RECOVER: SERVICES FOR THE MONITORING OF TROPICAL FOREST TO SUPPORT REDD+

Tuomas Häme¹, Laura Sirro¹, Edersson Cabrera², Jörg Haarpaintner³, Johannes Heinzel⁴, Jarno Hämäläinen⁵, Bernardus de Jong⁶, Fernando Paz Pellat⁷, Donata Pedrazzani⁸, Johannes Reiche⁹

ABSTRACT

Project ReCover aims at developing beyond state-of-the-art service capabilities to support fighting deforestation and forest degradation in the tropical region. The service capabilities mean provision of a monitoring system of forest cover, forest cover changes, and biomass including a robust accuracy assessment. This paper presents the forest monitoring concept and the first results on Recover study sites.

ReCover contributes to the efforts to reduce the errors in the estimates of the terrestrial carbon balance that result from uncertain rates of tropical deforestation. It develops methods for the REDD (Reducing Emissions from Deforestation and Forest Degradation) process by developing and implementing satellite image based methods for the monitoring of tropical forests. The REDD will be a major driver for the development of more effective and more reliable procedures for the monitoring of tropical forests. Many developing countries lack human resources and funding for detailed forest inventories.

This paper reports the achievements of the first year of ReCover and the results of services in Mexico, Guyana, Democratic Republic of Congo, and Fiji. Altogether 42 products were delivered to the users of Recover. The accuracy in forest and non-forest classification was from 85 % to 91 % with one exception (76 %).

INITIAL RESULTS

Recover project has completed successfully its first half of 18 months. The work has focused on the development of the statistical concept for the monitoring of the forest, acquisition of data and computing preliminary empirical results. The delivery date of the first services was in March 2012. New services that utilize the user feedback from the first services and enhanced methods will be provided by May 2013. The whole study will be completed in October 2013.

The empirical forest monitoring is being performed on the five study sites for the local users: The Chiapas state in Mexico, a sub-region of Colombia, the entire Guyana, a selected site in the Democratic Republic of Congo (DRC), and the territory of Fiji islands. The image data are available since the early
The user-defined variables of interest are land cover and forest cover, biomass, degree of disturbance and the changes of those variables from the early 1990’s until today. The disturbance is predicted with the help of biomass and the crown closure percentage of tree stems. The analysis of the spatial structure of the forest patches is also used to evaluate the disturbance. Monitoring of the persistence of the disturbance during time enables the prediction of the degree of degradation. Change monitoring and degradation monitoring with accuracy assessment will be specially focused during the second half of ReCover.

**Monitoring concept**

The overall forest monitoring concept that applies a two-phase (or multi-phase) stratified sampling design was preliminarily developed in an earlier study in Laos (Häme et. al 2011, Figure 1; Gautam et. al 2010). The first phase sample is taken from wall-to-wall medium resolution (Landsat, Spot, RapidEye in near future Sentinel 2) data and the second phase can be taken from one-meter to sub-meter resolution very high resolution imagery, airborne laser scanning (Light Detection and Ranging, LiDAR) data and (optionally from) the field sample plots. The synthetic Aperture Radar (SAR) data can augment or even replace the optical data in the cloudy regions. In the first phase, the area of interest is divided into population units (PU) that cover the whole surface. A 50 m by 50 m PU size has been selected. The variables of interest (land cover and forest cover, biomass, degree of disturbance and the changes) are predicted with wall-to-wall satellite imagery and available reference data for all the PU’s.

![Iterative processing chain to produce maps and statistical data](image)  

*Figure 1. Iterative processing chain to produce maps and statistical data.*
In the second phase, a statistical sample of the PU’s is selected and evaluated. A stratified sampling to two or three strata is applied. Mapping of change requires a specific stratification because of the small area of the change classes. If ground reference data are not available or if their amount is low, the second phase sample is located on available VHR images that preferably are also selected by applying a random procedure. Field plot data and LiDAR data, when available, are used to augment the VHR data sample.

In the estimation of biomass or growing stock volume, field observations are mandatory. On some sites, particularly in the Mexican site Chiapas, a high number of field plots for the land cover classes are available. On several other sites, the available ground reference data are very limited. Thus, the method has to adapt to different degrees of ground reference data availabilities.

