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Abbreviations

ALOS AVNIR	Advanced Land Observation Satellite Advanced Visible and Near Infrared Radiometer
ALOS PALSAR	Advanced Land Observation Satellite Phased Array type L-band Synthetic Aperture Radar
ALU-FR	Albert-Ludwigs-Universität Freiburg
AOI	Area of Interest
BFAST	Breaks For Additive Seasonal and Trend
COLPOS	Colegio de Postgraduados
COP	Conference of the Parties
DRC	Democratic Republic of Congo
ECOSUR	El Colegio de la Frontera Sur
Envisat ASAR	Envisat Advanced Synthetic Aperture Radar
EO	Earth Observation
FAO	Food and Agriculture Organization of the United Nations
FCPF	Forest Carbon Partnership Facility
FP7	Seventh Framework Programme
FTP	File Transfer Protocol
GFOI	Global Forest Observation Initiative
HR	High Resolution
ICESat GLAS	Ice, Cloud, and land Elevation Satellite Geoscience Laser Altimeter System
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia
INSPIRE	Infrastructure for spatial information in Europe
IPCC	Intergovernmental Panel on Climate Change
ISFL	Initiative for Sustainable Forest Landscapes
KARI	Korea Aerospace Research Institute
LAMP	Lidar-Assisted Multisource Program
LiDAR	Light Detection and Ranging

MLH	Maximum likelihood classification algorithm
MODIS	Moderate Resolution Imaging Spectroradiometer
MRV	Measurement, Reporting and Verification
NDFI	Normalized Difference Fraction Index
NGO	Non-Governmental Organization
Norut	Northern Research Institute
PU	Population Unit
REDD	Reducing Emissions from Deforestation and Forest Degradation
RMSE	Root Mean Square Error
RvoG	Random volume over Ground
SAR	Synthetic Aperture Radar
SLA	Service Level Agreement
SLC	Scan Line Corrector
SVM	Support Vector Machine classification algorithm
UN	United Nations
UNDP	United Nations Development Programme
VHR	Very High Resolution
WU	Wageningen Universiteit

Executive summary

The ReCover project was executed in 2011-2013 under the Framework Programme 7 of the European Union to develop science based remote sensing services to support REDD and sustainable forest management in the tropical region. More precisely, ReCover focused on the Measurement, Reporting and Verification (MRV) process of REDD+.

Nine research partners developed remote sensing services for the REDD MRV for users in Mexico, Guyana, Colombia, DRC and Fiji. The interaction with the users was close through the service level agreements, user workshops, and bilateral communications. The users expressed their content of the services.

Two-stage sampling approaches were developed for forest and land cover assessment. A statistical sampling ensures provision of objective statistical data of the variables with confidence intervals, relevant to REDD. The sampled data are also used to assess the accuracy of wall-to-wall mapping and they can be used to correct the bias in the map estimates. Very fine resolution satellite data were used to collect the statistical sample.

In General, (semi-)automated classification approaches based on high resolution (10 – 30 m) optical satellite imagery could distinguish forest land from other land with overall accuracy levels close to or above 90%. The classification accuracy exceeded 90 % in areas with high forest cover and limited anthropogenic influence. It could be somewhat below 90 % when a large proportion of forest was degraded and the changes between forest and non-forest were very frequent due to shifting cultivation, for instance. Classification using radar data of the lower frequency L-band with similar resolution led to similar or slightly lower accuracy levels.

The overall accuracy was somewhat lower when considering all six IPCC classes (between 60-70%) than in forest and non-forest classification. For example, the separation of grassland from cropland remained problematic.

Forest cover was monitored between 1990 and 2012 by moving backwards from near-present images for which ground reference data were available. Also experimental biomass and degradation (biomass reduction within the forest class 1990-2010) were computed.

Using the common concept that was developed and tested in ReCover, forest and non-forest mapping for REDD+ with optical data could be implemented operationally without major additional research efforts. The mapping should include a statistical sampling framework to produce reliable information on forest area and its confidence intervals.

The Sentinel-2 satellites with 10 m spatial resolution, 290 km image size, high radiometric resolution, and 5 days imaging cycle at the equator will dramatically improve possibilities for obtaining cloud-free and high quality data from forests globally. Radar data preferably from L-band sensors are important sources to provide timely information on changes in forest cover. Also the C-band instrument of Sentinel-1 will be applicable for monitoring. The Copernicus program will enable application of earth observation to support the MRV operationally.

Access to data should be made as easy as possible also for the developing countries. The development of the REDD services should be combined with national forest inventories. Capacity building is crucial if REDD+ countries are to monitor and account for the changes in greenhouse gases. Common standards for the MRV would make its development easier.

1 Project context and objectives

The ReCover project aimed at developing beyond state-of-the-art service capabilities to support fighting deforestation and forest degradation in the tropical region in the context of REDD (Reducing Emissions from Deforestation and Forest Degradation) process. REDD will be a major driver for the development of more effective and reliable procedures for the monitoring of tropical forests.

The ReCover project specifically contributed to the reduction of errors in the estimation of the terrestrial carbon balance which results from uncertain rates of tropical deforestation and degradation. The errors are reduced by developing and implementing satellite image based methods for the tropical forest monitoring. The need for effective use of space-borne techniques is motivated by the fact that many developing countries lack human resources and funding for ground-based forest inventories.

The project developed pilot service capabilities by providing a monitoring system for forest cover, forest cover changes and biomass. The system also includes robust accuracy assessment procedures. The capabilities use mainly space-borne earth observation data and in-situ data. The high impact value of ReCover was achieved by working directly for and with the users and with local research partners, creating novel, trustworthy and standardized but affordable services and applying them in an INSPIRE compatible service environment. The long-term service sustainability is concerned by evaluating the new satellite missions such as the Sentinels.

Main focus areas of research in ReCover were to:

- develop a sound statistical concept and validation procedure for the production;
- apply very high resolution image data to improve reliability of results;
- estimate biomass and degradation as well as their change;
- define the role of radar data in REDD related services;
- build a standardized service system with a capacity building concept.

The project consortium consisted of nine leading research and industrial partners. Three partners, two from Mexico and one from Colombia were from the REDD eligible countries. The project had users in Mexico, Democratic Republic of Congo, Guyana, Fiji and Colombia.

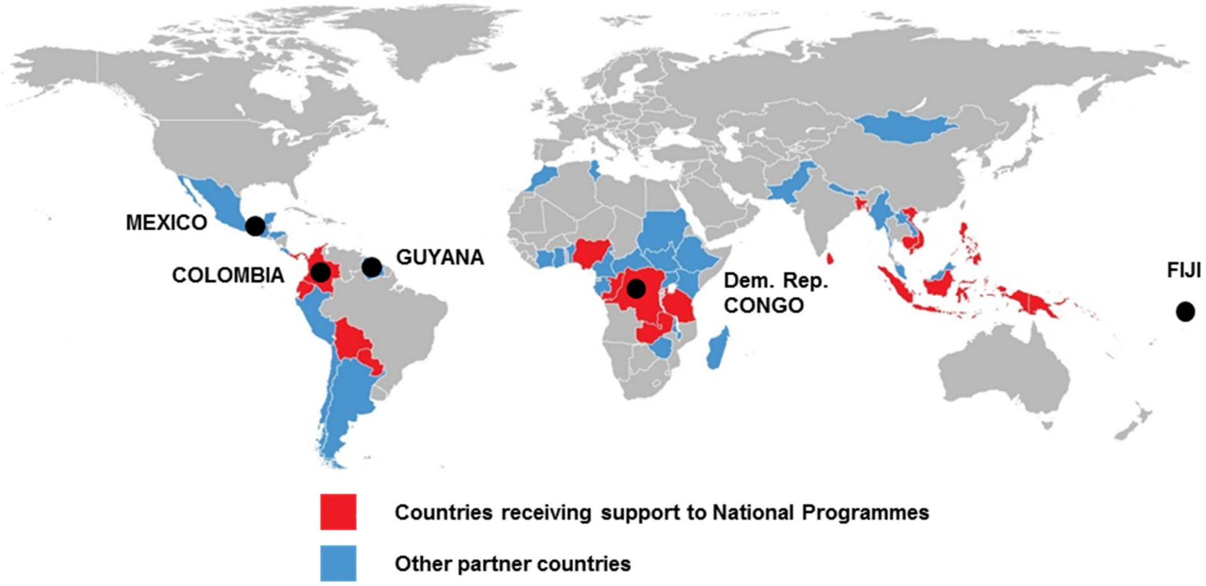

Figure 1. Study areas. Background map © 2014 UN-REDD (UN-REDD 2014).

The service development was controlled by specific user requirements that were expressed through Service Level Agreements (SLA) between the ReCover consortium and the users.

The project work was organized in eleven work packages from which four were for service development, four for service implementation, two for service roll out and expansion, and one for management. The project followed an iterative approach by applying two iterations for all work packages. After the first iteration the services were further developed based on the results, experience and user feedback from the first iteration.

2 Main scientific and technical results

2.1 Socio-economic context of ReCover

Table 1. Land area and population in ReCover user countries.

Country	Land area (km^2)	Population	Inhabitants/ km^2
Mexico	1943945	120286655	62
Guyana	196849	735554	4
Colombia	1038700	46245297	45
DRC	2267048	77433744	34
Fiji	18274	903207	49

The population density in most of the target countries was relatively low, at a similar level as the population density of the United States (34 inhabitants/km^2) and much lower than in Germany, for instance (232 inhabitants/km^2). An extreme case was Guyana with a very low population density. The size of the countries varied considerably from tiny Fiji to the DRC that is the 11th largest country in the World (https://www.cia.gov/library/publications/the-world-factbook/geos/cg.html). In the DRC the Human Development Index was clearly the lowest whereas Mexico and Fiji were above world average (Figure 2). Colombia is missing from this review since it joined in the ReCover project in a later phase.

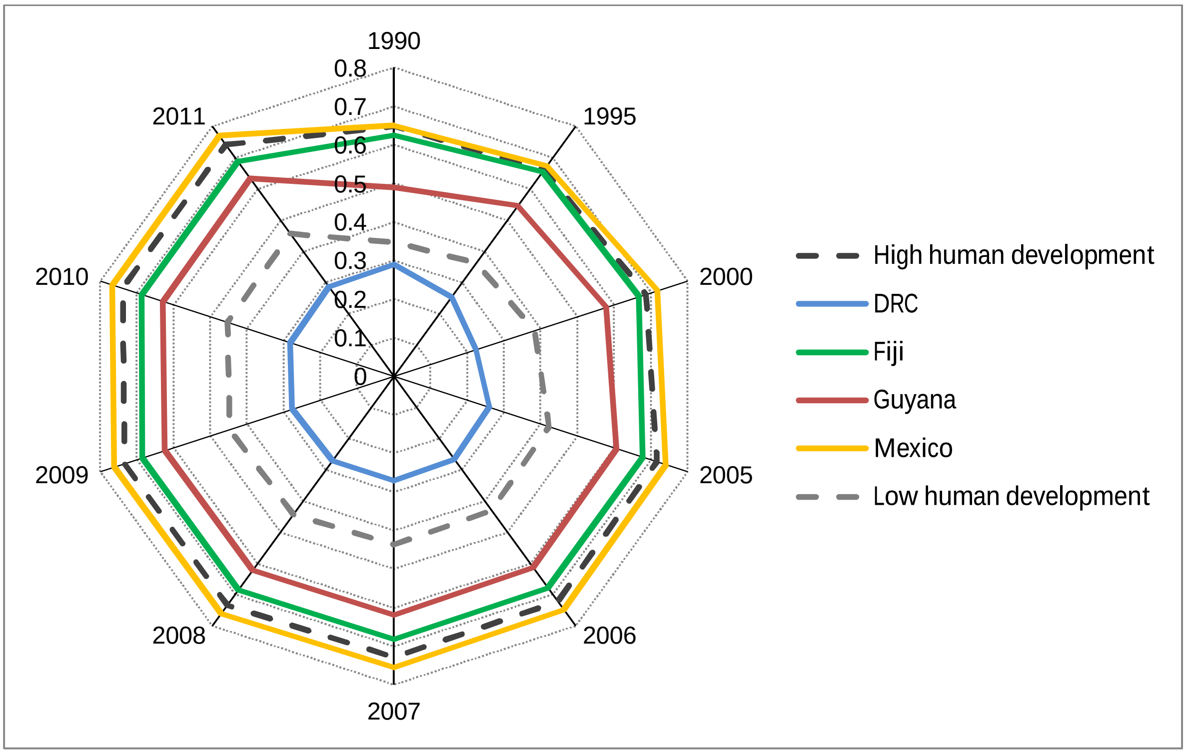

Figure 2. Human Development Index in ReCover user countries (UNDP 2012).

The forest proportion of land area is over 50 % in all the user countries except Mexico where forest is still a major land cover type (Figure 3). The forest cover in Fiji has increased from 2005 until 2008. In the remaining countries deforestation is observed (Figure 4).

