Deforestation evaluation by synergetic use of ERS SAR coherence and ATSR hot spots: The Indonesian fire event of 1997

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The synergetic use of the ERS SAR and ATSR data allows the evaluation of the Kalimantan deforestation during the Indonesian fire event of 1997. Changes in forest coherence signature given by the interferometric SAR data before and after the fire events are highly correlated to hot spots detected with the ATSR during the fire events themselves. These specific coherence temporal signatures are then used to perform a classification of the deforested regions. The validation with in-situ data is now ongoing in coordination with the TREES project. The method strongly suggests that regional maps of burned forest can be derived from ATSR and tandem SAR data.

Introduction

Every year in Indonesia, fires starting in July are extinguished in September with the beginning of the wet season [*O. Arino et al.*, 1998]. During the autumn of 1997, a particularly intense dryness associated with the absence of the monsoon engendered an exceptional fire event in Indonesia. This phenomenon, probably related to 'El Niño', saw the destruction of a large part of the Indonesian tropical forest and released a significant amount of trace gas and aerosols into the atmosphere. The main fires occurred in the eastern region of Sumatra, in the Indonesian part of Borneo (Kalimantan), in Sulawesi (Celebes) and in the Java mountains. At the beginning of October 1997, the World Wide Fund for Nature (WWN) estimated the burned areas in Indonesia as about 750 000 ha [*Le Monde, 08.10.1997*].

Because they embark several complementary instruments (optical to microwave spectral bands, low- and high-resolution), the ERS satellites were of particular interest in studying this exceptional fire event. The low-resolution ATSR-2 instrument allowed the location of active fires during night acquisition while the high-resolution SAR instrument allowed a more precise estimation of the extent of the burned areas. Furthermore, recent studies show that interferometric ERS tandem data, in particular the phase coherence, are a valuable source of land cover type information [*Wegmuller et al.,* 1997]. The main objective of the studies has been to assess the burned areas produced by the fire event during the period August-November 1997, by correlation of the information provided by ATSR data, together with intensity and coherence information derived from the SAR data.

Monthly maps of active fires detected by ATSR, August to November 1997, Borneo & Sumatra, Indonesia. Active fires corresponding to saturated pixels acquired at night-time in the 3.7 mm channel of ATSR have been plotted to display the fire event distribution.

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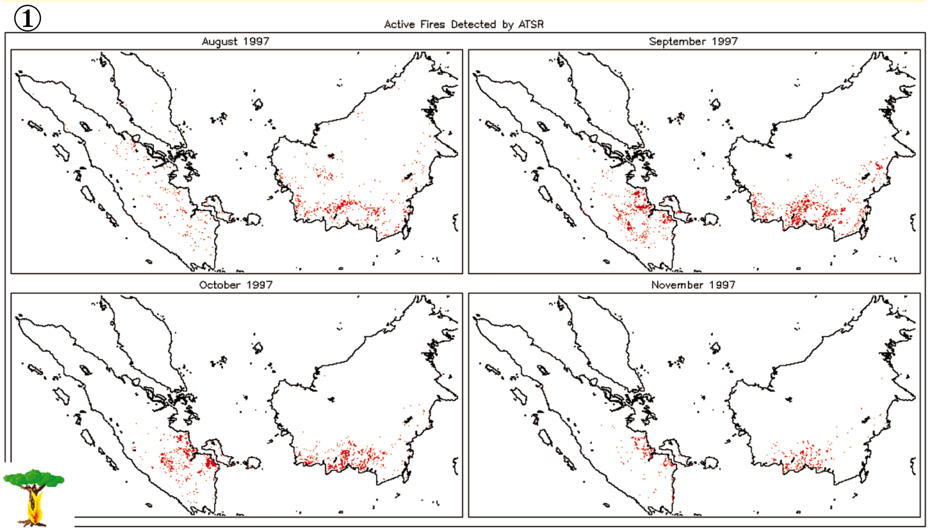
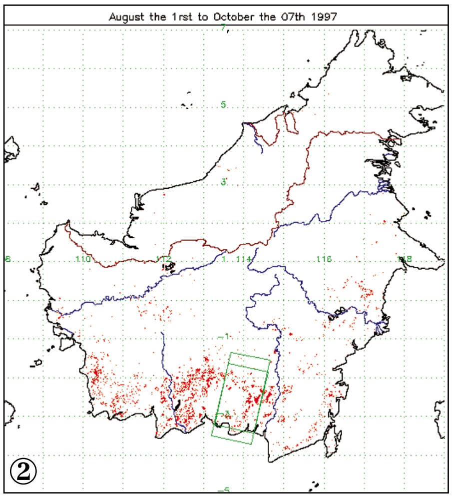


