for many people. Furthermore, in December 2010 United Nations Framework Convention on Climate Change (UNFCCC) in Cancun has finally agreed to implement a mechanism not only to reduce deforestation and degradation in tropical forest environments, but also to support conservation and sustainable management (UNFCCC, 2010). Hence, any form of a post-Kyoto climate agreement will contain a mechanism which will ensure a considerable knowledge transfer and financial support from the industrial to the developing countries, if they agree to switch to a sustainable forests management so that the remaining tropical forest are largely preserved.

Consequently, it is elementary to report steadily on the status and health conditions of the world's tropical forest resources in order to protect, preserve and manage them. Since 1946 the United Nations Food and Agricultural Organization (FAO) reports regularly in a five to ten year interval on the global forest status. However, according to self-critic comments from the FAO itself, those country reports, which are based on forest inventory data, exhibit still some uncertainty. Various statistical methods and individual definitions of each country hamper the compilation of the entire data. Yet, FAO applies corresponding corrections of the data. Though especially the human induced land cover change and the detection of natural land cover dynamics remains vague to some degree (FAO, 2000).

There is a broad consensus in the scientific community that these problems can be properly addressed by using the remote sensing technology. It is the only efficient tool to conduct a sound land cover mapping of entire regions. That is why the FAO decided to implement a global so called Remote Sensing Survey (RSS) within their last worldwide Forest Resources Assessment (FRA).

Nevertheless, some obstacles remain when using optical remote sensing data solely. There is for example the almost persistent cloud cover across the pan-tropical belt, which limits the use of optical remote sensing data considerably. Because active sensors are nearly independent of any atmospheric condition, they could supplement the optical instruments. Based on that logic FAO's RSS includes an experimental microwave remote sensing component to create maps which will help to fill in the gaps due to clouds. The corresponding maps are created within the project FRA-SAR 2010 (Forest Resources Assessment with Synthetic Aperture Radar for the year 2010) from single date high-resolution TerraSAR-X imagery.

2. INVESTIGATION AREAS

The RSS has a systematic sampling schema which encompasses nearly the whole globe. Virtually any latitude/longitude intersection over land will be sampled by a 10 by 10 kilometer sample box. Each of the 13.689 sample boxes will be classified using Landsat data from the past two decades (Ridder, 2007, Gerrand et al., 2009).

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All of the 350 FRA-SAR 2010 TerraSAR-X investigation sites are nested within the RSS. Hence, a first step was to identify the cloudiest regions in the world within the RSS boundaries. Using the results of a study on the mean annual cloud cover of each Landsat scene (Ju and Roy, 2008), we found 1.324 Landsat scenes having an average cloud cover fraction of 50% or more. To further select only those areas which have both a high forest cover fraction and are subject to highly dynamic land cover changes, we used the freely available land cover product GLOBCOVER was used together with information on the land cover change from South Dakota State University's Geographic Information Science Center of Excellence and the Joint Research Center of the European Commission. Slope maps were created using the freely available Shuttle Radar Topography Mission (SRTM) elevation model data, to account for typical SAR-image effects, i.e. foreshortening, layover and shadow, in the site selection process. Finally, all mentioned parameters were used in a weighting algorithm to select the 350 most appropriate places for the TerraSAR-X data acquisitions. The result is displayed in Figure 1.

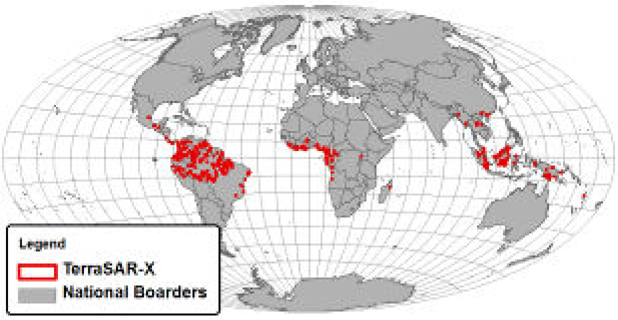

Figure 1. Geographical distribution of the available TerraSAR-X images. Note the original geographical spread had a much better coverage in central Africa and less in Latin America, but do to the political unrest in the Democratic Republic of Congo it was impossible to get TerraSAR-X high resolution spotlight images from that particular region.

3. DATA

Within the FRA-SAR 2010 project all 350 investigation areas have been recorded by the German radar satellite TerraSAR-X only once. The satellite operates at the X-Band frequency, i.e. 9.65 GHz (Breit et al., 2010). Generally, all images are recorded with incidence angles ranging from 38° to 50°. This is to enhance the contrast between forest and non-forest areas. Only dual polarimetric data sets have been ordered, i.e. HH and VV. Every image was acquired in the High-Resolution Spotlight Mode of the satellite. Table 1 summarizes the sensor specific parameters for the images.