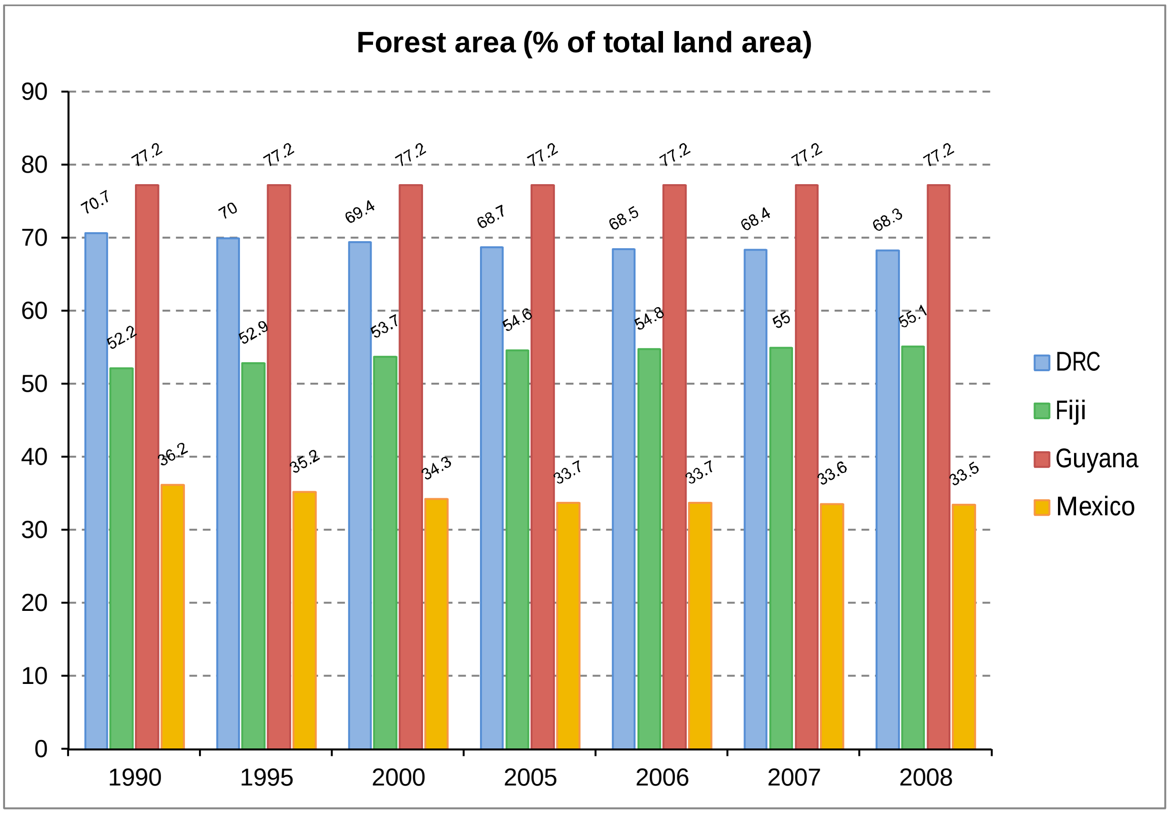

Figure 3. Forest area (% of the total land area) in the user countries (UNDP 2012).

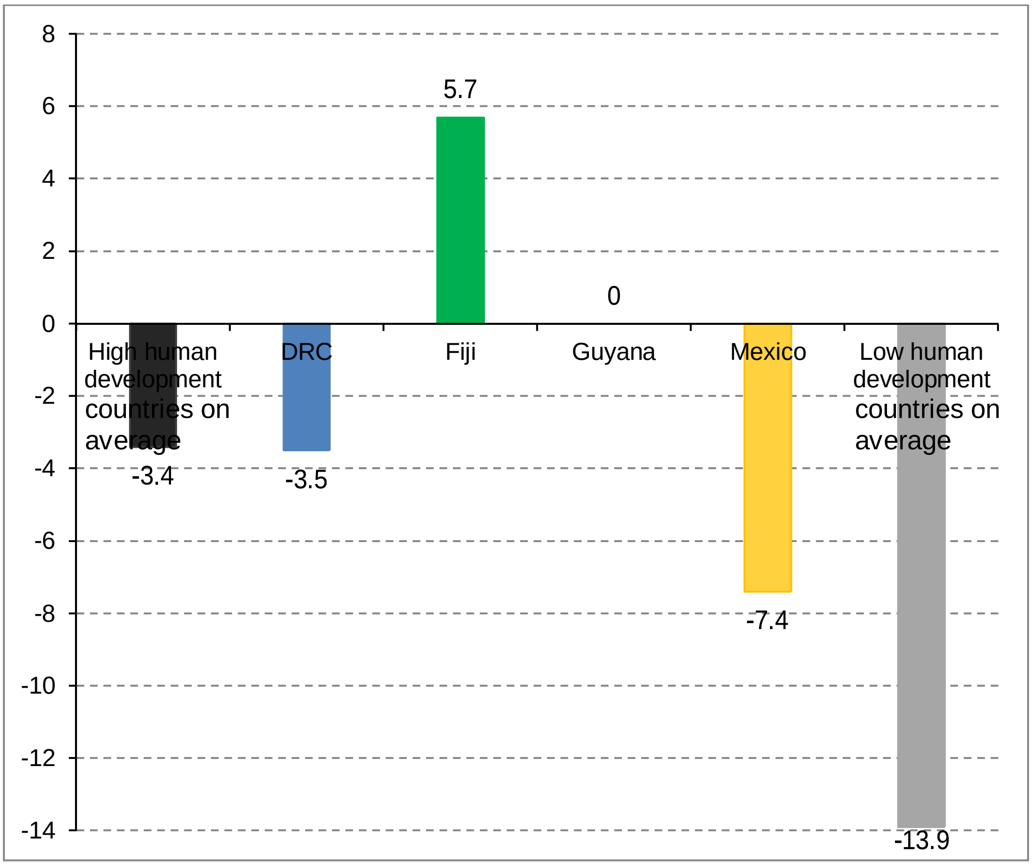

Figure 4. Change in forest area over the period 1990 to 2008 (%) in the ReCover user countries (UNDP 2012).

Agriculture was the main driver of deforestation in all the countries except Guyana where the deforestation was almost negligible. Logging was the main cause of degradation.

Table 2. Main drivers of deforestation and degradation on national level and main efforts as part of ReCover to address them (Herold *et al.* 2012).

Country	Most important drivers of deforestation on national level	Most important drivers of degradation on national level	Change processes addressed and monitored as part of ReCover
Guyana	Mining (66 %) Agriculture (31 %) Infrastructure (3 %)	Logging Fuel wood/Charcoal	Mining as priority in study sites Mahdia. Logging and agriculture as priority in GEOS sample sites Guy-1 Guy-2
Fiji	Agriculture (63 %) Infrastructure (25 %) Mining (13 %)	Logging	Agriculture, logging and mining is priority at the Fiji demonstration site on Viti Levu
DRC	Agriculture (50 %) Mining (38 %) Infrastructure (12 %)	Logging Fuel wood/Charcoal	Logging is the priority in the DRC service region
Colombia	Agriculture (75 %) Mining (25 %)	Logging Fuel wood/Charcoal	Illegal logging is the priority in the Colombia service site.
Mexico	Agriculture (66 %) Mining (33 %)	Logging Fuel wood/Charcoal	Slash and burn and other agriculture, logging.

2.2 Concept for forest mapping

A monitoring concept that can produce reliable evaluation of the credibility of the image analysis results was one of the key focuses of ReCover. For this purpose, a statistical concept that applies ideally two stage sampling was developed. The first stage is random selection of VHR images over the area of interest. When the number of classes is limited or some classes (as forest and non-forest) are of particular interest, a stratified sampling in the selection of the VHR data should be applied. The stratification can be done with the help of a wall-to-wall land cover map. Simulation tests in Laos showed that approximately one-per cent stratified sample of VHR data is adequate to define the forest area with ±5 % confidence interval at the confidence level of 95 % (Häme *et al.* 2013).

The second stage sample is plots that are selected within the VHR images. The variables of interest are evaluated visually from the plots. In case of the mixed plots the within-plot proportions of land cover classes are estimated. Plot size of 50 m by 50 m and plot distance of 800 m by 800 m was found to be applicable in the simulations (Figure 5). The plot size was large enough to enable interpretation of tree crown cover, for instance, but small enough to be managed by the interpreter. The between-plot distance was large enough to minimize spatial autocorrelation. The plot size was the same as the population unit of the sampling.

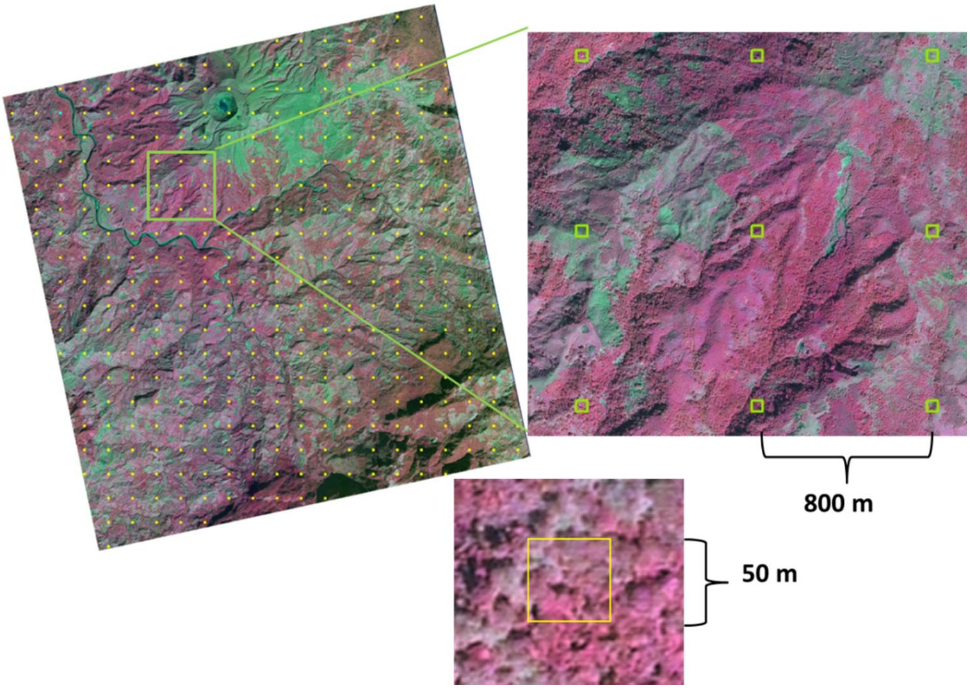

Figure 5. Plot (PU) selection within VHR images. Includes material © KARI (2008).

If the VHR images cannot be selected randomly due to limited image availability, a two-phase sampling can be applied. The first phase sample is the wall-to-wall map, covering all the population units. The second phase sample is the population units that are randomly selected within the available VHR images. Although the randomness is only true within the VHR images, this approach can give a realistic figure on the performance of wall-to-wall mapping when all the land cover classes are represented in the VHR images. In the Recover project, the two-phase approach was applied on most sites but in the Mexican site a sampling that resembled a two-stage design could be used although the available VHR images did not cover 100 % of the study area of state Chiapas.

The wall-to-wall image interpretation was done in an iterative manner to reduce the risk of biased estimation (Figure 6). First, an initial map was made by using any available reference data. Then this map was tested with partial reference data, and the model was improved if necessary. Another reference data set was used to test the improved map and so on. Two to three iterations were applied. Finally the map was evaluated with independent reference data.

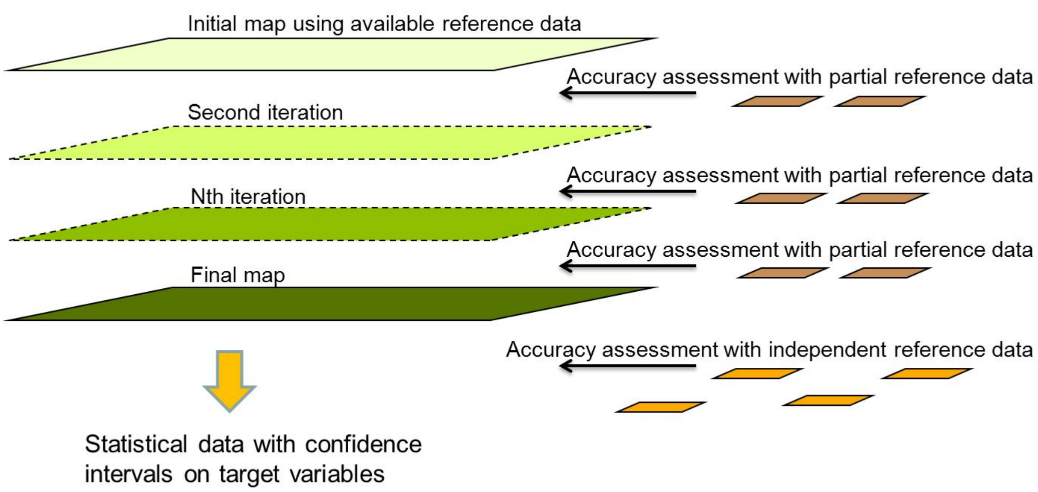

Figure 6. Iterative processing chain to produce maps and statistical data.

