## EVALUATION OF THE POTENTIAL OF SAR ERS AND ASAR ENVISAT SENSORS IN MULTI-INCIDENCE AND MULTI-POLARISATION MODES FOR LANDSCAPE STUDY IN FRENCH GUYANA: EXAMPLES OF KOUROU AND SAINT LAURENT DU MARONI

J. L. Kouamé<sup>a, \*</sup>, P. L. Frison<sup>a</sup>, A. Mascret<sup>a</sup>, J.P. Rudant<sup>a</sup>

<sup>a</sup> Laboratoire des Géomatériaux, Institut Francilien des Sciences Appliquées, Université de Marne La Vallée, 5, Bld. Descartes – Champs sur Marne – 77454 Marne La Vallée cedex 2, France – jacob.kouame@univ-mlv.fr

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## **ABSTRACT:**

This study aims to assess the contribution of ENVISAT ASAR data for the monitoring of the littoral plains of Kourou and Saint Laurent du Maroni (French Guyana). It presents results of qualitative and quantitative analyses of SAR ERS and ASAR ENVISAT data based on the following comparative criteria for landscape types discrimination:

- Comparison between SAR ERS and ASAR ENVISAT in same configuration acquisition (mode IS2)

- Seasonal influences (dry vs rainy season effects),

- Incidence angle influences (exploitation of ASAR ENVISAT incidence angle range),

- Polarization influences (exploitation of ASAR ENVISAT Image and Alternating Polarization modes data).

The calibration of the different considered radar images allows their inter comparison in order to obtain information about landscape type's properties (dielectric, moistures, real evolutions) and on homogeneous parcel of land. The study showed that different parameters, like the season, the incidence angle, and the polarization, strongly influence the radar signal observed over such landscape types. In addition, results show that ASAR-IS2 mode, similar to ERS SAR configuration ensures the continuity of SAR ERS-1&2 for land surface monitoring.

However, it arises that discrimination between various types of landscape are confusing when analysing the backscattering coefficient values alone. The backscattering coefficients only cannot allow discriminating all the different landscape classes. Other parameters like texture, structure, geographical position, form and size are needed for landscape type's discrimination from radar images.

### 1. INTRODUCTION

### 1.1 Context

The use of radar imagery in French Guyana, since the launching in 1991 of the first european radar satellite, ERS-1, is justified by the impossibility of obtaining favourable conditions for aerial photography and optical satellite images (SPOT), because of the quasi-permanent cloud cover.

However, the characterization of a surface (like water, buildings, vegetation) based on multiple observation criterion (incidence, polarization) was limited. Sensors SAR ERS-1 and SAR ERS-2 could only acquire images at C band ( $\lambda = 5.6$  cm) in a single configuration: at 23° of incidence angle in VV polarization. The launch of ASAR ENVISAT sensor in Mars 2002, with different acquisition modes (*multi-incidence (15° to 45°), multi-polarization (VV, HH, HV, VH), multi-resolution (30 m, 150 m to 1000 m)*) invites to reconsider landscape types study with C band SAR system.

#### 1.2 Objectives

Methodological study of calibrated satellites data aims to bring out their interpretation keys and to retrieve different types of landscape backscattering characteristic. It is to describe factors, to find indicators, if possible independent of the study site, influencing the backscattering coefficient in radar data. The backscattering coefficient is thus evaluated for: - comparison of two radar images acquired in the same configuration respectively by SAR ERS sensor with fixed configuration (23°, VV) and ASAR ENVISAT sensor with flexible configuration (*multi-incidence, multi-polarization*);

- comparison of ASAR ENVISAT images in different modes of acquisition, by studying the influence of acquisition parameters (*incidence ranges from 15° to 45°*, *polarization modes like VV*, *HH*, *VH*, *HV*) and Seasonal influences (dry *vs* rainy season effects).

## 1.3 Study sites

The study was undertaken in French Guyana on the littoral plains of Kourou (near Guyana Space Centre) and Saint Laurent du Maroni-Mana (West of Guyana). The French Guyana arouses a scientific interest due to a strong littoral landscape dynamics, but also to its immense reservoir in biodiversity.

