SAR SYSTEMS FOR OPERATIONAL FOREST MONITORING IN INDONESIA

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ABSTRACT

To enforce national legislation for sustainable forest management or to verify implementation of guidelines for sustainable forest management as proposed by the International Tropical Timber Organization (ITTO), detailed information on terrain, forest and tree characteristic is needed. Among others, systems should be available to monitor logging activities and to detect illegal logging, allowing timely action to be taken. Because cloud cover severely limits the application of aerial photography for this purpose, the use of airborne SAR is proposed as an appropriate alternative of complement. Interferometric high-resolution images collected by the Dornier SAR system over a forest concession area at the East-Kalimantan Tropenbos test site will be used to demonstrate new algorithms for automatic generation of 3-D tree maps.

Other types of information needs exist and are related to frequent observation of large areas. An analysis of ERS SAR data over the same test site reveals its good possibilities for surveillance of land cover change and logging operations, early detection of illegal clear cut and early assessment of fire damage extent and intensity.

Clearly, it can be concluded that a single sensor would not suffice to efficiently such a variety of information needs. Using dedicated airborne radar systems in combination with operational satellite systems would provide promising solutions in support of prudent future forest management.

For both types of systems mentioned above thematic processing algorithms for operational application are currently being implemented in Indonesia.

1 INTRODUCTION

1.1 Background

Current remote sensing and geographic information techniques enable a significant increase of capabilities for data processing, analysis, simulation and presentation. When incorporated in current information systems, these could fulfil requirements for a prudent forest and environmental management. Indonesia as a member of the International Tropical Timber Organization (ITTO) has carried out the National Forest Inventory (NFI), a national broad project for assessing the forest resources in attempt to comply with a provision required under the ITTO Guidelines for the sustainable management of natural tropical forests. The latter embodied permanent forest estate as a pre-requisite clause to initiate sustainable forest management. The guidelines have been accepted by 53 member countries of the ITTO and were considered as a core in promoting continued supply of tropical timber and non-timber forest products. To support sustainable management of forests there is a need to regularly update NFI’s. Therefore ITTO established *dynamic inventory* requirements for NFI. Dynamic inventory is to assess possibilities for timber harvesting and longer-term timber production. Quantitative information should be gathered on both commercial and presently non-commercial species, including the lower diameter classes, and regeneration. These are described in the document “ITTO guidelines for the sustainable management of natural tropical forests” [ITTO, 1992]. To implement these dynamic inventory requirements the capabilities of modern remote sensing and geo-information techniques for updating and analysis should be utilized, and may prove to be essential for a successful cost-effective implementation. The 1996 Indonesian

Radar Experiment (INDREX) Synthetic Aperture Radar (SAR) campaign demonstrates examples of the capability for identifying accurate tree positions and tree crown dimensions. This latest technology is being developed and researched to provide a complementary timeliness for sustainable forest monitoring since the current remote sensing such as the aerial photo interpretation could be outdated when it is ready. Several aggregation approaches were studied to ensure that dynamic inventory requirements for NFI could be fulfilled. Aggregation techniques are needed because the Ministry of Forestry and Estate Crops has an abundance of multi-scale spatial data including the use of aerial photo interpretation that needs to be integrated in order to comply the aforementioned ITTO Guidelines.

Tropical rain forests cover large parts of the Earth's land surface. The significance of these forests, and the need for information, can be seen from several perspectives:

(a) Tropical rain forests play an essential role in global hydrological, biochemical and energy cycles and, thus, in the Earth's climate;
(b) Tropical rain forests are among the Earth's most complex ecosystems and have large biodiversity. The functioning of this ecosystem and the significance of its genetic resources are still not well understood;
(c) Tropical rain forests are of large economic value as a major source of timber and other products, and as a source of land. Large areas are converted into forest plantations, arable land and pastures.

An urgent need exists for accurate data on the actual forest extent, deforestation, forest structure and composition. These data are needed as input for climate studies, for selection and monitoring of forest reserves (with or without sustainable use) and monitoring of environmentally sensitive areas, the latter related to mining and selective logging activities in areas under sustainable management.

1.2 Objective

The object of this paper is to assess the use of dedicated airborne radar systems in combination with aerial photography and operational satellite systems in order to provide a sound basis for efficient acquisition of data in support of prudent future forest management.

1.3 Outline

In this paper several forestry information requirements and radar remote sensing subjects are briefly introduced including result of studies done in Indonesia under the MOFEC-Tropenbos co-operation. First, existing rules concerning the use of remote sensing and the ITTO recommendations are introduced. Second, describing the existing remotely sensed data used by the Indonesian forestry sector and in the Section 4, the new high-resolution SAR data will be discussed including the further integration with the existing geo-database at Section 5.

2 EXISTING INFORMATION REQUIREMENTS AND ITTO RECOMMENDATIONS

2.1 Information requirements concerning the use of remotely sensed data for tree cutting

Based on the latest evaluation on the forestry information system at the Indonesian Ministry of Forestry (Anonymous, 1997), the Directorate General of Forest Utilization uses of remotely sensed data for considering tree cutting, i.e. the use of aerial photographs for considering the Annual Allowable Cutting (AAC). However, cloud covers caused delays to acquire aerial photographs.

2.2 ITTO recommendations

The ITTO Guidelines contained of several principles and related recommendations. With regard to remote sensing aspect, the National Forest Inventory is the major concern. In Appendix 2 of the ITTO Guidelines for the sustainable management of natural tropical forests, it is indicated that information on the state of forested land should be available (ITTO, 1992).