The VHR images were divided into three parts, A, B and C, for model development and accuracy assessment with some modifications by study sites (Figure 7). Visually evaluated plots of part A were used as reference data to compute the initial model, part B for the second iteration, and part C for the accuracy assessment. The VHR images were divided geographically to keep the spatial autocorrelation minimal. Another alternative that was considered poorer would have been to make a random sampling of all the plots within the images.

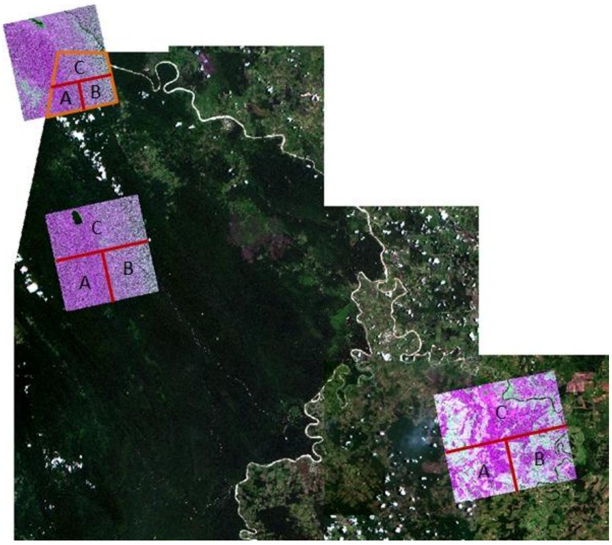

Figure 7. VHR image division into training and accuracy assessment set. Includes material © KARI (2008-2010) and © (2009) RapidEye S.à r.l., all rights reserved.

2.3 Image interpretation approach

One aim of ReCover was to create a harmonized production chain for all service providers. The methods that were used in the chain were developed throughout the whole project to manage the geometric errors in the received EO data, large data volumes, and seasonal differences in the data, for example. The main elements of the developed chain are shown in Figure 8.

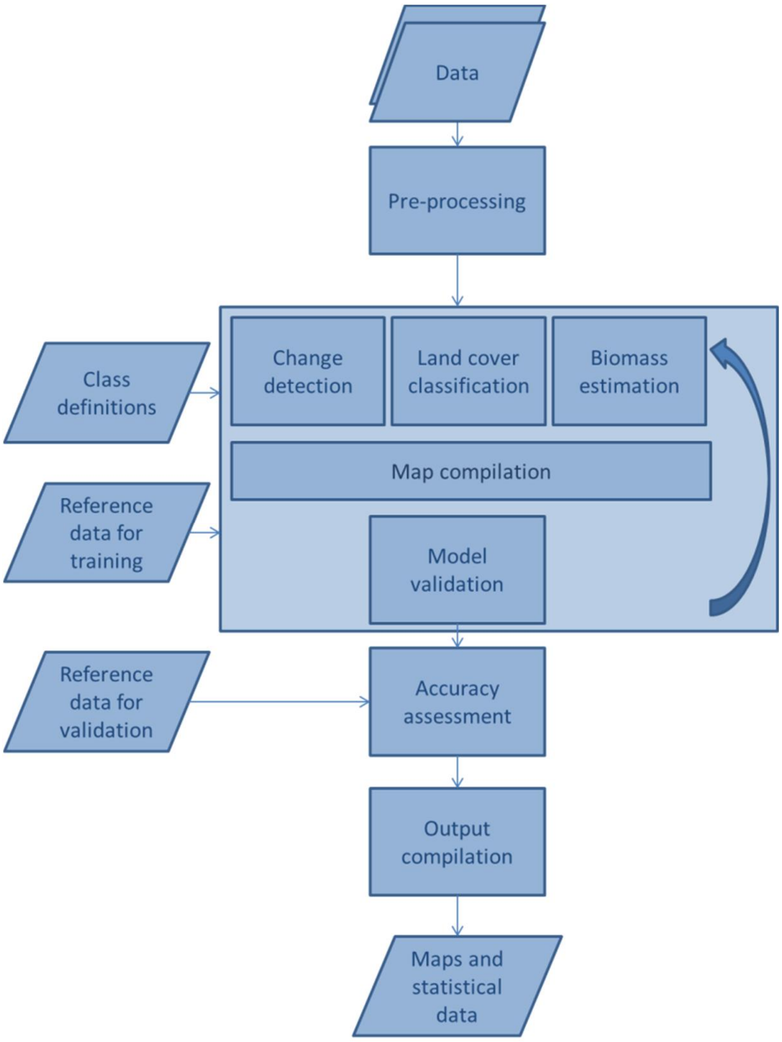

Figure 8. Overview of the ReCover processing chain. The upright curved arrow illustrates the iterative approach in classification. The model is iterated and validated internally before compiling the map.

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.

Harmonization of the chain meant identification of common elements and the elements that can use complementary methods in the processing chain. The common elements include collection of reference data from VHR images, iterative usage of reference data, model validation in the classification process, and the accuracy assessment of the maps. Image pre-processing, classification, change detection, biomass estimation and map compilation methods may vary depending on the service provider. The reason for using different methods for different service cases was that ReCover service providers had already image processing methods available.

The methods were compared in a separate study, in which the service providers of the project produced the land cover class estimates by applying different image interpretation methods but using the same image and training data sets. The test was done in Chiapas, Mexico over a site of approximately 100 km by 100 km (Figure 9). The study gave information on the sensitivity of the estimation to the applied analysis method, image data type and working practises of the service providers.

2.3.1 Forest and land cover

The land cover products of ReCover applied six land use categories that are consistent with the IPCC (Intergovernmental Panel on Climate Change) Guidelines (IPCC, 2003): forest land, cropland, grassland, wetlands, settlements and other land. A more detailed or different class division was applied if it was required by the user. ReCover applied the class definitions that are used in the national greenhouse gas reporting of each country. The land cover change products used the same IPCC compliant classes as the land cover products.

Biomass was estimated as a continuous variable. For transformation of forest variables into biomass in the ReCover project, the so called 'direct remote sensing approach' was applied. This approach directly used satellite image intensity data and reference data of above-ground biomass to predict the biomass using machine learning algorithms.

2.3.2 Degradation

The term forest degradation usually refers to permanent decrease of carbon stored in forest while the area in question still meets the requirements of forest definition. However, the exact definition of forest degradation is still unestablished. In ReCover, forest degradation and improvement were measured by estimating carbon, *i.e.* biomass change using multi-temporal data. A long monitoring period and frequent image coverage are needed to confirm that the detected change is permanent. The longest applied period was twenty years from 1990 to 2010. If appropriate multi-temporal data were not available, in forest disturbance grade was estimated using image data from one date. Forest disturbance may indicate forest degradation. Degree of forest disturbance was evaluated also in the visual interpretation of the VHR plots.

2.4 Classification results

2.4.1 Comparison of methods and sensors in Mexico

The six land use classes that are compatible with the good practice guidance (IPCC, 2003) were used in the accuracy assessment of the classifications. For forest, the FAO definitions, forest cover larger than 10 percent and minimum height of 5 meters (FAO, 2000), was applied.

The data sets that were used for wall-to-wall mapping included RapidEye, Landsat TM, Envisat ASAR and ALOS PALSAR data. Each partner pre-processed the data sets using their own methods. Exception to this was RapidEye data that was pre-processed by one partner for all the service providers.

Visually evaluated plots from VHR data were used as the main reference data source for training and accuracy assessment. For the reference data collection a regular grid of 50 by 50 m^2 square plots with 800 meter interval was created on each VHR image. The percentage of each land use class within a 50 by 50 m^2 plot was evaluated using visual interpretation with the help of ArcGIS software.

An iterative classification approach was applied in the map compilation and each service provider used their own selected method for classification. The image interpretation was done using an in-house method Probability (Häme *et al.* 2001), maximum likelihood classification (MLH), Support Vector Machine (SVM), and SAR-optical feature level fusion with a decision tree classifier. The main criterion for an acceptable classification result was to maximize the classification accuracy and minimize the difference between the omission and the commission errors of the resulting maps for the training data.

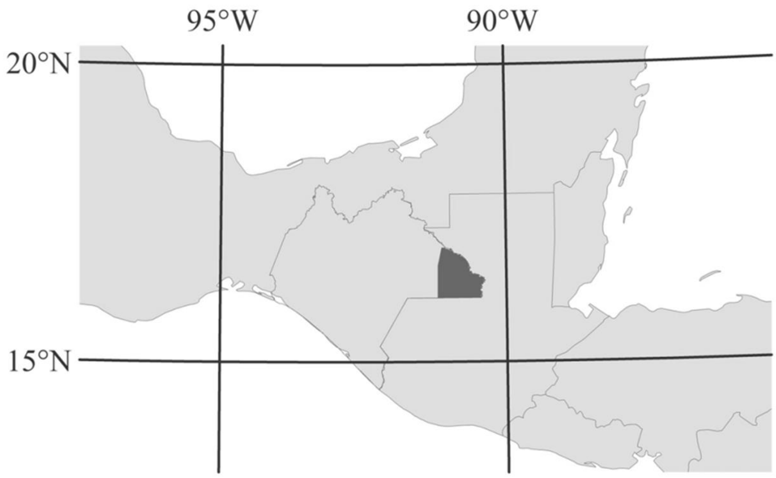

Figure 9. The location of the method comparison study site.

The estimations were assessed with a statistical VHR sample that was not in the possession of the service providers. A party that did not conduct the estimation was responsible for the testing. For each plot the corresponding class was extracted from the wall-to-wall maps. A confusion matrix was created for each map. Overall accuracy for the six IPCC compatible classes and the overall accuracy for the forest – non-forest classification were computed. In addition, the user's and producer's accuracies and omission and commission errors were computed from the confusion matrices.

As can be seen in Table 3 and Figure 10, all the results were similar and the differences between the results depended more on the data than the image analysis method. The basic data for the accuracy assessment was identical but clouds restricted the number of available observations in the classification with optical data. The accuracies with the L-band ALOS PALSAR data were almost at the same level as with the optical data. The accuracies in the classifications to the six IPCC compatible classes was about five percentage units lower than those in forest and non-forest classifications. Grassland and cropland classes were largely mixed. The test was also done by using plots that were exactly the same for all the classifications but the results were practically identical to those shown in Table 3. It should be noted that the high proportion of forest in the study areas automatically gives a relatively high overall accuracy when the accuracy in forest and non-forest classification is high.

Table 3. Overall classification accuracies in the method comparison test in Mexico.

No.	Source data and main method	Forest-non forest overall accuracy (%)	IPCC class overall accuracy (%)	User's accuracy for forest class (%)	Producer's accuracy for forest class (%)	No. of obs. in reference data (where valid map data)
1	RapidEye MLH	94.3	83.5	97.6	94.6	704
2	RapidEye Probability	93.8	85.7	97.9	93.5	704
3	PALSAR Probability	89.1	82.1	91.7	93.6	805
4	Landsat MLH(A)	88.3	81.3	91.9	92.9	589
5	Landsat MLH (B)	90.9	78.5	93.5	94.5	503
6	Landsat NDFI + MLH	88.3	81.3	91.9	92.9	589
7	Landsat Probability	91.1	85.7	94.9	93.3	392
8	ASAR Probability	78.7	-	86.5	85.1	798
9	PALSAR and ASAR MLH	92.6	-	93.1	97.2	785
10	PALSAR and ASAR Probability	88.6	81.2	92.5	92.6	765
11	Combination of 5 and 9	91.0	-	91.7	96.6	740
12	Combination of 2, 3, 7 and 8	93.6	85.5	97.3	93.8	840