The landscape is staged from coast towards interior of the territory and divided into three well marked sets: coastal band, littoral plain and dense forest on ferralitic soil (Lescure and Tostain, 1989; Zonzon, J, Prost G, 1997; Fromard and al., 1998; Proisy, 1999) (Figure 1).

The littoral plain on sandy soil consists of a diversity of vegetable formations. Man distinguishes marshes, various types of savannas (dry, grassy, flooded), a mosaic of forest formations (marshy, easily flooded) and degraded vegetations.

<sup>\*</sup> Corresponding author



Figure 1. Study areas on radar image of French Guyana

#### 2. DATA AND METHODS

#### 2.1 Available satellites data

Some satellites images have been acquired by SAR ERS-2 and ASAR ENVISAT on Kourou and Saint Laurent du Maroni between 1998 and 2004 in different polarisation and incidence modes (Table 1). Thematic maps of Land cover have been used as reference data during the interpretation of the radar images. In addition, a mission of ground truth in May-June 2003 made it possible to supplement our knowledge on the French Guiana geographical environment and to collect specific GPS data.

| Sensor       | Date       | Incidence | Polarisation | Season | Tide  | Site         |
|--------------|------------|-----------|--------------|--------|-------|--------------|
| SAR ERS-2    | 05.11.1998 | 23°       | VV           | Dry    | 0.1 m | Kourou       |
| ASAR ENVISAT | 06.11.2002 | IS2 (23°) | VV (IMP)     | Dry    | 0.7 m | Kourou       |
| ASAR ENVISAT | 24.04.2003 | IS7 (44°) | VV (IMP)     | Rainy  | 2.0 m | Kourou       |
| ASAR ENVISAT | 30.04.2003 | IS2 (23°) | HH (IM)      | Rainy  | 0.6 m | Kourou       |
| ASAR ENVISAT | 09.10.2003 | IS4 (34°) | VV (IMP)     | Dry    | 1.7 m | Kourou       |
| ASAR ENVISAT | 19.05.2004 | IS2 (23°) | HH (AP)      | Rainy  | 0.6 m | Kourou       |
| ASAR ENVISAT | 19.05.2004 | IS2 (23°) | VV (AP)      | Rainy  | 0.6 m | Kourou       |
| ASAR ENVISAT | 28.07.2004 | IS2 (23°) | VV (IM)      | Rainy  | 1.2 m | Kourou       |
| ASAR ENVISAT | 01.07.2003 | IS2 (23°) | VV (AP)      | Rainy  | 0.9 m | St Laurent M |
| ASAR ENVISAT | 01.07.2003 | IS2 (23°) | VH (AP)      | Rainy  | 0.9 m | St Laurent M |
| ASAR ENVISAT | 05.08.2003 | IS2 (23°) | HH (IM)      | Rainy  | 1.4 m | St Laurent M |

Table 1. List of available satellites data on French Guyana

#### 2.2 Methods

The radiometric pre-processing of radar data consisted in carrying out the calibration of satellite radar images. The backscattering coefficient of a surface is a value related to the relationship between returned energy and transmitted energy. It represents its spectral signature and characterizes its physical and geometrical properties (Ulaby and al., 1982; Curlander and McDonough, 1991; Dallemand and al., 1993).

The backscattering coefficient estimated in SAR ERS-1&2 images can be expressed as follows (Moore, 1983; Laur and al., 1998; Laur and al., 2003):

$$\sigma_{i,j}^{0} = \frac{CN_{i,j}^{2}}{K_{SARERS}} * \frac{\sin(\alpha_{i,j})}{\sin(\alpha_{ref})} \stackrel{i=1...L}{\underset{j=1...M}{\overset{(1)}{=}}}$$

Where  $\sigma_{i,j}^{0}$ : Backscattering coefficient of pixel (i,j)

 $K_{SAR ERS}$ : Absolute constant of calibration  $CN_{i,j}^{2}$ : intensity value of pixel (i,j)  $\alpha_{ref}$ : reference incidence angle (23°)  $\alpha_{i,j}$ : incidence angle on pixel (i,j).