ITTO issued a special guideline on fire management in tropical forests (ITTO, 1996). The guidelines is intended for the forest managers and national planners to overcome problems they face in achieving the sustainable management of their forests. For forest fire monitoring, assessment, prediction, and monitoring of fire risk, as well as means of quantification of forest fires are prerequisites for fire management planning purposes. The recommended actions are (ITTO, 1996):

- Seek the access to meteorological information from ground stations, and spaceborne systems;
- Use the existing orbital remote sensing systems for fire detection and prediction to obtain real-time information on the geographic location of fires;
- ITTO member countries should join others in supporting the development of international mechanisms (early warning systems), to predict wildfires. Such a system would not predict occurrence, but rather would report the development of conditions, which can be counted on to, result in serious fires. It would have to gather and interpret information from a number of sources, including satellites, and land-based stations.

3 EXISTING REMOTELY SENSED DATA USED FOR INDONESIAN FORESTRY

3.1 Aerial Photograph

The use of aerial photographs was the major activity done by the Bureau of Planning for forest inventory purposes after the independence of Indonesia. The forest information extracted from the aerial photographs consisted of (Rimba Indonesia, 1955):

- Dense forest;
- Moderate dense forest;
- Sparse forest;
- Logged over forests (several stands were found);
- Shrub;
- Bush;
- Nipah;
- Swamp forest;
- Rubber and/or Sago;
- Lowland forest

Current forest information extracted from aerial photographs consists of:

- 111
  - C1 Crown density 10-40%
  - H1 Stand height 10-20m
  - D1 Crown diameter 0-10m
- 222
  - C2 Crown density 41-70%
  - H2 Stand height 21-30m
  - D2 Crown diameter 11-20m
- 333
  - C3 Crown density 71-100%
  - H1 Stand height >30m
  - D1 Crown diameter >20m
- Swamp forest
- Settlement, ladang, bare land
- Grassland, plantation, cloud cover
- Logged over, base camp
- Class Potency of 50cm diameter up
  - Volume 20-39 m^3/Ha
  - Volume 40-79 m^3/Ha
  - Volume >80 m^3/Ha

3.2 Landsat Thematic Mapper (Landsat TM)

The early use of digital Landsat TM was introduced by the National Forest Inventory (NFI) project in 1991 (Anonymous, 1996). In general optical systems, like SPOT or Landsat-TM, yield higher accuracy than ERS SAR. For example, Trichon *et al*. (1999) shows that high accuracy, i.e. in the order of 70-80%, can be obtained for mapping a large number of vegetation types in the Indonesian province Jambi. However, cloud cover prevents optical systems to make the repetitive and frequent observation that is needed for monitoring. Statistics derived from the study of spatial and temporal distribution of cloud cover using geostationary meteorological satellites reveal that the probability of acquiring SPOT or Landsat-TM images with less than 30% cloud cover are definitely very low (Gastellu-Etchegorry, 1988a,b). For the Jambi test site, the mean probability to acquire images with less than 70% cloud cover is only 26%.

3.3 ERS SAR

The current study at the East-Kalimantan *Tropenbos* test site relates to land cover change and fire damage monitoring with main emphasis on early detection. The terrain is very hilly and typical for the rugged topography encountered in most Indonesian forest areas. The modulating effects of slope angle and slope aspect on the backscatter intensity complicate processing of data of hilly terrain. New multi-temporal segmentation techniques (Oliver and Quegan, 1998) in combination with backscatter change classification techniques have been applied to deal with this problem.

Preliminary result shows that fire affected areas can be delineated well, but that it is sometimes hard to estimate the intensity of the fire damage accurately. Combining ERS SAR observations during the fire period with land cover class information obtained by ERS SAR in the pre-fire period and observations of 'hot spots' (i.e. fires) by NOAA-AVHRR, together with knowledge of the types of fire occurring in this area, can be shown to yield very reliable results. An example is given in Section 5.2.

4 3D TREE MAPPING USING HIGH-RESOLUTION SAR

4.1 Dornier SAR Characteristics

To study the potential of radar for tropical rain forest management the Indonesian Radar Experiment (or INDREX-96 campaign) was executed in Indonesia in 1996 under the auspices of the Indonesian Ministry of Forestry and the European Space Agency ESA (Wooding *et al*., 1998). The Dornier SAR system (Faller and Meier, 1995) collected data in several modi over *Dipterocarp* rain forest test sites in the provinces of East-Kalimantan and Jambi. In this paper results of high-resolution (1.5 m) C-band interferometric SAR data (one of the six modi tested, see also table 1) of one of the East-Kalimantan test sites ('site A' located in the ITCI concession) are shown.

Table 1. Dornier SAR sensor and image parameters [1)].

Centre frequency	5.3 GHz
Bandwidth	100 MHz
Polarisation	VV
Incidence angle at mid-swath	63 degrees
Swath width	2 km
Number of looks	4
Operating altitude	3200 m
Range resolution	1.75 m
Azimuth res. (single look)	0.34 m
Slant range pixel spacing	1.25 m
Azimuth pixel spacing	1.36 m

[1)] One of the 6 modes selected for the 1996 deployment.

4.2 3D Tree Mapping Algorithms

As indicated previously using aerial photographs, parameters such as tree position, tree crown dimensions, canopy cover and terrain slope angle, and the location of skid trails and logging roads, are of particular interest for forest management. In principle such information can be retrieved on a routine basis over large areas from aerial photographs. Repetitive observation would allow assessment of logging intensity, erosion and fire susceptibility, verification of reforestation obligations, etc. However, cloud cover too often prevents timely observation.

