Satellite based monitoring of the national forest resources in the pacific island state of Vanuatu

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Summary: Deforestation of tropical forests contributes a significant amount to the global greenhouse gas emissions. International discussions are currently underway within the UNFCCC to build incentives for developing countries to protect their national forest resources and thereby reduce or avoid deforestation and the resulting carbon emissions. To assist this policy development process, a number of related case studies are ongoing to test different carbon credit approaches. This paper summarizes the outcomes of a study that is part of the Vanuatu Carbon Credits Project. The remote sensing component of the project aims to develop a historical deforestation database for the pacific island state Vanuatu based on historical satellite observations. The analysis was based on Landsat, ASTER and SPOT imagery for the time steps 1990 and 2000. Image classification and change detection was applied to map in a wall-to-wall approach the forest cover for the year 2000, to assess the forest changes for the period from 1990 to 2000 and to derive the historical deforestation rates for the individual islands. The observed deforestation rate in Vanuatu is comparatively low, but the proven technical approach could be directly transferred to other national circumstances in the south pacific region and beyond.

1 Background and objectives

Deforestation accounts for 20 % - 25 % of global greenhouse gas emissions, making it the most significant source of emissions in developing countries. If these emissions are not reduced, they have the potential to undercut reductions in industrial and energy emissions. Deforestation also has significant negative impacts on soil quality, biodiversity, local livelihoods and indigenous communities. Despite the negatives impacts of deforestation, creating incentives to mitigate this source of emissions from developing countries has not been adequately addressed in either the UN Convention on Climate Change (UNFCCC) or the Kyoto Protocol. International negotiations are currently underway within the UNFCCC to build incentives for developing countries to reduce or avoid emissions from deforestation and forest degradation (REDD). These negotiations were initiated at COP-11 in 2005 by the Governments of PNG and Costa Rica, and the Coalition of Rainforest Nations (of which Vanuatu is a member). In that context, the Vanuatu Carbon Credits Project (http://www.vuw.ac.nz/geo/research/climate-change/vanuatu-forests/index.html) was designed to build capacity in Vanuatu to utilize carbon markets to help fund REDD and associated sustainable development activities. In order to model and test a national mechanism for the use of carbon finance for REDD, it is necessary to undertake a detailed national forest cover area change assessment. This was done through a remote sensing analysis those results are presented in this paper. The key objective was to build a historical deforestation database for Vanuatu including forest cover and deforestation maps and associated area estimates for two

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time steps: 1989/90 and 2000-2003, using primarily LANDSAT TM and ETM. In addition, this project directly contributes to the international process to coordinate and synthesize the experiences for different case studies ongoing in different parts of the world (i.e. Bolivia, Cameroon, SE-Asia, PNG). Hence, the results contribute to strategic planning for sustainable development both nationally (in Vanuatu) and internationally (through lessons/models that can be applied to other forested nations). This project was funded by the British High Commission in New Zealand and lead by the Victoria University of Wellington.

2 Study area

The Republic of Vanuatu is an island nation located in the South Pacific Ocean, approx. 1.750 km east of Australia and 500 km north-east of New Caledonia. It consists of a north-south oriented chain of 13 principal islands and about 67 smaller islands with a total area size of 12.190 km² and a north-south extension of about 650 km (Figure 1).