In case of ASAR ENVISAT, the relation between the backscattering coefficient and the value of the numerical account (pixel value) is given by (Rosich B. and Meadows P., 2004):

$$\sigma_{i,j}^{0} = \frac{CN_{i,j}^{2}}{K_{ASAREnvisat}} \sin(\alpha_{i,j}) \qquad \underset{J=1...M}{\overset{i=1...L}{\underset{j=1...M}{i=1...M}}}$$
(2)

Where  $\sigma_{i,j}^{0}$ : Backscattering coefficient of pixel (i,j)  $K_{ASAR Envisat}$ : Absolute constant of calibration  $CN_{i,j}^{2}$ : intensity value of pixel (i,j)  $\alpha_{i,j}$ : incidence angle on pixel (i,j).

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Determination of  $\sigma^{\circ}$  in SAR ERS and ASAR ENVISAT images for homogeneous surfaces in French Guyana is carried out with a minimum number of samples of 1000 pixels, in order to attenuate as well as possible the speckle, inherent radar data, and reduce radiometric resolution errors (Fellah, 1995; Henry, 2002; Laur and al., 2004). Estimation precision is lower than 0.5 dB with a confidence of 95%.

## 3. RESULTS OF RADAR IMAGES ANALYSIS

Comparison of SAR ERS and ASAR ENVISAT images has been conducted in order to evaluate the influence of each following parameter for some land use types detection: type of sensor, season, incidence angle and polarization. Landscape elements used are presented below:

|                | F F F F F F F F F F F F F F F F F F F |                       |
|----------------|---------------------------------------|-----------------------|
| 1. mud bank    | 6. flooded savanna                    | 11. dense forest      |
| 2. ocean       | 7. easily flooded savanna             | 12. coastal mangrove  |
| 3. river       | 8. swamp low vegetation               | 13. interior mangrove |
| 4. water pond  | 9. swamp high vegetation              | 14. degraded mangrove |
| 5. dry savanna | 10. marshy forest                     | 15. buildings         |
|                |                                       |                       |

#### 3.1 Multi-sensor signatures analysis (ERS vs ENVISAT)

The two compared images, ASAR ENVISAT IMP (06/11/2002) and SAR ERS PRI (05/11/1998), were acquired in dry season and in identical mode  $(23^{\circ}, VV)$ .

Figure 2, shows that the two types of acquisition radar SAR ERS and ASAR ENVISAT IMP have the same sensitivity compared to target surfaces backscattering values (Figure 3).

The urban area of Kourou (15) has a strong retrodiffusion in the two images. The backscattering value is respectively 5.8 dB (ENVISAT) and 5.6 dB (ERS). The strong urban density in image ENVISAT ( $23^{\circ}$ , VV) is due to new constructions between 1998 (ERS image) and 2002 (ENVISAT image).

Savannas surfaces (5, 6, 7), homogeneous and smooth zones, present strong contrasts with other landscape elements (dense forest, vegetation cover, buildings). They have a weak backscattering value (6), even very weak (5).

ASAR ENVISAT acquisition mode with incidence of 23° and a polarization VV, thus ensures the continuity of ERS-1 (23°, VV) and ERS-2 (23°, VV) acquisitions. However, the images acquired by ASAR ENVISAT seem to have a higher radiometric dynamics and a strong potential of discrimination.



Figure 2. Comparison of backscattering values of SAR ERS and ASAR ENVISAT in 23°, VV mode



Figure 3. *Above*, SAR ERS-2 (1998); *Below*, ASAR ENVISAT IS2 (2002): Comparison of landscape elements discrimination by radar images

#### 3.2 Multi-temporal signatures analysis (season effects)

The season effects (dry *vs* rainy) analysis was conducted with ASAR ENVISAT IMP IS2  $(23^{\circ})$ , acquired on 06/11/2002 (dry season) and 28/07/2004 (rainy season).

The quantitative analysis of ASAR images shows that vegetable formations like dry (5), flooded (6), and easily flooded (7) savannas, and the marshes (8 and 9) have backscattering values most dependent on the period of the year (Figure 4; Figure 5).