During the first service iteration, the two phase sampling approach with utilization of very high resolution data was applied on the DRC and Guyana sites because no other reference data were available. On the Mexican site, ground plots were used for the assessment. On the Fiji site and on the new Colombia site, the assessment will be done during the second service iteration. During the second service iteration that is due in spring 2013 the approach will be extended to all the sites.

Image interpretation approach

Several image interpretation methods were used in the first service provision. The feedback of the results is used to harmonize the methodology and select the best practices for the second service round. The applied methods include the Probability method (Häme et al. 2001) and methods that are available in the commercial software packages ENVI/IDL and Gamma (2012). The Probability method initially predicts all the variables, including the categorical variables, as continuous values, which enables flexible post processing of the results.

The interpretation of wall to wall data aimed at processing as large units at the same time as possible. For this purpose, the optical data were calibrated into surface reflectance values. Similarly, a radiometric calibration was performed to the SAR data in addition to the mandatory geometric correction. For the change detection, among other things the in-house method and software, AutoChange is applied (Häme et al. 1998).

The independent reference data for the accuracy assessment are sampled from the reference data that are not used as training data for the computation of the models to predict the variables of interest. The reference data includes ground plots and using visually interpreted PU’s from VHR images (Figure 2). With reference data, the accuracy figures with confidence intervals of the predicted variables are computed. For the assessment of biomass predictions, independent ground data have to be available.

In addition to the principal methods, novel methods for image interpretation are developed in a specific work package. These methods test among other things the feasibility of machine learning methods. A specific topic of investigation in the work package of novel methods is application of airborne and spaceborne LiDAR samples. These data can drastically support the estimation of biomass in the tropics where collection of ground reference data is slow and expensive. For the forest areas with LiDAR coverage and difficult access, a vast number (e.g. thousands) of surrogate sample plots can be generated to supplement field measured data (Gautam et. al 2010). Surrogate plot values are estimated using
regression models based on the statistical relationship between field observed values and LiDAR pulse data derived metrics.

Mapping results of first service iteration

In the Mexican study site that comprised the state of Chiapas of 73,240 km$^2$, the first biomass estimates, land cover and land cover maps change maps were produced. The target years for mapping were 1992, 1994 and 2009. For the early 1990’s Landsat Thematic Mapper data and for 2009 RapidEye data were used, respectively. Figure 2 shows an extract from the change and biomass maps. The estimates were generated with the help of ground plot data that correspond to the Mexican National Forest Inventory. The Probability method was applied to the EO and ground reference data plot data sets (forest cover plot data courtesy of Conafor, biomass data courtesy of B. H. J. de Jong). The biomass model was first created using EO data and the ground plot data. The biomass estimate for each pixel was then computed using the model.

![Figure 2](image_url)

Figure 2. From left to right: Landsat TM image 1994, RapidEye image 2009, change map 1994-2009 (forest removal red), forest biomass map 2009 (maximum prediction 184 t/ha). Area size 2.7 km by 2.9 km.

The DRC case service area is about 68,000 km$^2$ and located in the west of DRC, bounded by 0º 03’ N and 3º 15’ S, the Congo River in the west and Lake Mai-Ndombe (18º 30’ E) in the east. Figure 3 shows the first iteration results of optical and SAR image mosaics and their forest / non-forest (FNF) maps for year 2010. The FNF maps were derived by a supervised maximum likelihood classification (MLC) with training polygons extracted from Kompsat-2 VHR data. A more complete overview over the first iteration results of the DRC including earlier years is presented in Haarpaintner et al. (2012).

An object-oriented forest change mapping from 2007 - 2009 was conducted over the main Guyanese mining area located around Mahdia in Central Guyana, using dual-year ALOS PALSAR Fine Beam Dual (FBD) data. Around Mahdia the main drivers for deforestation and forest degradation include large-scale mining, forestry, agriculture expansion and shifting cultivation (Pöyry Management Consulting (NZ) Limited 2011). The dual-year FBD data was pre-processed to 25 m pixel resolution using Gamma (2012). A Gamma-MAP SAR filter was applied for speckle reduction of the dual-polarized intensity images. For the object-based analysis the commercial software package eCognition
Figure 3. Optical and SAR image mosaics and their respective FNF maps for the year 2010: ALOS AVNIR-2 (a) mosaic (RGB = bands 3, 2, 1) and (b) FNF map, (c) Envisat ASAR APS mosaic (RGB = VV, VH, VV/VH), (d) ALOS Palsar FBD (RGB = HH, HV, HH/HV) and (e) FNF map from a maximum likelihood classification using all polarisations VV & VH (ASAR) and HH & HV (ALOS Palsar). In (b) and (e): Black = outside ROI and masked areas, green = forest, beige = non forest, and blue = water bodies.