Table 1. Sensor specific parameters for the image acquisitions within the FRA-SAR 2010 project

Sensor	TerraSAR-X
Frequency	9.65 GHz
Acquisition Mode	High Resolution Spotlight
Polarization	HH and VV
Slant Range Resolution	1.48 m – 3.49 m
Azimuth Resolution	2.20 m
Incidence Angle	38° - 50°
Footprint	10 x 5 km

Since there was no complete archicve for TerrSAR-X data available, each scene had to be ordered separately. Therefore, it was possible to schedule the acquisitions so, that the annual movement of the inner tropical convergence zone could be taken into account. However, it was not always possible to get data of the dry season.

4. METHODS

All TerraSAR-X images have been multi-looked to a spatial resolution of 5 m, to reduce the SAR typical speckle. Thereafter the images have been geocoded based on the precise satellite orbit parameters. A too coarse elevation model didn't allow for topographic normalization. If the topography in an image was too steep it was rejected and could not be processed any further.

To estimate an initial separability between the different land cover types and to check the radiometric stability Probability Density Functions (PDF) of 4 land cover classes (Tree Cover (TC), Tree Cover Mosaic (TCM), Shrub Cover (SC) and Water (W)) have been modeled based on the backscatter intensity of each polarization of a single multi-look image with 5 m spatial resolution. Figure 2 a) and b) depicts the results of each polarization in a separate plot. It is apparent that there is a strong overlap between the different PDFs almost independent of the polarization.

Thus, to further enhance the radiometric stability of each land cover class, every scene was subject to speckle filtering using the FROST-algorithm twice. First with a window size of 3 by 3 pixel and then with a window size of 5 by 5 pixel. Again the PDF-result is depicted in Figure 2 c). Even though the equivalent number of looks increased considerably and the separability between TC and SC is a better, the overall discrimination between TC, TCM and SC remains difficult and the results look quite similar to Fig 2 b).

Illuminating a tropical forest, the main backscatter signal from a co-polarized X-Band sensor (~3 cm wavelength) comes from the direct interaction between the wave and the surface (neglecting the target's dielectric properties), i.e. the signal would not penetrate deeply into a shrub or tree canopy, or even into the soil. Therefore, a lot of information originates directly from the relatively small surface features, i.e. leafs and/or twigs of the uppermost strata. Tropical forests are characterized by an extremely diverse canopy structure. Consequently, there is a lot of tonal variation. In in other words the texture changes continuously throughout a forest. Hence, to examine several texture features as input data for a classification seems to be logical.

Different methods have been proposed to derive the texture of tropical remote sensing images (e.g. van der Sanden and Hoekman, 1999, Oliver, 2000, Weishampel el al., 2001, Podest and Saatchi, 2002). One of the major project goals was to develop an operational algorithm. Therfore, eight Haralick-texture parameters have been selected (i.e. mean, contrast, variance, homogeneity, dissimilarity, second moment, correlation and entropy). Those are already implemented in many software tools. It is beyond the scope of this paper to explain each parameter. The definitions are given by Haralick et al. (1973).

The possibilities to derive Haralick-texture parameters can easily increase exponentially (depending on the selected pixel window sizes and distances). Hence, it is useful to do an

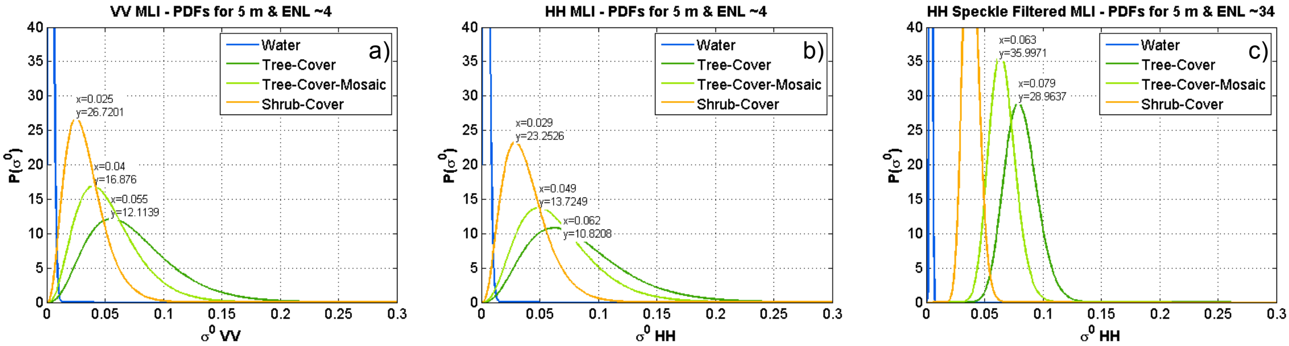

Figure 2. Probability Density Functions for four different classes of a single TerraSAR-X High Resolution Spotlight Mode image, geocoded to a spatial resolution of 5 m. Plots a and b depict the pure backscatter intensities for both co-polarisations, i.e. VV and HH. Plot c shows the modelled PDFs after speckle filtering of the HH-polarisation, using the FROST algorithm twice. Speckle filtering leads to a remarkable increase of the equivalent numbers of looks (from 4 to 34), but the class separability stays difficult.

autocorrelation analysis beforehand. In our case we examined variograms for backscatter intensities of several different land cover classes. The results for the classes TC and SC revealed that a distance value of three to five pixels provides with the best separability. Accordingly, the eight different Haralick-texture parameters have been calculated for distances of one, three and five pixels. Only two different window sizes for each parameter, 3x3 and 5x5 pixels, were calculated to preserve as much spatial resolution as possible. Finally, with a separability analysis, using the Jeffries-Matusita distance algorithm, the most useful texture parameters for our aspired classification have been identified.