Figure 4. Backscattering values during dry vs rainy seasons



Figure 5. *Above*, dry season image; *below*, rainy season image: season's alternance has effects on physiological and biological state of vegetable formations

In dry season, contrast between dry savannas (5) and other vegetable formations is high. It is observable on image ASAR ENVISAT IS2 (06/11/2002). Dry savannas appear dark and have a backscattering value of -12 dB.

In rainy season, the aspect of these dry savannas (5) is greydark and their backscattering value is close to -7,2 dB

Alternation between dry season and rainy season has, thus, considerable effects on the physiological and biological state of the vegetable formations. Different types of land use restitution on a given study site passes through a combination of dry and rainy seasons ASAR ENVISAT images.

## 3.3 Multi-incidence signatures analysis (ASAR ENVISAT)

Three ASAR ENVISAT IMP images in three different ranges of incidence IS2 (23°, VV, 06/11/2002), IS4 (34°, VV, 09/10/2003) and IS7 (44°, VV, 24/04/2003) are selected to analyze incidence influence in landscape elements discrimination. ASAR ENVISAT sensor possesses 7 ranges of incidence (Table 2).

| Incidence | Incidence | angle (°) |        |
|-----------|-----------|-----------|--------|
| Ranges    | proximal  | Centre    | Distal |
| IS 1      | 15,0      | 19        | 22,9   |
| IS 2      | 19,2      | 23        | 26,7   |
| IS 3      | 26,0      | 29        | 31,4   |
| IS 4      | 31,0      | 34        | 36,3   |
| IS 5      | 35,8      | 38        | 39,4   |
| IS 6      | 39,1      | 41        | 42,8   |
| IS 7      | 42,5      | 44        | 45,2   |

Table 2. Incidence range characteristics of ASAR ENVISAT

The analysis of graphics represented on Figure 6, shows that: - in general, the vegetable formations have weak radiometric variations with respect to incidence angle variations.

- On the other hand, urban areas (high buildings (15), infrastructures), rivers (ocean (2), river (3), and lake (4)) and strong topography areas have different radiometric answers according to radar sensor antenna's orientation (Figure 7).

The urban space (15) has radiometric variability in these 3 radar ENVISAT images. It appears less and less brilliant when incidence angle increases:  $\sigma^{\circ} (23^{\circ}) = +4.2 \text{ dB}$ ,  $\sigma^{\circ} (34^{\circ}) = -3.9 \text{ dB}$  and  $\sigma^{\circ} (44^{\circ}) = -5.5 \text{dB}$ . The difference between buildings backscattering at 23° and 44° is  $\sigma^{\circ} (23^{\circ}) - \sigma^{\circ} (44^{\circ}) = 9.7 \text{ dB}$ . This variation is very visible on Figure 7.



Figure 6. Backscattering values measured in ASAR ENVISAT images acquired with incidence angle of 23°, 34° and 44°.



Figure 7. Illustration of incidence angle influence for buildings backscattering capacity: the radiometric variability is explained by the geometrical configuration formed by the normal plan of buildings roofs and radar incident waves as illustrated here.

#### 3.4 Multi-polarization signatures analysis (ENVISAT)

The objective of this section is to evaluate the contributions of ASAR ENVISAT polarization types in Image mode acquisition (IMP) and in Alternating polarization mode acquisition (APP). ASAR ENVISAT sensor can acquire images in these two modes of acquisition. The Table 3 presents the characteristics of ASAR ENVISAT images IMP and APP (Atterna et al., 1998; Buck et al., 2000; Desnos et al., 2000).

|                          | ASAR ENVISAT            |         |                      |         |
|--------------------------|-------------------------|---------|----------------------|---------|
|                          | Mode Image<br>IMP (PRI) |         | Mode AP<br>APP (PRI) |         |
|                          | range                   | azimuth | range                | azimuth |
| Nombre de vues           | 1                       | 4       | 1                    | 2       |
| Résolution nominale (m)  | 27,5                    | 28,1    | 28,7                 | 29,7    |
| Pixel (m)                | 12,5                    | 12,5    | 12,5                 | 12,5    |
| ENL origine              | > 3                     |         | > 1,8                |         |
| Résolution radiométrique | 1,50 à 2,0 dB           |         | 2,46 à 2,50 dB       |         |
| Exactitude radiométrique | 1,17 à 1,38 dB          |         | 1,62 à 1,81 dB       |         |
| Stabilité radiométrique  | 0,32 à                  | 0,40 dB | 0,50 à               | 0,55 dB |

