PALSAR TROPICAL FOREST COVER MAPPING, MOSAICING AND VALIDATION, CASE STUDY BORNEO

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ABSTRACT

The production of spatially detailed maps of (very) large areas, and time series of these maps, requires dedicated processing approaches. This paper introduces finite mixture modelling and Markov Random Field classification as a tool for production and mosaicing of detailed thematic maps. Results are shown for a multi-temporal classification of the entire island of Borneo for the year 2007 using 50 m resolution PALSAR FBS an FBD strip data. First results indicate that more than 20 classes of forest and land cover can be distinguished well, even though strips have been collected over a 46-day cycle of observation.

Validation of the Borneo map is still ongoing using large ground data sets and other reference sets spread over Borneo. It is pursued to develop legends in compliance with LCCS and IPCC guidelines. These results may be of key interest to develop REDD projects for the humid tropics.

This work has been conducted in the framework of the JAXA Kyoto & Carbon Initiative [1].

1 INTRODUCTION

Significance of tropical rain forests

Deforestation and degradation of tropical rain forests is continuing and currently may occur faster than ever before. It threatens the livelihoods of millions of people depending on the forests, and threatens biodiversity conservation, carbon storage capacity, and other important functions these forests provide.

Environmental awareness and consumer demand for more socially responsible products from tropical forest areas increased in recent years. As a result, all biofuel for the European market for example should be produced in compliance with forthcoming EC regulations on greenhouse gas emission reduction. This will prohibit conversion of tropical forest to biomass plantations.

Moreover, agreements are negotiated under the UN Framework Convention on Climate Change (UNFCCC) to compensate tropical nations for reduced emissions from deforestation and forest degradation (REDD).

The availability of credible and regularly updated spatial information on forest and land use/cover change will be a precondition for successful implementation of initiatives such as mentioned above. In cloudy tropical forest areas new radar satellite imaging techniques will play a key role as one of the most objective methods to measure forest, land cover, biomass and hydrological changes.

Information needs

Ongoing consultation with potential user organisations indicates that satellite observations are needed, as area change is typically dynamic and covers large geographic areas. It is the only objective approach to support reduced deforestation and sustainable biomass production projects in developing countries, providing proof that deforestation rates have decreased and that plantations have been developed inside or outside forest areas.

The following satellite based information maps are required:

- Land use/cover
- Land use/cover change (including deforestation and degradation)

Emerging international guidelines require that these maps are made available at multiple time intervals using a transparent and consistent methodology. Spatial resolution in the order of 10-100 m is sufficient.

High attention and expectation for the inclusion of forest degradation in payment agreements for reducing emissions from deforestation and forest degradation requires new approaches for mapping crown canopy structure of (tropical) forests at high spatial detail. To monitor forest degradation (canopy openings) details smaller than 20m should be clearly visible requiring a spatial resolution of less than 5m; 1-2 m would be ideal.

Permanent clouds are making optical satellite imagery useless; again the use of radar satellite imagery is needed (Figure 1).

Figure 1. Persistent cloud cover prevents optical remote sensing monitoring of the world’s tropical rain forest areas. The colour code shows the estimated number of months per year LANDSAT fails to deliver useful images (Source: [2]).
2 PALSAR STRIP DATA HANDLING AND MOSAICING

The production of a high resolution continental scale map requires the use of a very large number of (radar) images. Within K&C this problem is mitigated by using strip data, which have the same swath width as standard PALSAR radar images (i.e. 70 km, for Fine Beam data), but may span the entire area of interest (up to several thousands of km). For a complete coverage of the entire area of interest many strips may be needed. Borneo, for example, requires 22 of such strips (Figure 2). Often a single coverage will not suffice to meet the required information needs. For forest and land cover mapping in tropical rain forest areas it is advantageous to combine wet and dry season observations, and to combine HH and HV polarisation. For monitoring tropical forest cover change repetitive yearly observation is needed. Very dynamic areas, notably wetlands and agricultural areas, may require even more observations per year to fulfil specific information needs.