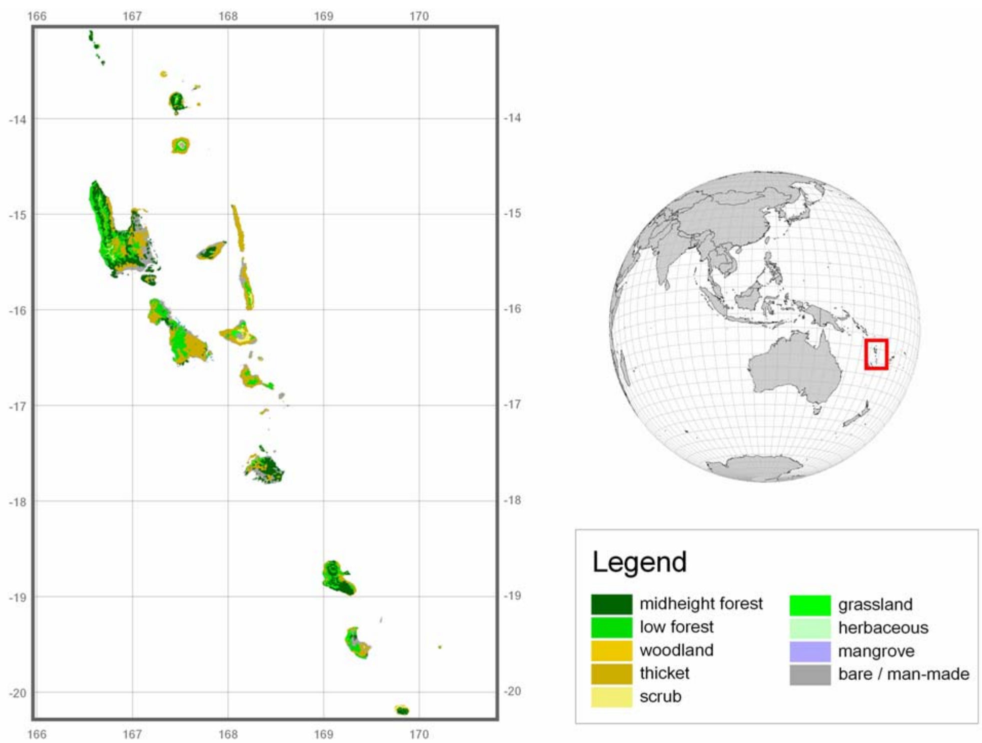

Figure 1: Map of Vanuatu (data source: VANRIS, BELLAMY 1993)

The islands of the archipelago are mostly of volcanic origin and mountainous. Some volcanoes are still active. The capital of Vanuatu is Port-Vila located on the island of Efaté. The population is about 209.000 inhabitants which are predominantly Melanesians, with some Polynesians; but also Chinese settlers and Vietnamese laborers. The economy is based mainly on agriculture, cattle raising, and fishing, but also with an increasing tourism sector. Vanuatu has comparatively low rate of historical deforestation.

3 Satellite and ancillary data

The study integrated a number of satellite data following the observation model of GOFC-GOLD (DE FRIES et al. 2006) for monitoring tropical deforestation using primarily historical LANDSAT TM and ETM data for high-resolution change monitoring. Coverage for Vanuatu was available for the periods 1989/90 and 2000-2003 with some cloudy areas remaining. Additional data from the European SPOT sensor (1990) and ASTER (2000) have been acquired to increase the spatial cloud free coverage and enhance the forest mapping capabilities through multiple observations. For covering 1990, this project used 17 Landsat TM scenes and 16 SPOT scenes. To cover the 2000 time frame 14 Landsat ETM and 14 ASTER scenes were used. The temporal coverage of the satellite observations vary up to 2 or 3 years difference from the 1990 and 2000 dates. These temporal differences were considered in the deforestation rate analysis.
To complete the data set for the project additional data sources have been used. The Vanuatu Resource Information System (VANRIS GIS, BELLAMY 1993) was provided by the Vanuatu Forestry Department and yields spatial information on vegetation type (from 1984 air photo interpretations), land use intensity and type of land use. The use of these vector data was useful but limited due to geolocation shifts observed for some islands, resulting from different original cartographic data sources used during the developing process. For consistent coastline we applied the SRTM water bodies product available for free (http://www2.jpl.nasa.gov/srtm-/cbanddataproducts.html). Available high resolution Qickbird images on Google Earth provided an additional reference information source for visual interpretation.

4 Methodology

4.1 Satellite data pre-processing

The analysis of deforestation dynamics in this specific area needs to be based on high-quality and comparable satellite data. Such data can be provided by a comprehensive pre-processing including georeferencing and co-registration, mosaicing, masking and radiometric normalization of available satellite data (Figure 2).

