# BURN SCAR MAPPING AND FIRE DAMAGE ASSESSMENT USING ERS-2 SAR IMAGES IN EAST KALIMANTAN, INDONESIA

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## ABSTRACT

Burn scar identification and fire damage assessment was done using ERS-2 SAR radar images in East Kalimantan, an Indonesian province severely affected by wildfires during a drought period in 1997/1998. A total of 46 ERS-2 SAR Precision Images were used to map the total burned area in the province. Effects of fire on radar backscatter were investigated in test areas representing different degrees of fire damage that were visited during ground and air surveys. The degree of accuracy of burn scar and fire damage mapping was assessed using random samples of geocoded photographs and videotapes recorded during five air surveys and block forest inventories in one damaged forest area. Changes in Radar backscatter induced by fire proved to be strong. In images acquired during the drought period, a decrease of 2-4 dB was observed in burned areas. Under dry conditions of three fire damage classes could be discriminated by different types and degrees of change to radar reflectivity and image texture. The total fire-affected area was 5.2 Mio. ha. Mapping accuracy was assessed to be higher than 90 percent for burn-scar identification, while the accuracy of discrimination of different damage classes was less than 70 percent. Ground and aerial evidence suggest that the marked decrease in backscatter can be attributed to the removal of the vegetation cover and subsequently higher contribution of backscatter from dry soil. The high mapping accuracy for burn scars allows assessment of fire affected areas using standard ERS-2 satellite imagery to become operational.

## KURZFASSUNG

In Ost-Kalimantan, einer während einer starken Trockenperiode 1997/98 schwer durch Vegetationsbrände geschädigtem Provinz Indonesiens wurden Brandflächen und Feuerschäden mit Hilfe von ERS-2 SAR Radarbildern kartiert. Insgesamt 46 ERS-SAR Precision Images wurden verwendet, um die gesamte Brandfläche der Provinz zu erfassen. Zur Erforschung der Auswirkungen der Brände auf die Radar-Rückstreuung wurden Testgebiete unterschiedlicher Schädigungsstufen untersucht, die bei Boden- und flugzeuggestützten Kampagnen aufgesucht wurden. Die Genauigkeit der Kartierung wurde mit Hilfe zufällig ausgewählte Stichproben aus geocodierten Fotografien und Videoaufnahmen, die während fünf Befliegungen aufgenommen wurden, und mit Block-Inventuren in einem geschädigten Waldgebiet geschätzt. Änderungen in der Radar-Rückstreung waren deutlich. In Bildern, die während der Trockenperiode aufgenommen wurden, betrug der Rückgang in verbrannten Gebieten 2-4 dB. In während der Trockenzeit aufgenommenen Bildern konnten drei Schadensklassen aufgrund von Veränderungen der Radar-Rückstreuung und der Bildtextur unterschieden werden. Die gesamte feuergeschädigte Fläche beträgt 5.2 Mio. ha. Die Genauigkeit der Kartierung ist höher als 90% für die Identifikation der Brandflächen und weniger als 70% für die Unterscheidung der Schadensklassen. Boden- und luftgestützte Beobachtungen legen nahe, daß der Rückgang der Radar-Rückstreuung auf die Zerstörung der Vegetationsdecke und die darauffolgende Erhöhung des Rückstreuanteils von unbedecktem, trockenen Boden zurückzuführen ist. Die hohe Genauigkeit der Kartierung erlaubt es, feuergeschädigte Flächen mit ERS-2 operationell zu erfassen.