Radar does not have this limitation. Moreover, images acquired by short-wave high-resolution radar, in principle, may give sufficient information for such applications. Since other physical mechanisms underlie radar imaging, radar images can not be treated in the same way as aerial photographs. Notably effects of 'radar shadow' and 'lay-over' should be handled with care. Layover, for example, occurs where two tree crowns with different heights are located at the same range distance (figures 1 and 2). In non-interferometric (i.e. conventional) radar images these two tree crowns will be imaged on top of each other, without being able to detect such a situation. In interferometric images this situation can be detected through the measurement of *phase coherence*. In tropical forests height differences between individual trees can be substantial and are common. Emergent trees in primary and logged-over forests can reach more than 10 m above other upper canopy trees. The same is true for secondary forest, which often comprises remnants of the former primary forest. In theory the problem of layover may be solved to a large extent by making use of the observed interferometric phase coherence. Loss of coherence is indicative for layover and can be modelled as a function of vegetation height differences. The larger the height differences in a certain range cell the lower the observed coherence. In Hoekman and Varekamp (1998) the observed coherence as found for such emergent trees is compared with predictions following application of the Van Cittert-Zernike theorem. Results clearly show that the interferometrically derived height can be a substantial underestimation of the true tree height, while, at the same time, large displacement errors for individual trees can occur. Application of the Van Cittert-Zernike theorem can correct for both types of error and may be basic to the development of inversion algorithms for automated production of tree maps.

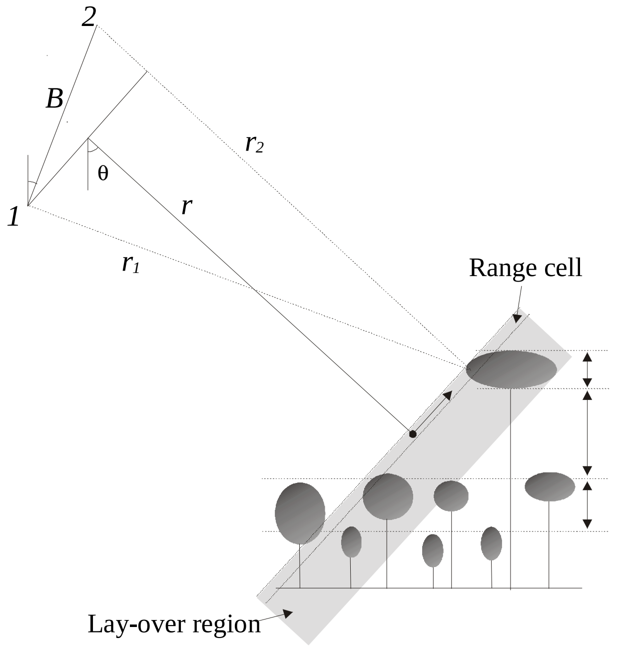

Figure 1. InSAR and layover. The antenna positions are numbered as 1 and 2 and are separated by the baseline distance *B*. The echo of the large tree is mixed with the echoes of smaller trees.

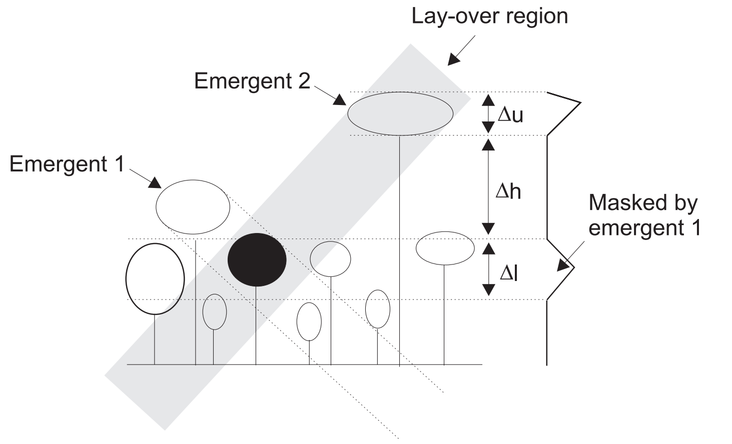

Figure 2. InSAR and shadowing. Compare with figure 3. The echo of the large tree (emergent 2) is well-defined because smaller trees at the same distance are in the 'radar shadow' of another large tree (emergent 1) and cannot interfere.

Several approaches for tree mapping are currently being developed and tested. In one approach tree crown boundaries are fitted to the radar data by positioning a deformable template in such a way that the slope of the interferometric height at the boundary of the crown is maximised (Varekamp and Hoekman, 1999). An example is given in figure 3. Here a radar image sub-scene of part of a 7.2 ha fully surveyed area (Prakoso *et al.*, 1999) is shown. In this figure colour relates to interferometric height and intensity to radar backscatter intensity. The result of tree detection and boundary fitting is shown in figure 3 (right) using figure 3 (left) as a backdrop image. These results are subsequently transformed in a geometrically corrected map of tree crowns in orthographic projection (figure 4). Each tree is labelled and parameters like position, height, crown projected area, crown shape (resulting from boundary height and top height) and radar backscatter properties are listed for further information processing. A comparison with field data is made in the paper of Prakoso *et al.* (1999).

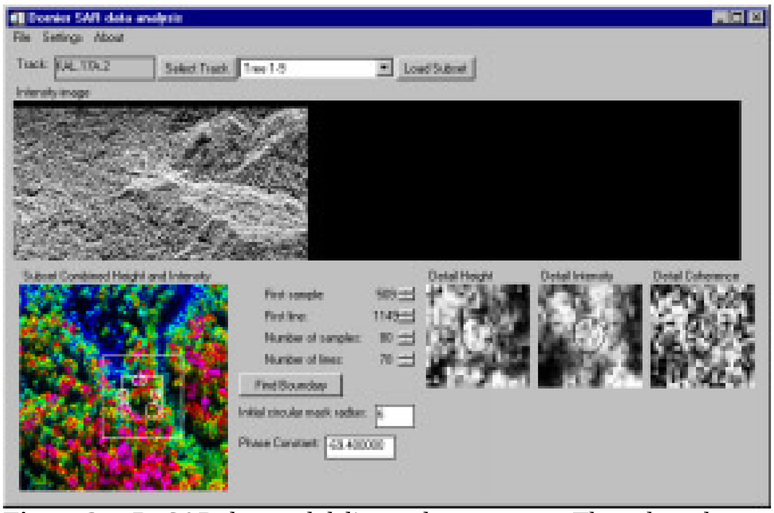

Figure 3. DoSAR data and delineated tree crowns. The color relates to the interferometric height and the intensity to radar backscatter intensity. The result of tree detection and boundary fitting is shown on the left using the image on the right as a backdrop image