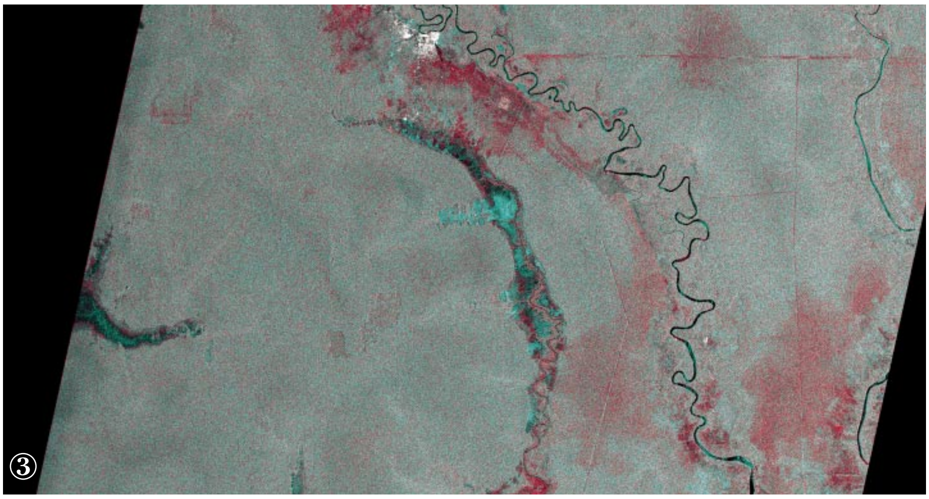
Data processing and location

The ERS-2 Along-Track Scanning Radiometer (ATSR-2) data acquired during the autumn of 1997 have been calibrated and geolocated. The active fires (i.e. hot spots) correspond to the saturated pixels in the 3.7 mm channel (values higher than 312 K) of ATSR acquired at night-time, i.e. ascending pass [*Buongiorno et al.,* 1997]. Hot spots centre coordinates have been recorded in latitude and longitude (Fig. 1).

The first phase of the study was limited to the area with the highest ATSR hot



Accumulation of ATSR hot spots between 1 August and 7 October 1997 over Borneo. ERS SAR tandem data used for the study are indicated.



ERS SAR multi-temporal intensity image; red channel: 22 October 1996; green & blue channels: 7 October 1997.

spots located close to the Teluk Sebangan Bay in Kalimantan (Fig. 2). ERS SAR data covering the area before and after the fire events were then selected (Table 1).

Since several studies indicated the ability of SAR intensity data to assess burned areas [*Rignot et al,* 1994*; Bourgeau-Chavez et al.,* 1997), a multi-temporal SAR PRI image was generated first. Potential burned areas were indeed identified (Fig. 3), but supervised and unsupervised classification did not produce convincing results. However, because the fire event occurred during the ERS tandem mission (1-day repeat interval) dedicated to SAR interferometry (InSAR), it was then decided to use InSAR coherence data as an additional source of information. Two tandem couples, one acquired before the exceptional fire event (April 1996) and one afterwards (October 1997) were used in order to study the temporal behaviour of the tandem coherence.