## 1 INTRODUCTION

### 1.1 Scope of the study

More than 80% of vegetation fires are estimated to occur in the tropics and subtropics (Dwyer et al. 1998). Monitoring inaccessible tropical areas for the sake of fire control and fire damage assessment is therefore an important remote sensing application. Fire detection and monitoring with optical sensors faces limitations due to frequent cloud coverage in tropical regions, while microwave sensors are able to penetrate clouds and haze. This paper deals with the identification of burn scars and fire damage assessment using radar images in an area severely affected by wildfires during a drought period in 1997/1998 in East Kalimantan, Indonesia. Vegetation fires significantly alter land surface properties. The surface structure changes since leaves and parts of the branches are consumed by fire. A greater portion of the incoming radar beam therefore is reflected or scattered by the ground, while scattering from canopy or volume scattering from stands becomes less important (French et al. 1996, Siegert and Ruecker, 2000). Due to changes in the surface and soil hydrology induced by burning, soil moisture patterns are altered (Holdsworth and Uhl 1997). These fire induced soil moisture and vegetation cover changes are affecting ERS-1/2 C-Band radar backscatter to a varying degree depending on vegetation type, site ecology and weather conditions prevailing during image acquisition (Wang et a. 2000). Thus, French et al. (1996) found in Alaska, that Radar backscatter increased after a forested site was affected by fire. They attributed this effect to changes in soil moisture, namely an increase in soil water content due to melting of the underlying permafrost. Siegert and Ruecker (2000) also suggested that soil moisture has a strong influence on radar backscatter from burned surfaces in Indonesia. It was found that radar backscatter decreased strongly after a fire event when weather conditions are dry, but increased when rain fell on the burned surfaces. In this case, backscatter increases strongly due to the higher dielectric constant of the wet soil, but also from wet living vegetation. Discrimination of burned from unburned surfaces is thus hampered by an overall higher backscatter and a noisier picture. Generally, backscatter behaviour seemed to be dependending on the type of vegetation existing in each area before the fire impact and on the degree of damage each particular vegetation type suffered from fire.

The study presented here was commissioned by a cooperation of the Integrated Fire Management Project and the Sustainable Forerst Management Project, both of GTZ (Deutsche Gesellschaft für technische Zusammenarbeit mbH) and operating in Samarinda, East Kalimantan during the exceptional fire event that struck this Indonesian province in late 1997 and early 1998. It aimed at producing a map of fire damage at a scale of 1:200,000 for almost the entire province discriminating the most severely affected areas from the less damaged. This is of great importance for regional planning endeavours in the fire's aftermath. Prior studies mapping the fire damage (Liew et al. 1998, Fuller and Fulk 2000) were hampered by availability of optical data due to cloud and haze coverage, did no provide the required spatial resolution or were conducted before the fires came to an end. Since no optical data at the desired spatial resolution were available, it was decided to make use of the cloud-penetrating capabilities of satellite-born imaging radar. Results of a pilot study have already been published elsewhere (Siegert and Ruecker 1999, Siegert and Ruecker 2000, Siegert and Hoffmann 2000). In this article we shall describe results of an empirical study about the ability to discern degrees of vegetation damage by fire in tropical lowland ecosystems with the help of C-band imaging radar. We also present the fire damage map compiled from a multitemporal mosaic of 46 ERS-2 SAR images.

### 1.2 The study area

The study area covered about 130,890 km² or 66% of the territory of the Indonesian province of Kalimantan Timur on the island of Borneo. This comprises more than 90% of the province's lowland area. The province of Kalimantan Timur is divided in basins and mountain ridges. From north to south, there are three basin areas with large river systems, the largest of them being the Mahakam basin, which is also the region most inhabited and most severely affected by fire. The major part of the central mountains of Borneo with large inaccessible forest areas in the West of the province was not struck by fire. Only part of this mountain area was covered by the radar satellite mosaic. The Mahakam basin area is marked by large central wetland and swamp areas which are quite inaccessible as well as three lakes with populated shores and shifting cultivation by villagers along the river. Further away from the centre large plantations and forest concessions are to be found. The province's southern and coastal areas are more populated and land cover is dominated by degraded vegetation, agriculture and plantations. A large part of the province is covered by lowland dipterocarp rainforests of varying degree of man-induced degradation.

## 2 MATERIAL AND METHODS

### 2.1 Radar image processing

A total of 48 ERS-2 SAR Precision Images from three adjacent orbits was used to investigate changes in radar backscatter in areas affected by fires of different severity and to map the total burned area in the province of Kalimantan Timur. Images were acquired for three dates: August 1997 (at the beginning of the fire season), April 1998 (at the end of the fire season) and July 1998 (after the fires had been extinguished by heavy rainfall). Due to failure to record images from two satellite orbits in April, only images for the central orbit were available for April. While images from August and April were acquired under extremely dry weather conditions, the images from July 1998 was recorded during a period of heavy rainfall.
Images were subsampled to a pixel size of 25 meters, calibrated to represent radar backscatter, co-registered, and mosaiced together to cover about two third of the province of Kalimantan Timur. Calibration was done to linear

units using an algorithm provided by ESA (ESA, 1998). For some images calibration had to be corrected for replica power.

