Mapping Burn Scars in Indonesian Tropical Forests Using InSAR Coherence Technique

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Abstract

Tropical forests are important within the global Earth system as they have several functions that make them valuable ecosystems. InSAR coherence technique has been shown to offer useful information for forestry applications, especially in cases of forest monitoring and burn scar detection. Four ERS-1/2 tandem image pairs have been used in the study area in Central Kalimantan, Indonesia. These images have been analyzed in order to generate InSAR coherence maps for detecting burn scars. The resulting maps have been compared with burn scars of the same area that have been obtained by optical remote sensing images. Coherence was found to be a good tool for rapid assessment for burnt areas. The coherence of burnt forest area was increased by 0.2 during 1997 fire ; whilst the minimum coherence was found to be more than 0.35. InSAR coherence technique results proved to be fast and accurate enough to estimate the extent of the burnt areas on a provincial scale. It provides valuable information about their locations for reducing the risk of future fires in the study area.

Keywords: ERS, InSAR, Coherence, burn scars, Tropical forest.

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صناعة خرائط مناطق الحرائق في الغابات الاستوائية الأندونيسية باستخدام تقنية الترابط التداخلية للرادار ذي المستقبل المحاكي

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الملخص

الغابات الاستوائية ذات أهمية عالية ضمن نظام الأرض العالمي، لأنّها تحتوي على العديد من الوظائف التي تجعلها نظماً بيئيةً قيمةً. أظهرت تقنية الترابط التداخلية للرادار ذي المستقبل المحاكي (InSAR coherence) أنّها توفر معلومات مهمة للتطبيقات ضمن الغابات، ولاسيّما مجال مراقبة الغابات وتحديد مناطق الحرائق. استخدمت أربع مزدوجات صور أقمار صناعية للقمر الأوروبي (ERS1/2) لمنطقة الغابات الاستوائية بمقاطعة كلمنتان الوسطى في أندونيسيا. حلّلت الصور للحصول على خرائط الترابط التداخلية للرادار ذو المستقبل المحاكي لتحديد مناطق الحرائق. قورنت الخرائط الناتجة مع مناطق الحرائق للمنطقة نفسها التي تم الحصول عليها باستخدام صور أنظمة الاستشعار عن بعد البصرية. وجد أنّ مقدار الترابط هو أداة جيدة للتقييم السريع للمناطق المحروقة. ازداد مقدار الترابط لمناطق الغابات المحروقة بمقدار 0.2 خلال حريق عام 1997 في حين كان أقل مقدار للترابط أكثر من 0.35. أثبتت نتائج تقنية الترابط التداخلية للرادار ذي المستقبل المحاكي بأنها سريعة ودقيقة دقةً كافية لتقدير مدى مناطق الحرائق على مقياس المحافظات. توفر هذه التقنية معلومات قيمة عن أماكن مناطق الحرائق من أجل تقليل الخطر من الحرائق المستقبلية في منطقة الدراسة.

الكلمات المفتاحية: القمر الأوروبي ERS، التقنية التداخلية للرادار ذي المستقبل المحاكي، الترابط التداخلي، مناطق الحرائق، الغابات الاستوائية.

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1. Introduction

Tropical peat swamp forests are important within the global Earth system as they have several functions that make them valuable ecosystems. Large areas of tropical forest in Indonesia are under threat from land clearance for agriculture and plantations, degradation and fire, putting their natural functions as reservoirs of biodiversity, carbon stores and hydrological buffers at risk (Page et al. 2006).

The 1997/98 fire was the worst ever fire catastrophe encountered in Central Kalimantan, Indonesia. 5.2 million ha or about 25% of the entire province was fire affected. Almost 2.3 million ha was tropical swamp forest. Almost 75% of the plantation areas (forest, oil palm, etc.), that were located within the 1997/98 fire zone have been fire affected, a large number of them severely.

Obtaining information on burn scar area, topographic information and burn scar rates in tropical peatland is important for further land-use management and the development of mitigation strategies in order to reduce peat subsidence rates, and hence, CO_2 emissions from peat mineralization, and to protect sensitive wetlands for nature conservation.

2-Synthetic Aperture Radar (SAR)

Synthetic Aperture Radar (SAR) is a powerful remote sensing system, enabling observations of the Earth's surface day or night, in all weather conditions from airborne platforms and from space.ERS1/2 Synthetic Aperture Radar is working in C-band and this radar signal cannot reach the ground in forested areas with the water content and the structure of the canopies mainly influencing the backscatter (Kuntz ,2010). However in burnt forest areas with canopy removed, the radar signal indicates the scattering from this burnt ground layer. The ground soil's radar reflectivity depends on its moisture content, so dry soil appears dark in radar images while moist soil has a bright signature.

