FOREST MAPPING IN TROPICAL REGION USING MULTITEMPORAL AND INTERFEROMETRIC ERS-1/2 DATA

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Abstract

The paper presents a study to assess the use of ERS SAR data to map and monitor deforestation in Sumatra, a region characterized by rapid depletion of the rain forest, mainly due to logging and permanent or semi-permanent settling of transmigrated population.

Two approaches were used and compared (with reference to optical data) for forest / non forest mapping :

1- Temporal Change approach : in the frame of the TREES/ERS-1 SAR'94 project, previous studies have shown that up to a certain limit forested areas could be distinguished from non forested areas using the particularly stable temporal behavior of the backscatter values of the forest.

2- Interferometric approach : coherence images are realized from the interferometric pairs. Forest/non forest maps are realized based on the contrast between coherence of forest compared to that of the other land covers.

Both methodology have been applied over different test sites in Central Sumatra and South Sumatra. This paper presents the results obtained over one specific site : Kayuagung in Southern Sumatra which currently undergoes active deforestation.

1. Introduction

In Indonesia, the tropical rain forest is one of the major natural resources, covering about 60 % of the total area (110 MHa in 1990 [1]). Much of the existing forests have been destroyed, mainly by shifting cultivation, by logging and above all, by the increasing number of people involved in agricultural activities. Therefore the magnitude of deforestation and its consequence on natural processes need to be evaluated.

In such regions under frequent cloud cover, SAR data present optimal means for regular observations. With C band SAR data (ERS-1/2, RADARSAT) the backscatter intensity of tropical forest has stable value and the contrast between forest and other surfaces depends on the backscatter values of the non forested area, which are highly variable. Thus the use of a single SAR image is not relevant. One approach has been developed using the temporal variation of backscatter intensity to map forest covers [2]. Recently, interferometric information have been used for land cover classification [3] [4].

The aim of this paper is to assess and compare multitemporal intensity change and interferometric approaches.

2. test site and data acquisition

Fig. 1 : test sites

The site under study is situated in Indonesia in Sumatra island (fig. 1). It is located in South-Sumatra near the city of Kuayagung. It is a flat area with current active deforestation. Most of the primary forest of the area have been converted to secondary forest or plantation (mainly oil palm but also coconut or rubber). Moreover this site includes young tree plantations (oil palm) as well as short vegetation like shrubs mainly in swampy region.

Two ERS PRI data have been acquired in April and May 96 and one ERS-1/2 SLC pair in May 96. One SPOT HRV of May 96 was also available.

3. the approaches

<u>The Temporal Change Approach</u>

In this approach, the temporal change in backscatter intensity is considered.

At C-band, VV, 23°, the backscatter signal comes from the volume scattering from the foliage (leaf and stem) of the upper part of the canopy (a thickness not exceeding 4 to 5 m). The value of the backscatter depends on the distribution in size, orientation and density of the scatterers (mainly leaves). Rain forests correspond to value of -7/-8 dB, whereas temperate coniferous species have lower responses (-8/-9 dB). Oil palm and coconut can have higher responses (-5/-6 dB) due to their large leaves compared to the wavelength. Previous backscatter modeling studies on coniferous forests have shown that for a forest canopy of more than 50 tons by hectare, the backscatter reaches a stable value which also does not change significantly with time . For canopies less dense in terms of biomass (<50 t/ha), the radar signal results from both the tree backscatter and the underlying soil or undergrowth vegetation. The resulting value depends on the development of the canopy and the conditions of the underground layers which is strongly dependent on weather conditions. Thus, this category of canopy will have a temporal variation, especially between dry and wet seasons, mainly due to changes e.g. in soil moisture and underlying vegetation conditions.

For low canopies (crops), the backscatter results from the volume and surface scattering, leading to variable radar backscatter and variable temporal change.

In summary, for ERS-1 SAR, three categories of canopies can be distinguished. They are characterized by the radar backscatter values and their temporal change [2].

