RECOVER: A CONCEPT FOR TROPICAL FOREST ASSESSMENT FOR REDD

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ABSTRACT

Project ReCover, funded by the 7th Framework Program of the European Union, developed beyond state-of-the-art service capabilities to support fighting deforestation and forest degradation in the tropical region in the context of the REDD process (Reducing Emissions from Deforestation and forest Degradation).

A monitoring system for forest cover mapping by combining wall-to-wall mapping and a sample of VHR imagery was introduced. Also biomass and changes of forest cover changes were estimated.

ReCover provided close to one hundred products for the study sites in Mexico, Guyana, Democratic Republic of Congo, Colombia and Fiji using optical and SAR data and their combinations. The accuracy in forest and non-forest classification varied from 85 % to 97 %.

1. INTRODUCTION

REDD+ is an international effort to mitigate climate change. It aims to provide positive incentives to developing countries through enhancing carbon stocks in forests. The REDD+ has five mitigation actions:

a) Reducing emissions from deforestation;
b) Reducing emissions from forest degradation;
c) Conservation of forest carbon stocks;
d) Sustainable management of forests, and;
e) Enhancement of forest carbon stocks. [1]

Project ReCover, funded by the Framework Program 7, Theme Space of the European Union, contributed to the Measurement, Reporting and Verification (MRV) element of REDD. It developed novel methods for the collection of activity data, *i.e*. information on the IPCC-compatible six land use classes: forest land, cropland, grassland, wetlands, settlements, other land [2]. The method development was based on the use of satellite imagery which is one of the three pillars of the MRV, the other two being national forest inventory and national greenhouse gas inventory [1].

Although the REDD+ process with its financial compensations is not yet part of a climate treaty, REDD+ process has started as pilot projects with significant investments by the industrial countries.

ReCover contributed to the efforts to reduce the errors in the estimates of the terrestrial carbon balance that result from uncertain rates of tropical deforestation.

ReCover provided pilot services and developed novel methodologies at five study areas. The services were based on the service level agreements which ensured a close cooperation with the service providers and users.

The target variables in satellite image analysis were IPCC compatible land cover classes and their changes as well as above-ground biomass and degradation.

2. STUDY SITES AND DATA

1.1 Target areas

Recover study sites and pilot services were performed in five study areas in different countries: state Chiapas in Mexico, Guyana, tropical forest areas in central Colombia and in the DRC (Democratic Republic of Congo), and Fiji (*Figure **1***).

The service level agreements described the responsibilities of the service providers and the users as well as the technical details of the services. The

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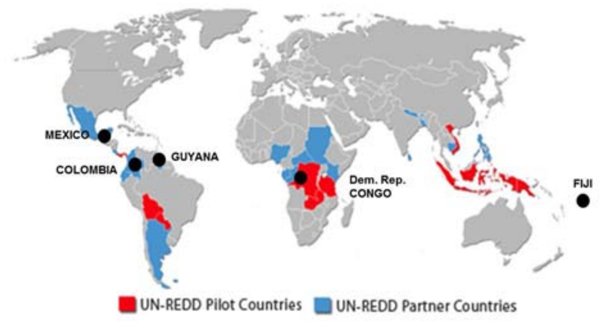

Figure 1. Study areas.

technical details included quantitative definitions of the geometric and thematic accuracies and result delivery formats, for instance.

The users provided reference data for the image interpretation and in some cases also satellite data. During the services user communication was done bilaterally – reflecting users' requests. In all cases the service providers visited the users in their home countries. After the delivery the users evaluated the quality and usefulness of the service. At the end of the project a user workshop was held in November 2013 in the context of COP19 (United Nations Climate Conference) in Warsaw.

1.2 Principal data and reference data

Versatile satellite data were utilized for the services. For wall-to-wall mapping the main optical data were from Landsat and RapidEye satellites. The principal radar data were from the ASAR instrument of the Envisat satellite and PALSAR of ALOS. MODIS data were utilized as part of the atmospheric correction process in Mexico. Data from the GLAS instrument of ICESat and TerraSAR-X data were experimentally utilized for forest biomass and height estimation, respectively. Very High Resolution (VHR) optical data were central in the forest monitoring concept. These data were used as reference data to train the models and make the accuracy assessment. The VHR data were collected by applying sampling.