SAR is capable of mapping the fire scar in tropical forests for two reasons: the first one is related to the increased moisture in post-fire soil while the second reason is about SAR's sensitivity to soil moisture. Huang and Siegert (2006) found that fire scars had a backscatter signal 2-4 dB higher than the surrounding unburnt forest. Siegert and Ruecker, (2010) Evaluated of an area severely affected by fires in 1998 in East Kalimantan, Indonesia, using a multitemporal series of ERS-2 Synthetic Aperture Radar (SAR) images. The impact of fire was found to cause a strong decrease in backscatter (2-5 dB) for all land-cover classes while areas not affected by fire showed only slight variations in backscatter (maximum0.5dB). However, the backscatter dynamics of fire scars strongly varied with seasonal changes. Bourgeau-Chavez et al. (2002) found that seasonal variations of fire scar visibility in SAR images occurs all over the boreal region.

Page et al. (2002) used a combination of Landsat TM/ETM and multi-temporal, synthetic aperture radar (SAR) to estimate the extent of peatlands, pre-fire land cover types and burnt area after the severe 1997 El Niño event in Central Kalimantan, Indonesia. The combined evaluation shows that 32.0% (796,907 ha) of the investigation area was burnt, 91.5% (729,500 ha) of which was peatland and 70.0% of fragmented peat swamp forest were destroyed by fire.

3-Interferometric Synthetic Aperture Radar (InSAR)

Interferometric Synthetic Aperture Radar (InSAR) is a powerful technique that uses differences in reflected radar signals acquired from nearly the same antenna position (viewing angle) but at different times (Rosen et al., 2000). By combining two or more SAR images of the same area, it is also possible to generate elevation maps and surface change maps with unprecedented precision and resolution. InSAR has demonstrated dramatic potential for many application including: the observation of land cover change, forest mapping and monitoring, tropical forest fire scar, tropical forest biomass estimation, and Land Cover Classification

Interferometric Coherence is an important parameter to measure the correlation between two complex SAR images taken from slightly different orbital positions; hence, it measures InSAR data quality in repeat-pass interferometry. The fact that interferometric coherence does not rely on actual backscatter from the target but random dislocation of the scatterers between the two passes, makes it an independent physical parameter that is different from the SAR backscatter. The coherence will be high if the recorded radar echoes represent nearly the same interaction with the observed target between the two images (Zebker and Villasenor, 1992). The signatures of backscattering intensity and coherence have been used for land cover classification (Zahid, and Haque, 2017, Ma et al., 2018) especially in forest mapping (Canisius et al., 2019; Balzter, 2001).

Early results obtained using European Remote Sensing (ERS) repeat-pass data by Hagberg et al., (1995) showed that the interferometric coherence is significantly lower over forest than over open canopies, short vegetation, bare soils, burn scars, deforestation and urban areas. Subsequent studies of ERS-1/2 tandem data demonstrated in particular that the one-day repeat pass coherence is useful in land use mapping (Strozzi et al., 2000).

Coherence properties have been used by (Treuhaft et al., 2015) to identify forested/non-forested areas and the interferometric effective height of the forest. (Wegmüller and Werner 1997) used ERS SAR coherence interferometry to map different types of land changes due to farming activity, vegetation development and meteorological influences. They found that during the main growing season, low interferometric correlation resulted from both dense vegetation and farming activities. Harvesting was recognized by the high interferometric correlation of the post-harvest bare or stubble fields

Various assessments have been made of the amount of land in Indonesia that was damaged by the 1997 fires. Kwoh et al.,(1989) used the interferometric coherence component of tandem ERS 1/2 data to study the extent of some 1997 forest fire scars near Banjarmasin, Kalimantan, Indonesia. InSAR coherence technique has been shown to be a very reliable tool for discriminating between vegetated and non-vegetated areas. The InSAR technique has not been tested in Block C in former Mega Rice Project to identify burn scar forest areas.

4-Materials and methods

4.1 Study area

The study area is located between Sebangau river in the west and Kahayn river which is called block C in former Mega rice Project. The study area is located in the east in Central Kalimantan which is the biggest province on the largest island (Borneo) in Indonesia (figure 1). The climate is tropical, hot and humid and 67% of the land is forest and woodland.

