Integrated Forest Fire Management Project (IFFM)

East Kalimantan – Indonesia

Evaluation of the 1998 Forest Fires in East-Kalimantan (Indonesia) using multitemporal ERS-2 SAR Images and NOAA-AVHRR data

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ABSTRACT

Boosted by the 1997/98 El Niño phenomena uncontrolled fires have destroyed huge areas of rainforest and bushland in Indonesia. Thick smoke covered large areas over SE-Asia for months. Due to their cloud and haze penetrating capability SAR sensors could complement existing fire monitoring systems based on NOAA-AVHRR data, providing a 900 times higher spatial resolution. This paper describes results of the combined synergistic use of NOAA-AVHRR hotspot data received and processed by the IFFM/GTZ project and multitemporal ERS-2 SAR images for burned scar mapping. Burned areas detected by ERS were verified using AVHRR sensor hot spot data and extensive field surveys during the fire season in April 1998. Furthermore, a vegetation classification discerning five classes was derived from the ERS-2 SAR images and compared to the mapped burned scars. Temporal sequences of NOAA-AVHRR hotspot were used to show the development of fire patterns, trace the origins of fires and could help identify potential causes and actors. The total burned area of scars is estimated to be 4 mil. ha in the province of East-Kalimantan in 1998.

INTRODUCTION

In the last two decades, fire has become one of the greatest threats to tropical rainforests, especially in Indonesia. The process of selective logging produces millions of tons of dead biomass, which serves as fuel for fires. Fire is used for large-scale land clearing, e.g. for pulpwood and industrial crop plantations as well as by farmers to clear land and burn agricultural waste (SCHWEITHELM, 1998). Because of the severe drought caused by the 1997/98 El Nino phenomena, fires could spread uncontrolled over large areas of rainforest, grass- and bushland. Economists estimated the economic damage due to smoke alone in 1997 to more than 1.4 billion US$ (SCHWEITHELM, 1998). The damage to the forest resources such as timber and plantations is uncertain due to a lack of comprehensive data. Data is also lacking for the effects on the precious and fragile ecosystem of tropical rainforest, on species diversity, soil erosion. Furthermore, biomass burning plays an important role as a major source of trace gases and aerosols in the atmosphere. This results in a strong contribution to the anticipated climate change (KAUFMANN et al., 1990) and particularly in emissions of Co_2 fixed in the biomass as the important "greenhouse" gas (HAO et al., 1990)

The use of remote sensing data is an efficient way to analyse the size and damage level of a burned area and following from that the ecological and economic impacts of these large scale fire events. Several approaches were undertaken to determine the extent of the 1997 forest fires in Indonesia using optical and microwave sensors. Studies were based either on the visual interpretation of multitemporal SPOT quicklook mosaics, the evaluation of NOAA (National Oceanic and Atmospheric Administration)-AVHRR (Advanced Very high Resoultion Radiometer) and ATSR (Along Tracking Scanning Radiometer) hot spot data or the combined use of ERS-2 SAR (European Radar Satellite-2-Synthetic Aperture Rarar) coherence data and ATSR data (FULLER & FULK, 1998; WOOSTER ET AL., 1998; FANG & HUANG, 1998; LIEW ET AL., 1998; ANTIKIDIS et al., 1998; BUONGIORNO et al., 1997).

The AVHRR sensor provides the capability to detect the presence of active fires using channel 3 (3,8 µm). However, due to the low spatial resolution of AVHRR data images (1.1 km^2) it is difficult to exactly quantify the size of burned areas and the type of burned vegetation (MALINGRAEU, J.-P., 1990). The evaluation of high resolution Landsat TM or SPOT images is hampered by frequent cloud cover and haze during active burning. The ERS-2 SAR sensor is able to penetrate clouds and haze and provides the high spatial resolution (25 m) necessary to identify and estimate areas. Therefore, we investigated whether multitemporal ERS-2 images could be used to survey the extent and impact of recent forest fires in Indonesia. Burned scars mapped in multitemporal ERS-2 images were verified by NOAA-AVHRR hotspots and field study. By overlaying NOAA-AVHRR hotspots onto the ERS images the temporal and spatial distribution of fires were investigated.

The study was conducted by the German sponsored and GTZ (German Technical Cooperation) implemented IFFM project (Integrated Forest Fire Management Project). The project based in Samarinda, East-Kalimantan receives and processes NOAA-AVHHR satellite images. The IFFM project is a technical cooperation project under bilateral agreement between the Governments of Indonesia and Germany. It is under the responsibility of the Ministry of Forestry, and implemented by the two provincial forestry agencies. A major aim of the study was to investigate whether multitemporal ERS-2 SAR images can complement and expand the existing NOAA-AVHRR fire detection system. Specific objectives were **1.)** to detect and quantify burned areas at high spatial resolution, **2.)** to compare AVHRR hotspots and burned scars detected by ERS-2, **3.)** to perform basic vegetation mapping using enhanced ERS-2 images and **4.)** to produce a fire risk map for future fire prevention. Here, we focus on the results of the first three objectives.