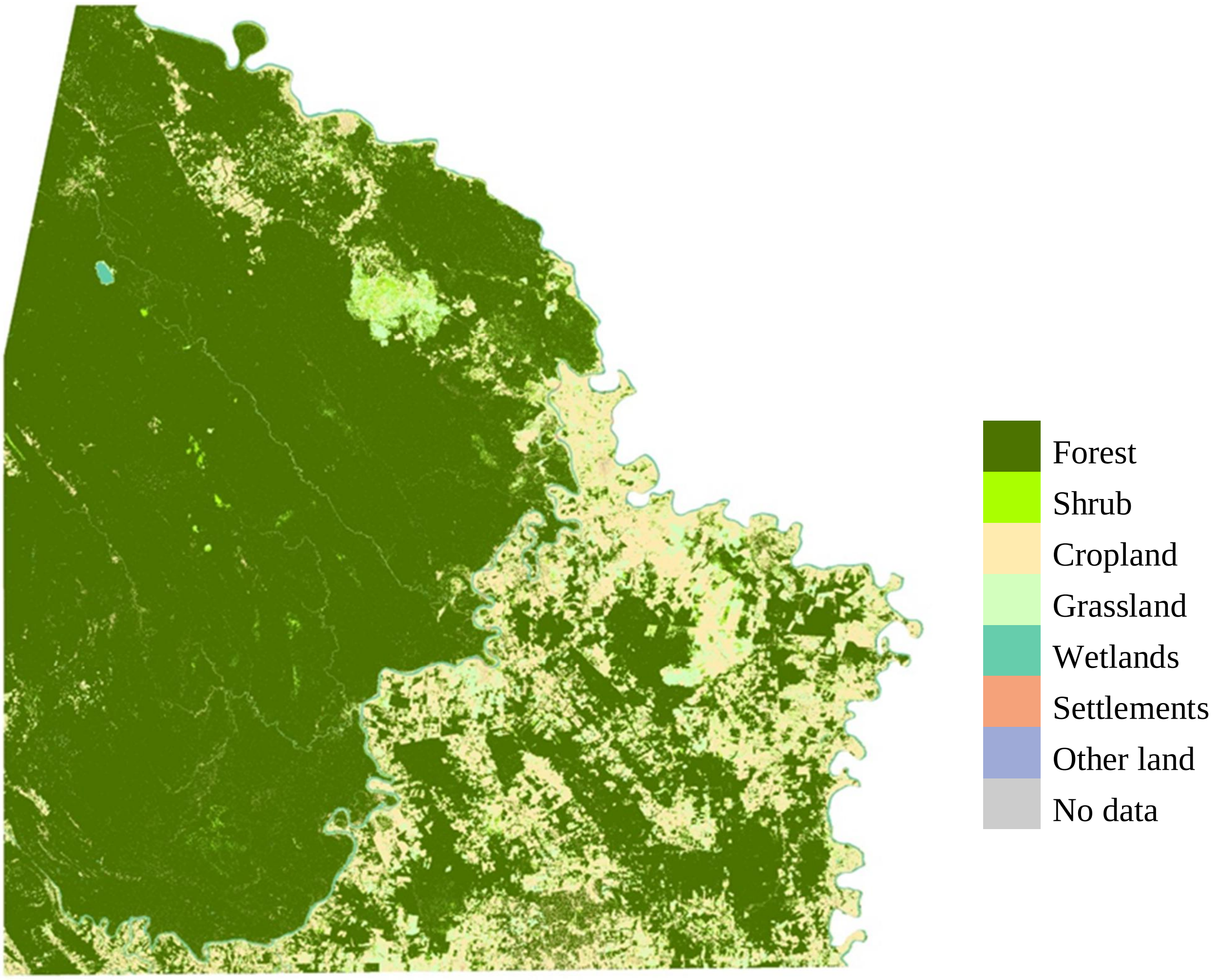

Figure 10. Example of the results of method comparison. The map was produced by augmenting the map made using optical data with map based on SAR data (map no. 12 in Table 3).

2.4.2 Results at ReCover sites

ReCover partners successfully delivered more than 100 products to the users in Fiji, DRC, Guyana, Colombia and Mexico in two service phases in 2012 and 2013. The classifications involved more than 1000 images. In most sites, an accuracy assessment procedure based on reference data from VHR imagery was applied. Despite the challenges of working with big datasets and a non-availability or very limited field inventory datasets, the project was largely successful in meeting the user requirements.

<u>Mexico</u>

In total, 42 products were delivered from the Chiapas service area of 73289 km^2 in Mexico. In the first service delivery, land cover, forest cover and biomass maps were produced for years 1992, 1994 and 2009 using Landsat TM and RapidEye data. In the second delivery, land cover and forest cover maps using Landsat data for years 1990, 1995, 2000, 2005 and 2010, and land cover and forest cover maps using RapidEye data from 2011 (Figure 11) and 2012 were produced. Experimentally, a degradation and recovery map, and a series of maps characterizing the spatial distribution and potential degradation (Figure 12) from optical data and a biomass map from ALOS PALSAR data were also computed.

The accuracy assessment procedure was the same as in the test for the comparison of the methods. The accuracies in forest and non-forest classification varied from 81.5 % to 87.9 % when reference plots that included only one land cover class were accepted (Table 4). The accuracies varied from 75 % to 83 % when also mixed reference plots were considered.

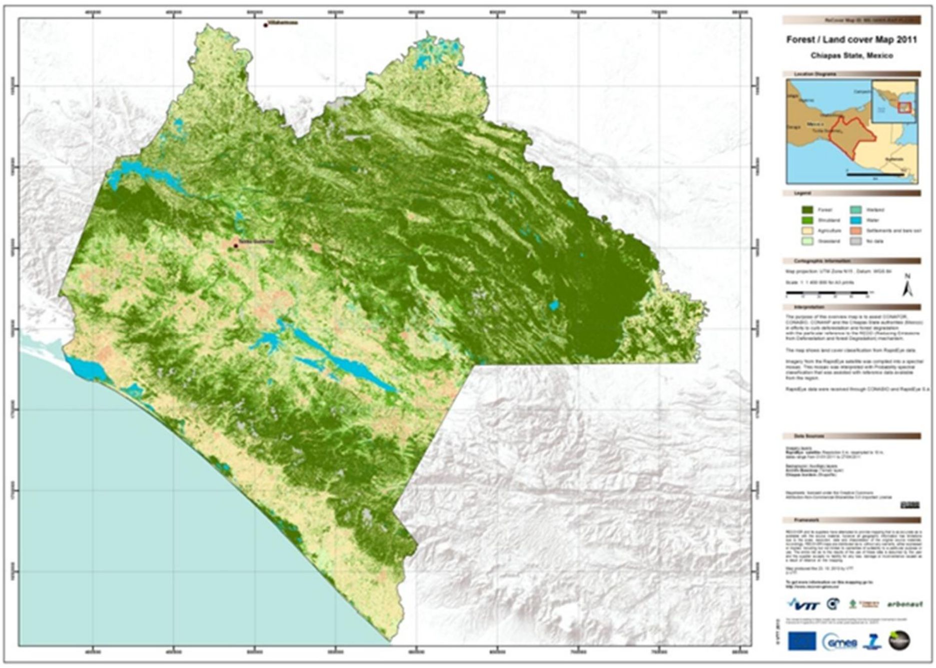

Figure 11. Land cover map of year 2011 in Mexico service area.

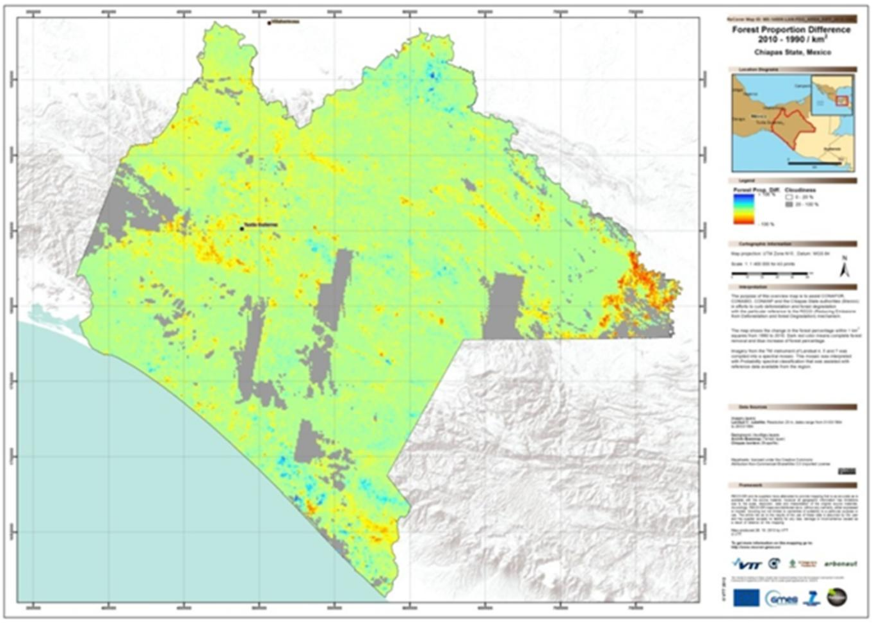

Figure 12. Forest proportion difference per square kilometer 2010-1990.

The forest and non-forest accuracies were at the same level in the classification with ALOS PALSAR radar data as with the optical data. The user's and producer's accuracies were in most cases similar, which suggested unbiased estimation. The exception was RapidEye classifications in which the user's and producer's accuracies varied. The reason for such variability needs further investigation because comparison of the Landsat-based and RapidEye maps did not explain such big differences in accuracies. However, it can be concluded that the higher spatial resolution of RapidEye did not offer an improvement from the viewpoint of the accuracy assessment with 50 m by 50 m plots.

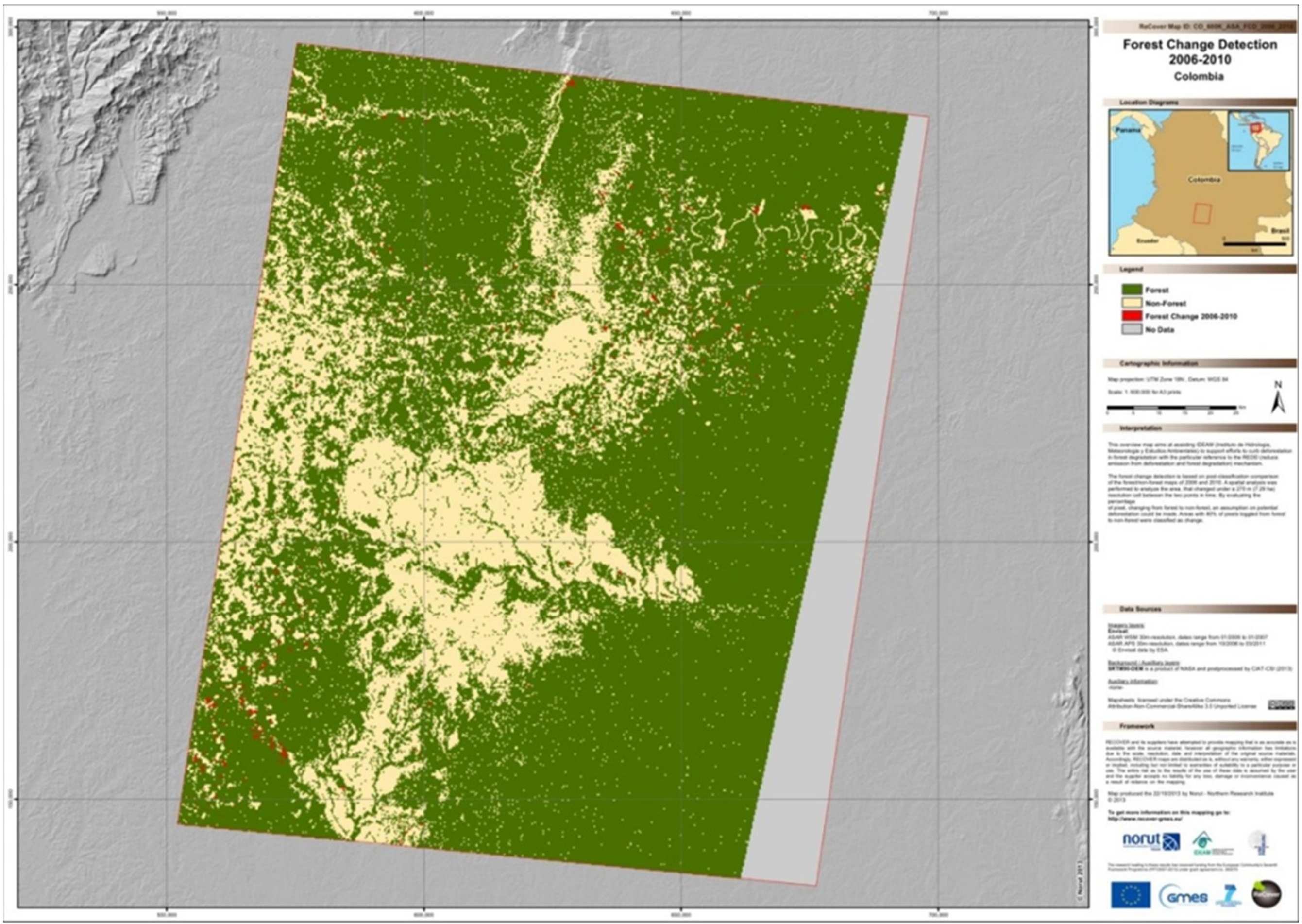

Figure 13. Forest change map 2006-2010 for Colombia service area.

<u>Colombia</u>

For Colombia, service started in the second phase of the project when IDEAM joined the consortium as a partner and a user. The services were produced for an area of 18900 km^2 in south-central Colombia. In Colombia service area, forest cover, forest cover change (Figure 13) and biomass maps were produced using both optical and SAR data. The target years of the mapping were 2006 and 2010. Because of the lack of other ground reference data the maps were compared to other forest cover maps and optical high resolution data. Accuracies for the forest-non-forest maps were 93.5 % for the map of 2006 and 92.8 % for 2010 and the differences between user’s and producer’s accuracies were small.

According to the limited accuracy assessment the forest and non-forest mapping of the years 2006 and 2010 could achieve the target accuracies. Large hot-spots of deforestation were well identified in the SAR-based forest change products. Also a method that would be applicable for near-real time deforestation alert was successfully tested.

<u>Guyana</u>

In Guyana, SAR-based image products, forest cover and forest cover change products and a national biomass product were produced. Part of the products was compiled for the Mahdia demonstration site (7467 km^2) and part for the whole country (196849 km^2). During the first project phase, forest cover and forest cover change products were developed, using primarily ALOS PALSAR L-band data. Medium-resolution SAR-based products were particularly useful in Guyana to cope with the persistent cloud cover in central Guyana.