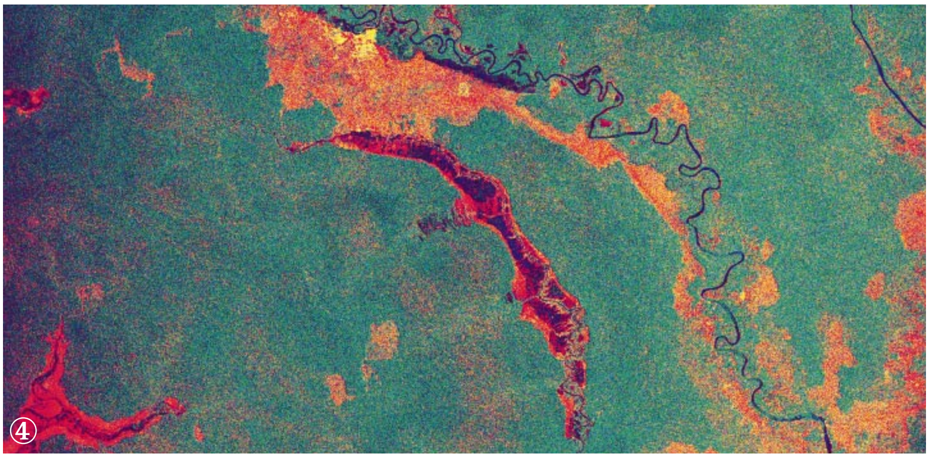
The coherence images were generated with the Interferometric Quick Look (IQL) processor. This processor, essentially used to assess the quality and the potential of the ERS InSAR data, is able to generate intermediate images with variable pixel spacing ranging from 35 to 200 m [*Laur et al.,* 1998]. Together with the coherence image, the IQL generates three other ground range co-registered images: the interferometric phase image, the intensity image of the first pass and the intensity image of the second pass. For this study, a combination of 50-m pixel spacing images, i.e. co-registered images of coherence (red channel), average of intensities (green channel) and intensities difference (blue channel) (Figs. 4 & 5) were used. The areas with high coherence appear in red. The green/blue areas correspond to low coherence and medium intensity, i.e. probably to the tropical forest. The areas with low coherence and low intensity (i.e. water) appear in black. Finally, the areas with high coherence and high intensity appear in yellow and correspond most likely to villages or cities.

In order to use the possible synergy between both instruments, ATSR hot spots were co-registered with the two SAR tandem images. The hot spot representation is arbitrary as more than one hot spot of variable size and temperature may saturate the ATSR pixel [*Dozier et al.,* 1981].

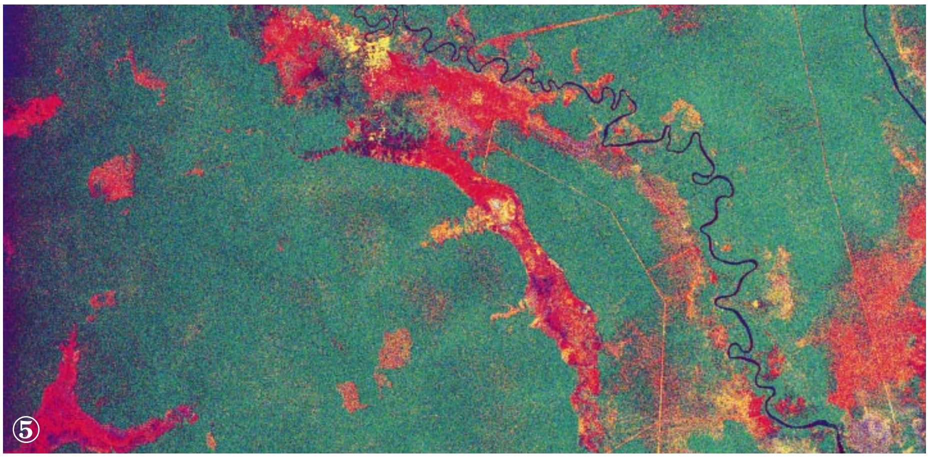
Coherence temporal behaviour
The coherence, for repeat-pass interferometry, describes the ‘similarity’ of two complex SAR signals. Basically, when two signals are the same, the corresponding coherence values are close to one. If the signals are completely different, the coherence values are close to zero.