For the backscatter study, the images from the three different dates were combined to form a three channel image with floating point datatype.
For visual change detection, each of the two images from April and July (post-fire) were subject to principal component analysis with the pre-fire image from August 1997. In a two-band image, principal component two holds the change information, while principal component one holds information on common properties of the two images. Principal component one was then discarded, while principal component two was combined with the speckle-filtered datasets from August and April and August and July, respectively (Siegert and Ruecker 1999). The images were assigned to the colour guns as follows: Red: PC band 2, Green: image one (August), Blue: image two (April or July, respectively). The images were contrast-stretched and converted into a 8-bit RGB-image. These two images were then georeferenced to UTM co-ordinate system, Zone 50 N, WGS-84 ellipsoid. Due to lack of ground control points and reliable maps this had to be done using the orbital information from the ERS-satellite. In the central area of the mosaic (Mahakam basin and surroundings) GPS-measurements were available for assessing registration accuracy. From this data it is estimated that accuracy of registration is in the order of four pixel sizes, i.e. 100 m.
To enhance changes in image texture induced by burning, another series of image products was generated following a method developed by Siegert and Kuntz (1996) for radar-aided classification of land-cover. This method is based on occurrence-based textural filtering of the raw image with very large kernels (15 x 15 and 25 x 25) in order to enhance image texture. The results are assigned to the red and blue colours while the green channel is the adaptively filtered radar image is assigned to the green channel. This allows for identification of areas deprived of their vegetation cover when comparing two images acquired on different dates due to unveiling of the underlying relief (Siegert et al. 1999).
This image product served as an additional reference for burn scar assessment, while the PCA image was the base image for mapping. Images were loaded into a GIS and burn scars were mapped by visual interpretation to comply with a final map scale of 1:200,000.

### 2.2 Damage classification

A classification scheme to map fire damage in timber concessions was established by the Sustainable Forest Management Project (SFMP), a partner organisation. This scheme was adapted for the SAR analysis. Depending on the type of vegetation and fire impact it was possible to discriminate 4 different damage classes (Figure 1). In class 1 25–50% and in class 2 50–80 % of the vegetation have been killed by the fire. This type of damage was found predominantly in logged over Dipterocarp forests in which ground fires of variable intensity killed tall trees but left most of the biomass unburned (Figure 1 A and B). Class 4 indicates that more than 80 % of the vegetation cover has been consumed by the fire. This class was typical for strongly degraded forests and *Imperata cyclindrica* (alang-alang) grasslands. For ecological and fire prevention reasons we introduced a fourth class (class 4) which could not be discriminated using backscatter values alone. In peat swamp forests almost 100% of the trees have been killed by the fire but most of the above ground biomass was left unburned thus causing a high fire risk in future (Figure 1 C).

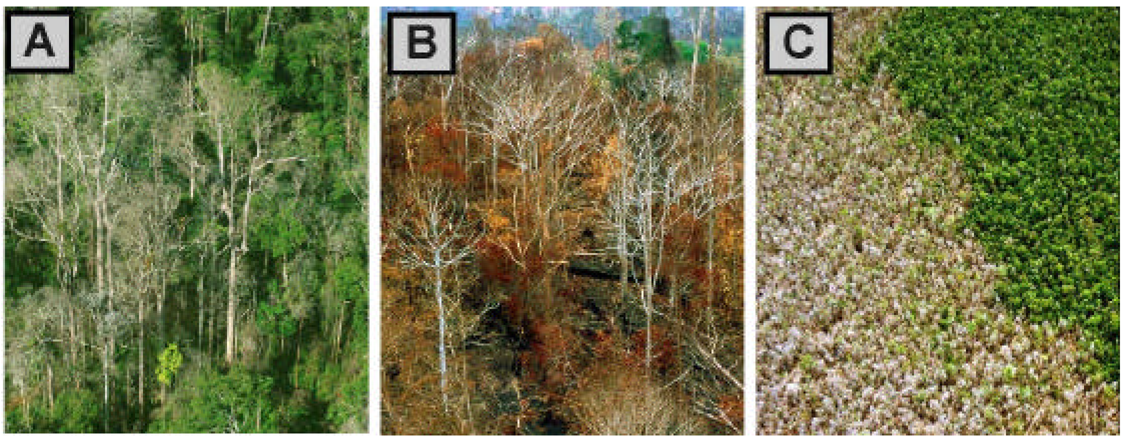



Figure 1. Fire damage classes. Fig. 1 A corresponds to damage class 1 less than 50% of the trees have been killed. Fig 1 B to damage class 4 with more than 80% of the tress dead and the lower left part of Fig 1 C to damage class 3, with more than 80% dead, but the canopy structure almost remaining intact, while the upper right part of the image shows undamaged swamp forest.

