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SAR IMAGERY FOR URBAN AIR QUALITY

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ABSTRACT : This study focuses on the assessment of the potentialities of the Synthetic Aperture Radar imagery to study urban micro-climate and air quality. In urban area, air quality is quite dependent on the air flow drag which is influenced by the aerodynamic roughness parameters of the ground. These parameters are linked to the urban structural features and their typologies. They characterise the evolution of the vertical wind profile with the altitude. To extract structural features, the structure function (also called variogram) is processed on ERS images of the city of Nantes (France). A classification according to the structure function is done that leads to a mapping of the aerodynamic roughness by allotting a roughness parameter to each class.

1 INTRODUCTION

Streets network and buildings modify the aerodynamic roughness of the ground and alters the natural landscape. The urban aerodynamic roughness generates turbulence which acts on the dispersion of pollution layers and also on streets ventilation. The alteration of the natural landscape creates micro-climates such as heat islands where atmospheric reactions are increased (Oke, 1987). Numerous studies deal with the modelling of the air flow drag in relation with the air pollutants diffusion in and above a city. These modelling of the urban climatology need the knowledge of aerodynamic roughness parameters (Bottema, 1997). These parameters are the aerodynamic roughness length z_0 and the zero displacement height z_d. They characterise the evolution of the vertical wind profile. They are related to the urban morphology which influences the turbulent air flow.

This investigation particularly aims at the assessment of the potentialities of SAR imagery for the extraction of urban features and their typologies. The studied site is the city of Nantes, along the Loire river, west of France. At first, we have assessed the time variability of the multitemporal SAR images over the city. Images are averaged for increasing the quality of information over the city. The mean image demonstrates the relevance of the SAR imagery for the study of urban features. Then the mean image is visually inspected with respect to a map of the city and aerial photographs. Main urban features of our interest are present, that proves the significance of the SAR imagery in urban detection. Structure function is used for the automatic discrimination of the districts related to the aerodynamic roughness of the ground. Indeed, in a previous study, we have shown that the structure function was a suitable tool to discriminate types of buildings and their organisation (Basly et al., 1997). A classification of the mean image according to the structure function is made. Finally, a map of aerodynamic roughness based on this mathematical method is made, which demonstrates the usefulness of the SAR imagery for urban air quality.

2 DATA USED AND TIME VARIABILITY

The data are ERS-1 and ERS-2 SAR images provided by ESA. The set of data contains seven images in Precision Image format (PRI), taken from May 1995 to October 1996. All images have been taken in descending mode. Radial direction is almost East - West. In PRI format the speckle is slightly decreased by a multilook processing. The pixel size is 12.5 meter in both directions. The images were geometrically corrected to fit a IGN map with a scale of 1:100 000 in Lambert III projection. The speckle is not filtered out in images to not alter the structures any further after the geometrical rectification.

The time variability of the SAR signal over the city is assessed. The morphological urban structures are always present in each image. We can consider that these structures are invariant in the time span of our dataset. Beside the speckle effect, meteorological conditions affect the signal quality. The wind vector (direction and velocity) mostly affects the contrast between rivers and their banks, but also between rivers and bridges. Rainfall affects the contrast between urban area and vegetation area. Urban structures are perceived in a single image, but the change in quality avoid a good interpretation. So, we have averaged multitemporal images. This average decreases the level of speckle, without using sophisticated filters, preserving the structures. It allows a better discrimination of the urban features.