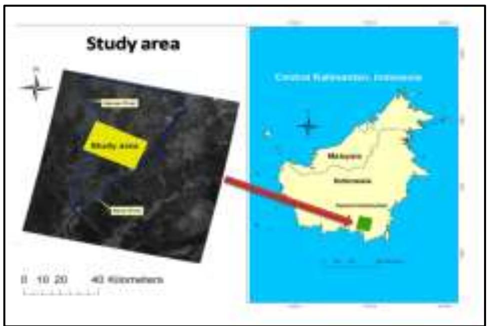


Figure (1): Location of the study area overlaid on ERS image

4.2 Data source

In this paper, the primary sources of SAR data for analysis were from the European Space Agency (ESA). Eight ERS-1 and ERS-2 SAR data were acquired over Central Kalimantan between 1996 and 2000 as it shown in Table 1.

Table (1): List of ERS tandem data used in this study.

Sensor	Date	Orbit	Parallel baseline	Perpendicular baseline
ERS1	19960325	24540	-50	-109
ERS2	19960326	04867		
ERS1	19960429	25041	-53	-98
ERS2	19960430	05368		
ERS1	19971006	32556	194	383
ERS2	19971007	12883		
ERS1	20000124	44580	58	209
ERS2	20000125	24907		

Burn scar areas were detected by Hoscilo (2009) using a time series of satellite images obtained from several sensors, including the Landsat MSS, TM, and ETM+. The Tropial Ecosystem Environment Observation by Satellite (TREES) classification scheme was used to classify the land cover area and extract burn scars for the fires that occurred in the south and south east part of Central Kalimantan, Indonesia.

4.3 Software environment

Gamma software, a product of Gamma Remote Sensing and Consulting AG, supports the entire processing from ERS raw data to products such as coherence maps (Wegmuller and Werner 1997). ArcGIS10.3 software by Environmental Systems Research Institute (ESRI) and ERDAS 14 software were used for further analysis.

4.4 Data processing

Raw data were processed and transformed into a Single Look Complex (Slc) image format by ESA before distribution of SLC images. The procedure that employed to generate coherence map includes the following stages: namely: co-registration and resampling, and Computation of interferometric products.

4.4.1 Co-registration and resampling

In this step the co-registration polynomial that describes the transformation of the slave to master image, which is subsequently used for the re-sampling of slave image to the master grid is determined.

4.4.2 Computation of Coherence

Coherence was used to estimate how much two SAR images are correlated with each other. It represents the similarity of two complex SAR images and defined as the magnitude of the complex correlation coefficient. Coherence images have been generated using a search window size (7x7) and with a constant weight function. Geometric correction was applied to correct the spatial distortion using the Landsat 7 image and all resulting images were stored in the Universal Transverse Mercator (UTM) projection system, zone 50 south. Finally, the coherence maps were extracted by the polygon that presents the study area.

Liew et al., (1990) used InSAR coherence in mapping burnt areas in South Kalimantan , Indonesia ,during the 1997 South east Asia forest fire episode. pixels with coherence less than 0 .5 were deemed to be vegetated. Vegetated areas were classified by their low interferometric coherence in both the 1996 and 1997 imagery while the burnt areas were delineated by their increased coherence in 1997.

By applying different coherence value, it was found that the value (0.35) was the best fit to differentiate burn scars that have been identified by optical data from other forest areas. The coherence values were classified into two classes: coherence values more than or equal to 0.35 and less than 0.35. This classification depends on assumptions that the high coherence in tropical swamp forest should not be more than 0.35.

The results of the signature analysis carried out by Siegert and Ruecker (2000) suggested that the most suitable image pairs for burn scar identification were the ones with both images acquired under dry weather conditions, since differences between burnt and unburnt areas were most pronounced. In this study, only one tandem SAR image, taken in October 1997, which is in a dry season, was available. Therefore, the two image pairs that have been used for burn scar identification were acquired in the wet season. The other images pair have been used to analyze the coherence changes in the study area.

To identify the burn scar area, two coherence images have been used, the first one represents the coherence between images that were taken in March 1996 before the big fire in 1997 and the second image was obtained from January 2000 after three years of the occurrence of fire. To identify the burn scar area, the similar height coherence (more than 0.35) in both coherence images was excluded from the calculations and only high coherence in 2000 were chosen. These results were compared with burn scar areas that have been mapped by optical data for the same area. Another approach have been used by using coherence change maps to identify the burn scar based on three time intervals.