MATERIALS AND METHODS

Study area and ground verification

The IFFM project area covers the whole province of East-Kalimantan (~200.000 km^2) on the island of Borneo (see **Figure 1**, square in map insert). The radar project area covers 20.000 km^2 within the Kutai district (Kabupaten). Lowland Dipterocarp forest and (peat) swamp forest as well as grasslands (Alang-Alang) dominates the vegetation. All forests in the project area have already been subjected to selective logging. Shifting cultivation prevails close to the rivers. Several large pulp wood and oil palm plantations have been established in the past decade. An extensive ground survey was undertaken during the fire season in April '98. In the field we used a laptop computer in which processed and georeferenced ERS-2 images from February and March 1998 as well as NOAA-AVHRR hotspot data were stored. By connecting a Garmin 12 GPS to the laptop we were able to ascertain our actual position in the georeferenced ERS images at any given time. Most importantly, we were able to access specific areas, which we suspected as burned from SAR backscatter signals and NOAA-AVHRR hotspot data. By overlaying up-to-date hotspot data onto ERS images, their relevancy was proved directly in the field. We used the continuous track mode of the GPS to record all travel routes.

NOAA-AVHRR data processing and analysis

The Integrated Forest Fire Management Project (IFFM) provides information on fire and fire occurrences in East-Kalimantan. Since April 1996, IFFM has received images from NOAA 12 and 14 satellites four times per day. The display and the quantitative analysis of the AVHRR satellite imagery is performed by Sea Scan STARS (Satellite Analysis and Research System) software. The AVHRR data is acquired by the HRPT (High Resolution Picture Transmission) Reception System, which was supplied by Sea Scan and built up by Dundee Satellite Systems (WANNAMAKER, 1996).

The AVHRR sensor (a five channel scanning radiometer; visible, near infrared, mid infrared and far infrared) is designed for meteorological and oceanographic applications therefore special algorithms have been developed for fire detection. The most suitable channels for fire detection are the first two 'thermal' infrared channels, channels 3 and 4. The fire detection process is based on surface temperature measurements taken by channel 3. A pixel is detected as a fire pixel or as a hotspot when channel 3 is saturated by a specific temperature much below that of burning vegetation (MALINGREAU 1990, KAUFMANN et al. 1990a, 1990b, KENNEDY et al. 1994). Therefore, to avoid false alarms detection due to high background temperature (soil), highly reflective clouds or sun reflection of water, the satellite processing program uses special algorithms. The IFFM receiving station uses several day-time and night-time tests. In particular, it uses the Multiple Threshold algorithm after ARINO & MELINOTTE, 1995 which refers to the algorithm proposed by KAUFMANN et al. 1990a which updated the DOZIER, 1981 algorithm. The threshold temperature for channel 3 is set manually for each image obtaining the given temperature from a screen tool. During the fire season of January to May 1998 the threshold temperatures for day-time images were normally between 322° and 317° Kelvin and between 303° and 308° Kelvin for night-time images. **Figure 1** shows channel 3 of a processed NOAA 14-AVHRR day-time image and the given subset area of the IFFM receiving station. Each black spot on the East Coast of Kalimantan represents a potential fire pixel or hotspot (HS). With a threshold temperature from 322° Kelvin, 1273 HS were detected. Since the system does not yet provide a sea mask to mask out false detection due to sun glint on the sea surface the processed images were re-checked and false detection eliminated. All detected hotspot coordinates have been stored in a data bank.

Given the fact that a fire pixel or a hotspot is a defined area of 1.1 km^2 it means that the suspected fire or fires are inside this area, but it tells nothing about the number and the size of the fires and the burned area (MALINGREAU, 1990). The hotspot coordinates represent the centre of a detected fire pixel and are not real in-situ fire coordinates. The fire or fires could be located around 500 m from the centre coordinate. Additionally it is extremely difficult to guarantee a good pixel or image registration of successive NOAA-AVHRR images. Due to this fact more than 250 images (period January-May 1998) were manually chosen and visually inspected for their suitability to re-register them again on the basis of low cloud cover over the fire area and a mainly central swath position of the AVHRR sensor to avoid excessive distortion of pixel geometry. Since the internal program format from the STARS program is not a common format, all chosen images had to be manually converted into a common format. All images were again re-registered using ERDAS IMAGINE.