3 PHOTOINTERPRETATION OF THE SAR MEAN IMAGE

Figure 1 displays the mean image obtained by averaging the six best images. Major roads are well perceived, they appear in dark as the rivers. Arable land and unbuilt areas appear in grey. Built-up areas appear in bright. The visual inspection demonstrates the importance of the geometry of the object because in urban area reflection backscattering prevails on diffuse backscattering (Gouinaud, 1996; Dong et al., 1997). The relative orientation of the object with respect to the direction of the radar wave also affects the backscattering. If the relative orientation of the object is perpendicular to the radar wave direction then the backscattering is high, and the object is clearly visible. If the relative orientation and the wave direction are the same then the object is less visible and even not visible, except for objects with metallic elements such as railway track, bridge, roof of commercial and industrial buildings, etc. An example of the importance of the orientation is the Malakoff group which is made, in part, of eleven 20-storey buildings of 20 meters wide. This group is located on the north of the Loire river and on the east of the downtown. It covers a surface of approximately 10 km^2. The hip of the buildings face the east, so the frontages do not face the radar wave and the backscattering is very low. Indeed, the backscattering is similar to the waste ground area which is located on the north of the group. On the contrary, we can see a large imaging anisotropy situated in the south of the town of Rezé, in the south of the Loire river. This anisotropy is the result of the backscattering of a shopping market which is about 140 meters long and 80 meters wide. This anisotropy allows the determination of the relative orientation of this shopping center, and it approximately faces the radar wave.

Concerning the roads or the streets, they appear dark because of the specular reflection. However, if they are situated in a high density built-up area and if they are transversally orientated then they are not visible.

Regarding the main urban features, we conclude that :

- the industrial buildings are well perceived and highly reflective (i.e. appear in bright),
- the areas comprising buildings with more than one store are well distinguished if they are mostly orientated perpendicular to the direction of propagation of the radar wave,
- the residential areas are homogeneous and low reflecting (grey tone),
- the unbuilt areas are low reflecting (dark tone).

It appears clearly that SAR imagery is linked to the structural features of the urban area. The main factors for the perception of structural features are :

- the height and the width of the buildings (mean and variance),
- the orientation relative to the spacecraft orbit,
- the surface onto the ground,
- the density of buildings (*i.e.* the number of buildings per area unit),
- the contrast between built-up area and the surrounding,
- the materials of the buildings.

These structural and morphological features alter the roughness of the ground which influences the air turbulent flow, hence they are linked with the aerodynamic roughness parameters z_0 and z_d.

4 AERODYNAMIC ROUGHNESS

The aerodynamic roughness length, z_0, characterises the surface state and characterises the interaction of the air flow with the ground surface. z_0 is dependent on the irregularities of the ground (Monin and Yaglom, 1971). Thus, z_0 is influenced by the local morphology.

The zero-displacement height (or zero-plane displacement), z_d, represents the physical height of the obstacles on the ground surface. z_d is used for method of calculation and it is not fundamental for the understanding of the phenomena happening near the ground.

Both roughness parameters take place in the description of the vertical wind profile U(z) which allows the knowledge of the evolution of the wind velocity with the altitude above the ground surface.

On the assumption of neutral conditions *i.e.* when having an air flow with a constant momentum above an infinite and homogeneous surface, the vertical variation of the horizontal mean velocity can be described with the formula (1) :

$$U(z) = \frac{u}{K} \ln\left(\frac{z - z_d}{z_0}\right) \qquad (1)$$

where :

- z is the height above the ground,
- u_* is a scaling variable representing the friction velocity,
- K is the Von Karman constant.

U(z) is used in modelling of the diffusion of pollutants layer above cities but also for modelling the streets ventilation (Bottema, 1997 ; Mills, 1997).

The relationships which link z_0 and the local morphology are complex, and the evaluation of z_0 is complex too.

We have demonstrated that local morphology, which is related to the aerodynamic roughness length, influences SAR imagery. Hence we have explored the possibility of using SAR images to derive aerodynamic roughness map of cities.

5 THE STRUCTURE FUNCTION AS AN INDICATOR OF THE LOCAL VARIABILITY

It is found that the structure function (also called variogram) is well suited to distinguish different kind of built-up area. Indeed, the structure function respect the anisotropy and the variance of the considered area. The degree of anisotropy of the structure function is a function of the density, of the type of buildings, and of the overall orientation of the area. The variance of the sample is given by the value of the larger scale. The closer to the pixel size the objects and the more homogeneous the district, the smaller the variance. We have used a bi-dimensional structure function in order to have information in both directions (Basly et al, 1997).