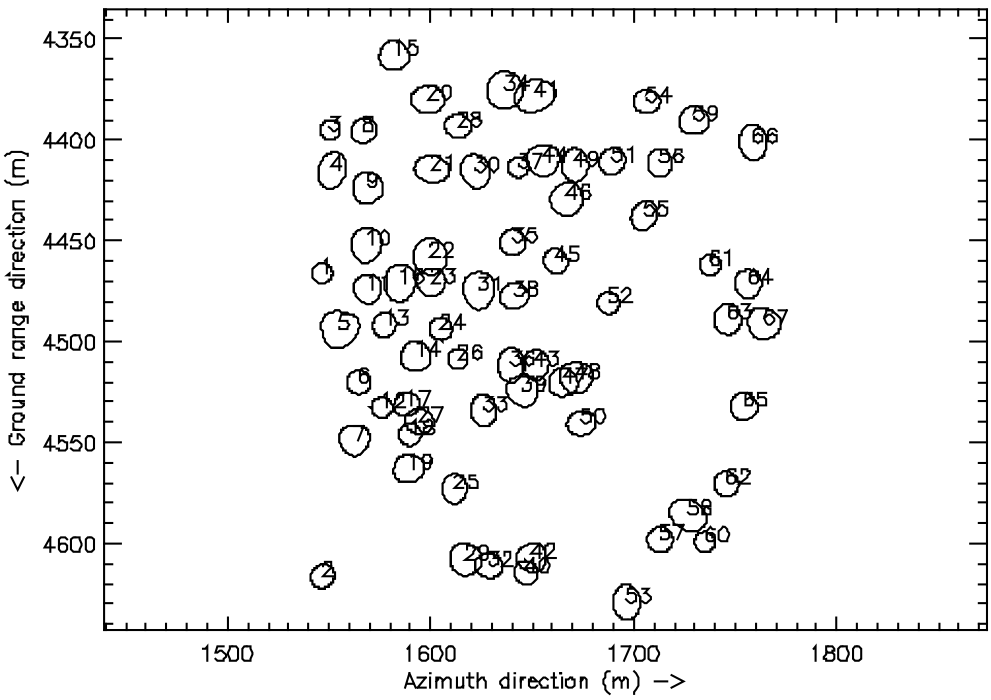

Figure 4. Radar tree map: A geometrically corrected map of tree crowns in orthographic projection

Tree maps derived from radar data differ from tree maps made terrestrially, such as by the FIEPLP method (Smits, 1999). Special features of interest for both types of products may be summarised as follows.

(1) Tree maps derived from radar data:
- In principle, can be made fast, cheap and for large areas.
- They accurately indicate positions of tree crowns, which can be used for referencing.
- They show *most* canopy trees.
- They show tree crown dimensions, which can be useful to determine the direction of tree felling in order to minimise damage.
- They can be used to select areas for fieldwork (e.g. to make FIEPLP tree maps).
- Furthermore, when multi-temporal observations are made, radar image change detection can be applied very easily to detect areas of unexpected change (illegal logging), and for these selected areas radar tree maps can be made. Note that this implies it is not always necessary to produce radar tree maps in order to get results; this can speed up the process and reduces costs to a minimum.

(2) Tree maps derived from terrestrial surveying, such as FIEPLP tree maps:
- Show trunk diameters in excess of 20 cm, for *all* trees.
- Show species. (Radar may only give broad categories. This is still subject to further study.)
- Show terrain topography (while radar shows canopy topography).

Clearly these products are complementary. Radar tree maps facilitate fieldwork for production of FIEPLP tree maps and at the same time can give additional information. The real value of radar tree maps is that, in principle, they can be made fast and cheap, for all areas needed. They may give sufficient information to enforce legislation for sustainable forest management. Where more detail is needed more detailed information can be added by field surveys.

5 INTEGRATION HIGH-RESOLUTION SAR AND GEO-DATABASE FOR ASSESSING DEFORESTATION

5.1 Illegal Cutting Detection

Though each of the SAR techniques has its own intrinsic value for meeting information needs it is worthwhile to study how these can be combined efficiently within an operational monitoring environment. The fact that certain systems are already operationally available, while other systems are planned, proposed or experimental, makes it necessary to differentiate between short term and long term solutions.

In figure 5 four levels of radar observation are distinguished, related to an increasing scale and a decreasing observation frequency and coverage. At the lowest level very frequent observations (several times per week) at medium satellite resolution is achieved, completely covering the area of interest (e.g. a whole country). Examples of systems at this level could be ESA's ASAR (to be launched in 2000) in “Wide Swath” mode. A non-radar example is NOAA-AVHRR for fire detection, which is already operational in Indonesia. In “Wide Swath” mode ASAR could detect areas of special interest, which could be subsequently monitored at level 2 using high satellite resolution at a lower observation frequency (roughly once per month) to update mapping or detail selection of areas of interest. Already a lot of information could be obtained using ERS SAR images ranging, for example, from monitoring the expansion of the timber road network and the progress of strip cutting to detection of small areas (less then 1 ha) of illegal clear-cut and fire damage. When proper use is made of level 2 information, airborne radar (or photography) flight can be planned much more efficiently. Airborne radar, at high resolution, can be applied to efficiently map large areas in detail (see also: Van der Sanden and Hoekman, 1999). An example is the “250,000 km^2 protected forest area” mapping campaign executed by Dornier in Indonesia in 1997. Similar images (from the INDREX campaign) also appeared to be useful to accurately check strip cutting and enrichment planting activities. Systems with larger wavelengths (L- and P-band) may appear very useful for mapping forest and land cover type, biomass and forest flooding. At the highest level individual trees, instead of land cover units, are observed and requires short-wave very-high resolution interferometric airborne SAR. It can be operated in areas with legal logging activities and in areas of special interest identified through the first three levels of observation. On the other hand, when level 4 data are available, these could contribute to mapping accuracy by combining the information with level 3 mapping systems.