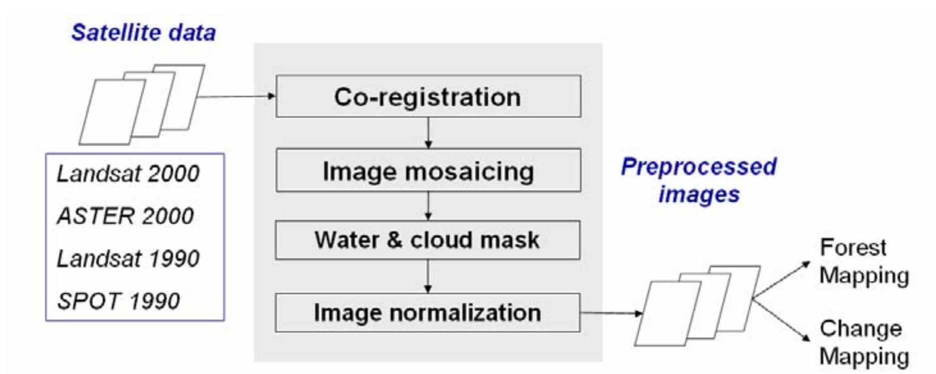

Figure 2: Workflow for the satellite imagery preprocessing

The rectification was performed to a unique geodetic system (Geographic Lat/Long, ellipsoid and datum WGS84). The 2000 Landsat Geocover dataset provided the spatial reference for image-to-image registration of the other satellite data. A transformation was done for each scene, whereas ground control points (GCP) were set visually with regard to the quality of the scene and the percentage of land coverage. Using a polynomial second order transformation and a nearest neighbor resampling, mean RMS errors less than one pixel resolution were achieved for each of the respective scene. After geo-referencing all data were processed to image mosaics. Landsat bands 4 and 5 thresholds (tuned for different regions) have been applied to exclude water bodies and cloud shadows. A Landsat band 1 threshold value was used to detect clouds. This approach worked well for thick clouds. Thin clouds and haze were either excluded through manual editing or kept for the analysis. In particular the spectral bands with longer wavelength penetrate thin clouds and haze and can be used for the interpretations. Standard multi-temporal image normalization through histogram matching was performed to reduce radiometric image differences.

4.2 Forest mapping and change assessment

The mapping and data analysis process contains two individual work items. The forest mapping for the year 2000 provides the baseline data for existing forest and tree cover for Vanuatu. The change mapping 1990-2000 is a different process and employs change detection methods to identify areas of forest cover change. In the final step, both products can be combined to derive a historical forest map for 1990. In general, both mapping items were done on an island by island basis to accommodate the heterogeneity of input data and tune the supervised analysis to the specific circumstances of the major island groups.

4.2.1 Deriving the forest cover map

The approach to derive the forest cover map is to classify pseudo spectral channels and label the spectral classes using the reference data into three categories defined by the amount of tree canopy cover (Figure 3).

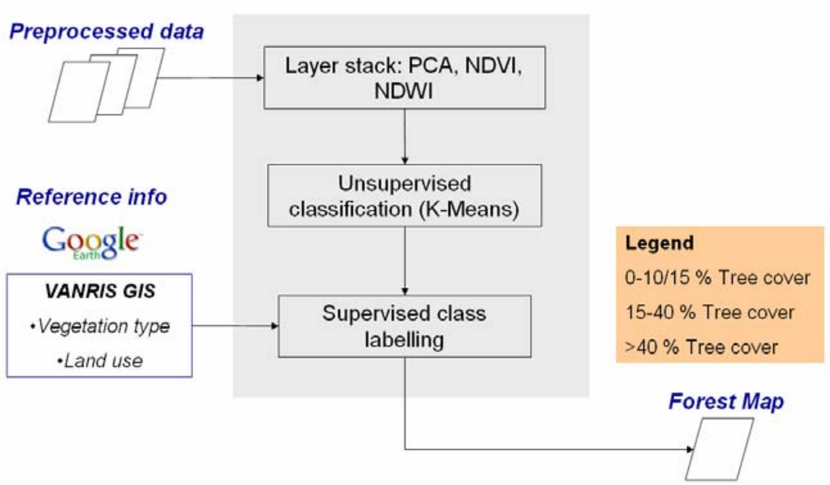

Figure 3: Workflow to derive the forest cover map for the year 2000

The use of pseudo spectral channels is required to reduce effects of different illumination conditions due to topography. It is known that image ratios and principal component analysis reduce such topographic effects while maintaining the majority of image information. The first ratio is the Normalized Difference Vegetation Index (NDVI) that is defined as the difference between the near-infrared (NIR) and the red radiation reflected by the surface, normalized by the sum of both ([NIR-RED]/[NIR+RED] TUCKER, 1979). The Normalized Difference Water Index (NDWI) works in a similar manner using the NIR and short-wave infrared band (SWIR, GAO 1996). In addition, the principal component analysis reflects the general surface illumination pattern (including topographic variations) in the first component. The subsequent principal components 2-4 have been used for the image classification. The minimum mapping unit applied is three Landsat pixels of 900 km² each. Thus, the Minimum mapping Unit can be estimated with about 0.3 ha.

4.2.2 Forest change detection

The forest change detection aimed to identify areas of significant loss in tree canopy cover and thus areas of deforestation. The technical approach is illustrated in Figure 4. The input data are the Landsat TM and SPOT data for 1990 and the Landsat ETM and ASTER data for 2000. With two datasets available for each of the two time steps, there is a maximum of four change observations for each location if all datasets are available.