Figures 2, 3, and 4 display example of structure function processed on different urban area. Figure 2 exhibits the structure function for the Pornic bridge.
This metallic bridge crosses the Loire river, south of the Beaulieu island. The bridge is north-south oriented and appears in bright. The structure function is totally anisotropic, showing very high correlation between north - south pixels (variance is about zero), and very low correlation between east - west pixels even for short distance. Further, finite variance means that the size of the sample (here 7 pixels, that is about 120 meters) is larger than the typical size of the structures observed. Figure 3 shows the structure function for downtown. This part of the city is situated on the north of the Loire river. There is no privileged direction for small scales (here scale is taken as a distance). At larger scale the north - south direction imposed by two main streets is reinforced by large administrative buildings lining these streets. Accordingly the structure function is isotropic for small scales (up to 50 meters) and becomes anisotropic with a larger variance in the east - west direction. Further the variance is finite and the maximum value is not high, because this part of the city is homogeneous, and the typical size of the structures are close to the pixel size. In figure 4 is displayed the structure function of a residential area, the Grillaud district. This district is situated on the west part of the city, and it is made of small buildings and houses barely spaced. There is no privileged direction and no typical scale for the objects. Hence the structure function is isotropic for all scales under concern, and the variance is not finite, indeed the variance increases as the size of the sample increases.

We conclude that the structure function is a suitable tool to discriminate different types of built-up area and their structures related to the aerodynamic roughness.

6 CLASSIFICATION OF THE CITY ACCORDING TO THE STRUCTURE FUNCTION

Considering the results obtained with the structure function, a classification of the mean image is done by computing the structure function for each point of the image.

For the classification, in order to avoid excessive computing time, we have characterised the structure function with only nine points instead of 64. These points represent the following information :

- anisotropy,
- slope,
- orientation of the observed structure,
- maximum level.

After extracting the characteristic points, nine image layers are built. Then an unsupervised hierarchical descending classification is made using hash coding processing (Albuisson, 1995).

Comparing the area covered by each class with the mean image, the IGN map and also with aerial photographs, we have found correspondences between classes and urban local morphology (density in built area, mean height, height variability, orientation, spacing of buildings,...). It means that this classification corresponds to a classification of the urban morphology. We have seen that this morphology is related to the aerodynamic roughness.

Hence, a mapping of the aerodynamic roughness is possible by allotting an aerodynamic roughness parameter to each class.

7 MAPPING OF THE AERODYNAMIC ROUGHNESS LENGTH

The z_0 values are taken from the literature (Scherer et al., 1996). z_0 is 0.01 meter for rivers, up to 3.0 meter for industrial buildings. Figure 5 displays the aerodynamic roughness length map of the city of Nantes. The brighter the grey level, the larger the z_0.

Looking at figure 5 we recognise the shape of the Loire river and guess the Beaulieu island. The valley of the Erdre river and the airport are also visible and appear in dark, so a weak z_0 value. The boundary between urbanised area and country is not conspicuous. The result is difficult to interpret because some classes have close z_0 values, so they have close grey level. Further, the structure function gives information for a sample of 8 pixels in both directions, so for a sample of about 140 meters in both direction. This precision is sufficient to describe different districts, but their boundaries are not respected.

The accuracy of the map has not been assessed yet. A means to assess the accuracy would be to compare the results with measurements of z_0 values or to their assessment by means of conventional methods.

8 CONCLUSIONS

The main urban features related to the aerodynamic roughness are mostly present within a SAR image. Averaging multitemporal data is necessary due to the high variability of the quality of the images. This average decreases the speckle and allows a better discrimination of the urban features that shows the usefulness of SAR imagery for urban studies.

The orientation and the geometry of the objects with respect to the radar wave direction play a major role for them to be perceived.

A method has been devised to map the aerodynamic roughness length z_0 over the city of Nantes that proves the relevance of SAR imagery for studies of urban air quality.