### 2.3 Backscatter study

Effects of fire on radar backscatter were investigated in a total of 56 test areas representing the classes of fire damage introduced in section 2.2. Some of these areas were visited on ground surveys during and after the fire event, while others were flown over in the aftermath of the fires by low flying air plane. Fire damage was assessed visually from air photographs and videotapes taken during the flight survey.
Test areas were delineated in the geographic information system and then transferred to the image processing software. Backscatter statistics for these test areas were calculated and evaluated.

### 2.4 Accuracy assessment

Validation of the ERS-SAR PCA burned scar map and damage assessment was done during four ground surveys conducted between April 1998 and September 1999 covering more than 4500 km in the fire affected area (see Figure 4 B). Locations in 10 timber concessions and 4 plantations were checked on ground and compared to the ERS derived burned scar and damage map. Two methods were used to assess degree of accuracy of burn scar and fire damage mapping:

- 143 Random samples of geocoded photographs and videotapes recorded during air surveys were assigned a damage class by visual inspection and compared to the corresponding classification on the map.
- A block inventory of ground data by SFMP in some 178,000 ha of a forest concession was available for interpretation in the GIS. Each block was assigned one of the damage classes explained in section 2.2 during the inventory. This block inventory map was intersected with the damage map compiled from the radar image product and each inventory block was paired with the corresponding area on the radar burn-scar map according to the mapped class which covered most of it.

Mapping results and classes from the two reference datasets were than cross-tabulated and classification accuracy was calculated for each class as well as for the overall discrimination of burned and unburned areas.

## 3 RESULTS

### 3.1 Backscatter Analysis

Changes in Radar backscatter induced by fire proved to be strong. In images acquired in April, during the drought period, a decrease of 2-4 dB was observed in burned areas (figure 2 A). Under moist weather conditions (in July, figure 2 B), radar reflectivity was slightly higher in areas severely affected by fire than in unburned areas. In turn, the standard deviation of backscatter increases for all damage classes except for class 2 (> 80% burned) from August 1997 to July 1998, while in the April 1998 images, standard deviation is slightly lower for burned test areas than in August 1997, although this difference is not supposed to be significant.

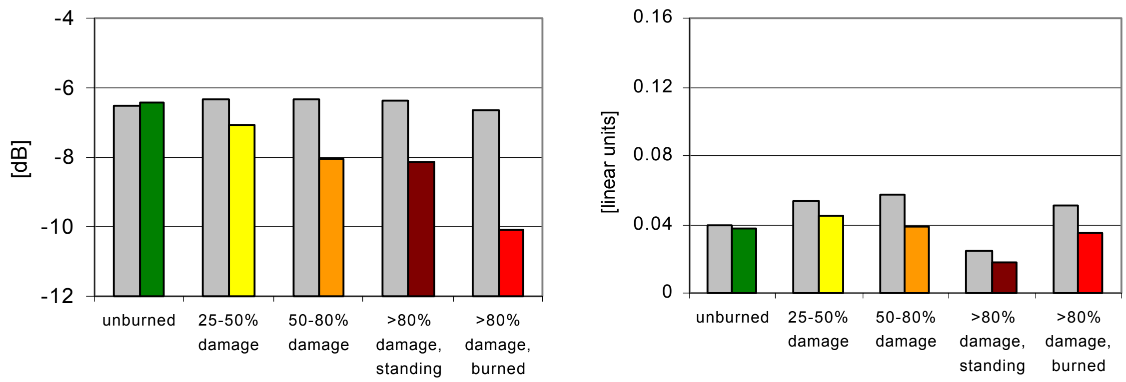
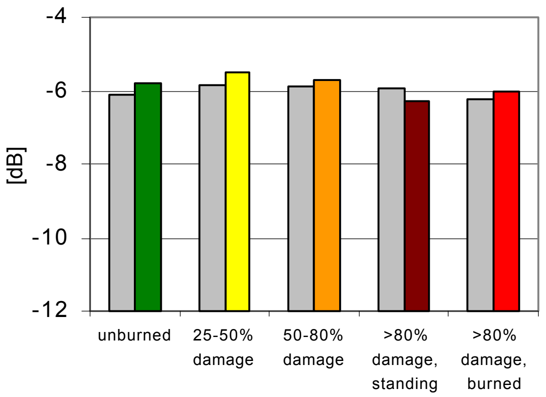