Digital elevation models from Aster satellite data [3] or Shuttle Radar Topography Mission (SRTM) [4] were applied for the geometric correction of radar data and for the ortho-rectification of the VHR data.

The imagery was geo-coded over most sites by using control points from Google Earth that appeared in the tests to be more reliable geo-location reference than the available maps. In Chiapas, Mexico, the RapidEye mosaic of 2011 that were available from the user, were used as the geo-reference.

Over some sites ground plot data of variable quality and representativeness were available. From Mexico a large ground plot set were available but the definitions of the classes did not completely match with the IPCC compatible land cover classes and the plot geo-coordinates could be somewhat unreliable. From Guyana, Fiji, DRC, and Colombia limited plot data were available from the user or were collected by the project team.

3. METHODS

1.3 Monitoring concept

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 % [5].

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 applied (*Figure* ***2***). The plot size corresponded to the population unit of the sampling.

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 Chiapas state.

The wall-to-wall image interpretation was done in an iterative manner to reduce the risk of biased estimation (*Figure* ***4***). 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

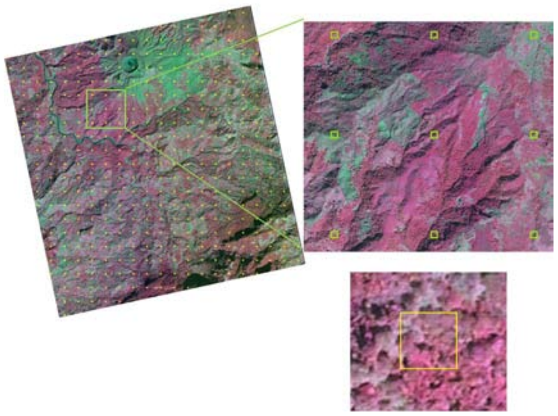

Figure 2. Plot (PU) selection within VHR images (Images © KARI).

the improved map and so on. Two to three iterations were applied. Finally the map was evaluated with independent reference data.

The VHR images were divided into three parts for model development and accuracy assessment with some modifications by study sites (*Figure* ***3***). Visually evaluated plots of part A were used for the first 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

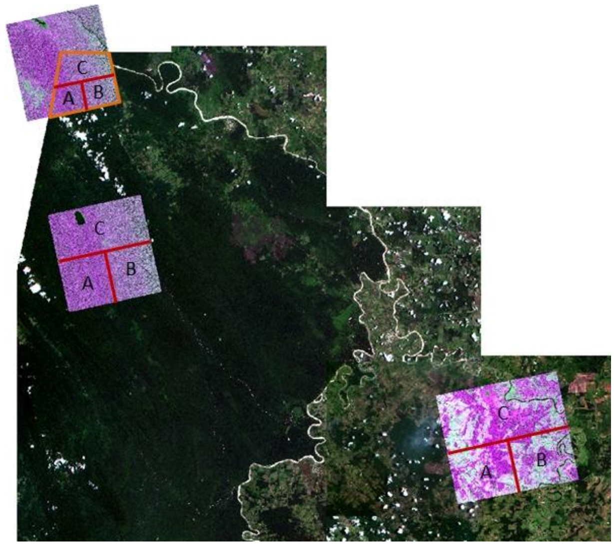

Figure 3. VHR image division into training and accuracy assessment set (Image data © RapidEye and KARI)

would have been to make a random sampling of all the plots within the images.