For our work in Insular SE Asia and PNG systematic observations were used for modes summarised in Table 1. The selected cycles are shown in Table 2. To be able to produce a 2007 forest and land cover map of Borneo, for example, all the strips collected during the ascending passes of cycle 9 (FBS mode) and cycle 13 (FBD mode) should be used. For technical reasons which are not discussed here, it is not always possible to collect radar data for every pass of the satellite over the area of interest. The success rate in some areas of the world may even drop below 80%. Consequently, most mosaics cannot be created with strips collected within one cycle of systematic observation. In such a case replacement data may be available from a preceding or following cycle. For example, when strips are missing from the FBS cycle 9 these can be replaced from the FBS cycle 8 acquisitions.

Table 1. PALSAR default observation modes

<table>
<thead>
<tr>
<th>Polarization</th>
<th>Incidence range</th>
<th>Swath width</th>
<th>Resolution (4 looks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(FBS) HH</td>
<td>36.6°~40.9°</td>
<td>70 km</td>
<td>10 m</td>
</tr>
<tr>
<td>(FBD) HH+HV</td>
<td>36.6°~40.9°</td>
<td>70 km</td>
<td>20 m</td>
</tr>
<tr>
<td>ScanSAR (HH)</td>
<td>18.0°~43.0°</td>
<td>361 km</td>
<td>~100 m</td>
</tr>
</tbody>
</table>

Table 2. Selected cycles for this study

<table>
<thead>
<tr>
<th>Default mode</th>
<th>Polarisation</th>
<th>Cycles 2007</th>
<th>Cycles 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBS</td>
<td>HH</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>FBD</td>
<td>HH+HV</td>
<td>13</td>
<td>21</td>
</tr>
<tr>
<td>ScanSAR</td>
<td>HH</td>
<td>7-16</td>
<td></td>
</tr>
</tbody>
</table>

The time structure within one cycle is such that the time elapsed between observations of adjacent strips is 17 days or 29 days. This can be explained as follows. Starting East and moving West adjacent strips make jumps of 17 days. For example when RSP412 is the first strip acquired, the adjacent strip RSP413 is collected 17 days later and strip RSP414 34 days later. The next strip RSP415 is collected 3x17 = 51 days later, but this is in the next cycle. To remain in the same cycle 46 days can be subtracted and a jump of 5 days with respect to the first strip RSP412 remains, which is -29 days with respect to the previous strip. For the Borneo mosaic of 2007 4 (out of 22) replacement strips have been collected from cycles 12 and 14 for FBD mode and 3 (out of 22) from cycles 17 and 18 (one year later!) for FBS mode.

The time laps are an inherent feature of any mosaic and these have to be dealt with carefully within classification procedures.

Backscatter of terrain is modulated by the surface geometry of hills and mountains. This modulation is a function of slope steepness, slope orientation and the scattering mechanism of the terrain. Results for an area in central Borneo which is almost completely covered by dense forest are shown in the Figures 3 and 4. In Figure 5 the entire mosaic, which is a multi-temporal aggregate of FBS and FBD data, is shown.

![Figure 2. Three strips of radar data projected over Borneo and displayed in Google Earth.](image-url)

![Figure 5. Backscatter modulation by slopes.](image-url)
Figure 3. Slope correction for all pixels in a small test area in a mountainous section of central Borneo; (a) backscatter (gamma in dB) as function of slope aspect; (b) idem, after correction (Note: the vertical lines present the radar orientation angles).

Figure 4. (a) PALSAR FBS/FBD aggregate for an area (~42x46km) typical for the mountainous forested terrain in the centre of Borneo; (b) idem, relief corrected. Some effects of overlay and shadow remain visible and are masked after classification.

Figure 5. FBS/FDB mosaics of Borneo after radiometric balancing and slope correction. The RSP strips and two patches of classified data are superimposed.