1) dense canopy - in terms of biomass (of an order of 50 t/ha) characterized by stable value of radar backscatter (except in mountainous areas) and small temporal change. This category includes closed primary forest, secondary forests and « older » tree plantations. Selective logging will not be distinguished, since the biomass will remain high. Different species of homogeneous tree stands (coconut, rubber, oil palms...) can be distinguished by their backscatter values resulting from the interaction of the wave with different tree structure, mainly size and shape of leaves.

2) less dense canopy (< 50 t/ha) characterized by small temporal change (± 2 dB and variable backscatter values). This category includes shrubs, thickets, logged over forests, young tree plantations.

3) low canopy characterized by highly variable radar backscatter and their temporal change (agriculture crops, clear-cut areas, young forest regrowth, new tree plantation...)

Other non temporally stable land covers include swamps, savannas and water bodies.

Urban areas appear particular with high backscatter values and no temporal variation

To distinguish forest from non forest it is necessary to have a maximum contrast between the temporal changes of forested and non forested area. This can be achieved if the delay between 2 ERS acquisitions is sufficient for significant changes in non forested areas. The optimum time interval depends on the seasonal and meteorological conditions. In most cases, the 1 day interval tandem acquisition or 3 days interval will not be sufficient. Optimal configuration would be a shortest possible interval between one acquisition during the dry season and one acquisition during the wet season.

<u>The Interferometric Approach</u>

In this approach, the module of the degree of coherence r, which is the correlation between two images acquired under slightly different geometrical configuration (fig. 3), is considered.

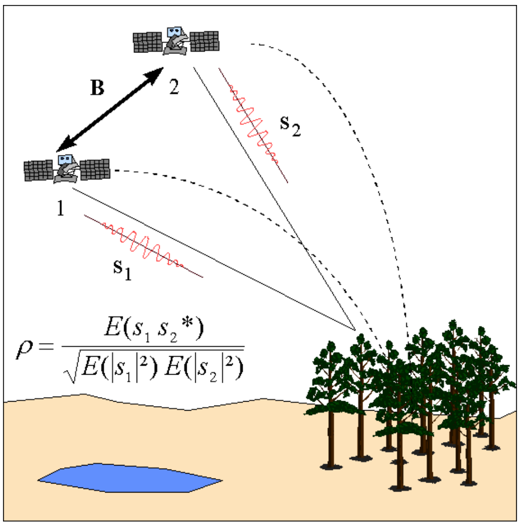

Fig. 2 : Basic principle of radar interferometry

The 2 main sources of decorrelation can be spatial or temporal decorrelation. The spatial decorrelation includes the difference in the geometry of observation between the two acquisitions. The temporal decorrelation, which is the most important in the case of ERS-1/2 repeat pass interferometry can be due either to environmental effect (e.g. effect of wind on leaves or branches) or to vegetation growth.

In terms of degree of coherence, bare surfaces present a high degree of coherence, if they do not undergo any modification in their characteristics (geometry, dielectric, vegetation regrowth) between the two acquisitions. Volume scatterers such as leaves or branches are more sensitive to structure variations due to vegetation growth or wind effect. In the case of repeat-pass interferometry, these scatterers have a high probability to move between acquisitions. Thus the volume scattering from vegetation corresponds to a low degree of coherence. The degree of coherence, as a function of forest biomass has been analyzed in a previous study over the temperate Landes forest [5].
Fig. 3 presents the variations of the coherence versus stand biomass. High temporal coherence is obtained for clear cuts and open fields whereas it decreases with stand age.

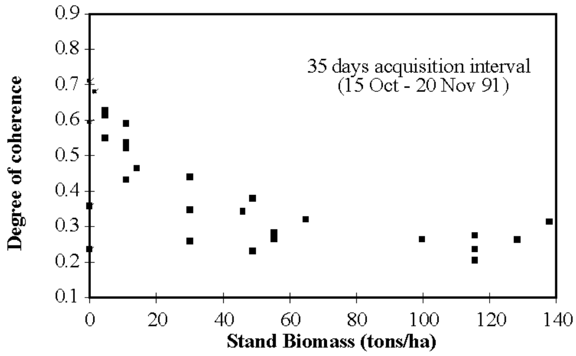

Fig. 3 : variation of the coherence vs stand biomass

The observations can be interpreted using the knowledge of the scattering mechanisms as follows. In the region where the soil contribution is dominant, the degree of coherence is high. On the other hand, the region where most of the backscatter comes from the volume contribution shows a low degree of coherence. In the intermediary region, the degree of coherence decreases with stands age/biomass, with a slope depending on soil/vegetation parameters. The optimum time interval is such that the contrast between the degree of coherence of forest and other surfaces could be maximized. The shortest time interval must be the best. However, depending on the study site and the seasonal, meteorological conditions, 35 days interval can provide good forest/non forest discrimination (e.g. fig. 3).