5- Results and discussion

5.1 Visual Inspection

The first method relies on the visual inspection of coherence images classification and comparing it with burn scar areas that were identified by optical data. Here, the focus is on the results of the period from March 1996 to January 2000, where the detection of coherence changes between the two coherence images are most likely to be due to fire in 1997. Figure 2 shows two coherence images that were processed by the same search window size (7x7) and with a constant weight function in the study area.

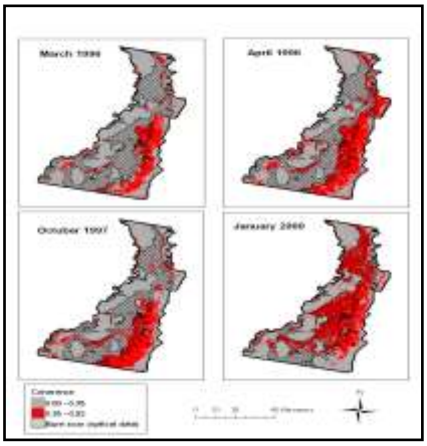


Figure (2): Coherence classification between March 1996 and January 2000 using value 0.35

It was shown that the coherence threshold from 0.35 is generally appropriate to differentiate between burnt and non-burnt areas in the coherence image compared to burn scar generated by optical data. Therefore, the value (0.35) was selected as the input for the burnt-unburnt forest classification and all coherence values which are greater than 0.35 will be considered as a selective parameter to detect burn area. In addition, there is a limitation of this method: urban or non-vegetation areas were classified as burnt due to high coherence.

Therefore, the areas that remained the same in both coherence images were excluded from the classification and the burn scar area were identified as shown in Figure 3. In the burn scar image, the burn scar are areas with new forest clearings and non-vegetated areas that also remained unchanged, while Unburnt areas are forest and vegetated areas that remain unchanged. Unburnt areas might be areas that have been burnt but now show re-growth, which could increase the coherence and lead to the area being classified as a burnt area.

5.2 Differential coherence

The coherence classification approach shows that the burnt forest area has a coherence value of more than 0.35 after three years from time of fire 1997.It was also shown that the coherence in January 2000 increased by over 0.2 with respect to forest coherence in the March 1996 image.

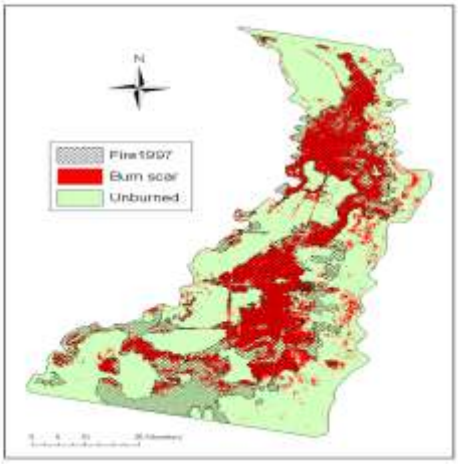
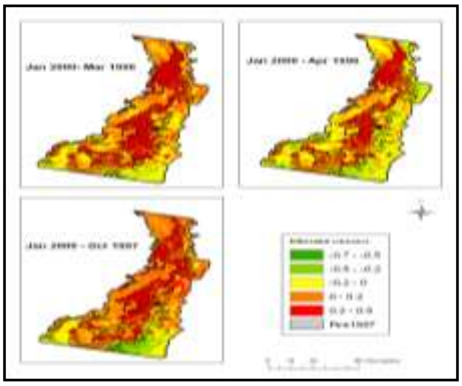


Figure (3): Burn scar 1997 in study area based on minimum coherence value 0.35. Crosshatch representsburn scar obtained by optical data.

Therefore, an alternative approach was adopted using differencing coherence of the two datasets in the study area. The coherence maps reported in Figure 4 allow the investigation of three different time intervals: from March 1996 to January 2000, from April 1996 to January 2000 and from October 1997 to January 2000. The coherence change shows that the coherence of burnt areas increased between 0.2 to 0.4 between March 1996 and January 2000.



Figure(4): The change of coherence of three different time intervals compared to coherence in January 2000.

The two coherence images (March 1996 and January 2000) have been chosen to be analyzed to decrease the seasonal effects on coherence estimation. Therefore, Burn scar areas have been detected as the differential coherence is more than 0.2 as it shown in figure 5.

A basic verification of burn scar mapping was done by overlaying burnt area that have been estimated by Page et al. (2002) and derived from analysis of post-fire Landsat TM 5 and multi-temporal ERS SAR images covering before and after the 1997 fires (Figure 6) onto the ERS-SAR coherence classification result.