Hotspot coordinates correction

By re-registering all the images, based on one reference image, the spatial error was figured out for each image and finally was used to shift 51700 hotspot coordinates representing 91% of the complete hotspot data set received. The re-registering process was done based on file coordinates (x and y coordinates), since the map coordinates were lost during the converting process. The spatial error was taken by pixel amounts for each image. On the assumption that each pixel corresponds to a length of 1.1 km^2 the given error in kilometres was converted into decimal degrees to shift all related hotspot coordinates. These corrected coordinates were implemented in a databank and then overlaid onto the processed ERS images to verify the burned scar detection result and show the temporal distribution of the fires. The registering process led to a spatial error for the already registered NOAA-AVHRR images of about ±3,5 km on average, meanwhile individual images contained errors of up to 16 km. This is because the accuracy of the AVHRR scanner deteriorates at wide viewing angles. Additionally the error depends on the operator's accuracy when overlaying the coastline to navigate the data. Due to the fact that the coastline has to be overlaid on a coarse scale the registration quality also depends on the image quality. The more clearly visible the image coastline is, the more accurate the navigation result will be. These might be the reasons that, concerning directions the main error is mostly facing out to the south and to the east. The average vèctorial error is 3 km to the east and 2.5 km to the south.

After re-registering the HS data set the maximum error could be reduced to 2 km. The most important issue of the corrected data set is that the most extreme errors have been eradicated. If the corrected HS's are now overlaid onto the burned scar mapping results from the ERS images, they match the burned scars much better. **Figure 2A** shows burned scars as detected in multitemporal ERS images (orange tones, see below), **Figure 2B** shows the uncorrected HS data set indicated in red, while **Figure 2C** shows the corrected coordinates. The spatial error has been visibly reduced. Considering the fact that a single fire is detected by NOAA 12 and NOAA 14 at maximum 4 times a day and that these images would have an error from 7 up to 16 km kilometres, it would never show the real spatio-temporal distribution and spreading of fires.

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ERS-2 Data Processing and Analysis

10 ERS-2 SAR Precision Images (PRI) acquired on five dates for two adjacent frames (3618 and 3600; 50% shifted to the south; Orbit 12067 11-08-97, 12568 15-09-97, 14572 2-02-98, 15073 09-03-98, 15574 13.04.1998 and 16075 18.05.1998) were evaluated. Here, we focus on the results of the fire period from January to April 1998, that is the detection of changes between the ERS-2 Orbit 14572 (02-02-98) and 15073 (09-03-98) and 15073 (09-03-98) and 15574 (13.04.1998). Adjacent scenes were mosaiced and all images were map-registered using a common set of ground control points derived from GPS measurements and topographic maps. Visual inspection of raw, unprocessed ERS images allowed only for discrimination between geomorphologic structures and large water bodies like lakes and rivers. Even a distinction between forest/non-forest was impossible. To be able to discriminate different vegetation and land use classes monotemporal ERS images were subjected to three separate speckle and texture filtering operations. The filter products (7 x 7 gamma map filter for speckle reduction, 10 x 10 variance filter, and 20 x 20 variance filter) were then combined into artificial ERS RGB composite images by assigning each filter product to a different colour channel (see also KUNTZ & SIEGERT, this volume; KUNTZ et al., 1996 and SIEGERT et al., 1995). A comparison of **Figures 3A+B** shows that more features can be discriminated visually in the RGB composites than in the unprocessed or simply speckle filtered ERS image.

Visual inspection of time series gamma map filtered ERS-2 images showed that there is a clear change in radar backscatter and/or image texture when fire has affected vegetation. Burned areas appear considerably darker in speckle reduced images. Ground verification showed that this can be attributed to a partial or complete removal of the plant cover. Severe burns, which destroy the vegetation cover completely result in a dramatic change towards a very low backscatter from reduced volume scattering and bare and dry soil and a decreasing dielectric constant (**Figure 4A+B**) .Two methods were employed for the detection of burned areas, both based on the multitemporal evaluation of the changes that occur between two ERS overpasses before and after the fires. One approach not described here was band ratioing with the filtered RGB image products (RÜCKER & SIEGERT, 1998). The other approach was a Principal Component Analysis (PCA). Two successive multitemporal ERS scenes were analysed. After the transformation the first component holds information on common features in both images – geomorphology and some texture information – while the second component contains the differences between the two images and thus indicates change. Component two was then combined with two gamma map filtered ERS images (e.g. February and March) to give a RGB colour-composite image for further visual interpretation. The advantage of this representation is that it displays the change and at the same time preserves the geomorphology and texture information at a high spatial resolution (**Fig. 4C**: Red: PCA band 2, Green: February image, Blue: March image). Burn areas are visible in orange tones of different intensity, unburned vegetation appears in blue tones. Visual interpretation of vegetation types and identification of burned scars was performed using the GIS-software ArcView 3.0 by manually delineating areas in the processed SAR images belonging to each of the various classes.