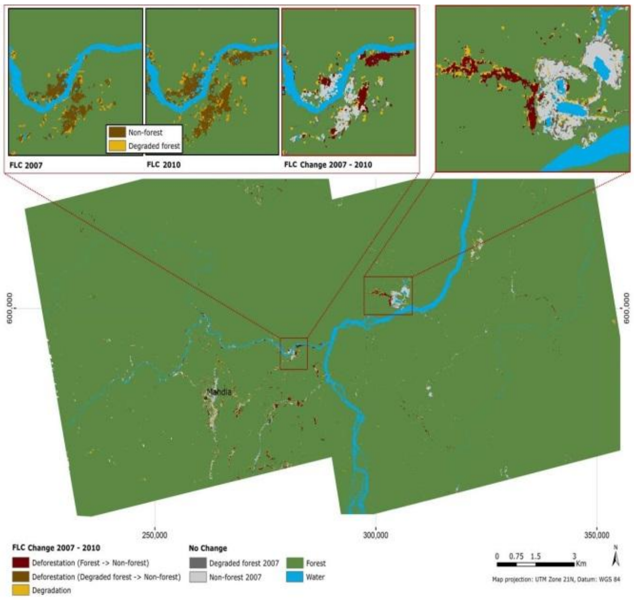

Figure 14. Forest and land cover change classification from Mahdia mining district, Guyana 2007-10, ALOS PALSAR and Landsat, area size 130 by 60 km.

During the second phase, an innovative approach was developed. The approach applied feature level fusion of multi-temporal and medium-resolution SAR with information at sub-pixel resolution from optical data. The application was used for mapping tropical forest cover and detecting deforestation and forest degradation (Reiche *et al.* 2013). The interoperable use of Landsat and PALSAR led to a strong reduction of Landsat (cloud cover, SLC-off) and PALSAR data gaps (SAR layover and shadow) while maintaining the desired thematic detail of detecting deforestation and forest degradation (Figure 14). The increased effective area of image interpretation served the requirements of Guyana to successfully implement REDD+. Another novel fusion method that integrates existing biomass maps with local reference biomass data (Yong *et al.* in review) was used to generate a country-wide biomass map at 1 km resolution.

Accuracy assessment was based on high resolution optical imagery. The overall accuracy was 96.6 %. According to the difference between user's and producer's accuracies the estimation was unbiased.

<u>DRC</u>

In DRC, optical and SAR image mosaics, forest cover maps, degradation maps and forest change maps were produced for years 1990, 2000, 2005 and 2010 (Figure 15) for an area of approximately 68000 km^2. During the first service delivery in 2012, single sensor products were produced. For the final service delivery in 2013 the existing products were improved. Also maps based on multi-sensor approaches and forest degradation maps were delivered for a sub-area. Multi-sensor products were developed by combing optical and SAR results. A multi-sensor approach was also used for the forest change products in the final service delivery. For biomass mapping, ICESat GLAS and RapidEye data were combined.

The overall accuracy of forest-non-forest classifications varied from 84.5 % of the ALOS AVNIR map to 93.4 % of the Landsat classification. The bias varied between the maps. The smallest difference between user's and producer's accuracy for forest class was obtained with Landsat data and the largest with ERS SAR and Envisat ASAR data (Table 4).

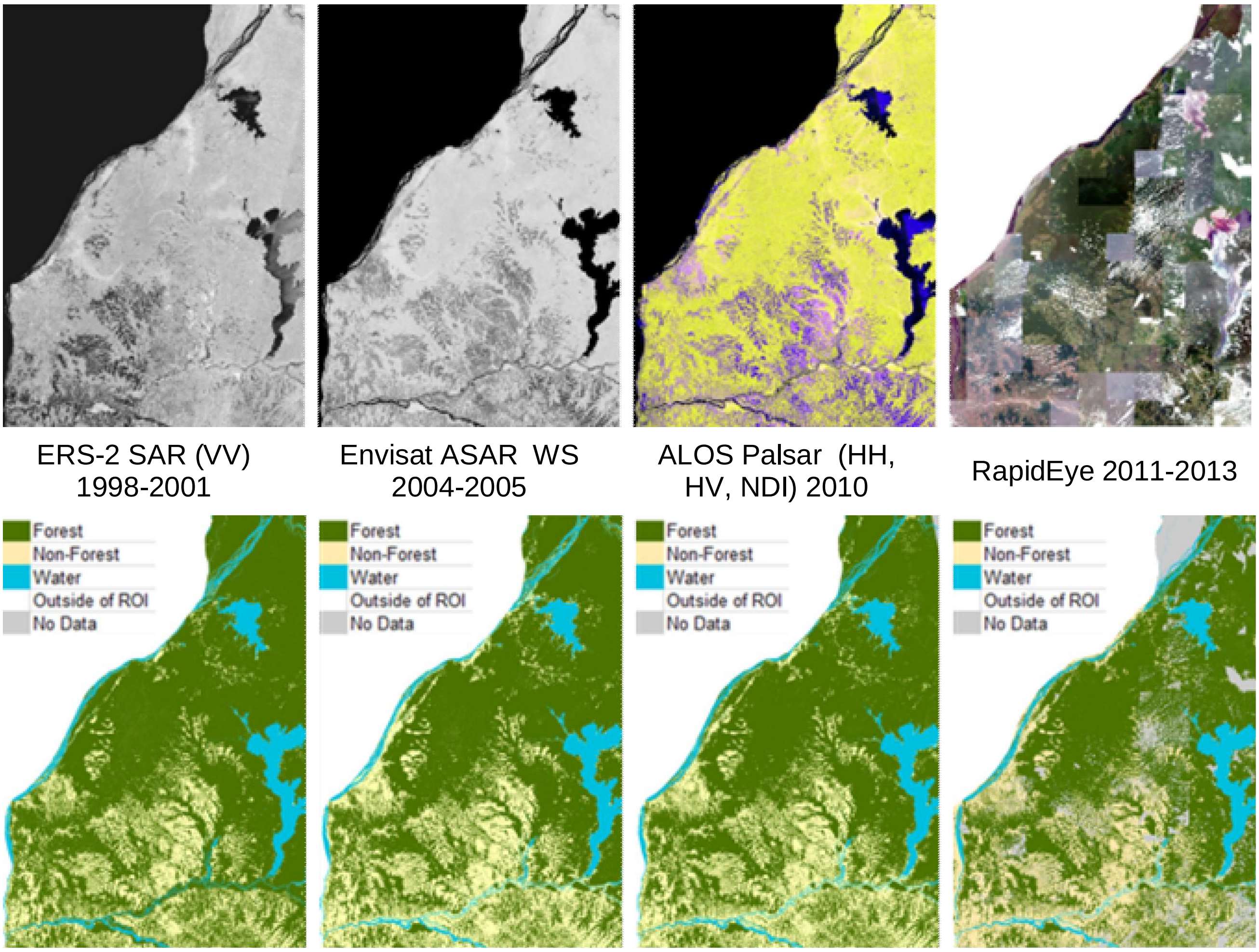

Figure 15. Source data and extracts of ReCover products from DRC service area: SAR mosaics from around years 2000, 2005, 2010. RapidEye mosaic from 2011-2013 and the corresponding forest/non-forest maps in DRC. Includes material © ESA (1998-2005) and © JAXA, METI (2010) and © RapidEye AG (2011-2013), provided under EC/ESA GSC-DA.

<u>Fiji</u>

In Fiji, most ReCover maps were produced for the whole country (18274 km^2). The main products were a country-wide SAR mosaic, cloud free image mosaics from optical data, and forest change and biomass products with VHR data. During the service delivery, classic SAR-based change products were generated. In addition, time-series change detection methods were tested by applying dense and long-term MODIS time-series. Positive and negative forest changes were detected on a yearly basis from 2005-2012 for entire Fiji at a spatial resolution of 250 m.

The service development for Fiji moved from MODIS to Landsat scale in the project phase. Landsat forest and non-forest map for the year 2000 was prepared using a SVM based classification. A processing chain was set up to (i) pre-process the entire Landsat time-series for Fiji and (ii) apply a further developed version of the BFAST (Breaks For Additive Seasonal and Trend) monitor time-series analysis method (Verbesselt *et al.* 2012) to detect forest changes. The processing chain was successfully applied to detect deforestation and forest degradation at a high temporal resolution (yearly-basis) for 2005-2012 at two demonstration sites in Fiji. Figure 16 and Figure 17 present product examples from the Fiji service area. Accuracy assessment of the forest and non-forest map suggested unbiased estimation with overall accuracy of 96.9 %.

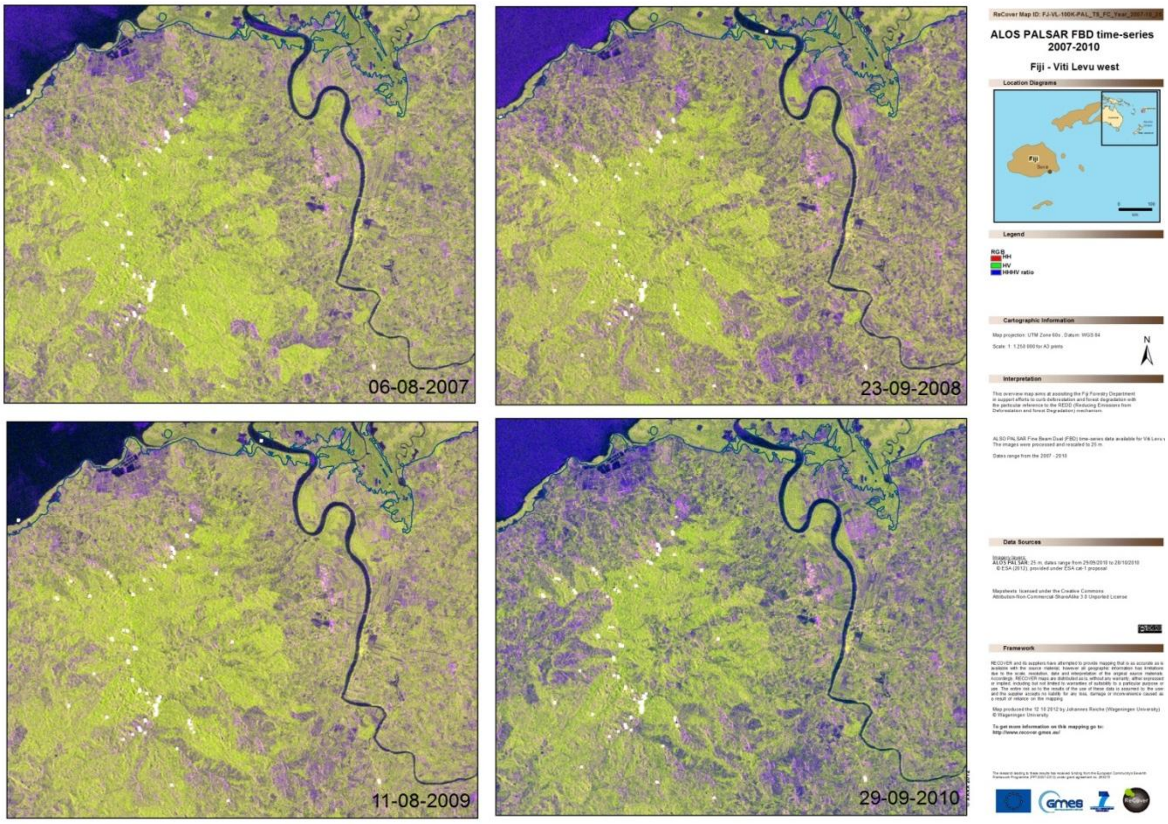

Figure 16. ALOS PALSAR radar image map time series of Fiji service area. ALOS PALSAR data © JAXA, METI 2007-2010, provided under EC/ESA GSC-DA.

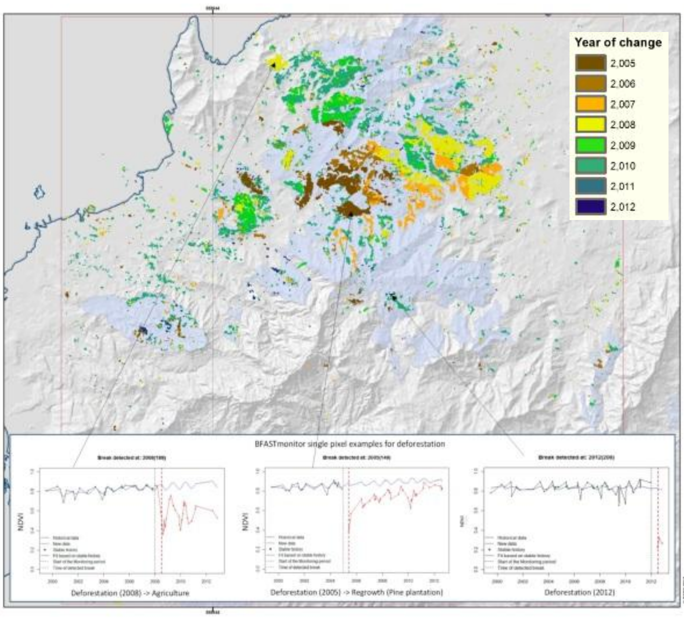

Figure 17. Forest yearly cover change in Fiji 2005 - 2012, Landsat, area size 50 km by 50 km.