The classification was done using object-based methodologies. First the images have been segmented. Then a rule set was developed, which encompasses a number of fuzzy membership functions to derive four final classes. Table 2 provides an overview of the classes and their definitions.

Table 2. FRA-SAR 2010 Classification Description. Note the Minimum Mapping unit is 0.5 ha.

Class	Description
Tree Cover	66-100% of the land cover are trees
Tree Cover Mosaic	11-65% of the land cover are trees
Other Land	1-10% of the land cover are trees
Water	River, Lake, Ocean etc.

5. RESULTS

The TerraSAR-X High Resolution Spotlight data form provides with highly valuable data for tropical forest mapping. This is especially true for very remote areas where the accessibility is difficult, because an expert with local knowledge could easily recognize different land cover types on the images. Hence, this particular data can be used for validation purposes.

However, to exploit the information content entirely automatically remains difficult. As obvious from Figure 2 the unfiltered backscatter intensities alone are not sufficient to reliably classify different land cover types. Therefore, speckle filtering is an essential prerequisite of any further automated data exploration.

The diversity of tropical forest canopy covers can be best addressed by using texture parameters, because all major interactions of a X-Band SAR system take place at the top of the canopies. Our investigation of eight different Haralick-texture parameters was accompanied by an autocorrelation analysis. T the distance has proven to be the most important parameter regarding the separability. Autocorrelation analysis helps to reduce the amount of data considerably. Together with the backscatter intensities the Haralick-textures parameters: dissimilarity, contrast, homogeneity and mean, with a distance value of five pixels and a moving window of 5x5 pixels, are the most useful inputs for the object-based image classification.

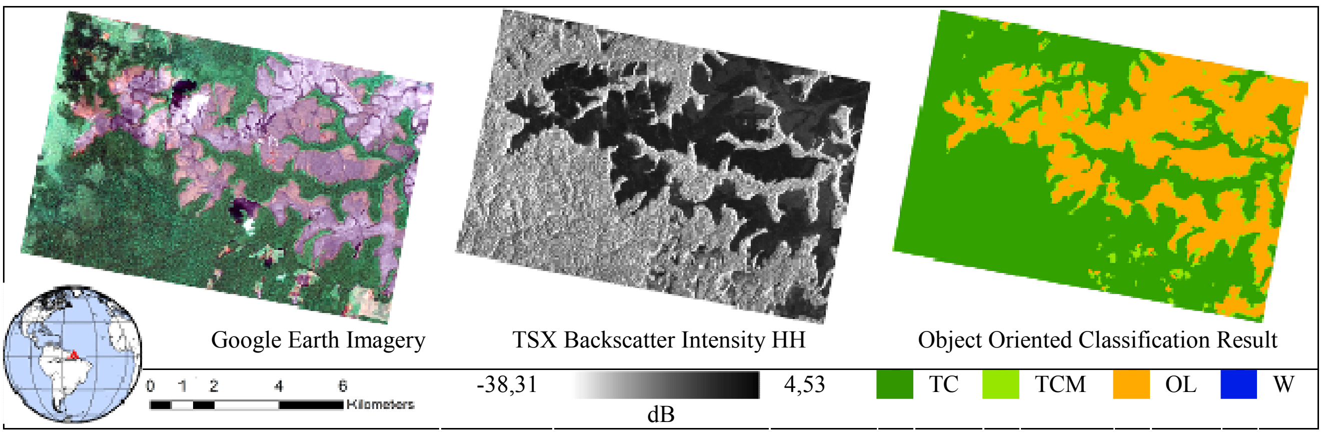

Figure 3. Comparison of a high resolution Google Earth image with the speckle filtered SAR image (HH-polarization) and the final classification result.

A brief visual comparison of the results to the freely available high resolution optical remote sensing data from Google Earth is very promising (cf. Figure 3). However, a more robust accuracy assessment is necessarily the next step and will be part of the validation efforts of the FAO and country specific forest experts.

6. CONCLUSION

Single date high resolution SAR-data from TerraSAR-X has been analyzed to support the RSS in the cloudiest regions across the pan-tropical forest domain. Altogether 350 SAR-images have been processed fully automatically. The data has been speckle filtered and geocoded to a 5 m spatial resolution.

Due to the divers canopy structure of tropical rainforests and its interaction with the X-Band signal the usefulness of Haralick-Texture parameters for a classification was investigated. The results confirmed that it is advisable to do an autocorrelation analysis before the texture computation. This is necessary to restrict the texture generation to a few useful distances. Accordingly, only a few Haralick-texture parameters have been automatically computed for all 350 TerraSAR-X backscatter images.

Finally, an object-based image classification approach was implemented for a semi-automatic classification of all images into two forest density classes, namely water and other land. Compared to high resolution optical data the initial map products represent the land cover quite well.

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