RESULTS

NOAA-AVHRR data evaluation

The dry weather conditions created by the El-Niño phenomena in East Kalimantan lasted until May 1998. No substantial rainfall was recorded in Samarinda and Balikpapan from January until the end of April, whereas all the other provinces in Kalimantan and Sumatra and northerly parts of East Kalimantan had experienced normal to heavy rainfalls. This is clearly visible in **Figure 1** by swollen rivers in Central Kalimantan (e.g. Barito River) and the higher elevation areas of the Kutai district (Upper Mahakam River). In mid January NOAA-AVHRR detected hotspots (HS) figures began to rise correlating with the fire danger index (a metric index based on rainfall and temperature data derived from the Keetch-Byram Drought Index after DEEMING, 1995 for the IFFM project). **Figure 5** shows the relationship between all detected NOAA 14 day-time HS (period Jan.-May), the cloud coverage taken by calculating the NDVI (Normalised Difference Vegetation Index) and the drought index. Due to the fact that the NOAA-AVHRR receiving station was not running all the time, the hotspot graph is not continuous. The actual receiving time is shown in grey columns, meanwhile the off-time is indicated by white. Additionally, the detection is also depending on cloud coverage, since the AVHRR sensor is not able to penetrate clouds. Therefore, generally the HS correspond with lower figures to higher cloud coverage although the cloud coverage is given for the whole processed image (as shown in **Figure 1**) and not only for the fire area. In spite of that, a significant correlation is clearly shown between the rising drought index and numbers of detected HS. In the end of February the detected HS rose up to 600 and peaked at the beginning of March with more than 2000 HS meanwhile the drought index had almost achieved its maximum value (2000). **Figure 6** shows the temporal evolution and the spatial distribution of the detected HS within the study area. By the time the rain started at the beginning of May almost all of the basin area in the district of Kutai had been burned. The fire affected the whole of the Mahakam basin, its tributaries and as can be seen in **Figure 7** up as far as to the Sankulirang peninsula. Yellow, indicates HS detected in February, red, HS detected in March and purple, HS detected in April. The fires started from the centre of the basin and propagated south and only stopped in the mountainous regions to the west and north where humidity is much higher and primary forests dominate as well as the logging process has not yet progressed that far.

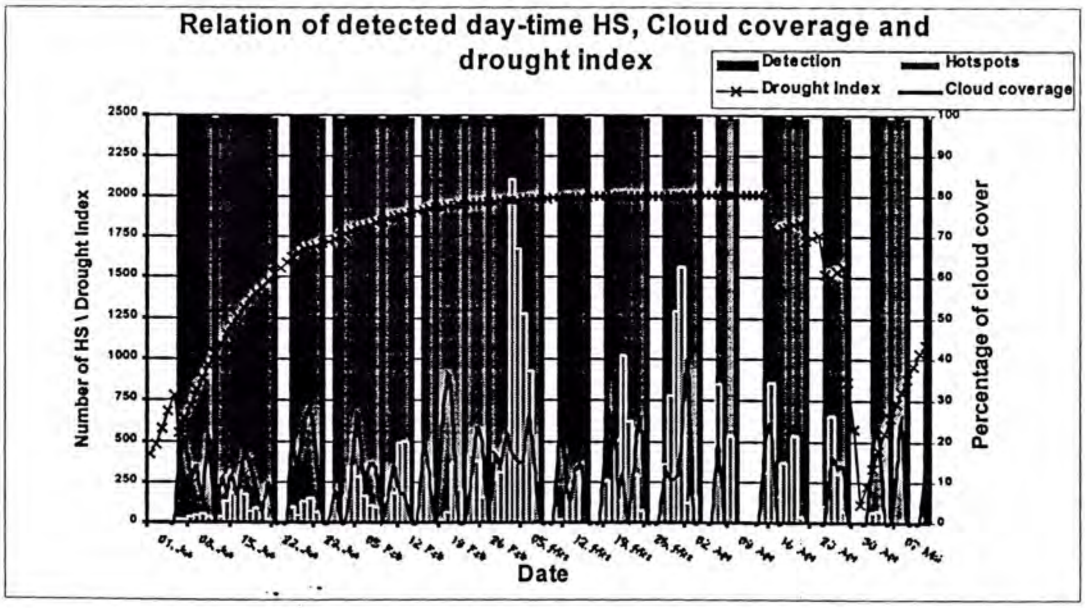

Figure 5: Relationship between detected HS, cloud coverage and drought index.