Table 4. Accuracies of forest/non-forest classification.

Site	Instrument	Method	Overall accuracy forest/non-forest (%)	User's accuracy for forest class (%)	Producer's accuracy for forest class (%)
MX Chiapas	Landsat 2005	Probability	81.5	87.0	84.3
	PALSAR 2008	Probability	87.0	90.2	91.5
	Landsat 2010	Probability	87.9	92.2	92.0
	RapidEye 2011	Probability	87.5	86.7	94.7
	RapidEye 2012	Probability	78.5	89.9	82.8
DRC	1986 Landsat	MLH	93.4	94.2	95.6
	2001 Landsat	MLH	91.7	90.8	96.6
	2010 ALOS AVNIR-2	MLH	84.5	84.5	90.8
	2011-2013 RapidEye	SVM	86.7	86.2	92.7
	1998-2002 ERS/Envisat	MLH	88.7	87.3	96.2
	2004-2005 ASAR	MLH	87.6	91.7	88.0
	2010 ALOS PALSAR	MLH	88.5	88.4	92.7
Mahdia Guyana	ALOS PALSAR, Landsat	Feature level fusion	96.6	92.5	93.0
Fiji	Landsat	SVM, Boot-strapping	96.9	96.9	96.7
Colombia	Envisat ASAR 2006	MLH	93.5	95.6	95.9
	Envisat ASAR 2010	MLH	92.8	95.8	93.6

2.5 Web map service tool

The ReCover Toolbox 2.0 that was developed in the project 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. The products of ReCover were uploaded to the Toolbox where they could be accessed by the registered users. The allowed operations are search, download, and visualization of products through the catalogue of the ReCover system. Figure 18 shows an example of the user interface. The tool remains available for the users also after the ReCover project.

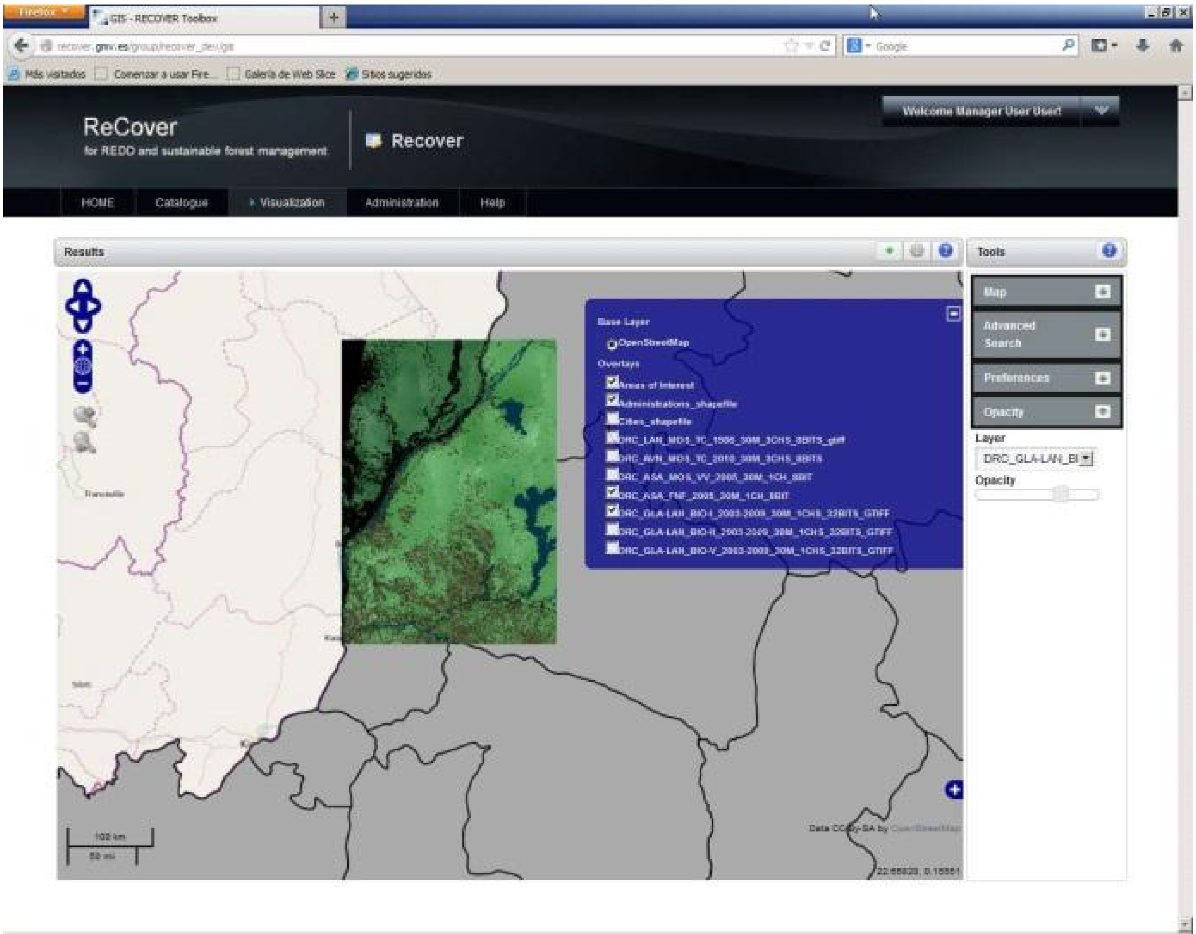

Figure 18. Example of user interface for the WebGIS. A product has been selected and visualized on a map: two layers are visualized, with different transparency levels.

2.6 New sensors and techniques

In addition to the principal methods, novel methods for image interpretation were developed in a specific work package. These methods tested among other things the feasibility of interferometry to Tandem-X SAR data for the prediction of forest height and application of LiDAR data for forest biomass estimation. The applicability of airborne LiDAR data was tested on a European site and space-borne ICESat data on the Fiji and DRC sites for biomass estimation.

Besides high resolution optical data, SAR provides another convenient means for the assessment of forest state and forest dynamics. A RvoG-based algorithm was developed for tree height estimation using ALOS PALSAR multipolarization data to improve the accuracy of biomass prediction. With a number of promising SAR sensors due for launch in the near future, these algorithms can be tested to evaluate the potential benefits of using multipolarization data for improved mapping of land cover, forest biomass, and vertical structure of vegetation canopy.

LiDAR has developed as a highly influential data source of forest analysis within the last decade because it allows accurate extraction of vegetation heights and other additional parameters related to interior structure of the canopy. Therefore it could be used within all product groups of the ReCover project. Excellent results have been reported earlier using the airborne LiDAR datasets, but in the ReCover project the potential of space-borne LiDAR was tested. Methods were developed for using ICESat I full-waveform data in single sensor as well as multi-sensor techniques. The potential of space-borne LiDAR instruments can be realized once the upcoming ICESat II system becomes operational. The canopy penetration capability of ICESat II instrument is however somewhat questionable but on the other hand it has potentially several advantages over ICESat I including improved elevation estimates over rough areas and steep slopes. ICESat II is scheduled for launch in early 2016.

To support REDD and sustainable forest management in the tropical region, the broad recommendations which can be proposed based on the experiences gained can be summarized as:

- Moderate resolution (10 – 30 m) optical datasets may be recommended due to their ability for wall-to-wall coverage and availability for time series analysis, although for validation and training set generation, very high resolution sensors are indispensable.

- TerraSAR-X and TanDEM-X are recommended as an efficient twin system offering multitemporal, multi-polarization, interferometric and polarimetric interferometric imaging capabilities. Sentinel-1, which is directly related to the Copernicus services provides an important platform for future forest monitoring,

- LiDAR technologies have a significant potential for future forest monitoring, which has been highlighted by the use of airborne LiDAR sensors. Algorithms for extraction of vegetation heights using ICESat/GLAS, the only space-borne LiDAR data system available, are important tools for forest biomass estimation.

- Using multisensor data fusion approaches involving optical, SAR, and LiDAR sensors can be recommended over single sensor based approaches.

- For future method development it is recommended to have a focus on automation approaches that enable a near real-time monitoring of forest resources.

3 Potential impact

3.1 User feedback on services

Image mosaics and forest cover products were considered by the users as the most useful services. The users requested usually an annual mapping frequency. The potential of radar (SAR) was anticipated high in near future. However the optical data is the principal remote sensing data source when cloudiness enables their use. The users were interested to combine development of national forest inventory and forest monitoring for REDD.

Biomass was considered an important variable but its priority was lower than with the forest and land cover variables. The prioritization is understandable taking the requirements of the reporting for REDD and the uncertainty in biomass estimation into consideration.

All the users were interested to continue cooperation with ReCover partners and several saw a role of ReCover in the development of national REDD. Despite the developed ReCover Toolbox, most users preferred product delivery through a courier on a hard disk and the rest preferred an FTP delivery. The Toolbox seemed to be somewhat a premature way for product delivery because the present speed of the networks makes use of an on-line tool too slow or practically unfeasible.

The approach of the project to have two phases of the service provisions allowed not only for improvement of the service products due to user feedback, but it also improved the overall user-service provider cooperation. This will be especially necessary for the usefulness and ReCover’s contribution to a future roll-out of the service. The quality of the final service products satisfied users’ expectations.

An important aspect to be reviewed in the future is the overall concept of having service providers on one side and users on the other. The general feedback was that most users are keen on being more involved in the whole product development and production in order to be able to perform such tasks in future without depending on external capacities and expertise. Capacity development inside the countries is therefore a key issue in establishing a sustainable forest monitoring and MRV system. Future projects could involve the user countries as R&D partners because short capacity building workshops will not be able to really build the necessary capacities. This would also enhance the south-south cooperation.

3.2 Data requirements

Present and near-future satellite systems can be applied well to support REDD MRV. The working horse will be Sentinel-2 with 10 m spatial resolution, high spectral and radiometric resolution, large image size and high frequency with image acquisition. Together with Landsat, data can be collected from the same location every third day. This increases possibilities for having at least annual cloud-free imagery also from moist tropics. The increasing revisit frequency and new operational satellite missions for the operational use will improve the relative competitive position with respect to SAR data.

Despite the good potential of optical data, also SAR data will have an increasing role in forest monitoring. SAR is capable in monitoring changes several times within a year. Acquisitions monthly or every second month will allow monitoring of shifting cultivation operations, for instance. Annual frequency may be already too low due to fast vegetative succession. Sentinel-1 with its C-band SAR is not optimal for forest monitoring but availability of a high imaging revisit can compensate the suboptimal C-band. At the time of writing of this document the data policy of ALOS-2 SAR is unknown. In principle the L-band SAR is better for forest and land cover applications than the C-band.

The availability of very fine resolution optical data is good and improving. The VHR data are integral part of a reliable monitoring system for forest cover. Also the prices of data are decreasing. It should be agreed with the commercial VHR satellite operators that they would collect a sample of images in a systematic manner over the tropical region. This would make it possible to apply two-stage sampling in forest monitoring and ensure computation of reliable statistical characteristics of the accuracy of wall-to-wall mapping.

Evaluation of land cover classes may not need ground reference data as long as optical VHR data are available. On the contrary, in biomass estimation ground reference data are compulsory. Also these data should be collected by applying statistical random sampling. Information on forest height from satellite would improve the accuracy of biomass prediction. In addition to space-borne LiDAR, SAR interferometry with Tandem-X data has a high potential in height estimation but the operational applications are still to be developed.

Collection of ground data should be better harmonized with satellite image analysis than what is the case presently. The whole monitoring system including satellite and ground data collection should be designed as a whole. The ground plots should be larger than in the traditional inventory to reduce the edge effect and possible errors in geo-location.

3.3 Cost-benefit and market analysis

3.3.1 Customers for a ReCover product

A customer for a ReCover product is a government of a REDD eligible country. It is an unlikely scenario that a private forest owner would be directly the customer.

The original funding for the government to implement the MRV can come from several sources. The government receives financial compensation based on proven REDD operations. The original funding sources include at least:

- The government itself
- Bilateral development aid organizations of industrial countries
- UN-REDD
- World Bank
- Foundations and nature conservation NGO's
- Private sector from an industrialized country

A service provider should communicate primarily with the REDD country government but also with the donors in cooperation with the government.

3.3.2 Current market

The ReCover team is discussing potential continuation of the cooperation with the REDD users in Latin America and Africa, for instance. In addition, discussions continue with private value-adding companies. Also software licencing agreements have been made. One project partner was an SME that already has started to utilize the results of ReCover in their REDD business.

Estimation of the REDD market size is difficult because the post-Kyoto climate treaty does not exist yet. The market is also fragmented; only some tropical countries qualify for REDD process. In short, the current market size is small but existing.

Current budgets

Although the current budget volumes are related to all of the REDD process activities, only part of the budget is targeted to MRV mechanism. The budget of present REDD-related activities is approximately USD 2.2 billion but also higher figures have been presented (Kojwang and Ulloa 2012). These activities are based on voluntary and mostly bilateral contributions. A step towards the actual REDD was taken in the last United Nations Climate Change Conference COP19 where the establishment of The BioCarbon Fund Initiative for Sustainable Forest Landscapes (ISFL) of USD 280 million was announced. This fund will be coordinated by the World Bank[1].