Table 3. Characteristics of ASAR ENVISAT images provided by ESA in IMP and APP modes

## **3.4.1** Comparison of IMP and APP modes in HH polarisation:

The analysis of landscape elements backscattering values measured on two images in polarization HH, ASAR ENVISAT IMP (IS2, 30/04/2003) and APP (IS2, 19/05/2004), shows that:

- all the physical values of backscattering measured on ASAR images in APP mode remains lower than the values measured on ASAR image in IMP mode (Figure 8).

- However, the radiometric dynamics of images with polarization HH, in IMP and APP modes, is strong and in the same order.

It is important to note that, the flooded vegetable formations in rainy season (flooded savanna (6), marsh (8)), marshy forest (10) and interior mangrove (13) have a strong backscattering (clear) and are better seen in ASAR images in IMP mode than in ASAR image APP mode (Figure 9).

The difference between the intensity of backscattering in ASAR image IMP and in ASAR image Alternating Polarisation (APP) varies between 1.2 dB and 2 dB.

In this way, the comparison of the potential in IMP and APP modes according to HH polarization showed that the radiometric dynamics is identical



Figure 8. Graphs of compared backscattering coefficients of ASAR images according to the nature of image mode (IMP and APP) in polarization HH on the site of Kourou.



Figure 9. Compared potentials of ASAR ENVISAT according the polarisation: *above*, IMP (HH, IS2, 30/04/2003); *middle*, APP (HH, IS2, 19/05/2004); *below*, IMP (VV, IS2, 28/07/2004), on the site of Kourou

# 3.4.2 Comparison of polarisations HH vs VV in IMP mode:

Analyzing, ASAR ENVISAT IMP images in polarizations HH (30/04/2003) and VV (28/07/2004), it is noted that (Figure 9):

- for rough surfaces, as agitated water surface, the backscattering values polarization VV, are higher than values in polarization HH ( $\sigma^{\circ}_{VV} > \sigma^{\circ}_{HH}$ ) (Figure 10);

- at the reverse, the moisture of soil plays an important part in flooded vegetable formations strong backscattering in ASAR ENVISAT IMP polarization HH images. By effect of double rebound of the wave radar, the flooded vegetable formations return an important energy in polarization HH:  $\sigma^{\circ}_{HH} > \sigma^{\circ}_{VV}$ ;

- the radiometric dynamics of radar image in polarization HH is higher (Le Toan et al., 1994; Mattia et al., 1995).



Figure 10. Polarizations HH and VV in ASAR ENVISAT IMP

## 3.4.3 Comparison of polarisation VV vs VH in APP modes:

This study concerns ASAR ENVISAT images in APP mode with crossed polarization V (VV *vs* VH) on site of Saint Laurent du Maroni-Mana.

The analysis of the backscattering values showed that there is an important difference (> 4 dB) between values measured on the image in polarization VV and those of image in polarization VH (Figure 11). Paddy fields (*16*) have a diversity of radiometric answers in the two ASAR APP (VV vs. VH) images according to rice's development stage and level of flooding (water). The outlines of paddy fields are better identifiable in ASAR APP (VH) that in ASAR APP (VV). The cultivated lands (*17*) have a dark colour in near dense forest and along road network. In polarization VH, backscaterring is weak (-14.2 dB), whereas in polarization VV, it is average (-7.6 dB) (Figure 12).



Figure 11. APP mode: polarization VV vs VH (01/07/2003)



Figure 12. Crossed polarization V potential on paddy site (Mana): *above*, VV (01/07/2003) and *below*, VH (01/07/2003)

#### 4. CONCLUSION

The study showed that parameters like season, incidence angle and polarization have strongly influence landscape elements backscattering during radar images acquisitions. It arises, however, that discrimination between different types of landscape seems less easy according physical values analysis. Confusions between some landscape elements persist.

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