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SAR Imagery in Urban Area

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ABSTRACT: This paper deals with the major factors influencing the detection of urban fabrics in ERS-SAR images. Data, in SLC and PRI format, were acquired over the city of Nantes (West of France). The analysis of the data was performed in conjunction with aerial photographs, maps, meteorological data, as well as a field survey. The way urban fabrics and its environment, the data processing techniques, and the weather conditions affect the radar signal was examined and discussed. It was found that large effects originate from the geometry of urban features, as well as their orientation relative to the spacecraft orbit. This investigation adds evidence of the fact that the specular scattering prevails over the diffuse scattering in urban area. Practical conclusions concerning the capabilities and the limitations of ERS-SAR imagery are drawn.

1 INTRODUCTION

Almost 70% of the Europe's population live in cities, and urbanization is still continuing (EEA 1998). That is why urban planners and decision makers need tools for a comprehensive assessment of the urban environment.

A means for a better understanding of urban areas are remote sensing techniques (Bonn 1996). Satellite imagery can significantly improve the monitoring of cities in a wide range of applications, e.g., the detection of urban changing, mapping roads and streets (Couloignier 1998, Tupin et al. 1996), mapping urban demarcation (Weber 1995), mapping urban air pollution (Wald & Baleynaud 1999 ; Basly et al. 1999).

Nevertheless the number of studies using SAR data is much lower than that using optical ones (visible and infrared) notably concerning investigations on urban areas (Henderson & Xia 1997, Guerre 1995), though these studies brought to the fore the advantages of using radar images. Indeed, radar signal is sensitive to the geometry of urban fabrics, and is used for detecting built-up area as man-made features (Fellah et al. 1994, Carlotto 1996, Dousset 1997, Xia & Henderson, 1997, Lortic & Couret 1998). In addition, radar imagery may provide the third dimensional information (Dong et al. 1997). Hence, SAR imaging techniques are relevant tools to analyze urban land use patterns.

In that perspective, this paper examines the major factors influencing the detection of the urban fabrics, that is the orientation, the buildings materials, the meteorology, the SAR image format, and the quality of the data.

2 SAR DATA AND STUDY SITE

2.1 *Data and Pre-processing*

Two sets of images were used. One set of 5 ERS-SAR images in Single Look Complex (SLC) format, and one set of 7 ERS-SAR images in Precision Image (PRI) format. That represents 12 images spanning a time of almost 2 years, from October 1994 to October 1996. All data were taken in descending pass: radial direction is almost East-West.

It is worth noting that SLC data strongly differ from PRI data. On the one hand, SLC data are complex data, in slant range geometry (i.e. the range resolution varies with the incidence angle), and on the other hand, PRI data are system corrected, multilook processed (in order to reduce speckle noise), and in ground range geometry. Furthermore, the pixel size is also different (ESA 1993). After reducing the SLC data to magnitude images, they were remapped to a PRI image taken as a reference.

The speckle was not filtered out in each image. Several tools are available which are respectful of the most pronounced structures (see e.g. Ranchin & Cauneau 1994, Mathieu et al. 1998).

However we have preferred not to alter the structures any further after the geometrical rectification, and decided to reduce the noise by making a multi-temporal average for each kind of dataset. Furthermore, averaging the images decreases the level of speckle preserving the structures, and this simple processing decreases the effects of the variability of the multitemporal SAR images (Stroobants et al. 1996, Basly et al. 1997, 1999).

2.2 *The Study Area*

The city of Nantes is located in Western France at 54 km from the Atlantic ocean. Geographical coordinates are 47.23 N and 1.55 W. That location explains the oceanic climate which is quiet mildly. The city is crossed by the Loire river, and a natural island, the so-called "Beaulieu Island", is part of the city. Nantes comprises about 470 000 inhabitants, and was a very active harbor some centuries ago with many exchanges with America and Africa.

3 INTERPRETATION OF THE ERS-SAR MEAN IMAGES

Screening the two mean images, we notice that the PRI one (Fig. 1) is smoother than the SLC one, due to the multilook processing of the PRI which reduces the speckle noise. In both images, we observe a high variability of the backscatter due to the complexity of the urban landscape. Indeed, a town contains a wide variety of length scales. Large scales are provided by the ground and buildings themselves, while the small scales by the roughness of the surfaces (Taket et al. 1991).
In urban areas, the specular reflection prevails over the diffuse scattering because of the geometrical properties of the objects (Dong et al. 1997). Three mechanisms of specular scattering dominate:

- the simple bounce from tilted roof,
- the double bounce from wall-ground,
- the triple bounce from wall-wall-ground.