To integrate all the above data for illegal cutting detection, aggregation procedures are needed. A reason for aggregation is that the integration of multi-scale and multi-date data can affect the decision due to the produced errors. As indicated by Hoekman *et al.* (1999), the aggregation should be studied because much information should be integrated and analysed to fulfil the users' requirements. For the case of SAR and NOAA-AVHRR images, various sensors on different platforms (Figure 5) produce various spatial resolutions and consequently different level of details of information extraction.

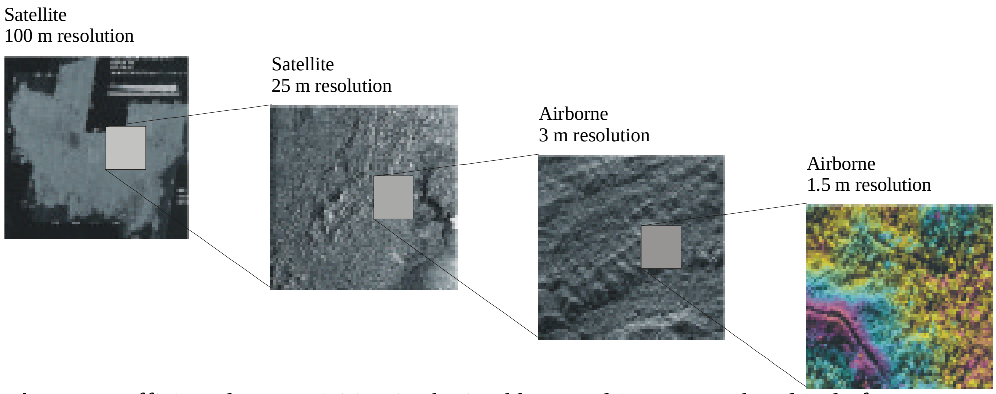

Figure 5. Efficient data acquisition is obtained by a multi-sensor and multi-platform approach. In this example medium to high resolution spaceborne SAR is used to monitor large areas and to select areas of interest where high to very-high resolution airborne SAR can be directed to collect detailed information.

5.2 Deforestation from Forest Fires

A large number of ERS-1/2 SAR scenes of the East-Kalimantan test site of the October 1993-November 1996 period have been studied by Hoekman *et al.* (1999) in support of the INDonesian Radar Experiment (INDREX-96), with the objective to study its potential for land cover change monitoring. Subsequently, an additional series of ERS-2 SAR scenes was acquired in support of studies to assess fire damage caused by a severe El Niño event, occurring at the same test site in the period June 1997-April 1998. The result shows that fire affected areas can be delineated well, but that it is sometimes hard to estimate the intensity of the fire damage accurately. Combining ERS-2 SAR observations during the fire period with land cover class information obtained by ERS-1/2 SAR in the pre-fire period and observations of 'hotspots' by NOAA-AVHRR, together with knowledge on the types of fire occurring in this area, can be shown to yield very reliable results.

1. Multi-temporal segmentation with the new CAESAR-algorithm by Prof. Chris Oliver, DERA-UK
2. 18 x 20 km intensive fieldwork area (mostly hilly)
   - Helicopter flight
   - GPS measurement (accuracy 20-40 meters) for 50 sample plot
   - GPS tracking for the roads and river (mangrove areas)
3. Inspection using NOAA-AVHRR derived from NOAA-14 imagery from January to December 1998
4. Multi-temporal Maximum Likelihood classification with *ML-class* algorithm by Dirk Hoekman and Martin Vissers
5. Image ratioing of the ERS Segmentation data sets to avoid effect of relief and to define threshold for fire risk map
6. Regrouping the training areas, which have high confusion of temporal signature to improve the accuracy

Table 2. *Two independent databases for training and evaluation*

Database Ruandha		Database Vincent		Pre-fire code
Landcover	**code**	**Landcover**	**code**	
Mangrove, including nipah	10	Mangrove	6	**1**
		Nipah	7	**2**
Forest, unburnt	4	Forest, unburnt	4	**3**
Forest, burnt	4	Forest, burnt	5	**3**
		Forest, severely burnt	5	**3**
Forest Enrich plant, burnt	2	Forest Enrich plant, burnt	4	**4**
		Forest Enrich plant, severely burnt	4	**4**
Rubber plantation	4	Rubber plantation, burnt	5	**5**
		Rubber plantation, severely burnt	4	**5**
Kebun	4	Kebun	4	**6**
Agriculture	4			**7**
Water		Water		**8**

Input is database containing labeled multi-channel data samples to produce a risk map with the procedure is as follows (Sugardiman *et al.*, 1999):