Figure 2 A. left: Mean backscatter for test areas in August 97 and April 98. Right: Mean of standard deviation of backscatter in test areas in August 97 and April 98.



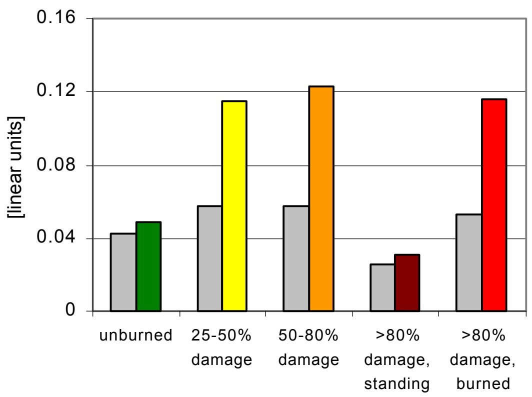




Figure 2 B. left: Mean radar backscatter in August 97 and July 98. Right: Mean of standard deviation of backscatter in test areas in August 97 and July 98

Seperation between classes by mean backscatter is clear in the comparison between August 1997 and April 1998 images only between the classes 1 (25-50%), 2 (50 –80% damage) and 4 (>80% damage with vegetation burned), while the class 3 ( >80% damage with unburned biomass) cannot be separated from its neighbouring class 2. Standard deviation of backscatter in this class is lower than in all other classes before and after the fire, making a discrimination of this class possible (figure 2 A).

Mean backscatter for images from August 1997 and July 1998 is almost equal for all test areas. In all fire damage classes it is slightly higher in July than in August, except for areas with more than 80% damage and most trees still standing, where backscatter is slightly lower. A better discrimination of burned from unburned classes is achieved with standard deviation: this texture-related parameter increased threefold between August 1997 and July 1998 in all classes except for the class 3 (figure 2 B). This indicates that for the other classes, differentiation of burned from unburned surfaces is good, but separation between classes may be worse.

The increase in standard deviation, which can be interpreted as an increase in image texture is illustrated in Figure 4: panel A shows the texture-filtered image mosaic of Kalimantan Timur as described in 2.1, generated from the ERS-2 SAR image from August 1997 (before the fires), while panel B is the same image product from July 1998 (after the fires). While in the central basin (the Mahakam area) green image tones predominate in both images, the hilly areas at the central coast as well as north of the Mahakam basin appear in green tones in the August 1997 image and in pink tones in the July 1998 images. These pink tones are due to high values in image variance enhanced by textural filtering. The change in image variance indicates that these areas have been burned.

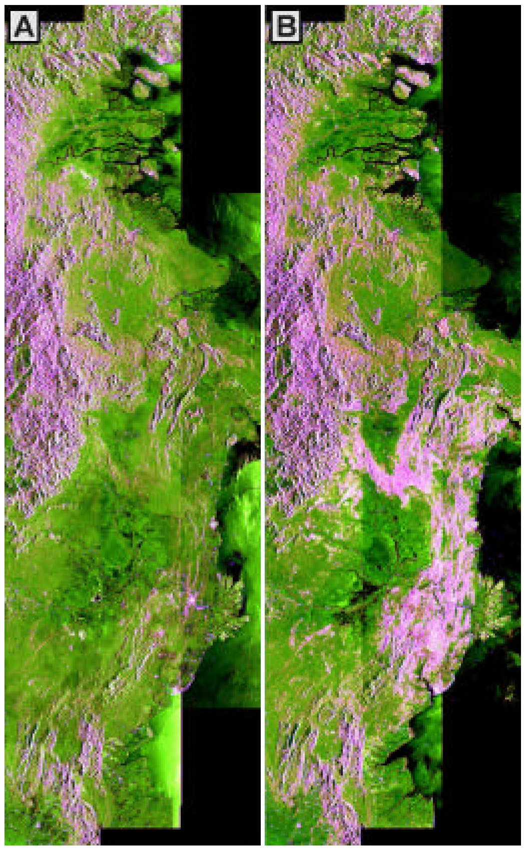



Figure 4. Artificial image composed from texture-filtered and gamma-filtered images from August 1997 (A) and July 1998 (B). For details see text.