The Figure 1 shows the values of the backscatter magnitude according to different type of areas.
Both images were analyzed in detail conjointly with aerial photographs, maps, meteorological data, as well as a field survey, in order to assess the influence of the factors above-cited.

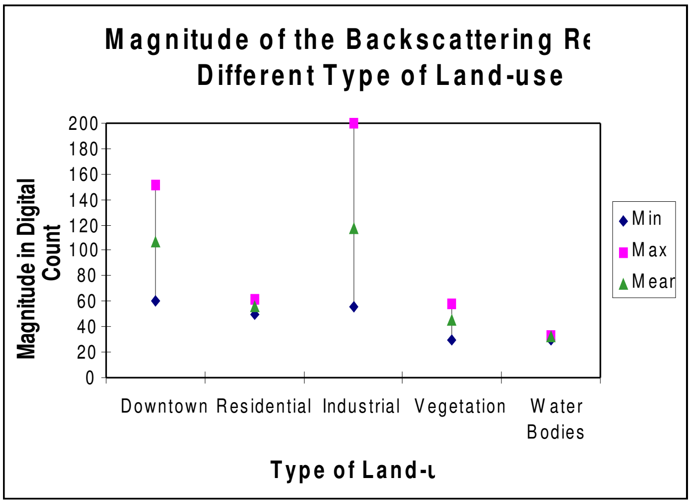

Figure 1. The return is large and highly variable in downtown and industrial area. The backscattering-echo is very low for the vegetation areas and water bodies. Concerning the residential areas, the values of the backscatter return are slightly larger and less variable than that of the vegetation areas.

3.1 *Artificial Areas*

3.1.1 *Downtown and Dense Urban*

The center town mainly comprises tall buildings with flat and tilted roofs. It is the ancient part of the city, and the density of buildings is large (Fig. 2 area (A)). The backscatter is large in average, but highly variable. The variability is due to the changes in street orientation and in building density.
A strong backscattering-echo come from two groups of buildings located on the both sides of a green park (Fig. 2 (B)), enhanced by the low backscattering of the park. Nevertheless, one cannot conclude neither on the major orientation of the buildings, nor on the number of buildings.
Large anisotropic backscattering may occur when particular conditions are combined (Fig. 2 (C)). If a street is aligned with the flight direction of the satellite (i.e. when the illumination azimuth is orthogonal to the street direction), and if the ratio building height/street width satisfies a condition relative to the incidence angle, favorable multiple reflections occur, resulting in a high backscatter return (Gouinaud 1996). The street direction may be thus determined.
Metal elements on the roofs generate enhanced diffuse backscattering. But, this is an isotropic backscattering, and the major building orientation cannot be deduced.
When the density is large, some buildings may be hidden from the radar illumination by the other buildings. This shading effect results into a weak backscatter.
In addition, on flat roofs, the radar signal is specularly reflected, so there is no return to the satellite.

3.1.2 *Residential and Mean Urban*

Most of the residential houses are single or two storey-buildings with tilted roof (Fig. 2 (D)). Like downtown there is no major orientation. In average the backscattering is lower than downtown.

High backscattering may arise from tilted roof facing the radar wave. The roof can be considered as a rectangular smooth surface (i.e. a mirror, by analogy with the optical physic). Such a surface gives very low radar return except in specular condition at near vertical incidence (i.e. when the incidence angle is close to 0°) (Simonett & Davis 1983).

In low density area, if a wall faces the illumination azimuth, a double bounce mechanism can occur resulting in a high return signal. In that case, the residential house can be compared to a dihedral corner reflector. The backscattering-echo of the double bounce mechanism is lower than single bounce from tilted roof, because there is a loss of energy for each reflection.

In both cases, the orientation and the bulk size of the buildings greatly affect the return of the backscattered energy. For example, a residential area made of eleven buildings with twenty stores, covering a surface of approximately 13 km², has a weak return (Fig. 2 (E), Fig. 2). The low return is mainly due to the orientation of the buildings: firstly the frontages are perpendicular to the ground with a wave incident angle far from 0°, secondly they cover a large surface and do not face the radar beam. Accordingly, neither the single bounce mechanism nor the double bounce one can occur.