In tropical regions, the vegetation (crop, forest regrowth) growth is such that in 35 days the coherence over non forested area would be too low to be distinguished from the forested area [4]. For forest/non forest mapping the time interval should be defined so that the coherence of non forest areas remains high. Thus the shortest (1-3 days) repeat pass acquisition is more appropriate to use interferometric coherence.

4. METHODOLOGY

The Multitemporal Approach

The temporal variation of the SAR signal can be measured based on differences in the magnitude of the signal intensity between 2 dates.

Differencing and ratioing are well-known techniques for change detection. Ratioing of the multidate radar intensities is shown to be better adapted to the statistical characteristics of SAR data.

The ratio is in addition very robust to radiometric errors which are exactly reproduced in repeat-pass imagery. Those errors include the error in antenna pattern removal, and , more important, the error in the computation of the scattering element size, e.g. in sloping areas. Both errors are multiplicative factors to the total radar intensity, thus eliminated in the ratio image. Furthermore, the effect of hilly terrain which yields very important spatial variation of pixels, which is also a multiplicative effect, will also be eliminated.

However, the ratio is very sensitive to the speckle noise. To detect changes in radar intensity less than 1 dB with a confident interval better than 80 % the equivalent number of looks (ENL) must be more than 128 [6].

The forest/non forest mapping algorithm :

1. Speckle reduction filtering : in order to provide a sufficient equivalent number of looks, appropriate temporal and spatial filtering processes have been applied to the ERS-1 PRI 3 looks SAR data [7][8].

2. Temporal image ratioing : after filtering, the intensity values of two images will be divided, pixel by pixels.

3. Forest/non forest Map : as established with the experimental data, a threshold corresponding to a variation of less than 1dB will be used over the ratio image to map forested areas.

The Interferometric Approach

1. Coherence image creation : first a sub-pixel registration is realized on the phase , followed by the calculation of the phase and the coherence over a window of 2 pixels in range and 8 pixels in azimuth. Then, a projection in ground range projection and finally a resampling at 12.5m are realized

2. Forest/non forest Map : as established with the experimental data, a threshold corresponding to a coherence of less than 0.4 will be used over the coherence image to map forested areas.

5. RESULTS

Fig. 4a shows the SPOT HRV acquisition of May 1996. Dark area (e.g. area n°1) correspond to dense forest, green area (e.g. area n°2) to non forest, mainly young oil palm plantation, and light red area (e.g. area n°3) to mature oil palm plantation. Area n°4 shows an example of swampy-non forested area.

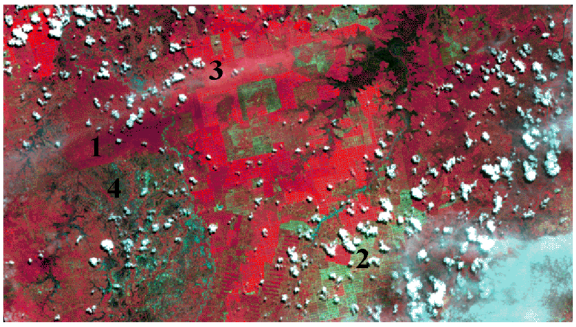

Fig. 4a : SPOT HRV image of May 1996

■ XS3 ■ XS2 ■ XS1

A ratio image have been realized with the 35 days interval SAR images, acquired in April 96 and May 96 (fig. 4b), whereas the coherence image have been calculated from the 1 day repeat pass images of 17 and 18 May 96 (fig. 4c).