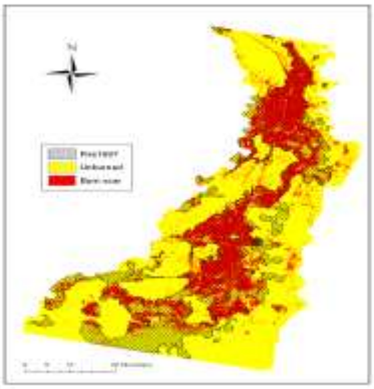


Figure (5): Distribution of burn scars from 1997 fires using coherence change method. Crosshatch represents burn scar obtained by optical data.

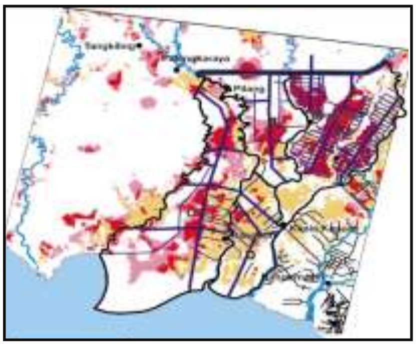


Figure (6): Burnt area derived by Page *et al.*, 2002.

The outlined area of the ERS-2 SAR burn scar map corresponded well with the fire affected area represented by Landsat TM 5 and multi-temporal ERS SAR hot spots. Figures 3 and Figure 5 show that fires were most abundant and persistent in the degraded peat areas and the forest edge while forested areas did not burn. Fires were relatively most numerous in the study area. Page et al. (2002) calculated that 32% (0.79Mha) of the area had burned, of which peatland accounted for 91.5% (0.73 Mha). Roughly half (47.4%) of the fire-damaged area was peat swamp forest, most of which was previously logged or fragmented.

5.3 Quantitative analysis

In this study, a quantitative analysis in the study area showed that, for 1997, the total area investigated by InSAR coherence was (333,121.03 ha). Out of this, up to January 2000, about 90,000 ha (28 %) had burnt. Table 2 shows quantitative results of this analysis.

Both coherence methods identified almost the same burn scar area. It can be seen that the SAR burnt area represented, on average, 71% of the areas identified by Hoscilo (2009). The burn scar estimates reported here for the study area are likely to be underestimates and are lower than those reported by Hoscilo (2009) by approximately 40,000 ha. Most of the different areas are located in the south of the study area. From the coherence image changes in Figure 2, it is clear this area has a low coherence even in the dry season of 1997 and it is less likely to be burnt.

Table(2): Comparison of burn scar area identified by different methods.

	Study area area(hec)	Burn scar (hec)	Percentage (%)
First method	333121.03	94345.14	28.32
Second method		89038.32	26.73
Optical method		133450.35	40.06

Indeed, many burnt areas which have been identified by Page et al. (2002) using only ERS SAR images were found undetectable by Landsat TM 5, because of re-growing of plant (Figure 6).These areas which are mostly plantation and pervious burnt areas have a high coherence in all tandem images since March 1996 and therefore could not be forest or plantation areas, so burn scar estimation based on coherence assessment seem to be more accurate than the estimation using optical data alone. However, as burn scar area has been identified by different optical and microwave methods; a one to one correspondence between the two burnt area estimates should not be expected.

6- Conclusion and recommendation.

To sum up, this study shows that InSAR technique can detect land cover change including old and new burn scar and deforestation areas using a coherence technique. Results obtained using ERS repeat-pass data show that the interferometric coherence is significantly lower over forest than burnt areas; therefore the one-day repeat pass coherence is a useful tool to define the position of burnt surfaces. Based on the verification results, it has shown that the burnt areas mapped by InSAR coherence maps have minimum coherence value around 0.35 and the coherence change not less than 0.2 before and after the fire in 1997. There was an excellent agreement between the classified burn scar and polygon burnt area obtained by optical remote sensing methods.

However, the burn scar areas that have been detected in this study show smaller affected area of 1997 forest fire compared to those obtained by optical data. This information on fire spread and fire distribution is important to tropical swamp forest fire monitoring and assessment because the region is covered by persistent cloud and haze during fire seasons, which makes optical sensors, of limited use.

The radar methodology applied in this study proved to be fast and accurate enough to estimate the extent of the burnt and deforested areas on a provincial scale. It provides valuable information about their locations for the prevention of future fires in the same area. If logging practices are not changed and fire prevention measures are not implemented, future fires will follow the logging activities even deeper into the central areas of Central Kalimantan. Fire management is a key issue in achieving the goal of sustainable forest management.

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