Developer was utilized. The dual-year FBD data was segmented using multiresolution segmentation (Baatz & Schäpe 2000) in order to create homogeneous image objects that comprise dual-year information. A bi-temporal difference change index (DCI) has been computed for HH and HV polarization according to equation 1.

\[
DCI(SAR_{\text{Polarisation}}) = SAR_{\text{Polarisation, YEAR1}} - SAR_{\text{Polarisation, YEAR2}} \quad \text{eq. 1}
\]

The DCI for HH and HV were employed into the object-oriented and knowledge-based classification scheme. Figure 5 shows the detected forest changes for 2007 -2008 and for 2008 – 2009. A comparison with a reference GIS dataset maintained by the Guyana Forestry Commission (GFC) indicates the high accuracy of the detected change areas that can mainly be traced back to expansion of mining areas.

Figure 4. ALOS PALSAR FBD object-based forest change detection for Mahdia mining area, Central Guyana (2007 – 2008; 2008 – 2009). The detected changes (red) are overlaid over FBD HV intensity image.
Figure 5. Arrangements for model training and accuracy assessment in Guyana. Orange parts of RapidEye image were used for the accuracy assessment and the lower left half for training. The extract of RapidEye data shows the location of the 50 m by 50 m sample plots (white dots).

Users can access the delivered products using the WebGIS platform developed in ReCover. The ReCover Toolbox 1.0 is a Web application that can be accessed by anybody with a standard internet connection with Firefox 3.5 or more recent versions or Internet Explorer 6 and 7. Only registered users can access ReCover products; operations allowed are search, download, and visualization of products through the catalogue of the ReCover system. Figure 6 shows an example of the user interface.

Altogether 42 products were delivered to the users. They included image mosaic maps and thematic maps. The accuracies in forest and non-forest classification varied with the optical data from 85 % to 91 % and between 75 % (ERS) to 88 % (ALOS PALSAR) with SAR data on the three sites where the assessment was made. The results will be published in more detail after the users have evaluated the products. The biomass prediction model was unbiased with respect to the ground data but the accuracy at plot level was low.

CONCLUSIONS

The different approaches in image interpretation led similar accuracies in image interpretation. Assessment of the accuracy with a sample of VHR imagery appeared a feasible procedure. The accuracy in forest and non-forest classification was similar with L-Band SAR data (ALOS PALSAR) and with the optical data. The tropical environment with strong anthropogenic influence can be very dynamic which means that frequent observations are needed to understand the change processes. The danger is particularly large in areas where the re-growth occurs fast after the clearing of forest. Such re-growth can be grass or shrubs, for instance. Another source of error is the vague border between forest and shrub land. Both these errors can be reduced by using VHR data as an additional source of information.

Assessment of the accuracy of change and degradation will be subject of the latter half of ReCover. It is hypothesized that mapping of degradation at Landsat equivalent resolution is questionable and VHR data should be used to support the estimation.
The differences between the acquisition times of wall-to-wall satellite imagery and reference data introduce challenges in the inventory. The image acquisition process is very complex and time consuming also for the research community that has got used to ordering of the imagery. Another challenge is the large data volumes when the spatial resolution increases. For instance, the size of the RapidEye data mosaic that was used as input in interpretation was over 70 GB. The geometric accuracy even of the ortho-rectified image products by the suppliers was not good enough but an additional geometric correction was needed to locate the field reference plots correctly and to perform change detection successfully. Major attention should be paid on the improvement of the image acquisition system and geometric image accuracy as well as radiometric calibration in the implementation of the GMES and the Sentinel programs.

Additional Contributors:
VTT: Heikki Ahola, Jorma Kilpi, Matthieu Molinier, Yrjö Rauste; Albert-Ludwigs-Universität Freiburg: Barbara Koch, Fabian Enßle; Arbonaut Oy Ltd: Tuomo Kauranne; GMV: Marta Gómez Giménez, María Teresa Mateos San Juan; Norut: Kathrin Einzmann; Wageningen University: Martin Herold, Dirk Hoekman; IDEAM: Gustavo Galindo

User representatives:
Conafor, Mexico: Rafael Flores, Carlos Zermeño
REFERENCES