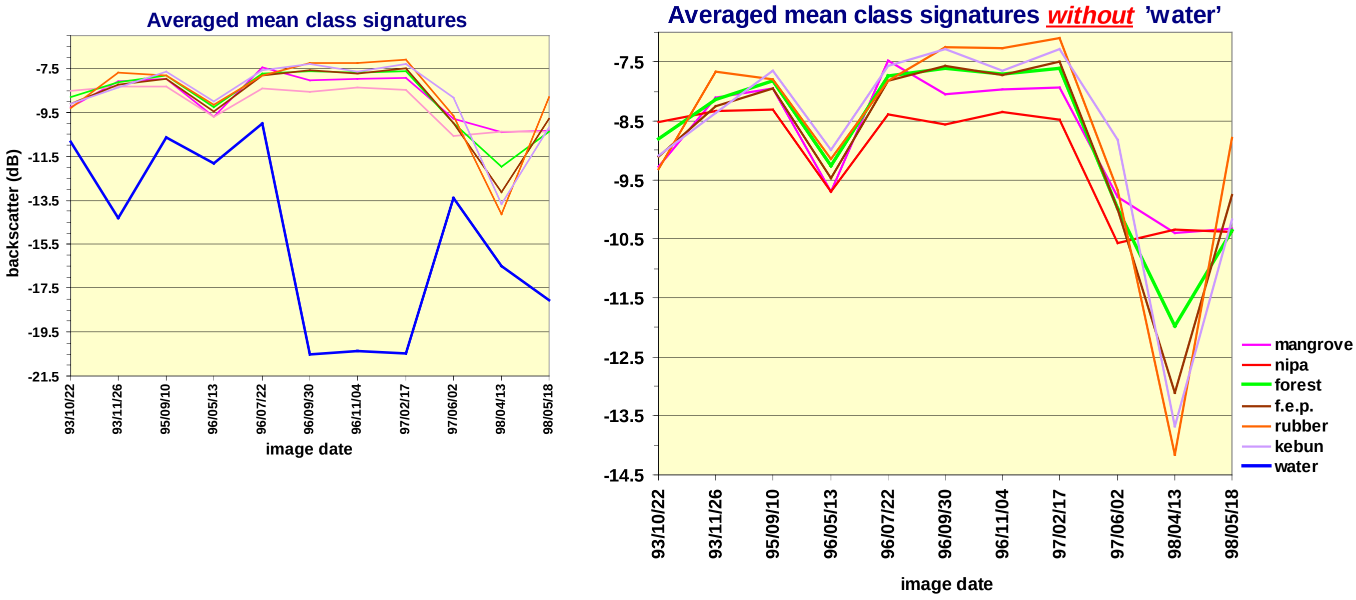

***Figure 5**. Averaged mean temporal signature of ERS-Segmentation*

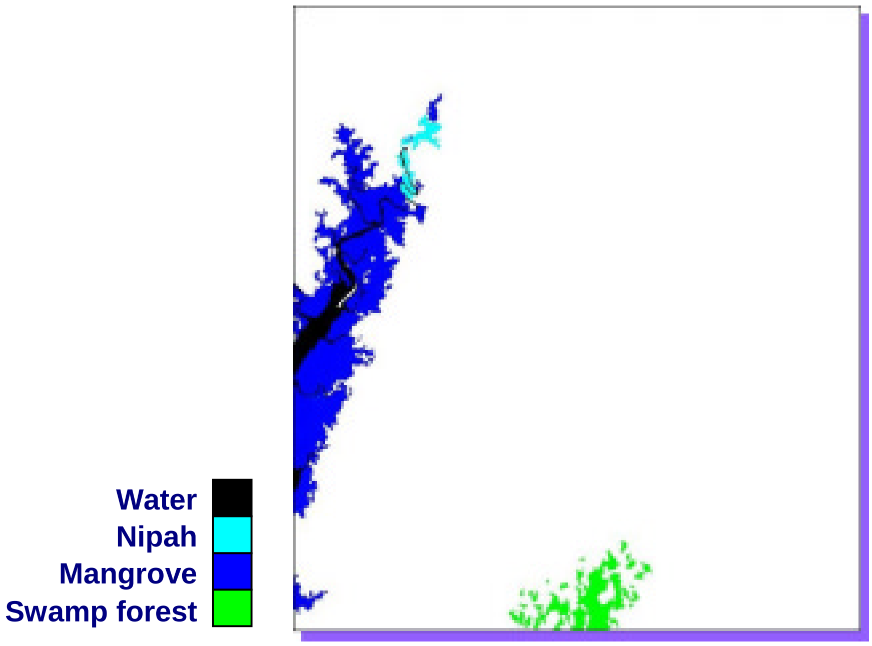

***Figure 6.** Creating the mask*

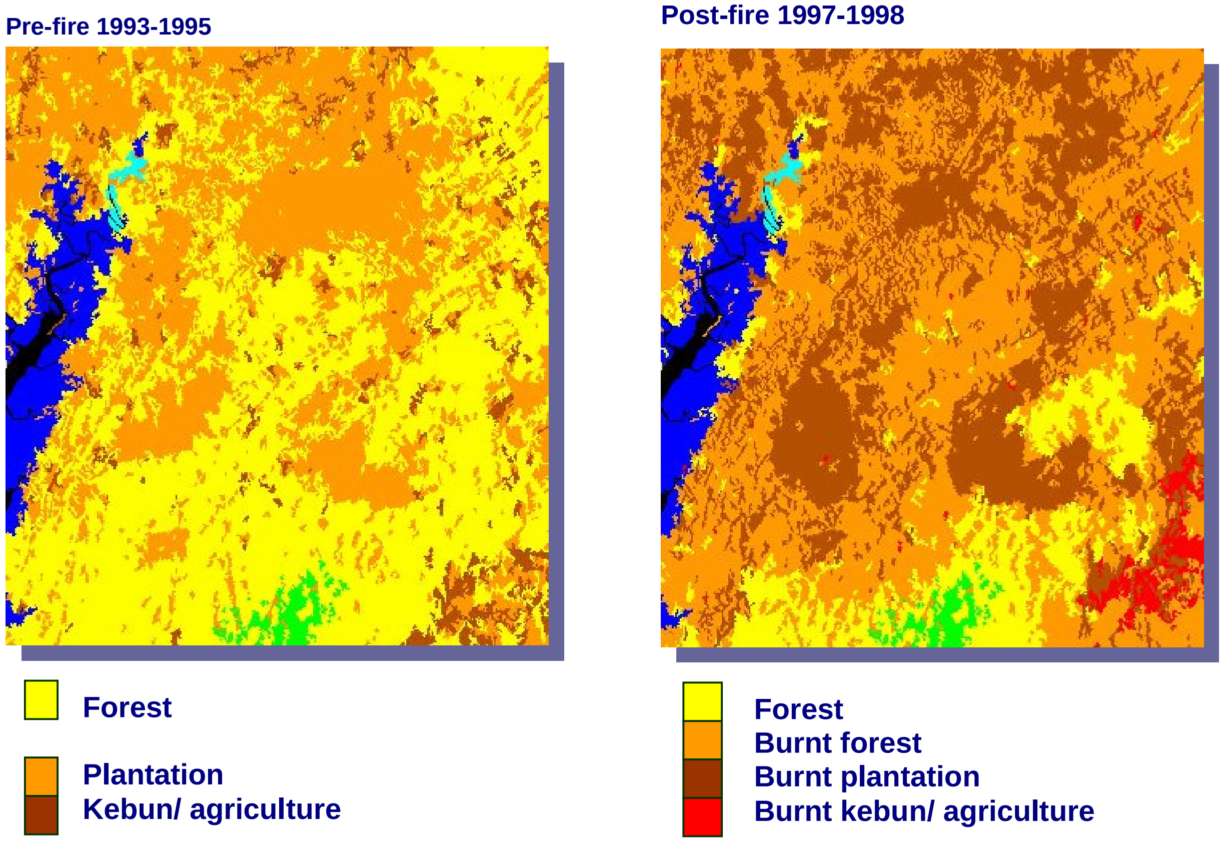

Figure 7. *Classification results after regrouping the classes*

Mask:	
Water	100%
Mangrove	100%
Nipah	100%
Swamp	unknown

Pre-fire:	
Forest	89.4%
Plantation	88.5%
Kebun/Agri	34.5%

Post-fire:	
Non-burnt Forest	98.8%
Burnt Forest	85.2%
Burnt Plantation	98.4%
Burnt Kebun/Agri	28.5%

Risk map

Using band 3 of the ratio images (d4-d3) with a cut-off set on -1.62 and the pre-fire classification result:
< -1.62 : Low-risk dark green
> -1.62 : High-risk brown

No.	Image Ratio	Image date
1	d2-d1	931126-931022
2	d3-d2	950910-931126
3	d4-d3	960513-950910
4	d5-d4	960722-960513
5	d6-d5	960930-960722
6	d7-d6	961104-960930
7	d8-d7	970217-961104
8	d9-d8	970602-970217
9	d10-d9	980413-970602
10	d11-d10	980518-980413