3.1.3 *Industrial and Commercial*

In those areas, buildings are often large, tall, with flat metal roof, and density is low (Fig. 2 (F)). For such building specular reflection occurs on the flat roof, and double or triple bounce mechanisms occur on the walls. Large returns occur if buildings face the illumination azimuth. In this case, they are well detected and their orientation and length (only one dimension) can be measured (Fig. 3). Otherwise, the buildings may be not detected or their dimensions remain unknown.

3.1.4 *Other Urban Features*

3.1.4.1 Bridges

All the bridges crossing the Loire river are visible. The radar return is large, because bridges are transversally oriented according to the radar wave. In addition, bridges are in contrast with their environment i.e. the Loire river. We note that two bridges built after the aerial photographs were taken (1993), appear on the ERS-SAR images (Fig. 4).

Nevertheless, most of the bridges crossing the Erdre and the Sèvre river are longitudinally oriented, so they do not appear unless they are made of metal.

3.1.4.2 Roads, Streets and Railway Tracks

Roads and streets are smooth surfaces, and the backscatter return is always low. They appear in dark in the images when oriented along the wave vector (Fig. 2 (G)). Otherwise, they can be detected if their width is large enough, the critical width being a function of the height of the lining buildings through the shading effect, the type of building, the density of buildings, and the presence of vegetation, water bodies, car-park ...

Railway tracks appear in bright because large diffuse backscatter arise from electrical wiring and rail made of metal (Fig. 2 (I)). The detection of railway tracks is subjected to their neighborhood whatever their orientation. If the backscatter return of the neighborhood is equal or larger than that of the railways, the latter be undetected. Otherwise, the railways may be shaded by high buildings.

3.1.4.3 Airport

The airport appears clearly in the image (Fig. 2 (J)). The runway and taxi-way are visible, and appear in dark because of the specular reflection.

3.2 *Natural areas*

3.2.1 *Inland Water*

Rivers appear in dark in the image because of the specular reflection on smooth surface (Fig. 2 (K)). However, by analyzing several multi-temporal images, we noticed a strong variability in the backscatter of the Loire river, both in time and space. We found that this variability varies according to the wave regime that modified the roughness of the river, and that the wind direction has a greater effect than speed.

3.2.2 *Vegetation*

Parks, sport fields and grass areas, have a very low diffuse backscatter return (Fig. 2 (L)). On the contrary, areas with trees, small shrubs, and tall vegetation may cause considerable isotropic backscattering-echo (Fig. 2 (M)). Though the intensity of this diffuse backscatter is lower than for built-up area, vegetation can preclude the detection of small urban fabrics.

We can note that stadium are well detected when rounding by terraces. The contrast between the terraces and the field helps in determining the major orientation (Fig. 2 (N)).

The cemeteries are also well detected by contrast with the built-up neighborhood which is brighter(Fig. 2 (O)).

4 CONCLUSIONS AND PERSPECTIVES

Different type of urban areas can be detected in SAR images once properly processed.

In high density built-up areas (downtown) the backscattering-echo is large and rarely anisotropic except in case of favorable multiple reflections.

In low density area (residential area, industrial area), the backscattering-echo may be large but is inferior, in average, to high density area. Anisotropic backscattering especially occur in industrial area where building are large-sized.

Though, the diffuse backscattering is not a dominant mechanism in urban area, that kind of backscatter can be larger than the triple-bounce mechanism, notably when metal elements are encountered.

Areas with vegetation are generally well distinguished (parks, field), but the presence of tall vegetation within urban fabrics can lead to misinterpretation.

The street, highways and rail networks are incompletely detected.

It is worth noting that the orientation of the urban fabrics greatly affect the backscatter return. Hence, making use of ascending and descending pass conjointly will be useful to determine the orientation of observed objects.

This study adds evidence on the complexity of the interpretation of SAR data over urban areas. SAR images can not be analyzed at the pixel level as in optical imagery. Each pixel has to be analyzed within its environment by a statistical or textural approach (Carlotto 1996, Basly et al. 1997).