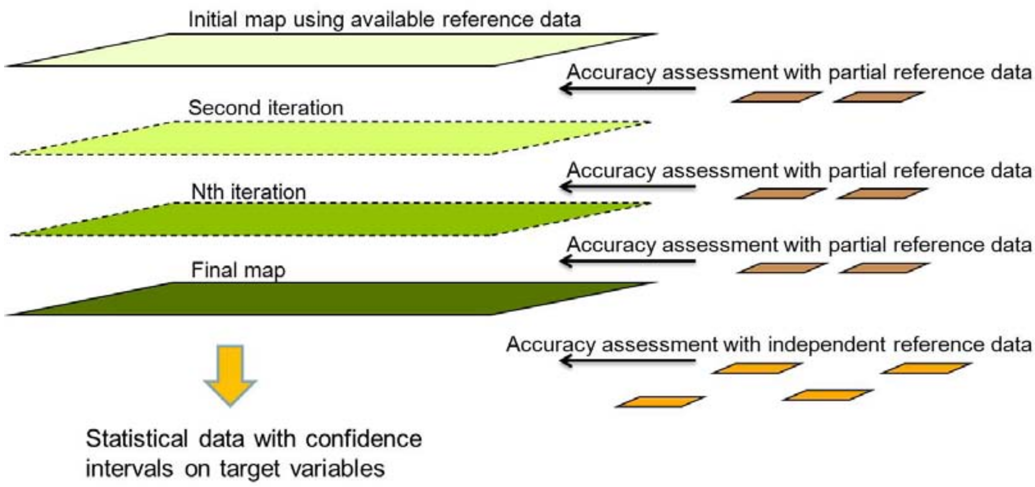

Figure 4. Iterative processing chain to produce maps and statistical data.

1.4 Image interpretation approach

The image interpretation methods and radar data pre-processing varied to some extent by project partners that provided the services. The image interpretation was done using an in-house method Probability [6], maximum likelihood classification (MLH), Support Vector Machine (SVM), and SAR-optical feature level fusion using a decision tree classifier.

The approach described above was applicable for the mapping of land cover classes. It can be adjusted for biomass mapping by introducing ground plots and airborne lidar observations.

The change detection was done on most sites by analysing the spectral change to avoid accumulation of errors that occurs when the change is extracted from the individual maps. For this same reason, the multi-temporal change in Mexico was computed pairwise using more recent image data with ground information available as the reference (*Figure **5***). Forest and non-forest maps from the past were computed with the help of the spectral change information and land cover map from the present by using logical operations.

In Guyana a change detection approach for feature fusion of multi-temporal and medium-resolution SAR and optical sub-pixel fraction information for tropical deforestation and forest degradation monitoring was developed. After independently processing SAR and optical input data streams the extracted SAR and optical sub-pixel fraction features are fused using a decision tree classifier [7]. The method was applied to ALOS PALSAR Fine Bean Dual and Landsat imagery of 2007 and 2010 acquired over the main mining district in central Guyana.

In Fiji, the generic change detection approach for time series by detecting and characterizing Breaks For Additive Seasonal and Trend (BFAST monitor [8]) was used for time-series analysis of Landsat time-series (TS) in addition to the common ReCover change detection approach. BFAST monitor enabled to monitor different forest change dynamics, such as deforestation and forest degradation at yearly basis.

For the DRC user case, FNF maps were produced using mainly MLH for both optical and SAR based classification, but also SVM in the case of RapidEye. Figure 7e shows the FNF result from RapidEye, ALOS PALSAR and the combined product for 2010. A decadal forest change map from 2000 to 2010 was produced by considering only forest changes where optical based and SAR based forest change results agreed.

A separate study, in which different service providers produced the land cover class estimates by applying different image interpretation methods but using the same image and training data sets was conducted in Chiapas, Mexico over a site of approximately 100 km by 100 km. 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. 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. 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.

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

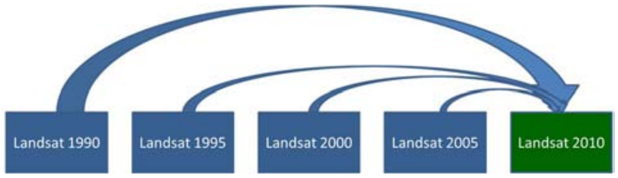

Figure 5. Computation of reflectance change of red band to the reference year 2010 on the Chiapas site.