Table 1. ERS SAR RAW Tandem & PRI Data (Frames : 3636-3654-3672)

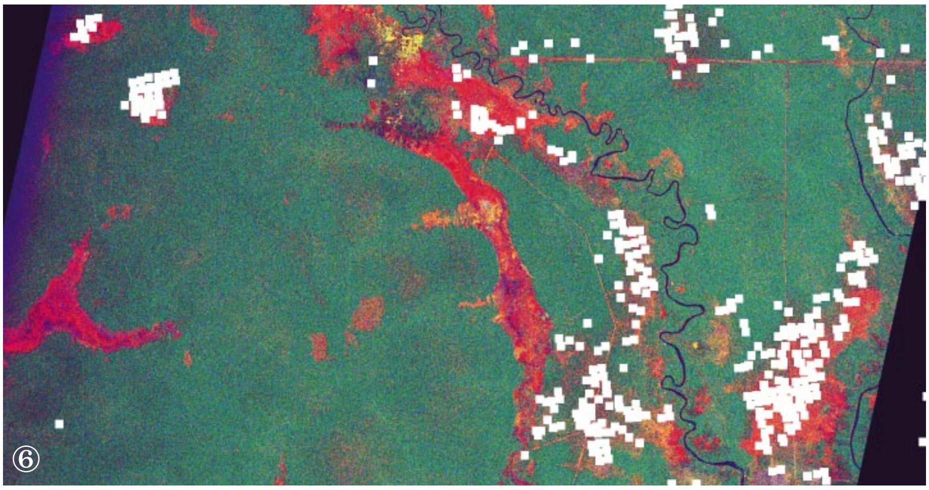
Satellite	*Date*	*Orbit*	*Ordered SAR Product*	*Perpendicular Baseline*
ERS-1 ERS-2	29/04/96 30/04/96	25041 05368	RAW RAW	100
ERS-2	22/10/96	07873	PRI	
ERS-1 ERS-2	06/10/97 07/10/97	32556 12883	RAW RAW & PRI	400



Interferometric quick-look image from ERS SAR tandem data of 29/30 April 1996.



Same as 4, on 6/7 October 1997. Red channel: tandem coherence; green: intensities average; blue: intensities difference. Areas with high coherence appear in red.



Geolocated ERS SAR tandem data of 6/7 October 1997 co-registered to ATSR hot spots (white).

The value of the coherence can be decomposed into two contributions [*Dammert et al,* 1995]:

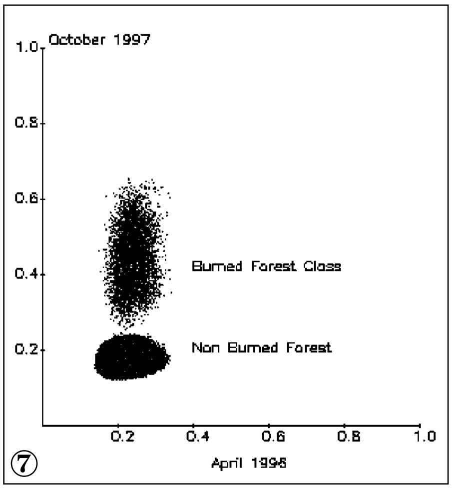
- the *temporal coherence*, inherent to temporal changes of the elementary scatterers within the resolution cell. If their geometric absolute locations and/or their dielectric properties change (e.g. due to humidity), the temporal coherence is reduced;
- the *geometric coherence*, related to the satellites inter-distance at the time of acquisition. When the inter-distance increases, the location of the elementary scatterers relative to the satellite varies and, by consequence, the geometric coherence decreases. In the case of volume scattering, this effect is amplified by the scatterers dispersion and the multiple reflections.