As in optical imagery, urban fabrics should be studied by means of multi-sources SAR imagery. For example, future studies making use of multi-incidence angles, multi-polarization and multi-pass orbiting will be more powerful in extracting valuable urban information from SAR data. That will be performed with the Advanced Synthetic Aperture Radar of the ENVISAT satellite (ESA 1998).

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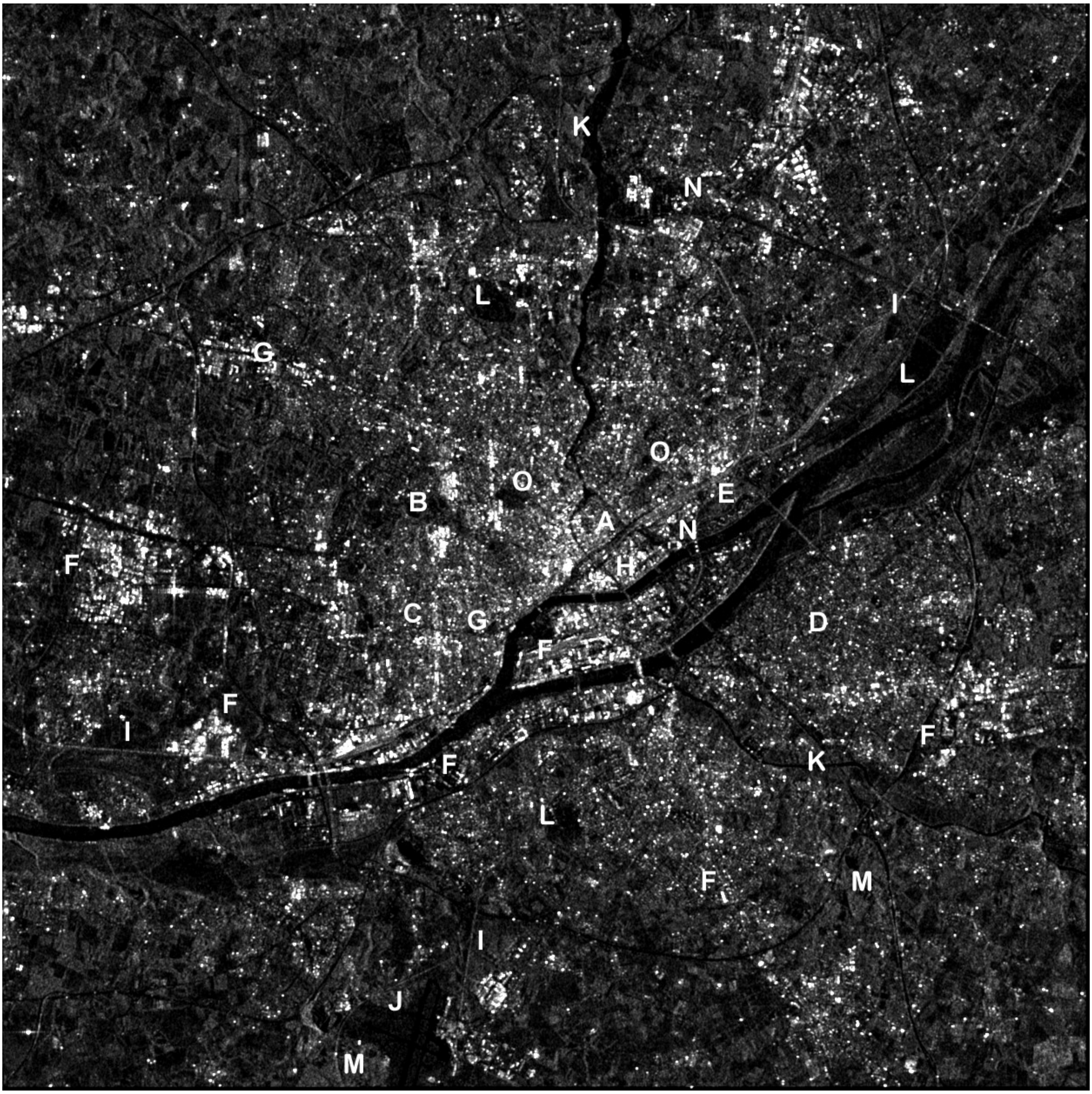
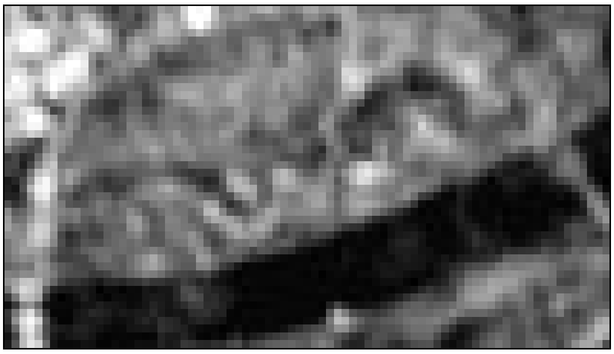