The main donor is the Norwegian government with USD 1.5 billion investment to support REDD in Brazil, Tanzania, and Congo basin. The budget of the Forest Carbon Partnership Facility with 18 donors including individual governments and the European Union is presently USD 300 million. Other donors include United Kingdom, Australia and Finland[2]. International organizations such as the European Union and the European Space Agency support REDD and the MRV for REDD separately.

Total addressable market for the MRV tools – an estimate

If few per cents of the REDD budget is available for the satellite based services for the MRV, the present market would be in the order of 50 – 100 million. However, the addressable market is much smaller today. Note that the estimated market size does not include the market for data acquisition. For instance the market for the VHR image suppliers and airborne laser scanning companies could be substantial.

Because REDD eligible countries are dispersed around the tropical regions, with varying practices of governance, there may be locally additional funding sources.

What is the biggest growth potential

Major growth of the REDD MRV services will happen if REDD will be part of a climate treaty. The underlying assumption for forests and biomass to be part of carbon trade is the availability of accurate valuation and independent verification tools. In case REDD and climate treaty would actualize together, the REDD market would multiply in size.

Largest growth in the MRV mechanism may happen either or both in the developed countries or in the developing countries. The developed countries have knowledge and expertise to produce ReCover products; the developing countries are interested in capacity building, and the actors want to monitor changes in forest areas and in carbon stock themselves. The growth in the capacity building may even actualize from governance issues: once a country's technological capability increases, it will result in increasing need for reference level monitoring and other MRV related activities.

Slower but substantial growth can be expected also if the post-Kyoto climate treaty will not realize in the near future. Investments in the monitoring of forests in general and tropical forests in particular will increase anyway to support more sustainable use of the natural resources. This means among other things development of national forest inventories. Satellite surveys, supported by airborne laser scanning observations and limited field observations can be assumed to become main stream approaches in all forest monitoring activities. The main reasons to this are improvements in satellite data supply and cost effectiveness and timeliness of the satellite based information.

Reporting for REDD requires a national forest monitoring system with determined reference emission levels. Expertise and funding should be available to establish a support system and required governance practices.

[1] http://www.worldbank.org/content/dam/Worldbank/document/SDN/BioCF_ISFL_Flyer.pdf
[2] http://en.wikipedia.org/wiki/Reducing_emissions_from_deforestation_and_forest_degradation

3.4 Key trends

Technology trends

There are three major technological trends affecting the REDD process. These are open source software tools, service customization and open EO data.

- **Open source** There is a need to fit inexpensive systems into particular customer needs (see e.g. Kogut and Metiu 2001 or Martines-Torres and Diaz-Fernandez 2014). The freedom to choose systems with a purpose built functionalities and low cost is a reason why customers choose open source solutions.
- **Customized service** Customers want tools and services tailored to their needs. Customers and end-users either prefer tools with low cost or tailored services with minimum additional effort.
- **Open EO data** Policy for satellite images is increasingly free data policy, such as in Copernicus[3].

Application of space-borne remote sensing together with airborne LiDAR observations can significantly improve accuracy particularly in forest biomass estimation with reasonable costs. One of such developments is the LiDAR -Assisted Multisource Program (LAMP)[4].

Many emerging technologies can be applied in the REDD+ scheme. For instance, the significance of radar is increasing in forest monitoring. Interesting emerging radar technologies include radar interferometry and radargrammetry for forest height estimation. Also new LiDAR technologies are going to be important in the future. The use of full waveform LiDAR and multispectral LiDAR are bound to be a great benefit for the field, and research around these technologies is going to be extensive. In general image analysis is moving towards more automated and intelligent methods. Already the huge data masses from Sentinels and other new satellite programs force development of new approaches in image analysis.

Regulatory trends

REDD+ related credit mechanism does not develop as planned if the post-Kyoto climate treaty will not come true. This will lead to a situation where alternative, supplementary and often locally driven needs will be used to set the REDD business requirements. In this case REDD will help local countries to develop their national forests inventories.

Regulations for the reference level definition as part of the MRV are still lacking. Scientific frameworks for the actual measurements have been developed, but the actualization of these as part of carbon trading is still to come.

Each significant MRV consultant or service provider can claim their process being the best and most accurate – whilst global regulatory decisions on rules and principles used are yet not defined. This is largely due to slower than anticipated interest in carbon trading especially among developed world.

3.5 Revenue potential

Customers in general terms are ready to pay for services, which either provide perceived value added or let them to save money. In the context of natural resources management, this is quite tricky. Natural resources market is not a classical economy model: when taking costs into consideration, indirect revenues and savings which make a service affordable should be evaluated.

[3] http://www.copernicus.eu/
[4] http://www.franepal.org/wp-content/uploads/downloads/publications/bulletin_vol1_issue1.pdf

One of the main challenges in this context is “educating” the customers to look behind the cost of the service. The REDD+ process should provide: financial value to carbon stored in forests and incentives to invest in low-carbon paths for sustainable development: EO-based services such as the ReCover ones, enter into the MRV process.

The governmental organizations in developing countries will be ready to pay for the REDD services if and only if the revenues in terms of funding, direct or indirect payments will overcome the costs. It is of vital importance that services can rely on low cost or free satellite images. ReCover services were designed having Copernicus data policy in mind, and in particular thinking about the use of the Sentinel data, once they become operational. Copernicus will provide free access to a wide swath data of relatively high spatial resolution free of charge, which will reduce preprocessing time and the number of images to be processes.

ReCover provided methods to set baselines out from satellite data and to monitor changes in forest cover and biomass estimations. These methods can use wall-to-wall mapping with HR data and sampling with VHR images, employed as ground reference information where no other data are available. This approach helps reducing the costs of field work (consequently also reducing the risks associated to contract people in remote and dangerous areas) but requires high processing capacity and trained personnel for the interpretation of the data, especially when mapping involves the entire country.

One of the main advantages of ReCover services is that they can be delivered on a yearly basis, considerably reducing the normal timeframe spent between the costly forest inventories. If the potential customer has not enough processing capacity or expertise to process the imagery nor forest ground information available, external contracting ReCover services should be an option.

ReCover services will be profitable in a large scale economy. The scale economy can be put into practice if long term contracts are made and at least regional monitoring are required. ReCover services are easily scalable and data from new satellites can be introduced in the chain without having to re-design the entire service.

The efforts made within ReCover to establish statistical methodologies which should guarantee the objectivity and homogeneity of results is one of the main values added of the project. ReCover results are validated according to a statistical accuracy assessment which reduces biases and decreases differences between the products by the service providers.

The above is written from the viewpoint of an external service provider but the same logic is applicable for an in-house service provision. The economic benefit from the improved management of the natural resources should exceed the costs of the effort invested in the monitoring system. The economy of scale is also valid: for larger areas a marginal utility of the investment is easier to achieve.

3.6 Production costs

A decision support tool was developed in ReCover to compute the service costs. The cost items of the service are input in a detailed table and the total costs for a service are output. The system takes into consideration all the technical elements of the services including the costs of the reference data. The baseline is that the reference data for the land cover variables are collected with the help of a sample from VHR satellite imagery. The VHR data are also used for the accuracy assessment.
For the biomass estimation, ground plot data are needed. The number of ground plots may be reduced by applying airborne laser scanning data. In particular the accuracy of biomass estimation can be improved.

The service providers estimated costs of different service cases using the developed tool. It was assumed that service is given by the ReCover partner organizations. The costs estimate per hectare of land cover (forest cover) was in the range of 0.01 - 0.03 € including accuracy assessment, excluding the image costs for the wall-to-wall data but including them for the commercial VHR data sample. The estimates vary greatly case by case depending on the area of interest, available reference data and required level of accuracy and spatial detail. The principal assumption was that the wall-to-wall classifications are done with data of 10 to 30 m spatial resolution and the overall accuracy requirement for forest and non-forest is approximately 90 %.

The main cost elements considered during the estimation were:

- Project set-up
- Data acquisition
- Preprocessing
- Processing
- Quality control
- Results and delivery

3.7 Benefits

The major benefit of the MRV can be achieved by reaching a sufficient Tier level. Tier levels are applied in the MRV mechanism for estimation of carbon stock changes due to land use change: estimation of changes in forest areas remaining forests and consideration of impact on five different carbon pools (Kojwang and Ulloa 2012).The financial contribution is correlated to the accuracy of the information, thus making the Tier level determination a fundamental topic. The ReCover products can be applied for Tier level 1 and they also support Tier level 3.

In addition, ReCover products include the following benefits:

- The products were designed and produced merging research and commercial aspects: not only companies acted as service developers, but also research institutes acted with an eye to the optimization and standardization for future roll-out.
- Different input data types were tested and it was proven that the image analysis chain is sufficiently flexible to guarantee that new satellite data can be integrated with minor modification (Sentinel data in particular).
- Multiple techniques were tested and the best results were delivered: this implies that in an operational scenario, knowledge about benefits and drawbacks of each technique is already part of the know-how of each partner, reducing setup and delivery time for any future roll-out.
- Big effort was put in the demonstration of the validity of the general approach. A test case was executed in which all providers delivered the same products in the same area of interest. The results of the trial demonstrated the equivalence of the products in terms of accuracy.
- VHR optical data were used in parallel with field and LiDAR data to train and validate the products. This approach is directly applicable in an operational application.
- The delivery of the service can be tailored to each user's need. Several methods are available:
    - WebGIS, which includes metadata and data viewer
    - FTP
    - delivery of hard-drive via courier

3.8 How Copernicus can support REDD

The recommendations below were prepared together with another REDD project REDDAF of FP7.

The initiative of the European Commission to provide operationally level 3 Sentinel-2 data, *i.e.* ortho-rectified, atmospherically corrected, and cloud-masked images and image composites can greatly benefit REDD+ services. However, the requirements for the data quality are very high. Earlier experience has shown that high level products with modest quality only may increase the work and costs compared to using lower level products. It is important that the original images can be easily traced from the higher level products to enable undesirable but sometimes necessary actions for corrections.

The access to data also for the developing countries should be made as easy as possible. This would mean among other things organization of fast data links. A promising option that is already being developed by the European Space Agency is to enable image processing distantly and offer the user a possibility transfer the final results only.

The development of the REDD services should be combined with supporting the national forest inventories. An essential element in the development is considering the statistical issues throughout the inventory systems. It is very important that the satellite image component is taken into consideration when the ground sample plot placement and size are defined.

The technological research should focus to satisfy the needs that had been described earlier in this document. The activities should be harmonized with the activities of other existing global initiatives such as UN-REDD, Global Forest Observation Initiative (GFOI), Forest Carbon Partnership Facility (FCPF) of World Bank, and other bilateral and multilateral initiatives.

The pilot countries for the FP7 REDD+ projects were at different levels in the establishment of national MRV systems. Besides Mexico, Brazil and Indonesia that are more advanced in their MRV developments, most of the other FP7 REDD+ pilot countries are in the infancy stage (Phase 1 Planning) which means institutional set up and identification of capacity building needs. Capacity building (institutional, infrastructure and human resources) is thus crucial if REDD+ countries are to monitor and account for the changes in greenhouse gases. In the scope of the FP7 projects, capacity building activities were limited to short-term training sessions to ensure methodological transfer and the provision of hardware. Whilst these efforts are laudable, the major challenge is to elaborate a long term capacity building strategy. Embedding academic and research institutions in the capacity building strategy will also guarantee a constant flow of remote sensing experts into the job market.

Common standards for the MRV would make its development easier. The guidelines by the IPCC should be more specific to support harmonized development of the MRV for REDD+.

4 Dissemination activities

Table 5 lists the main public dissemination activities of ReCover and Table 6 the scientific publications.

Table 5. The public dissemination activities of the ReCover project.

NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	*Web*	*VTT*	*ReCover web pages www.recover-redd.eu*	*2011–2014*		*Scientific community, industry*		*International*
2	*Presentation*	*Häme, T.*	*Science-based remote sensing services to support REDD and sustainable Forest management in the tropical region - ReCover*	*4-5 November 2010*	*Finnish Remote Sensing Days, Espoo, Finland*	*Scientific Community*	*100*	*National*
3	*Article published in the popular press*	*VTT*	*Trooppisten metsien muutoksia seurataan satelliitista (Monitoring changes in tropical forests from satellite images)*	*30 November 2010*	*Kauppalehti, Market and Trade newspaper (in Finnish) + online article in CisionWire (in Finnish)*	*Civil Society, industry, policy makers*		*National*
4	*Press release*	*VTT*	*Novel Services For Tropical Forest Monitoring With Satellite*	*30 November 2010*	*VTT news website, online article*	*Scientific community, industry, policy makers*		*International*
5	*Article published in the popular press*	*VTT*	*Suomalaistekniikka selvittää sademetsien määrää (Finnish technique measures rain forests)*	*5 December 2010*	*Helsingin Sanomat, leading Finnish daily newspaper, printed article*	*Civil Society, industry, policy makers*		*National*
6	*Press release*	*VTT*	*Novel Services For Tropical Forest Monitoring With Satellite*	*30 November 2010*	*VTT news website, online article*	*Scientific community, industry, policy makers*		*International*
7	*Presentation, publication*	*Häme, T.*	*Science-based remote sensing services to support REDD and sustainable Forest management in the tropical region*	*12-13 May 2011*	*Proceedings of Hungarian Space Conference, Budapest, Hungary*	*Scientific Community*	*50*	*European*
8	*Presentation, publication*	*Reiche, J.*	*Mapping and monitoring changes in forests and forest carbon stocks in Fiji and Guyana: Two service cases of the*	*2-3 June 2011*	*1st EARSeL SIG Forestry workshop, Prague, Czech Republic*	*Scientific Community*		*European*

			ReCover project					
9	*Presentation*	*Häme, T.*	*Towards operative monitoring of forests from space*	*30-31 August 2011*	*Nordic Remote Sensing Days, Tromsø, Norway*	*Scientific Community*	*100*	*European*
10	*Presentation, publication*	*Reiche, J.*	*Mapping and monitoring changes in tropical forest and forest carbon stocks in Fiji and Guyana: a PhD working concept*	*8 September 2011*	*3rd Remote Sensing Symposium, WUR, Wageningen, Netherlands*	*Scientific Community*		*National*
11	*Presentation*	*Enßle, F.,*	*Inside the RECOVER project - forest biomass estimation and change detection*	*18-23 September 2011*	*3rd iLEAPS Science Conference, Garmisch-Partenkirchen, Germany*	*Scientific Community*		*European*
12	*Presentation*	*Häme, T.*	*Overview of the ReCover project*	*10-11 October 2011*	*3rd Workshop on the Technical Initiativa Las Americas of GEO-FCT National Demonstrators (ND) Symposium on MRV and REDD+, Toluca, Mexico*	*Scientific community, policy makers*	*40*	*International*
13	*Presentation, publication*	*Enßle, F.*	*Evaluating height differences between global digital surface models and ICESat heights at footprint geolocation*	*23-25 January 2012*	*GIS Ostrava 2012 - Surface models for geosciences, Ostrava*	*Scientific Community*		*International*
14	*Presentation*	*Häme, T.*	*Overview of the ReCover project*	*6-10 February 2012*	*Forest Carbon Tracking Science Summit, Arusha, Tanzania*	*Scientific community, policy makers*	*50*	*International*
15	*Presentation, publication*	*Enßle, F.*	*Combining Forest Characteristics from high-resolution Satellite Data with Spaceborne LiDAR for Biomass Estimation*	*23-27 April 2012*	*ESA Sentinel-2 Preparatory Symposium, Frascati, Italy*	*Scientific Community*		*European*
16	*Presentation, publication*	*Häme, T.*	*Recover project to support REDD - first results on forest monitoring from Mexico*	*23-27 April 2012*	*ESA Sentinel-2 Preparatory Symposium, Frascati, Italy*	*Scientific Community*	*100*	*European*
17	*Presentation, publication*	*Pedrazzani, D.*	*Potential applications of Sentinel-2 data to forest monitoring*	*23-27 April 2012*	*ESA Sentinel-2 Preparatory Symposium, Frascati, Italy*	*Scientific Community*	*100*	*European*

			services in support to REDD activities: The Democratic Republic of Congo case within Recover project					
18	*Presentation*	*Pedrazzani, D.*	*ReCover: Forest Monitoring services in support to REDD activities*	*7-8 May 2012*	*6th GEO European Projects' workshop, Rome*	*Scientific Community, policy makers*		*European*
19	*Presentation*	*Häme, T.*	*Overview of the ReCover project*	*30 May 2012*	*Chinese-Finnish Seminar on Forest biodiversity and Ecosystem Services, Beijing, China*	*Scientific Community, policy makers*	*40*	*International*
20	*Presentation, publication*	*Haarpaintner, J.*	*Tropical forest remote sensing services for the Democratic Republic of Congo case inside the EU FP7 ReCover project (1st iteration)*	*22-27 July 2012*	*IEEE International Geoscience and Remote Sensing Symposium 2012, Munich, Germany*	*Scientific Community*		*International*
21	*Presentation, publication*	*Einzmann, K.*	*Forest monitoring in Congo basin with combined use of SAR C- & L-band*	*22-27 July 2012*	*IEEE International Geoscience and Remote Sensing Symposium 2012, Munich, Germany*	*Scientific Community*		*International*
22	*Presentation*	*Enßle, F.*	*An overview of the ReCover project, focusing on the Democratic Republic of Congo*	*4-6 October 2012*	*Dialogue on Satellite data and monitoring systems for REDD+, Bonn, Germany*	*Scientific Community, policy makers*		*European*
23	*Presentation*	*Häme, T.*	*Biomass estimation and accuracy assessment*	*9-10 October 2012*	*Globbiomass user consultation meeting, Jena, Germany*	*Scientific Community*	*80*	*European*
24	*Presentation*	*Koch, B.*	*Forest Stand Mapping*	*9-10 October 2012*	*Globbiomass user consultation meeting, Jena, Germany*	*Scientific Community*	*80*	*European*
25	*Presentation*	*Häme, T.*	*ReCover: Services for the monitoring of tropical forest to support REDD+*	*14–15 November 2012*	*Let's embrace space conference, Larnaca, Cyprus*	*Scientific Community*	*40*	*International*
26	*Presentation*	*Häme, T.*	*Presentation of ReCover in EU side*	*28 November 2012*	*COP18, Doha, Qatar*	*Scientific Community,*	*30*	*International*

			event of COP18			*policy makers*		
27	*Presentation*	*Reiche,, J.*	*Feature level fusion of multi-temporal ALOS PALSAR and Landsat data for mapping and monitoring deforestation and forest degradation in Guyana*	*21-26 July 2013*	*IGARSS 2013, Melbourne, Australia*	*Scientific Community*		*International*
28	*Presentation*	*Haarpaintner, J.*	*Improving the tropical forest remote sensing services for the Democratic Republic of Congo case inside the EU FP7 "RECOVER" project (2nd iteration)*	*9-13 September 2013*	*ESA Living Planet Symposium 2013, Edinburgh, United Kingdom*	*Scientific Community*	*100*	*European*
29	*Presentation, publication*	*Häme, T.*	*ReCover: A Concept for Tropical Forest Assessment for REDD*	*9-13 September 2013*	*ESA Living Planet Symposium 2013, Edinburgh, United Kingdom*	*Scientific Community*	*100*	*European*
30	*Poster presentation*	*Kohling, M.*	*Temporal Variability of SAR Backscatter over Tropical Regions in Tanzania, The Democratic Republic of Congo and Colombia*	*9-13 September 2013*	*ESA Living Planet Symposium 2013, Edinburgh, United Kingdom*	*Scientific Community*		*European*
31	*Presentation*	*Reiche J.*	*Efforts for Detecting Forest Change in Fiji and Guyana using ALOS PALSAR and Landsat Time-series Data*	*9-13 September 2013*	*ESA Living Planet Symposium 2013, Edinburgh, United Kingdom*	*Scientific Community*	*100*	*European*
32	*Presentation, publication*	*Sirro, L.*	*Comparison of Optical and SAR Data in Tropical Land Cover Classification for REDD*	*9-13 September 2013*	*ESA Living Planet Symposium 2013, Edinburgh, United Kingdom*	*Scientific Community*	*100*	*European*
33	*Presentation*	*Häme, T.*	*Overview of the ReCover project*	*23-24 October 2013*	*Finnish Remote Sensing Days 2013, Espoo, Finland*	*Scientific Community*	*100*	*National*
34	*Workshop*	*ReCover team*	*ReCover user workshop*	*12 November 2013*	*Warsaw, Poland*	*ReCover users*	*20*	*International*
35	*Presentation*	*Häme, T.*	*Presentation of ReCover in EU side event of COP19*	*14 November 2013*	*COP19, Warsaw, Poland*	*Scientific Community, policy makers*	*30*	*International*
36	*Press*	*VTT*	*VTT:Itä menetelmä*	*November*	*National and*	*Civil*		*National*

	releases, article published in the popular press, TV clips		*tropiikin metsäkadon seurantaan (VTT introduces deforestation monitoring method for tropical regions)*	*2013*	*local Finnish newspapers, TV, radio*	*Society, industry*		
37	*Article published in the popular press*	*VTT*	*Environment measurements without borders*	*November 2013*	*VTT journal Impulssi, in Finnish and English*	*Industry*		*National*
38	*Presentation*	*Häme, T.*	*ReCover Program*	*2-7 December 2013*	*9th Regional Workshop on Forest Monitoring GEO GFOI, Bogota & Leticia, Colombia*	*Scientific Community*		*International*
39	*Presentation*	*Häme, T.*	*ReCover User Workshop - Mexico*	*20 January, 2014*	*Main Auditorium, Zoológico Miguel Alvarez del Toro, Calzada Cerro Hueco S/N, Col. El Zapotal, Tuxtla Gutierrez, Chiapas, Mexico*	*Government (Chipas State, CONAFOR) and Academia*	*30*	*Mainly National*

Table 6. The scientific publications of the ReCover project starting with the most recent ones.

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
1	*Feature level fusion of multi-temporal ALOS PALSAR and Landsat data for mapping and monitoring of tropical deforestation and forest degradation*	*Reiche, J.*	*IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*	*Vol. 6, No. 5. Oct 2013*	*IEEE*	*New Jersey, USA*	*2013*	*pp. 2159 -2173*	*10.1109/JSTARS.2013.2245101*	*no*
2	*Improved mapping of Tropical forests with optical and SAR imagery, Part I: Forest Cover and Accuracy Assessment Using Multi-Resolution Data*	*Häme, T.*	*IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*	*Vol. 6, No. 1, Feb 2013*	*IEEE*	*New Jersey, USA*	*2013*	*pp. 74 - 91*	*10.1109/JSTARS.2013.2241019*	*no*
3	*Improved mapping of Tropical forests with optical and SAR imagery, Part II: Above ground biomass estimation*	*Häme, T.*	*IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*	*Vol. 6, No. 1, Feb 2013*	*IEEE*	*New Jersey, USA*	*2013*	*pp. 92 - 101*	*10.1109/JSTARS.2013.2241020*	*no*
4	*PolSAR Mosaic Normalization for Improved Land-Cover Mapping*	*Antropov, O.*	*IEEE Geosci. Remote Sens. Letters*	*Vol. 9, No.6, Nov. 2012*	*IEEE*	*New Jersey, USA*	*2012*	*pp, 1074 - 1078*	*10.1109/LGRS.2012.2190263*	*no*
5	*Dealing with locally-driven degradation: A quick start option under REDD+*	*Skutsch, M. M.*	*Carbon Balance and Management*	*Vol. 6, No. 16, Dec 2011*	*Springer Open*	*Heidelberg, Germany/ London, UK*	*2011*	*pp. 1 - 7*	*10.1186/1750-0680-6-16*	*yes*
6	*Options for monitoring and estimating historical carbon emissions from forest degradation in the context of REDD+*	*Herold, M.*	*Carbon Balance and Management*	*Vol. 6, No, 13, Nov 2011*	*Springer Open*	*Heidelberg, Germany/ London, UK*	*2011*	*pp. 1 - 7*	*10.1186/1750-0680-6-13/*	*yes*
7	*Mapping biomass with remote sensing: a comparison of methods for the case study of Uganda*	*Avitabile, V.*	*Carbon Balance and Management*	*Vol.6, No 7, Oct 2011*	*Springer Open*	*Heidelberg, Germany/ London, UK*	*2011*	*pp. 1 - 14*	*10.10.1186/1750-0680-6-7/*	*yes*
8	*Monitoring, reporting and verification for national REDD+ programmes: two proposals*	*Herold, M.*	*Environment Research Letters*	*Vol. 6, No.1, Jan 2011*	*IOP Science*	*Bristol, UK*	*2011*	*pp. 1 - 10*	*10.1088/1748-9326/6/1/014002*	*no*

5 Contact information

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Albert-Ludwigs-Universität Freiburg	Germany
Arbonaut Oy Ltd., (SME)	Finland
Colegio de Postgraduados	Mexico
El Colegio de la Frontera Sur	Mexico
GMV Aerospace and Defence SA Unipersonal	Spain
Norut - Northern Research Institute Tromsø AS	Norway
Wageningen Universiteit	The Netherlands
The Hydrological, Meteorological and Environmental Studies Institute (IDEAM)	Colombia

Users:

Conafor, National Forestry Commission	Mexico
Secretary of Environment and Natural History of Chiapas State Government	Mexico
Comision Nacional para el Conocimiento y Uso de la Biodiversidad,	Mexico
Comisión Nacional de Áreas Naturales Protegidas, Región Frontera Sur, Itsmo y Pacífico Sur	Mexico
PMC Mexican Carbon Program	Mexico

The Hydrological, Meteorological and Environmental Studies Institute (IDEAM)	Colombia
Guyana Forestry Commission GFC	Guyana
Observatoire Satellital des Forêts d'Afrique Centrale	The Democratic Republic of Congo
Fiji Forestry Department	Fiji

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