ERS SAR evaluation

Vegetation and land use mapping

In flat terrain, RGB color composites allow for discrimination of several vegetation and land use classes based on their vertical structure and water content. With the knowledge acquired during three field surveys (1995,1996,1998) in the project area a classification key for the interpretation of the ERS RGB-images was established. A thorough analysis of the ERS-2 RGB images made it possible to discern five different vegetation classes (**Figure 3C**):

1. Selectively logged *Dipterocarp* forest. In these forests the closed canopy has been opened up. On lone-standing trees corner reflection occurs and volume scattering is increased. Occasionally the radar signal can reach the ground and bare soil contributes to the backscatter signal. This class shows a mosaic-like pattern of green and magenta spots in the RGB-image, e.g. the Kutai National Park in the upper right corner of **Figure 3B.** There are no primary (undisturbed) *Dipterocarp* forests in the project area, which would have a different signature.
2. (Peat) Swamp forest. A relatively smooth canopy showing reduced volume scattering characterizes this forest type. This vegetation type appears homogeneously green in the RGB composites, e.g. the oval shape slightly left of the center in **Figure 3B**. This class may be confused with pulp wood plantations older than 4 years.
3. Clearings with sparsely covered soil, e.g. coal mining, appear in speckled white-magenta pattern, if the backscatter is dominated by relief features. Small-scale relief features are usually not visible since they are leveled out by the forest canopy.
4. Plantation areas, bushland and degraded forests: plantations or cultivated and fallow areas are characterized by low growing vegetation at different stages. In RGB-images of the dry season these areas appear as a heterogeneous pattern of light and dark green colors, roughly corresponding to the height/biomass of the vegetation, e.g. below and to the left of Kutai National Park in **Figure 3B**.
5. Alang-Alang, ferns, and low bushes: This vegetation class grows predominantly in areas frequently affected by fire and on degraded or siliceous soils, which dry out quickly. It has very low backscatter values in all channels due to backscatter from dry soil and a smooth, homogenous appearance of the plant cover, visible e.g. in **Figure 3B** to the left of the oval shaped swamp forest. In single RGB composites this class cannot be discriminated from land clearing operations e.g. for plantations in flat terrain. However, land-clearing operations can be distinguished in multitemporal series.

Figure 3C shows the results of the vegetation classification of orbit 12067. This orbit was chosen since it was acquired before the major fire events in August 1997. The visual interpretation was verified by available field data and compared with an already existing vegetation classification by INTAG (1992). In some areas there was a good correlation, in other areas there were great differences. These differences could be attributed to a likely change of the vegetation cover (e.g. clearings, plantations). In **Figure 3C** the georeferenced GIS interpretation was placed on top of the gamma-map filtered ERS image. Mountainous regions unsuitable for image interpretation were masked out. Dark green represents selectively logged *Dipterocarp* forest and bright green as yet undisturbed (peat) swamp forests. Clearings with open soil and relief features appear in red. The complex pattern of fields, fallow, plantations and regrowing forest is colored light yellow. Brown designates alang-alang grass, ferns, and low bushes.

Detection of burned vegetation

Figure 8A and **C** show burned scars, which occurred between February and March **(A)** and March and April **(C)** ERS-orbits. Burned scars are visible in orange tones of different intensity, unburned vegetation appears in blue tones. Areas that were burned before SAR image acquisition appear in dark brown. The burned scars identified in multitemporal ERS images agreed well with detected NOAA hot spots (compare **Fig. 6A-D** and **Fig. 8B+D**). There is a tremendous increase in the burned surface area between February and April. In the February - March image fires occurred mainly in areas with degraded forest or plantations. Meanwhile the relatively well preserved rain forests of the Kutai National Park (the square shaped feature in the upper right corner of **Fig. 8A)** and a timber concession (the mountainous region in the lower part of **Fig. 8A**) remained almost unaffected. By April, the fire has destroyed large parts of Kutai National Park and a timber concession, as is clearly visible in **Figure 8C**.

To quantify burned areas the PCA-composite was visually interpreted by interactive delineation in ArcView (**Fig. 8B+D**). Yellow colouring indicates strong damage to the vegetation, red almost total loss of the vegetation cover. The total area investigated by the ERS SAR study was 1.8 million hectare. Out of these 462.000 ha (23%) have been (85.000 ha complete destruction of the vegetation) up to the 9th of March (February-March composite). By April 13th 1.230.600 ha (66%) have been burned, with a complete destruction of 101.920 ha (5,5%).