In lowland areas more difficulties are therefore to be expected for assessing burned and unburned areas as well as degrees of damage with images from the moist season than in hilly regions. However, most of the lowland areas are covered by the image from April 1998, which according to the presented backscatter analysis is expected to provide for better discrimination between damage classes as well as between fire-affected and unburned areas.

### 3.2 Mapped area

The total area mapped as affected by fire in East Kalimantan was 5.2 Mio. ha. The colours in Figure 4 A indicate the four damage classes: A total of 34% have been assigned the two most severe damage classes 2 and 3. Although both of these classes indicate that more than 80% of the vegetation have been damaged it is important to be aware of the fact that the class 3 occurred mainly in ecologically important peat swamp and wetland areas while class three was typically to be encountered in plantation areas and degraded grasslands. 42% of the burned area have been assigned damage class 2 (50-80%) 24% have been assigned damage class 1 (25-50%). These classes typically occured in dipterocarp forest. The burned area extends across the central Mahakam basin and the coastland towards the slopes of the mountains in the north and west , where the fire extinguished.

### 3.3 Assessment of accuracy

Assessment of accuracy yielded quite different results for the air surveys and the block ground inventories. For the accuracy of burn scar detection, the error of omission (burned mapped as unburned) was 5.5% and error of commission (unburned mapped as burned) was 0.7%. Overall accuracy for discrimination of damage classes was 66.4%. More than 90% of all errors are assignations of an area to a neighbouring class and are therefore considered to be slight.
For the block ground inventories results are considerably worse. Error of omission for burn scar mapping was 21%, error of commission 1.5%. The overall accuracy for class assignment was only 27.3% indicating that it was not possible to discriminate damage classes.