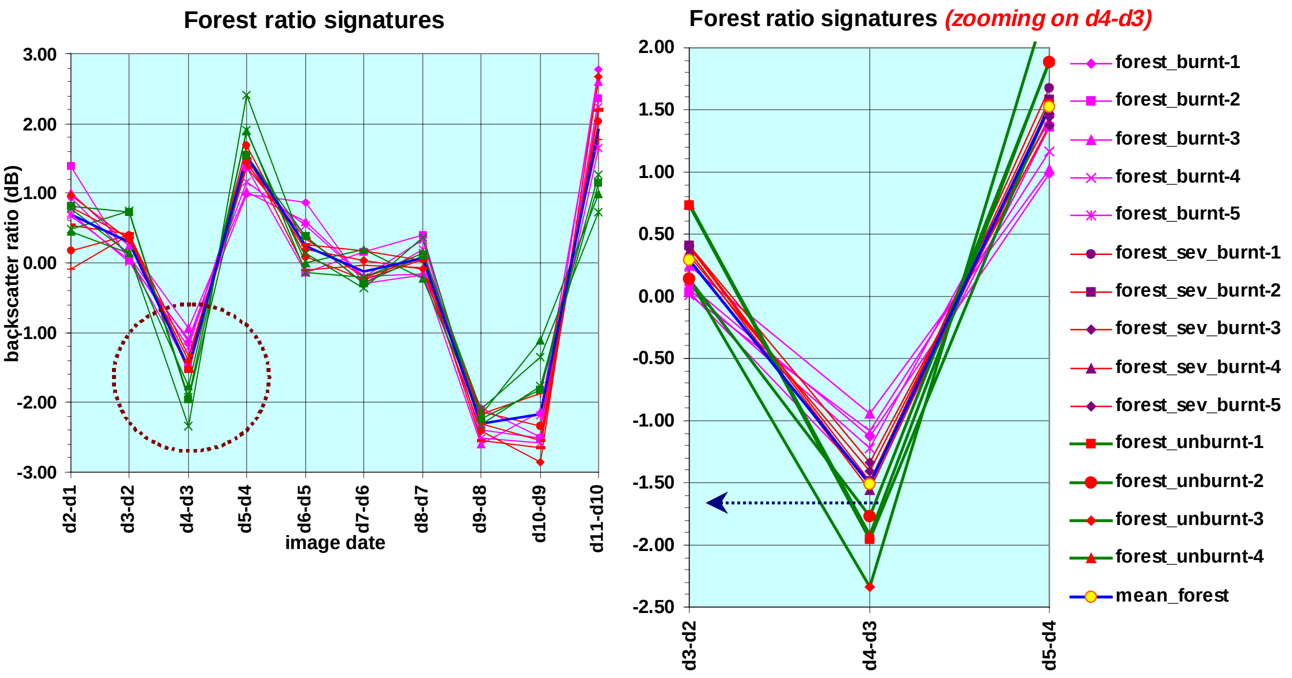

***Figure 8**. Image ratio signature for forest*

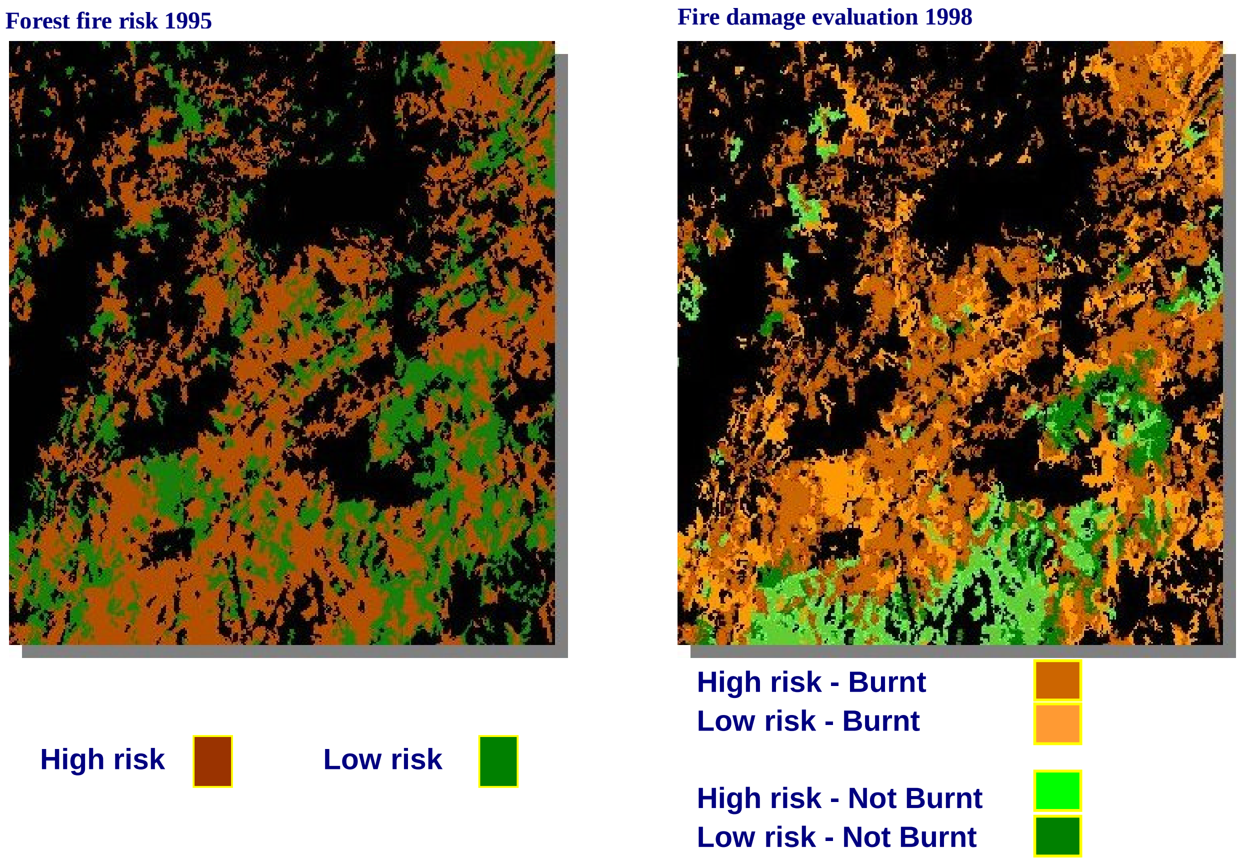

***Figure 9**. Fire risk map and fire damage evaluation*

Multi-temporal segmentation to support automating classification & detection is the key for a higher accuracy of forest fire hazard assessment. In this case the databases for training and validation should be verified or taken from a field-check activity. Signatures and ML_class results showed the best combination. Pre-fire assessment found to be difficult as indicated by low accuracy. Masks of water, mangrove and nipah are important to avoid any confusion of classification due to radar sensitivity of water and moisture. However, other land classes forest, forest enrichment planting, and rubber plantation, dry-land agriculture (kebun), agriculture could to be differentiated.

Surface fires were occurred but they were not easily detected because the C-band was not able to penetrate deeper into the understory. ERS coherence and NOAA AVHRR could be used to support the analysis.
It seems well possible to:

- Assess fire damage
- Verify extent plantations;
- Detect illegal logging.

Still unclear are:

- Accuracy of land covers classes mapping before fire
- Consequently, the risk of fire could be not predicted in an accurate way.

C-band could not be the most suitable (see case Guaviare), therefore time series and well-trained personnel needed to implement this analysis.

6 CONCLUSIONS AND RECOMMENDATIONS

To enforce national legislation for sustainable forest management or to verify implementation of guidelines for sustainable forest management as proposed by the International Tropical Timber Organization (ITTO), information on terrain, forest and tree characteristics is needed. Among others, systems should be available to monitor logging activities and to detect illegal logging, allowing timely action to be