Independence of the method with respect of data used has been assessed by applying it on the set of data used in a previous study (Basly *et al.*, 1997). Comparing the results we have found similarity although the formats of the data were not the same (Single Look Complex vs PRI). It demonstrates that the method used is reliable.

Accuracy of the computed maps is still to be assessed.

9 ACKNOWLEDGEMENT

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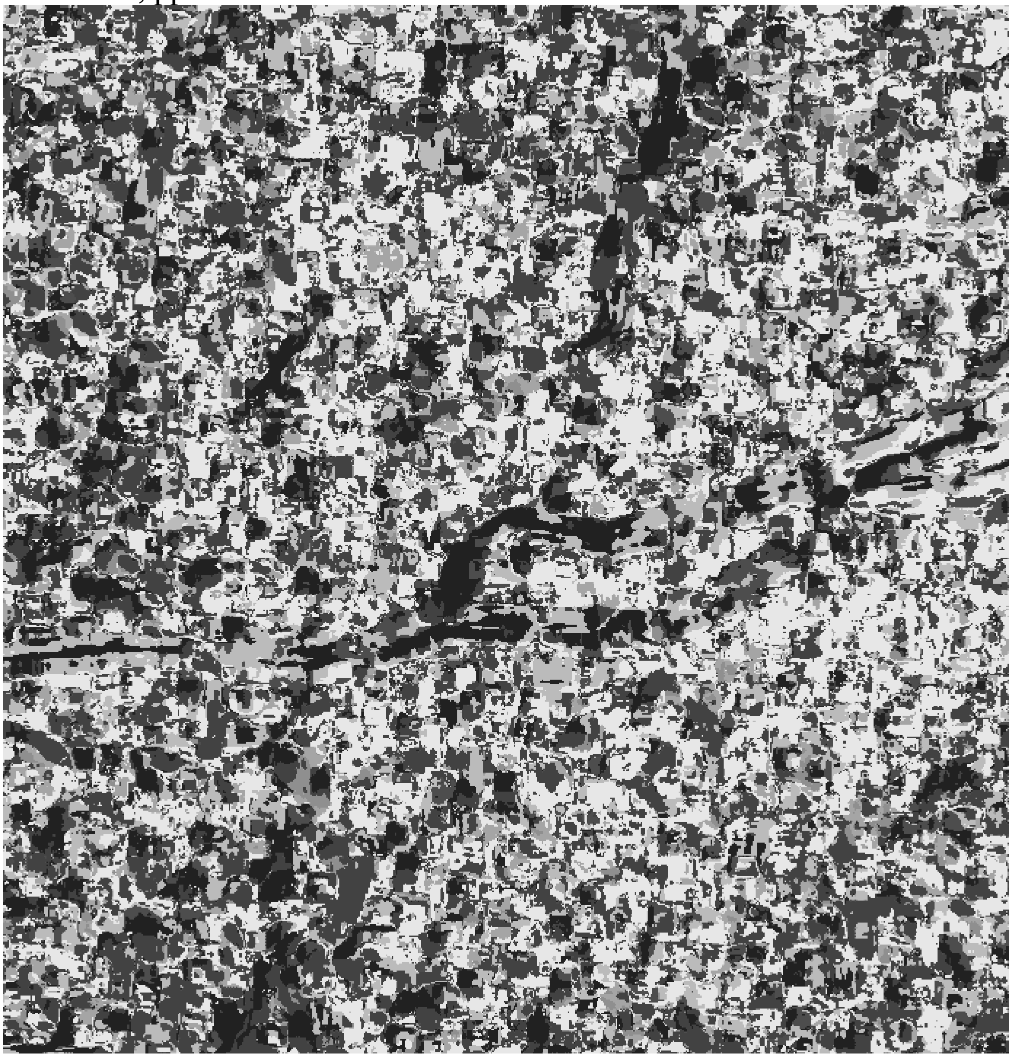


Figure 1.
Mean image computed from six SAR images. The Loire river appears in dark, crossed by several bridges in bright. In dark are the major roads, and the airport in the lower left corner. The island is the Beaulieu island, and is part of the city of Nantes. The area is mostly comprised of urban areas, but also of some agricultural lots and woods, which are not distinguished each from the other in this image.