A comparison of the GIS layers of vegetation classification based on the evaluation of RGB ERS-2 images (**Fig. 3C**) and the results of the multitemporal ERS image evaluation (**Fig. 8B** and **D**) allowed for determination of the type of vegetation which was destroyed by the fires. **Table 1** shows quantitative results of this analysis for all vegetation and land use types. As can be seen the fires affected predominantly degraded forests and selectively logged *Dipterocarp* forest. Up to the end of the evaluation period (9 of March 98) the swamp forests remained mainly unaffected.

Table 1. The area affected by fire, damage intensity and vegetation types inside the study area.

	Total area size in hectar	Mountains, generally *Dipterocarp* forest	Selectively logged *Dipterocarp* forest	(Peat) swamp forest	Plantation, bush and degraded forest	Alang-Alang, ferns, low bushes
Total area in ha and %	1.865.000 100 %	112.800 6 %	742.600 40 %	344.500 18%	518.500 27.5 %	146.900 8.5 %
Total loss of vegetation in ha and %	101.920 5.5 %	164 0.01 %	63.700 3.4 %	9.700 1 %	24.000 1.2 %	4.400 0.3 %
Severe damage in ha and %	1.230.600 66 %	62.070 3.3 %	511.800 27%	180.400 10%	374.800 20 %	101.600 5.7 %
Unburned or slightly burned	532.590 28.5 %	50.600 2.6 %	167.000 9.4 %	154.400 7.3 %	119.700 6.3 %	40.900 2.5 %

Synergetic use of ERS-SAR and NOAA-AVHRR Data

The examples mentioned above show those spaceborn systems NOAA-AVHRR and multitemporal ERS SAR complement each other and expand the possibilities of survey and monitoring. By combining the two data sources with available GIS and ground information on land use and forestry, it is possible to analyse the causes of the devastating forest fires in detail. Using the high spatial resolution of the ERS radar system and the high temporal resolution of the NOAA-AVHRR system it was possible to track the spreading of some fires and to detect the point of origin. **Figure 9** shows a time series of NOAA HS (yellow) and the multitemporal March – April ERS image. The rectangular shape to the right is Kutai National Park, the adjacent brown – orange areas belong to a big pulp wood plantation. As can be seen from the time series three large fires originated in a pulp wood plantation and spread into Kutai National Park. Another fire started from the north and was driven into the National Park by strong Northeast winds. It took about two weeks for the fires to spread across the whole National Park area. Where the damage by fire is severe AVHRR detected HS. If the damage was less severe and the fire propagated as ground fire (see discussion) without destroying the vegetation completely fewer HS were detected by NOAA.

Since there is a good correlation between NOAA hot spots and fire damage derived from multitemporal ERS SAR images it seems to be justified (and for lack of better data) to project the burned area for the whole province of Kalimantan Timur. It is assumed that NOAA/AVHHR hot spots outside the ERS SAR test site indicate burned scars with the same relation and reliability as within the SAR test site. The total area affected by fire as derived from NOAA-AVHRR was approx. 10 million hectare. Out of these approx. 4 million hectare land with different vegetation cover have been burned. This figure is much higher than official estimates as e.g. the Interim Report about burned area in East-Kalimantan (Dinas Kehutanan Tingkat I, Samarinda), which calculated 500.000 ha.

DISCUSSION

The analysis of multitemporal processed ERS-2 images acquired before and during the fire season allowed for the detection of burned scars at high spatial resolution, due to a significant reduction in the backscatter signal after burning, no matter what kind of vegetation was affected. Prevailing vegetation types in the project area are selectively logged forest, plantations, shrubs and grassland. With the use of the GPS and the geo-referenced ERS-2 images it was possible to verify specific signature changes caused by fire in the field. Field data suggests, that the decrease in backscatter is correlated to a decrease in volume scattering and soil moisture and thus an increased proportion of backscatter from extremely dry soil. Conversely in boreal forests it was found that ERS backscatter strongly increases on fire scars due to an increase in soil water (FRENCH et al., 1996). The damage to the vegetation caused by fire depends on many different parameters such as available fuel, the type and water content of vegetation, amount and type of dead biomass, wind, etc. As a result, the damage to the vegetation varies locally to a large extent. We found that three categories of burning can be identified in the processed ERS images – a complete burning of the vegetation, severe damage and a thinned out canopy. Undergrowth burning cannot be recognised in ERS images if the canopy of the forest remains mainly intact.