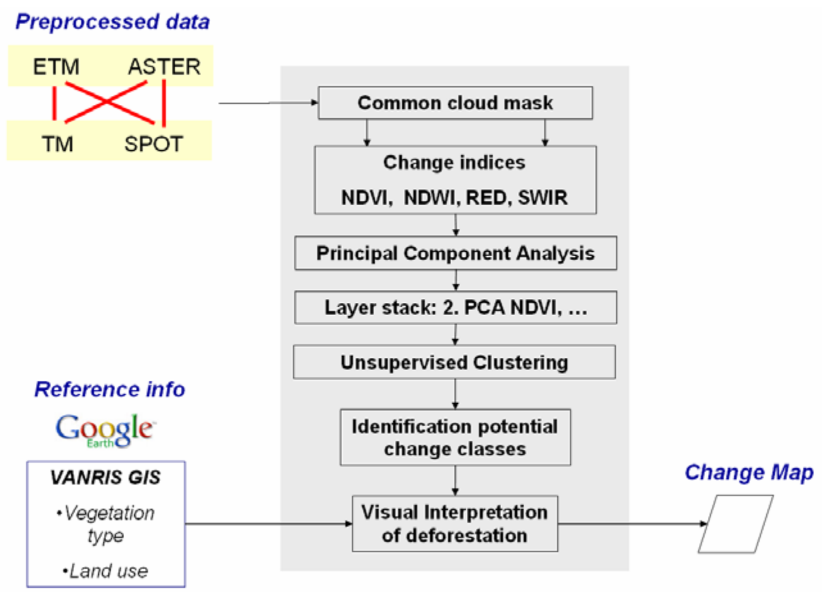

Figure 4: Workflow for the forest cover change detection

To derive information on what datasets are available for which location a common cloud mask was developed. The loss of tree canopy cover is highlighted in several spectral indicators including the NDVI, NDWI, the red spectra channel and the SWIR. Each of those bands were derived for the image data. To highlight the change a principal component analysis is performed between the associated change pairs, i.e. NDVI'90 and NDVI'00, NDWI'90 and NDWI'00 etc.. The first principal component contains the information that both have in common (i.e. similar NDVI for 1990 and 2000). The second principal component highlights the areas where things have changed between the dates. This second principal component for changes in the NDVI, NDWI, the red band and the SWIR band are then jointly classified using an unsupervised clustering. The classification contains classes of potential forest loss. There maybe other influences that may be manifested in the potential change classes (i.e. phenology, radiometric image distortions and other artifacts like cloud boundaries). Thus, all identified potential change locations are visually inspected whether they indeed reflect deforestation. All change areas including one pixel change areas (~900 km²) have been considered in the final map product.

4.3 Deriving deforestation rates

The rate of deforestation reflects the area of forest loss within a particular period, usually per year. The frame for this study was an assessment of deforestation between 1990 and 2000 for the whole of Vanuatu. The calculation of the deforestation rate includes an average annual rate for a 10 year period. As reference period we applied 1st July 1990 to 1st July 2000 (a total of 3.653 days). The original satellite change observations had to be adjusted according to this time period since the observation dates are varying from the reference dates. In addition, there are areas of persistent clouds where no change observations could be performed. To accommodate these two factors, reference period adjustment and no data adjustment, we used a linear interpolation approach, i.e. if the mapping period was 5 % longer than the reference period we assumed 95 % of the mapped deforestation happened in the reference period. A similar approach is used for the no data adjustment with the same relative amount of deforestation being assumed in the no data region of the same island.

5 Results

5.1 Forest cover

The derived forest cover map for Vanuatu contains three land cover categories based on tree canopy cover density using the thresholds defined by the UN Land Cover Classification System (LCCS, DIGREGORIO 2005). The lower threshold of 15 % tree cover has to be understood as a range of 10-15 %. Basically the areas in the classes 15-40 % and 40-100 % tree cover would constitute a forest cover as defined by FAO (if land use is not considered). The overall distribution of the forest cover classes derived for Vanuatu is shown in table 1 and emphasizes the dominance of areas with tree cover larger than 40 %. Following the pure “land cover” perspective taken in this study, the area of land with more than 10-15 % tree canopy cover is more than 1 million ha. It needs to be considered that these values may not be directly comparable with other existing estimates.