Forest is seen by radar sensor as layers of scatterers (volume scattering), which reduces the geometric coherence component. Additionally, the leave motion contributes to the temporal coherence loss. Consequently, the tropical forest appears incoherent. However, a burned forest should have a higher coherent response due to the strong reduction of volume scattering. Therefore, a multi-temporal image of the coherence should allow the discrimination of forests from deforested areas.

When comparing the tandem images acquired before (Fig. 4) and after (Fig. 5) the fire event, clear changes appear in the coherence channels (red channels): several areas of the image show an increase of the coherence (i.e. more red areas). This indicates a strong land cover change for those areas, most likely related to the fires.

The ATSR hot spots image is then co-registered with the SAR tandem images. Figure 6 shows the co-registration of the October 1997 tandem image (Fig. 5) with the ATSR hot spots. Most of the hot spots correspond to the land cover change areas previously identified, which confirms our previous assumptions. Because the burned forest should appear as areas where coherence has increased and active fires are detected, we deduce that these areas have probably burned between August and October 1997 (ATSR hot spots image).

Burned forest classification
The ATSR hot spots overlaid on the SAR images are used to select areas of interest (AOI) in order to compute coherence statistics on forest and burned forest classes. Figure 7 is the scatterogram of coherence for the two selected AOIs. Two different coherence clusters are completely discriminated. The coherence threshold method retains the coherence histogram part centred on the mode plus or minus the standard deviation. Table 2 gives these coherence thresholds for the two coherence images. The coherence for the same forest sample has decreased (Table 2) due to the baseline increase between the two tandem acquisitions (Table 1). As we want to emphasise



Scatterogram of burned and non-burned forest classes. The separation between both classes appears clearly.

areas where coherence has increased, it is not necessary to take a baseline effect into consideration. Moreover, the selected classes allow discrimination of deforestation areas (low coherence in April 1996 versus high coherence in October 1997). The resulting classification is shown in Figure 8. Red areas are burned forests, green areas represent forest unchanged between 1996 and 1997, and black areas are not classified. Figure 9 shows the ATSR hot spots (yellow) overlaying the classification.

Discussion
A high degree of correlation between the presence of ATSR hot spots detected during the fires events and the increase of SAR coherence, particularly in the north-east part of the image, can be seen in Figure 9.

Some areas were classified as burned forest even though no ATSR hot spots were detected. This effect might have several causes:

- deforestation which may be caused either by fire between April 1996 and August 1997 or forest clearing for infrastructure work (draining canals for the 1-million ha regional rice project: red straight lines in the image);
- non-forest surfaces displaying as deforested areas from a coherence point of view:
  – wetlands (visible meander in the south-west of the image might be assimilated to wetland area due to its form and intensities which are different from deforesed areas);
  – rice fields (red area located in the middle of the image in the centre of a black area is presumably rice fields location, close to a river, and its intensities behaviour).

Both types (wetland and paddies) were seen as incoherent in April 1996 because of flooding. However, during dryness (the fire event of October 1997) these surfaces appear coherent since they are essentially bare soil.

This supervised classification requires improvements and a validation with *in-situ* data, but results are significant and the synergy between SAR and ATSR provide confidence in these early results.

In order to validate these results, *in-situ* data are soon expected in coordination with the TREES Project [*Achard et al.,* 1998]. Method refinement (including deeper intensity analysis) and automatisation are expected within the next study phase in order to derive the complete Kalimantan deforestation mosaic.