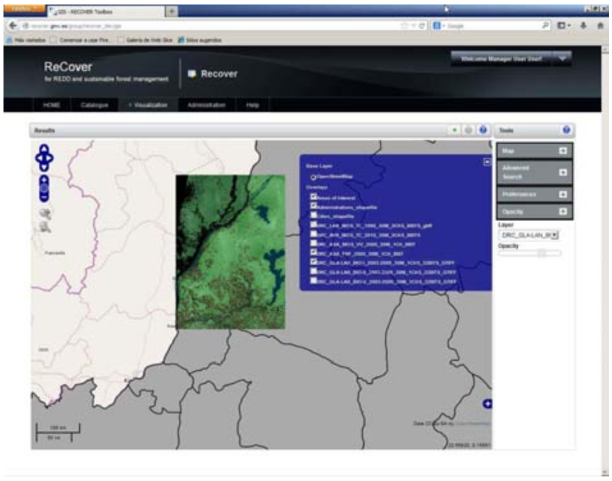

Figure 6. Example of user interface for the WebGIS. A product has been selected and visualized on a map: two layers are visualized, with different transparency levels.

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.

4. RESULTS

In total, close to one hundred image mosaics and thematic maps were delivered to the users. The products were delivered in most cases on hard disks because the files were large and the networks could be slow. The ftp delivery was applied in few cases. The users could access the delivered products through a WebGIS platform that was developed in ReCover.

The ReCover Toolbox 2.0 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 the ReCover products. The allowed operations are search, download, and visualization of products through the catalogue of the ReCover system. *Figure 6* shows an example of the user interface. The tool will remain available for the users also after the ReCover project.

Figure 7 gives examples of the products that were delivered to the users. The accuracy of the land cover products was assessed with the procedure that was described above. The accuracy assessment of the change and degradation products is so far quantitative.

As can been seen in Table 1, the accuracies on the sites are similar despite different input data and image interpretation approach. The overall accuracies in forest/non-forest classifications vary on the both sides of 90 %. *Table* 2 shows results of the method comparison study. The differences in the results depended more on data than image analysis method but all the results were similar. The basic data for the accuracy assessment was identical but clouds restricted the number of observations in the assessment. The forest area estimates in Chiapas and DRC where several classifications were made were similar except with the C-band SAR with which the area estimation may not have been fully consistent. In the ALOS AVNIR map of the DRC the forest area estimate was lower than in the other maps. The AVNIR data had 18 % clouds that covered the mostly forested areas whereas in the other optical data the cloud cover was below ten per cent.

The results with L-band ALOS PALSAR are almost at the same level as with the optical data and in DRC in some cases even better. The relatively poorer results with the AVNIR and RapidEye data may be partly explained by the small image size that results in challenging radiometry particularly when the images are from different seasons. The Landsat classifications in the DRC from 1986 and 2000 were evaluated using the sample geographical plots selected from the VHR input imagery, photo-interpreting the Landsat themselves. In Fiji the method for the accuracy assessment was based on randomly sampled validation points within the same population of training points. This method for the accuracy assessment was somewhat different from the other sites and the results are thus not fully comparable.

The border between forest and grassland, i.e. non-forest is gradual also on the field and the definitions of forest were not fully established in all of the countries that were subject to this study. Therefore a100 % accuracy in forest and non-forest classification is not a realistic figure when independent data are used for the accuracy assessment. The differences between user's and producer's accuracies varied between less than one to nine percentage units.

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 (Table 2). Grassland and cropland classes were largely mixed. 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.

5. CONCLUSIONS

An approach that combines wall-to-wall mapping of imagery with spatial resolution of 10 – 30 m and a sample of VHR images was developed and tested. The statistical framework can be two-stage or two-phase sampling. The concept is applicable for the general land cover classification but change detection and related sampling techniques as well as techniques for mapping of degradation should be further developed.

Forest and non-forest could be mapped with 90 % or higher overall accuracy with space borne data, depending on the overall forest proportion and structure. Tropical forests with anthropogenic influence are often under constant change and their structure is fragmented. The border between forest and grassland is gradual. Therefore accuracies close to 100 % may be unrealistic to achieve when the accuracy is assessed with independent data.

In the ReCover study sites the overall accuracy of the six IPCC compliant land cover classes was on the average 7.6 per cent lower than the accuracy of forest and non-forest classification. It should be noted that the forest proportion was high on all study sites. If the forest proportion were lower the overall accuracy would have decreased as well because the non-forest classes, grassland and cropland in particular mix in the image interpretation.