Figure 2. The city of Nantes viewed by ERS-SAR system imaging. This is a mean image derived from 7 PRI images. All the images were acquired in descending pass. The Loire river appears in dark. The airport is located to the South of the river. The island is part of the city.



(a)

(b)

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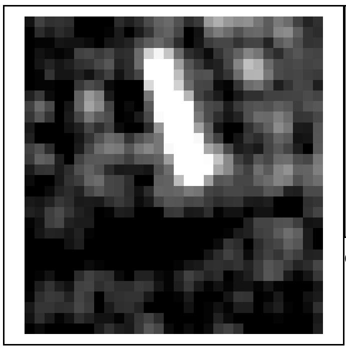
(c)

Figure 3. The Malakoff group. Figure 2-a, detail of the SAR image. The Loire river appears in dark. The Vendée bridge is clearly visible on the right. Figure 2-b, photograph taken from the Beaulieu island. We have estimated the height of the higher buildings, and we have found 20 stores, so about 60 meters. Figure 2-c, aerial photograph enables the estimation of the surface covered and also the buildings count. We find approximately 13 km^2 of covered surface, eleven 20-storey buildings, five long buildings and some other buildings.



(a)

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(b)

Figure 4. Here is a shopping center in the South of Rezé, a town on the South of the Loire river. Its dimension are approximately 150 meters long and 80 meters wide. Figure 5-a is a detail of the SAR image, the size of the pixel is about 13m. Figure 5-b is an aerial photograph taken in 1993 by IGN, the spatial resolution is about 0,7 meter. Although the shopping center don't exactly face the radar wave, the backscattering is very large. Indeed, the frontage has a considerable surface, and the car-park, in front of it, enable double bounce reflection. The detail of the SAR image features an anisotropy that allows the knowledge of the orientation of the building. The building on the left of the shopping center is not well perceived because of the shadowing effect, so the backscattering is caused by the diffuse backscattering of the roof which is certainly a metal one.

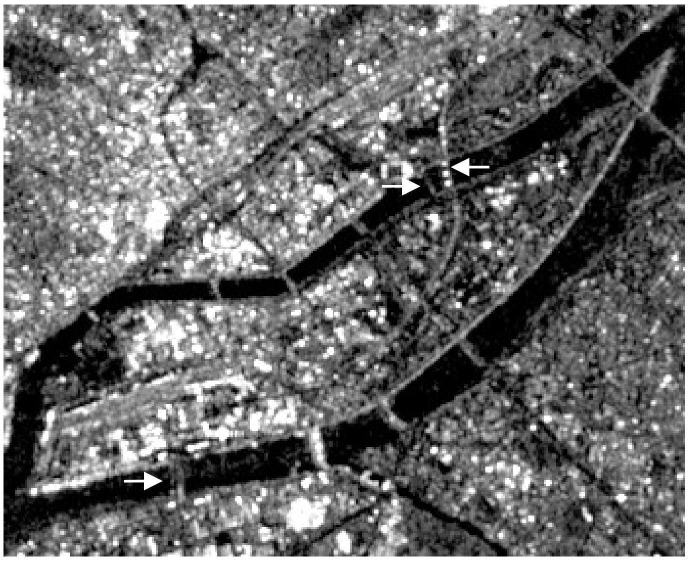

Figure 5. View of the Beaulieu island which is part of the city of Nantes. Detail of the PRI-SAR mean image showing the eleven bridges crossing the Loire river. The brighter one is made of metal. We notice that the pillars of one bridge in the Northern of the island are visible, that bridge is also made of metal (right arrow). The bridges showed with the right arrows are not visible on the aerial photographs (not shown here).