Figure 10 illustrates the different types of burning intensity and the damage they cause. All photographs were acquired during the field excursion of April 1998 and can be located in the ERS image (see circles in **Figure 8C**). **Figure 10A** shows a ground fire of weak intensity in a selectively logged forest Such fires propagate on the forest floor and cause varying amounts of damage to the trees depending on the density and desiccation of the understory vegetation. There is a clear correlation between the damage caused by fire and the prior intensity of selective logging (SCHINDELE et al., 1989). If the impact by logging was low, then the fire produced little thermal energy and the damage to the trees was correspondingly low. If the canopy was heavily disturbed, a dense understory vegetation of fast growing pioneer species could develop which gave an ideal fuel load. Huge amounts of highly combustible logging waste also increased the fuel load. Once ignited, tree stumps may glow for days and are a constant source of fire. **Figure 10B** shows a severely damaged selectively logged forest in the Bukit Soeharto forest reserve. Some larger trees survived the fire, but most of them have lost their foliage completely and died due to damage to the bark. Such areas are highly in danger of being starting points for future fires. They can be readily detected in multitemporal ERS-2 images as having a speckle-like appearance where intensely orange pixels (indicating a strong decrease in image brightness) are interlaced with blue-green pixels (indicating little change between the two images), e.g. in the lower part of **Figure 8A**.

Variety in damage to the vegetation can also be seen in Kutai National Park in **Figure 8C** (upper right), ranging from total destruction (intense orange) to a severe damage (orange and blue pixels mixed) to intermediate damage (few orange pixels interspersed with homogeneous blue). **Figure 10C** shows severe fire in a strongly degraded selectively logged forest, **Figure 10D** shows the remainder of the vegetation after such a fire. Plantations were especially prone to fire. In poorly managed 5-10 year old *Albicia* or *Gmelina* plantations we found a completely desiccated, highly combustible dense understory vegetation which gave rise to the most intense fires with complete destruction of the vegetation (**Figure 10E** and **F**).

Among the actual available remote sensing systems the NOAA-AVHRR system has proved to be very efficient for the detection and monitoring of vegetation fires (GRÈGOIRE, J.-M., 1996). Moreover, the NOAA-AHVRR system plays an important role as a data source in the development of a "Global Fire Product for Global Change Studies" (MALINGREAU & GRÈGOIRE, 1996). Within the Integrated Fire Management Project the NOAA/AVHRR fire monitoring system is used to provide information on fire occurrences mainly in East-Kalimantan. Since the IFFM/GTZ project receives in real-time and due the high temporal resolution at maximum four times a day the NOAA-AVHRR system guarantees almost continuous monitoring and therefore it could lead to take immediate action to suppress the fires or prevent further damage. Nevertheless the AHRR detection result is hampered by clouds.**(Figure 1)** and haze. Furthermore, to access the fire location precisly seems to be difficult because of the low spatial resolution of the AVHRR sensor and additionally due to the uncertain image registration (**Figure 2**). The coordinates might have an error of several kilometres and care should be taken when using the data for applications where precise location is needed. (GRÉGOIRE, et al. 1996). Using a re-registering process the maximum error could be reduced to 2km. It was determined that the main error direction is to the south and to the east. This information may help to access the fire location in the field. Although the NOAA-AVHRR system's ability to assess burned scars is limited it can assist in determining areas of interest prior to the acquisition and processing of high resolution imagery (GRÉGOIRE, 1996). Additionally we found that the burned scar mapping with high resolution imagery as ERS-SAR data can be verified by NOAA-AVHRR data. Furthermore, combining the high temporal resolution of NOAA-AVHRR HS and the high spatial resolution of ERS SAR allows the analysis of the temporal and spatial distribution of fires and to trace back the point of origin **(Figure 9)**. Within a Fire Information System (FIS) NOAA-AVHRR data provides, in addition to actual hotspot data, annual patterns of vegetation development (fuel conditions) derived from NDVI data. Integrated in a computer based FIS NOAA-AVHRR data combined with additional information such as climate data, vegetation and land use maps, human activities as well as burned scar mapping support attempts to find focus areas for community based fire management and to point out areas which are going to be at high fire risk.

Conclusion

After the 1982/83 fires Indonesia has again experienced one of the greatest natural disasters of its history as well as on a global scale. In order to be prepared to prevent such disasters in the future, the causes and the consequences of the recent forest fires have to be analysed carefully. Due to the large area affected by fire and the inaccessibility of the region the analysis has to rely on spaceborn remote sensing data. Our work shows that multitemporal ERS-2 SAR images can complement existing AVHRR sensor fire monitoring systems by three important parameters: 1.) during active burning fires, burned scars can be located with clear accuracy. In conjunction with daily NOAA-AVHRR hot spot data the burned scar mapping can be verified and the spreading of the fires can be spatially analysed. This can trace the origin of the fires and could help to identify possible causes and responsible actors. Furthermore, the analysis of HS data supports attempts for planning immediate action to prevent the spreading of the fires. 2.) different intensities of damage can be identified, thus improving estimates of economic and ecological impacts. 3.) derived from burn intensities the remaining fuel after the burning could be estimated hence, providing valuable information for the prevention of future fires in the same area. Furthermore, digitally enhanced ERS-2 images allow for basic vegetation and land use mapping (SIEGERT & KUNTZ, 1996). In conjunction with the exact location and extent of burned scars it becomes feasible to determine the type of burned vegetation thus providing important data on biomass burning and its contribution to global warming.