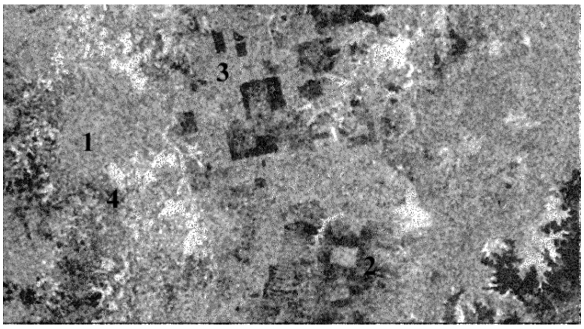

Fig. 4b : Ratio image

The resulting ratio image appears in gray tones. Areas with low temporal change have dark tones, whereas areas with a high temporal change present bright tones for a positive change (s° increasing between 2 acquisition) and black tones for negative temporal change (s° decreasing between the 2 acquisitions).

Fig.4c : Coherence image

On the resulting coherence image bright tones correspond to high coherence whereas dark tones correspond to low coherence.

Fig. 4d presents the ERS color composite image of April 96 (red), May 96 (green), and Ratio image (blue). Yellowish tones correspond to area with no temporal change whereas bluish and reddish to area with, respectively, positive and negative temporal change.

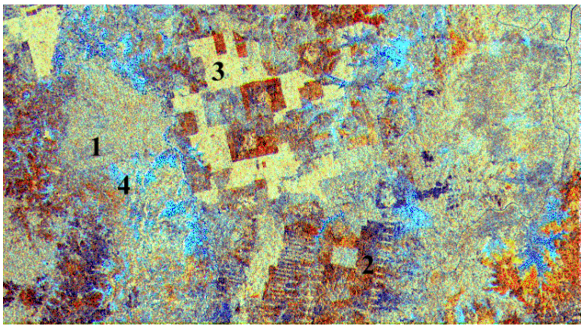

Fig.4d : Color Composite image

■ 13/04/96 ■ 18/05/96 ■ Ratio image

Fig. 4e presents the ERS color composite image of 17 May 96 (red), 18 may 96 (green) and coherence image (blue). Yellowish tones correspond to low coherence whereas bluish tones to high coherence area.

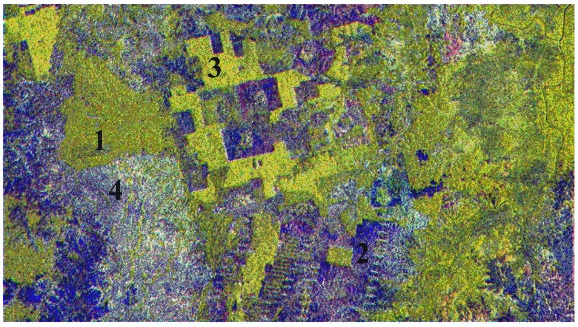

Fig.4e : Color Composite image

■ 17/05/96 ■ 18/05/96 ■ Ratio image

Area n°1 (dense forest) has a low temporal change and a low coherence. The backscattered intensity corresponds to a saturate value and the coherence, a lowest value, both not affected significantly by changes in ground conditions, since the forest backscatter results from volume contribution.

On the contrary, for area n°2 (young oil palm plantation) both temporal change and coherence are high because soil contribution is important.

For Area n°3 (mature oil palm plantation). The configuration is quite similar to the one of area n°2 (low temporal change and low coherence) because of no soil contribution. However the backscattered intensity of the mature oil palm plantation is higher than that of the forest, due, mainly, to their leaf size which are large compared to the wavelength. This permits to distinguish them from dense forest.

Area n°4 presents a low temporal change but a clearly high coherence. This swampy area, which is non forest, would be considered as forest with the ratio approach and as non forest with interferometry, because the s° has not changed between April and May 96 for most of the area.

This illustrates particularly well the problem of non optimum acquisition dates. April and May are situated in the same season (dry). Therefore, the moisture conditions remain the same for the 2 acquisitions as well as the sparse vegetation of this area.