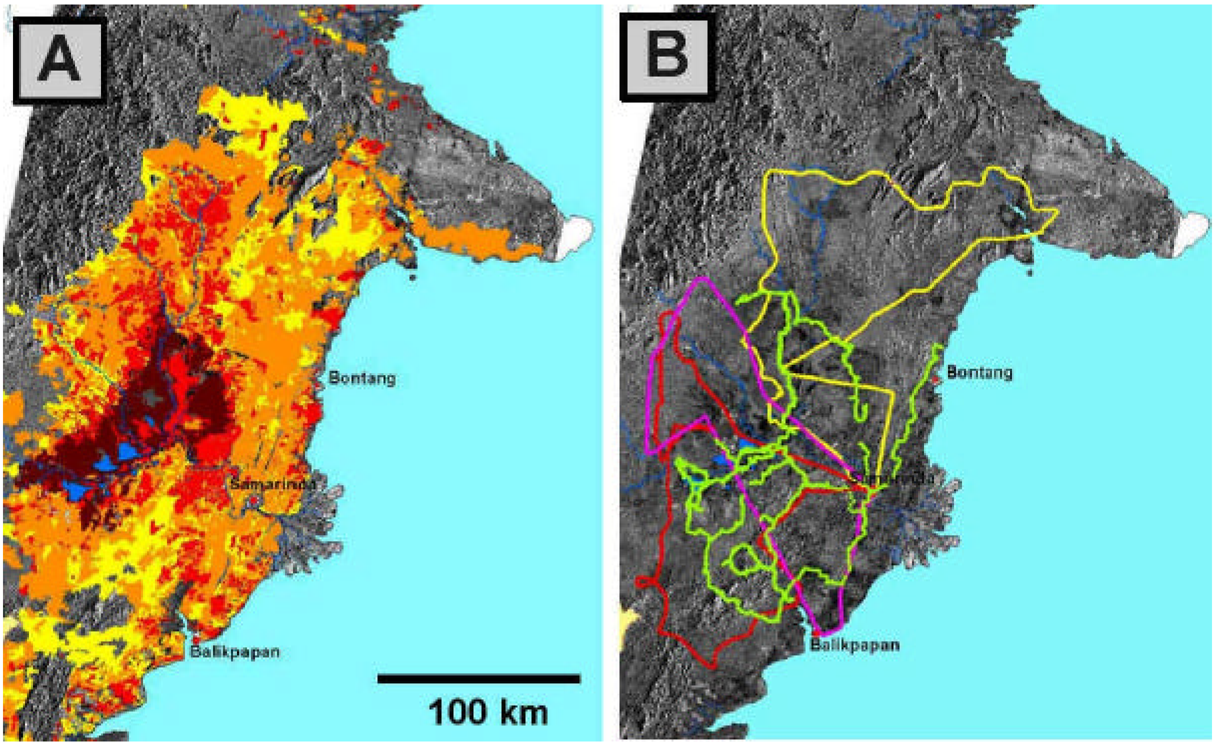



Figure 4. Mapped area and Ground surveys. A: The burn scar map. Yellow: 25-50 % damage, orange: 50-80% damage, brown: >80% damage, canopy remaining, red: >80% damage, soil widely exposed. B: GPS-recorded tracks of ground surveys in 1998 and 1999. The backdrop to both images is the gamma-filtered mosaic of ER-2 SAR images from August 1997.

## 4 CONCLUSIONS

Ground and aerial evidence suggest that the marked decrease in backscatter can be attributed to the removal of the vegetation cover and subsequently higher contribution of backscatter from dry soil. After rainfall, the soil becomes wet and thus has a higher dielectric constant, leading to a higher radar reflectivity (Ulaby et al. 1986). In Dipterocarp forests, the fire leads to a removal of the leaves, while the majority of the dead trees remain standing. This results in pattern of high spatial variability because the radar beam is reflected by remaining canopy ins some places while in others it may penetrate to the forest floor or double bounce from moist dead tree trunks when weather is wet. Forest canopy has a smoothing effect on relief – when it is removed during fire effects on small-scale topography affect the radar beam much stronger leading to an increase in image intensity variations in these areas (Siegert et al 1999). In large areas of the peat swamp forest, were most of the fire damage class 3 is located, fire causes vegetation death almost without altering vegetation canopy structure. Therefore, in many test areas, no change in mean backscatter nor in standard deviation of backscatter could be detected in the images acquired under moist conditions. This allowed for reliable mapping of fire damage and burn scars in these peat-swamp areas only under dry conditions. Discrimination of three damage classes based on mean backscatter is better for images taken under dry weather conditions, while under wet conditions, standard deviation of backscatter is a better indicator for fire damage. This can be interpreted as a consequence of a decrease in soil moisture during the drought leading to extremely dry soils when exposed after a fire (Holdsworth and Uhl 1997)), which in turn leads to a decrease in dielectric constant of the soil and subsequently in backscatter. During moist weather, in turn, the patchiness of vegetation cover and the interaction of the radar beam with the moist soil and the exposed underlying relief may need to a considerably higher image texture, manifested in an increase of standard deviation of backscatter for those areas.

Mapping accuracy for fire scars is generally good, although according to the ground inventory for one concession, the high error makes discrimination of damage classes not feasible. However, according to the air survey-study, damage class mapping is possible with an overall accuracy greater than 60%. This discrepancy in results is readily explained by two facts: Firstly, for the area investigated for the block inventory, only images from the moist period in July were available. As indicated by results of the backscatter study, these are not suited for accurate discrimination of damage classes. Secondly, assessment from the ground produces results quite different than damage assessment from the air. Thus, an observer from the air can not identify damage by low intensity ground fires that leave tree crowns unaffected. An assessment from the air tends therefore to be more conservative. This may also explain the better agreement between air survey and radar map. However errors of omission for the slightest damage class are more than 40% for both surveys, indicating difficulties in dedecting this damage class correctly. Although the ground survey was more detailed, the dataset produced from the air survey is to be considered as being more reliable, since the area covered by the air survey was much larger, covering different vegetation and relief types which influence the radar image properties in a different way before and after fire impact.

The high mapping accuracy for burn scars allows assessment of fire affected areas using standard ERS-2 satellite imagery become operational. With a lesser accuracy a fire damage estimation was possible. The total area to be assumed as fire affected is therefore to be considered much larger than was suggested by other investigations (Liew et al., 1998, MoFEC, 1999). It also has to be borne in mind that accuracy assessment of the radar map indicate that the estimate of the burned surface may be too conservative, since ground fires may have slipped detection.

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