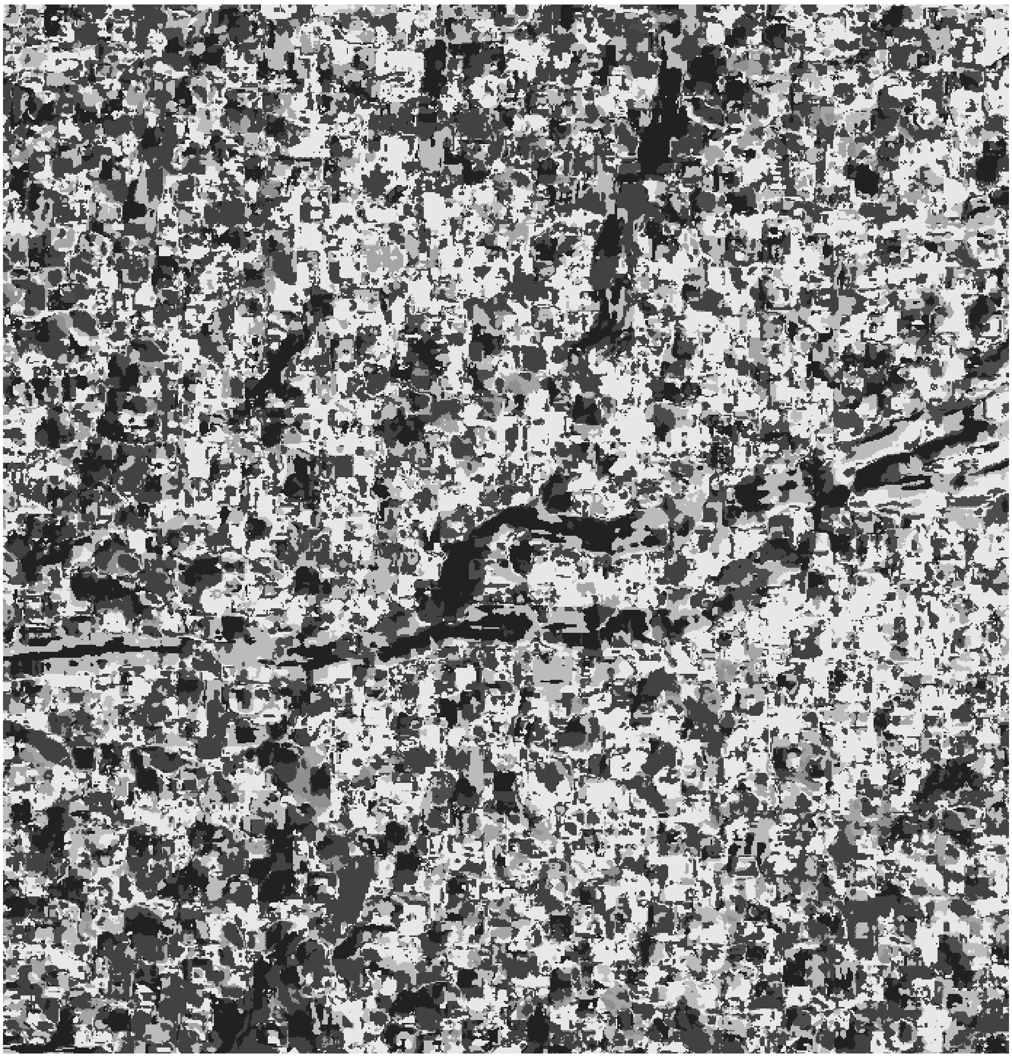


Figure 2.