Special attention in REDD-related applications should be paid on aiming at the similarity of the user's and producer's accuracies since their different values indicate bias in the mapping. In the trial ReCover services the differences were still too large in some cases already in forest and non-forest classification.

The differences between the acquisition times of wall-to-wall satellite imagery and reference data introduce challenges in the inventory. The image acquisition process was 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 in Mexico was over 70 GB. The geometric accuracy even of the ortho-rectified image

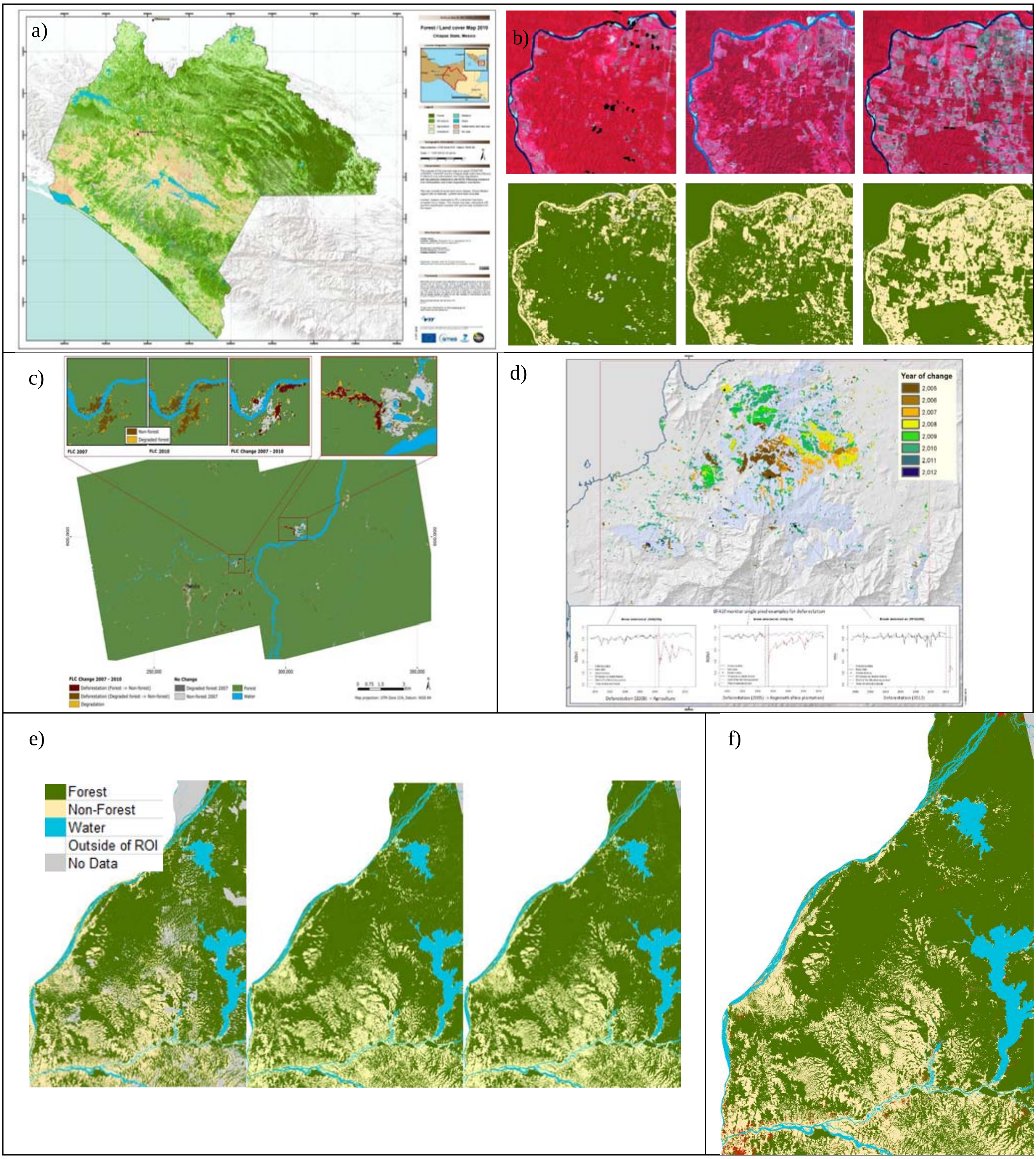

Figure 7. Examples of image interpretation results. a) Land cover map of Chiapas, Mexico from Landsat, area size 160 km by 140 km; b) Forest and non-forest map detail from 1990, 2000 and 2010 from Chiapas, Landsat, area size 11 km by 13 km; c) Forest land cover change classification from Mahdia mining district, Guyana 2007-10, ALOS PALSAR and Landsat, area size 130 by 60 km; d) Forest yearly cover change in Fiji 2005 - 2012, Landsat, area size 50 km by 50 km; e) Forest cover map from DRC, RapidEye 2011-2013, ALOS PALSAR FBD and FBS 2010, Combined RapidEye and PALSAR, area size 260 km by 360 km; f) Multi-sensor forest change map from 2000 to 2010. Only forest change areas are reported where optical based results and SAR based results agree.

Table 1. Accuracies of forest/non-forest classification.

Site	Instrument	Method	Overall acc. forest/non-for. (%)	User's accuracy (%)	Producer's accuracy (%)	Forest (%)
MX Chiapas*	RapidEye 2009	Probability	93.8	97.9	93.5	75.1
	PALSAR 2009	Probability	89.1	91.7	93.6	78.7
DRC	1986 Landsat	MLH	93.4	94.2	95.6	71.6
	2001 Landsat	MLH	91.7	90.8	96.6	70.7
	2010 ALOS AVNIR-2	MLH	84.5	84.5	90.8	65.9
	2011-2013 RapidEye	SVM	86.7	86.2	92.7	72.5
	1998-2002 ERS/Envisat	MLH	88.7	87.3	96.2	78.0
	2004-2005 ASAR	MLH	87.6	91.7	88.0	70.2
	2010 ALOS PALSAR	MLH	88.5	88.4	92.7	72.5
Mahdia Guyana	ALOS PALSAR, Landsat	Feature level fusion	96.6	92.5	93.0	96.8
Fiji	Landsat	SVM, Boot-strapping	96.9	96.9	96.7	56.6