taken. Because cloud cover severely limits the application of aerial photography for this purpose, the use of airborne radar seems to be a very promising alternative. High-resolution InSAR systems may be well capable providing data at the tree level, while ERS SAR monitoring could be applied for timely detection and identification of areas of interest.

The ERS SAR is an operational system and, in principle, data can be obtained routinely and frequently (every 35 days). The resolution of the ERS SAR is sufficiently high, for example, to detect small areas of illegal logging or to verify the spatial extent of plantations and reforestation obligations. Alternatively, data from RADARSAT or the future ASAR may be utilized. The NOAA-AVHRR hot spot monitoring system is also operational and makes two observations per day. In Indonesia, for example, it is already used for operational application in forest management. Combined use of these systems may yield accurate and up-to-date information on fire and fire damage on a national basis.

In the future more advanced spaceborne SAR systems may become available, which can achieve a much higher mapping accuracy and may be utilized for monitoring a wide variety of land cover dynamics at scales of 1:100,000 and smaller.

Airborne surveys in tropical rain forest areas are still incidental and airborne SAR systems dedicated to operational tropical forest inventory and management still do not exist. In principle they are well suitable to meet a variety of information needs in tropical rain forests areas, at scales of 1:50,000 and larger. Local permanent availability of InSAR tree mapping systems in tropical forest areas, used in combination with other remote sensing systems and satellite monitoring, would certainly be an important step forwards in support of achieving a prudent and sustainable forest management.

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