3 CLASSIFICATION METHODOLOGY

Several approaches for continental scale mapping (and monitoring) have been tested. The most promising and by far the most accurate approach is based on (unsupervised) mixture modelling followed by Markov Random Field (MRF) classification. The approach has
been tested very successfully on agricultural areas [3, 4, 5]. The approach is ideal for the complex and heterogeneous landscapes encountered in the tropics, where ground truth is often very limited or missing.

In mixture modelling the feature space is assumed to be a superposition of a certain number of clusters, each cluster having a certain pre-defined type of distribution, and pixels belong to one or more clusters. The model can be made for any number of pre-defined clusters. In case ground truth is available the optimum number of clusters can be found by trial-and-error and clusters, or aggregates of clusters, can be labelled with a class name. An example is given in Figures 6 for a polarimetric PALSAR image.

![Figure 6](image)

Figure 6. Mixture modelling followed by Markov Random Field classification of a small part of a polarimetric image over Central Kalimantan. Models of increasing complexity reveal a hierarchy of classes. For example, model 2 shows forest non-forest, model 3 adds the class water, while in model 10 re-generating forests can be distinguished (black arrow). Note that model 2 has 43 parameters, increasing to 219 parameters for model 10 and that the model number equals the number of clusters $g$.

In case the complexity of the terrain is not well-known the optimum number of clusters can be computed from the so-called Bayesian Information Criterion (BIC). Figures 7a and 7b show the value of BIC as a function of the number of clusters $g$ for a (complex) disturbed peat swamp forest terrain and an almost undisturbed mountain forest area, respectively. The results indicate, for the peat swamp area, that many clusters are needed to describe the information content of the image appropriately. Consequently, when ground truth is available many different classes could be distinguished. For the mountain forest area the result indicates that at least several classes (i.e. forest types) can be distinguished. It should be noted that the latter classes may not be present in the peat swamp area, and vice versa.

![Figure 7a](image)

Figure 7a. BIC as a function of mixture model number $g$ for a complex disturbed peat swamp area in Central Kalimantan (2007 FBS-FBD composite). The result indicates at least 25 clusters are needed to describe feature space.

![Figure 7b](image)

Figure 7b. BIC as a function of mixture model number $g$ for a typical undisturbed forest area in the heart of Borneo (2007 FBS-FBD composite). The result indicates that ~7 clusters are sufficient to describe feature space.

### 4 MAP FRAGMENTS OF FOREST AND LAND COVER

A first series of map fragments for Borneo have been produced according the methodology introduced in Sections 2 and 3. This involves the following steps:

1. Selection of strip data and, when necessary, replacement data;
2. Radiometric balancing, orthorectification and relief correction;
3. Cluster analysis in key ecological, deforestation and agricultural regions;
4. Selection of key clusters for the description of the entire Borneo data set;
5. Aggregation of key clusters into broad classes;
6. Classification and outlier analysis;
7. Evaluation of results and legend using reference data;
8. Optionally, refinements follow by (iteratively) repeating steps 3-7.

A first iteration of cluster analysis in 14 key areas yielded the following tentative legend (Table 3). It comprises classes typical for wetland areas, namely the mangroves and the peat swamps, several typical dry land forest areas, and other more general broad classes. The latter includes the class “other land cover types or mixed”.

The “class other land cover types or mixed” contains either (1) very fragmented small areas of mixed cover type which can not be classified well because of the abundance of mixed pixels, or (2) it contains an area for which an adequate representative cluster has not been selected yet. Since such an area can be detected, as a result of the outlier analysis, and the unknown area can be identified on the basis of appropriate reference data, the legend can be extended in the next iteration.