Tab. 1: Overview of the satellite imagery used in the project

	Total Area according to Vanuatu VANRIS data [ha]	**Area >40% tree canopy cover [ha]**	**Area 40-15% tree canopy cover [ha]**	**Area >15% tree canopy cover [ha]**
Total	1.224.304	981.785,5	193.227,2	4.9291,3
Total %	100	80,2	15,8	4,0

5.2 Deforestation

Deforestation maps have been produced for all islands. The analysis of forest change revealed a variety of change pattern for different parts of Vanuatu. One type is characterized by large scale removal of forests in managed land areas with parts of the cleared land being converted to agriculture. A second type comprises areas of forest clearing and logging in former undisturbed forest areas. The construction of new roads in these areas improved accessibility and can drive forest loss due to logging and building construction. A third case occurs mainly on the smaller, inaccessible island. In these regions no transportation infrastructure is visible in the imagery and the loss of forest is due small-scale changes in agriculture and plantation. One essential consideration during the change detection was to deal with data availability. Although data from a number of satellites have been used there are still remaining areas of persistent cloud cover. Such areas with no information from either 1990 or 2000 available were excluded from the change mapping process. About 80 % of the Vanuatu land area could be included in the change detection. Nearly 55 % of the land area is covered by 2 or more change observations. Basically, the more change observations are available the more confidence there is in the observed change.

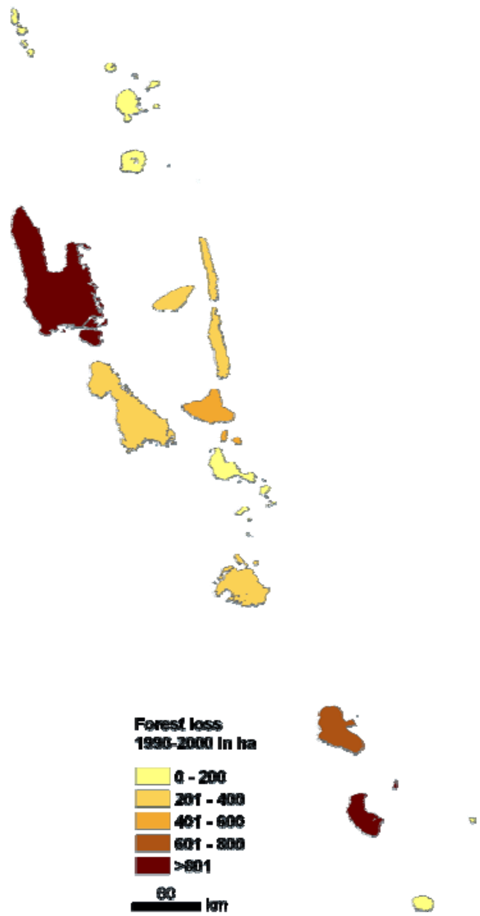

Figure 5: Forest loss in Vanuatu in the period from 1990-2000

The rates of deforestation were calculated from the satellite observed forest area change adjusted to accommodate the reference time period (1st July 1990 to 1st July 2000) and the areas with no data. The gross deforestation for all islands of Vanuatu between 1990 and 2000 is estimated with 4.677,6 ha or 467,8 ha/a. More than 1/5 of the total forest loss was observed on the island of Santo, the largest of the archipelago. The spatial distribution of the forest loss per island in figure 5 emphasizes Santo and Tanna as the Vanuatu areas with most gross deforestation.

6 Conclusions

The presented project aimed to provide a historical deforestation database using historical satellite observations. Applying such an approach to Vanuatu requires consideration of particular challenges. There are no major previous satellite based land cover or forest monitoring studies. Continuous optical satellite observations are challenged by persistent cloud cover. For remote island only limited satellite coverage is available. Furthermore, the topography of the volcanic islands complicates the image interpretation and mapping process. Despite such difficulties, the project results have proven the suitability of satellite-based assessment of forest cover change in the context of REDD.

The results have shown that an area of more than 4600 ha has been deforested. In an international context, such a rate of forest loss is comparatively low but there are distinctly different patterns for the different parts of Vanuatu. The different processes relate to industrial logging, changes in plantations and agricultural pattern, and subsistence timber extraction. Developments of policies and carbon crediting options have to consider these different processes at work.

The development of the Vanuatu deforestation database provides the first and essential step to further evolve the basis for Vanuatu's participation in any REDD carbon crediting system. There are a number of next steps to have to be pursued to further progress in this arena. An extended remote sensing survey 2006 to develop the Vanuatu historical deforestation is envisaged. A detailed study of the identified deforestation hot spots could help to further understand the processes and future threats for the loss of forest. The project results have proven the suitability of satellite-based assessment of forest cover change in the context of REDD. The technical approach used and proven in this Vanuatu case study could be directly transferred to other national circumstances in the south pacific region and beyond. Since major deforestation problems tend to be of international origin and involve regional impacts, the project will certainly aim to extend beyond the boundaries of Vanuatu.

7 Literature

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