A previous study has already been lead on this site with 2 images acquired in December 93 (wet season) and August 94 (dry season) [2]. Fig. 4f presents the ERS color composite image of August 94 (red), December 93 (green), and ratio image (blue). We can see that area n° 4 is no longer considered as forest because it has a high temporal change (bluish and reddish color).

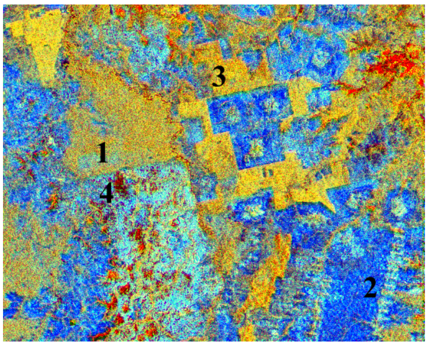

Fig. 4f : Color Composite Image

■ 05/08/94 ■ 01/12/93 ■ Ratio image

Fig. 4g and h present forest (green) / non forest (white) map using a simple thresholding of the ratio and of the coherence image.

The coherence gives more robust results for forest / non forest mapping (fig 4g and h) particularly for the swampy area.

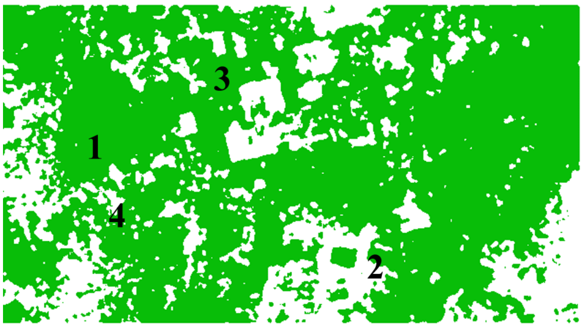

Fig. 4g : Forest / Non forest map with 96 temporal data

Fig 5 h : Forest / Non forest map with interferometric data

Fig. 4i presents the ratio image obtained from optimum acquisition dates. The mapping result is largely improved. Even areas of young oil palm plantation (area n° 2) are better delineated. This shows that the dates of acquisition are crucial for the temporal change method.

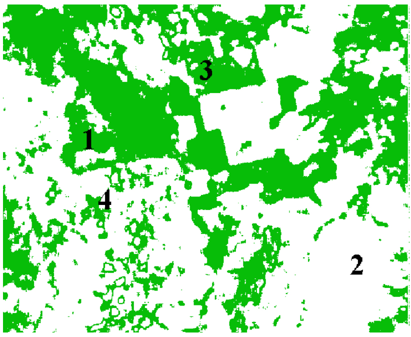

Fig 5i : Forest / Non forest map with 93/94 multitemporal data

For both methodology the use of intensity value for non mountainous area provide additional discriminations like forest / mature oil palm for example.

6. preliminary remarks

A comparison between Temporal Change approach and Interferometric approach have been assessed.

The criteria for forest / non forest discrimination are as follows :

For INSAR data forest classes are described by a coherence lower than 0.4. The optimum conditions are reached with a small temporal intervals as the results are more affected by changes of non forest conditions. If the delay between 2 acquisitions is too long the characteristics of non forested area will change and then their coherence will decrease, lowering the discrimination with forested area.

For ERS SAR intensity, dense forest classes area described by a temporal change lower than 1 dB. Optimum conditions are reached when using at least one dry and on wet seasons because the results are improved by the change of non forest conditions.

At C-band, the intensity of backscattered signal from bare soil surfaces depends on the soil parameters (moisture, roughness). Consequently, bare soil surfaces can present a large range of responses. These possible variations of the soil responses may impede the forest / non-forest discrimination because of the possible confusion between some vegetated and non-vegetated areas. Therefore, optimum acquisition date are needed in the case of temporal change approach in order to improve the contrast between forested surfaces and non forested surfaces. On the contrary, the degree of coherence of a bare surface or surface with low vegetation cover is, in most cases, higher than the degree of coherence characterizing forested areas, and this independently of the soil moisture and roughness parameters.

Further investigations at various geograhical locations are needed to validate the results and to quantify the accuracy of both methodology in order to define thresholds to be used in most conditions.

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