Outlook

To estimate the total area as well as the different vegetation types, which have been burned in East-Kalimantan in 1998 a second combined ERS-2-SAR-NOAA-AVHRR data project is being conducted. This project will cover the whole basin area of East-Kalimantan with ERS-2-SAR images and will lead to precise figures and classifications of the vegetation types, which have been affected by the fires. It is assumed that the affected forest area is much greater than the previously studied area, due to the fact that in the northern part of the fire affected area huge tropical rain forests still remain. The results will be used by two on-going GTZ projects in East-Kalimantan, the Integrated Forest Fire Management Project/IFFM and the Sustainable Forest Management Project/SFMP, which are both financially supporting the second ERS-SAR investigation.

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FIGURES

Figure 1. Channel 3 of a processed NOAA 14- AVHRR day-time image and the given subset area of the IFFM receiving station. Each black spot on the East Coast of Kalimantan represents a potential fire pixel or hotspot (HS). The insert shows the location of the IFFM project area in Kalimantan.

Figure 2. NOAA-AVHRR HS (red dots) before and after the image to image registration process. **A.** Burned scars (orange areas) as detected in a multitemporal ERS image. **B.** Uncorrected hotspot data set, **2.** corrected hotspot coordinates. As can be seen the spatial error has been clearly reduced.

Figure 3. Production of a ERS RGB image and the corresponding vegetation map. **A.** Gamma map filtered ERS-2 image mosaic acquired before the fires in August 1997. **B.** RGB composite of A. (Red: 10x10 texture filter, Green: 7x7 gamma map filter, Blue: 20x20 texture filter). **C**. Result of a visual vegetation classification. Different colors indicate different vegetation types. Dark green: selectively logged *Dipterocarp* forest, bright green: undisturbed (peat) swamp forests, red: clearings with open soil and relief features, light yellow: plantations and regrowing forest agriculture, brown: alang-alang grass and low bushes

Figure 4. Production of a multitemporal ERS PCA image. **A.** Gamma map filtered ERS-2 image mosaic acquired in February 1998 (Orbit 14572) and **B.** acquired in March 1998 (Orbit 15072). **C.** PCA composite showing unburned vegetation in blue

colors. Burned areas appear in different shades of orange depending on the severity of damage. Red: PCA channel 2 (see text), green: February gamma map filter, blue: March gamma map.

Figure 5. All detected NOAA-AVHRR 14 day-time HS (period Jan.-May), cloud coverage taken by calculating the NDVI (Normalised Difference Vegetation Index) and drought index. The time of NOAA acquisition is shown in grey columns, off-time is indicated by white.

Figure 6. Spatial pattern of detected HS within the ERS study area from January (**A**) to April (**D**) 1998. According to the HS data almost all of the basin area in the ERS study area has been burned.

Figure 7. ERS mosaic and NOAA-AVHRR HS showing the area (400 x 400 km) affected by fire. The ERS mosaic was made from Quicklooks downloaded from CRISP (Singapore). The fire devastated the whole Mahakam basin and went up its tributaries as far as up to Sankulirang peninsular. Yellow, indicates HS detected in February, red, HS detected in March and purple, HS detected in April.

Figure 8. Visual mapping of burned scars in multitemporal ERS PCA images. **A.** February-March composite. **B.** GIS overlay of the classification of burned scars. Red depicts total destruction of the vegetation by fire, orange severe damage. **C.** March-April composite and **D.** GIS overlay.

Figure 9. Synergistic use of AVHRR HS and ERS data. Time series of HS (yellow and yellow to red) and the multitemporal March – April ERS PCA image. The rectangular shape (bordered by the green line) to the right is Kutai National Park, the adjacent brown – orange areas belong to a big pulp wood plantation. Three large fires originated outside the Kutai National Park and spread later into the park.

Figure 10. Different types of burning intensity and the damage they cause. **A.** Weak ground fire in a selectively logged forest. **B.** Medium damaged selectively logged forest. **C.** Intensive fire in a selectively logged forest. **D.** Complete destruction of a selectively logged forest. **E.** Intensive fires in a pulp wood plantation. **F.** Completely destroyed pulp wood plantation.

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