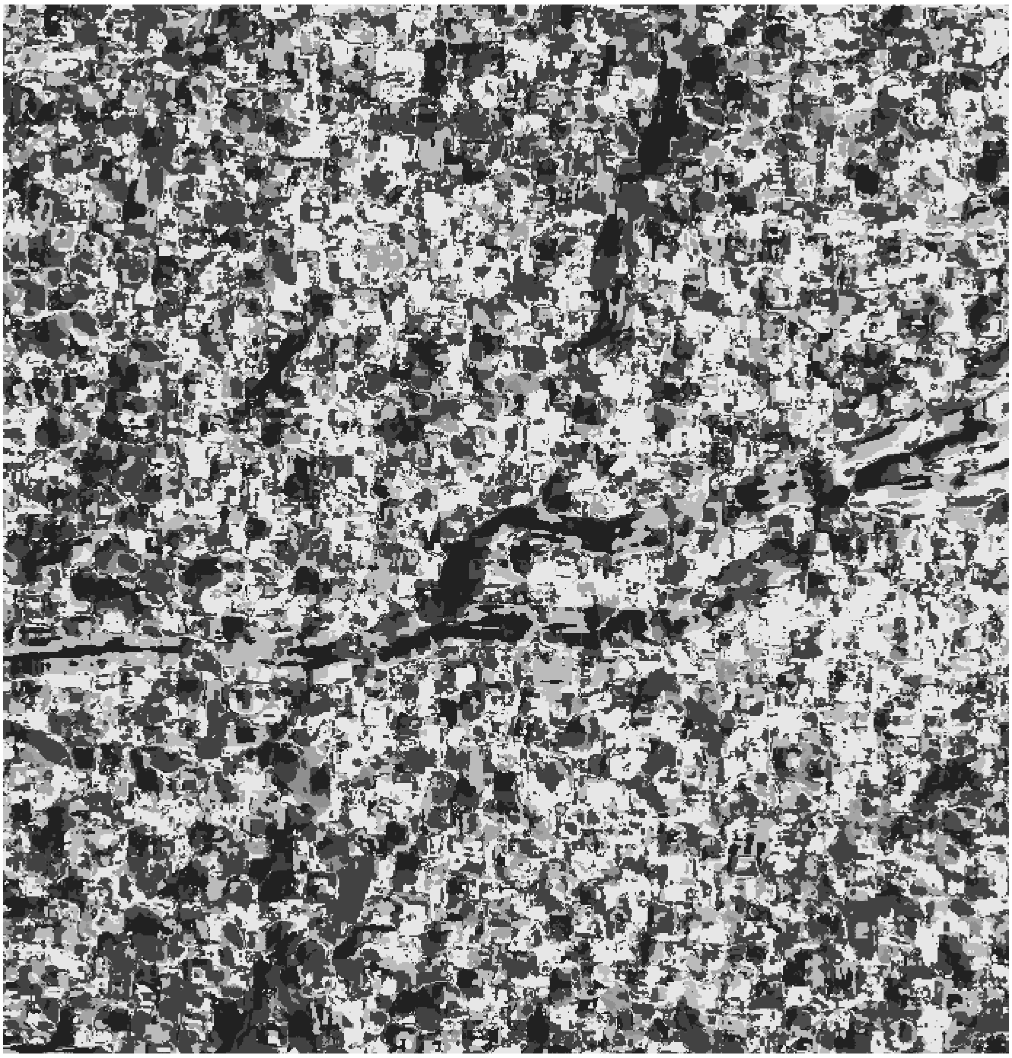
Structure function for the Pornic bridge.

Figure 3.

Structure function for downtown.

Figure 4.

Structure function for the Grillaud district, a residential area.



z_0 in meter

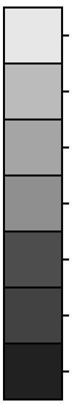


Figure 5.

Aerodynamic roughness map, achieved after classifying the structure function parameters computed in each pixel of the SAR mean image of the city of Nantes. The brighter the grey level the larger the z_0 value.