Table 2. Coherence threshold

Image layer	*Class*	*Coherence threshold*
Coherence 1996	Forest	0.16 - 0.27
Coherence 1997	Forest	0.12 - 0.24
	Burned Forest	0.27 - 0.56

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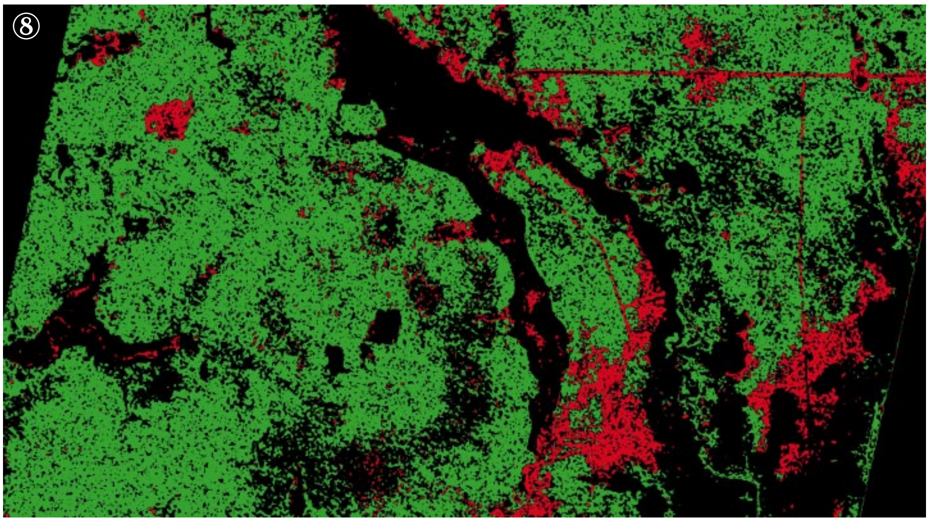
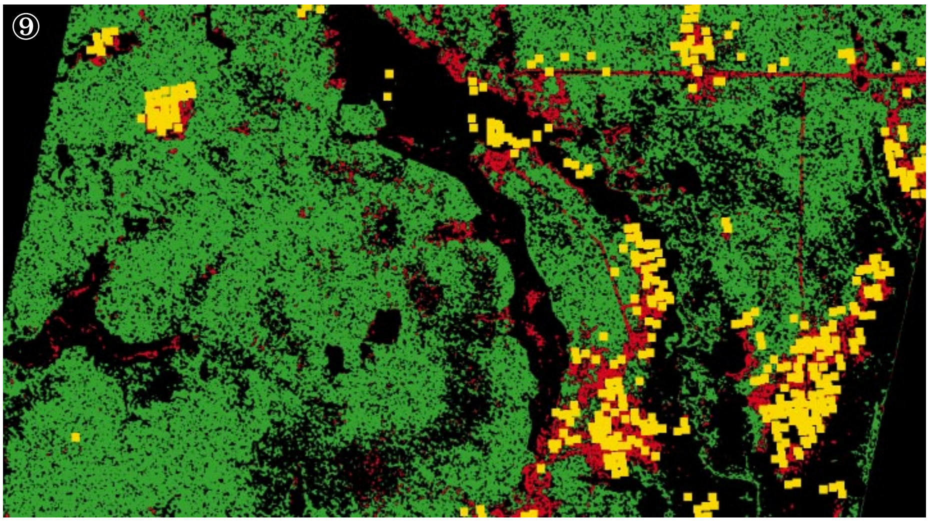


Deforestation classification & ATSR hot spots.

Red areas: deforested regions;
green: forest;
black: non-classified areas;
yellow: ATSR hot spots.

Location of images presented on Figures 3, 6, 8 & 9 :
longitude: 113.48 – 114.47 E
latitude: 2.17 – 2.71 S.
The river crossing the image is Kahayan.



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WEB sites
http://shark1.esrin.esa.it
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Acknowledgements
The authors wish to thank Josep Closa for processing the InSAR data.