Colombia	Envisat ASAR WSM	MLH	No valid. yet			
	Envisat ASAR APS	MLH	No valid. yet			

*at the time of writing, results only from 100 km by 100 km sub-area of Chiapas available

Table 2. Overall accuracies in classification to six IPCC compatible classes.

No.	Source data and main method	Forest-non forest over. accuracy (%)	IPCC class over. accuracy	Users acc. for forest class	Prod. 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	PALSAR and ASAR MLH	92.6	-	93.1	97.2	785
8	Combination of 5 and 7	91.0	-	91.7	96.6	740

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. The image supply system should be developed easier to use and the geometric accuracy and radiometric calibration improved in the Copernicus and Sentinel programs.

Sentinel 2 is foreseen to be an ideal basic data source for REDD. With Landsat and Spot 4 data the minimum mapping unit is 0.5 to 1 ha. With Sentinel-2 data the minimum mapping unit can decrease down to 0.1-0.2 ha. Sentinel 2 data should be augmented with SAR data on cloudy regions and for change and with VHR data for model training and accuracy assessment. The performance of C-band SAR was clearly poorer than the performance of L-band SAR. The potential of L-band remained somewhat unclear. The results in forest and non-forest classification were in comparisons almost as good as with the optical data but in earlier studies in the tropics the L-band data were performed poorer than the optical data (Häme et al. 2013). With the SAR data several acquisitions from the same location are usually needed for a good result.

Mapping of degradation requires usually application of time series data and ground resolution of ten meters or higher. An indirect method, based on detection of proxies such as logging roads and settlements is easier but less reliable indicator of degradation than the direct method.

The WebGIS platform is foreseen to become a common approach when the communication networks improve also in the developing countries. In ReCover project the users preferred off line delivery on hard disks because of too slow communication networks.

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