Table 3. Draft legend Borneo

<table>
<thead>
<tr>
<th>Wetland areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangrove 1 (Nipah)</td>
</tr>
<tr>
<td>Mangrove 2</td>
</tr>
<tr>
<td>Peat swamp less dense</td>
</tr>
<tr>
<td>Peat swamp low pole</td>
</tr>
<tr>
<td>Burnt (peat) forest and bare</td>
</tr>
<tr>
<td>Burnt shrubs and bare</td>
</tr>
<tr>
<td>Forest and forest on peat/heath</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dry land forest areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest - Lower biomass and/or degraded</td>
</tr>
<tr>
<td>Forest - Higher Biomass</td>
</tr>
<tr>
<td>Deforestation types</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Global types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riverine-ripenian and swamp forest</td>
</tr>
<tr>
<td>Shrub land</td>
</tr>
<tr>
<td>Shrub land – other types</td>
</tr>
<tr>
<td>Bare</td>
</tr>
<tr>
<td>Tree plantations and Palm oil</td>
</tr>
<tr>
<td>Dry land agriculture</td>
</tr>
<tr>
<td>Sawah</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other land cover types / mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
</tr>
<tr>
<td>No data (radar shadow and layover)</td>
</tr>
</tbody>
</table>

Selected results are shown in Figures 8-10.
5 FIELD DATA AND VALIDATION

For K&C dedicated data collection campaigns have been made (1) to collect extensive ground truth and reference data over Borneo in the framework of a systematic validation study funded by the Netherlands government; (2) to collect ground water level data in wetland areas to calibrate PALSAR for flooding fraction and ground water level [6, 7]. An accuracy assessment will be made for the Borneo map, as well as for each individual class of this map [8]. Guidelines provided by GOFC-GOLD [9] and GlobCover 2006 [10] for global mapping will be followed as much as possible. These state, for example, that the creation of an international expert network is the key element of the validation process [10]. This is also pursued within this project. An extensive partnership network of local end users in Insular SE Asia is already in place.

Within K&C it is pursued to produce maps to support UN conventions and development of REDD projects. Hence, two types of legend are under consideration: (1) using IPCC classes and (2) using the FAO LCCS system.

For validation the following reference data sets have been collected:
Landsat  
MODIS 2007 (year aggregate)  
Ministry of Forestry classification, 2005  
NRM classification, 1997  
GlobCover, 2006  
Selected validation data set (samples)

Because of rapid changes in vast areas many of the reference data, even those of the Ministry of Forestry, are already outdated. This forms a major complication in the validation process. Nevertheless, the first results (presented as maps during the conference) are promising.

6 DISCUSSION AND CONCLUSIONS

The demonstrated methodology for continental wide mapping of forest and land cover at high resolution yields very promising results, and is generally applicable. These results are especially relevant for the humid tropical rain forest areas where other (optical) techniques have a poor performance because of persistent cloud cover. For monitoring, or the development of future REDD projects, radar observation seems to be irreplaceable.

The tentative legend shown already contains six forest types which have typical biomass ranges, and which can be mapped fairly accurate. Since more classes can be differentiated (on the continental scale) than initially foreseen, more validation effort is required. The (ongoing) validation study likely may reveal that more types of deforestation, tree plantations and shrubs can be differentiated.

First validation results show good agreement with the maps of the Ministry of Forestry which are based on visual interpretation of Landsat, but in general are outdated. The PALSAR maps would be perfect to improve GlobCover [10] in tropical rain forest areas with persistent cloud cover.

It is expected that more characteristics of agricultural and peat forest areas can be obtained when the PALSAR ScanSAR cycles are included in the classification (or parameter retrieval) procedures. These features are mainly related to cropping cycles, hydrological/seasonal cycles and flooding events. The work will be continued within the extension (phase 2) of the JAXA Kyoto & Carbon Initiative.

7 ACKNOWLEDGEMENT

This work has been undertaken in part within the framework of the JAXA Kyoto & Carbon Initiative. ALOS PALSAR data have been provided by JAXA EORC. The (ongoing) validation study of the Borneo map is coordinated by the Netherlands Agency for Aerospace Programmes (NIVR) and funded by the Netherlands Government, Ministry of Housing, Spatial Planning and the Environment.

8 REFERENCES


