Mapping the aerodynamic roughness length using SAR images

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**ABSTRACT:** The aerodynamic roughness length characterizes the way the air flows over a surface, and more exactly the thickness of the layer above the surface wherein the airflow is influenced by the surface. This parameter is an input to several numerical codes that model dynamics of air flow. It is of interest in several domains, including air quality in cities and electricity production from windmills.

Satellite data allow the mapping of the aerodynamic roughness, through land cover and land use mapping. Usually, classification of optical data is used for land use mapping and attribution of roughness length to classes. Some studies have demonstrated the potential of Synthetic Aperture Radar for roughness mapping. This paper exploits these early results in order to establish an operational procedure.

We have designed a classification process based on a multi-resolution approach. The first step is the combination of a set of SAR images in order to reduce the influence of atmospheric conditions on the representation of structures. This multi-temporal image is processed in order to model the structures and to enhance their properties. Then a classification process is applied to the data set comprising the multi-temporal SAR image, and the modeling of the structures. The classes determined through the supervised classification process are affected to roughness length, based on the corresponding tables determined from the European Wind Atlas.

This paper presents this approach, its principle, and mathematical aspects. An illustration of the methodology is provided.

1 **INTRODUCTION**

Aerodynamic roughness is an important parameter for the evaluation of the land use impact on wind resources or for modeling of atmospheric fluxes for air pollution studies. This parameter allows taking into account the influence of the natural obstacles and of the landscape in numerical models. The larger this parameter, the thicker the boundary layer and the disturbances at a given altitude. Figure 1 presents the impact of $z_0$ on the wind speed. If a wind speed of 10 m/s is measured at 10 m for $z_0 = 0.0002$ (curve at the right side of the figure), this speed will be 3.5 m/s at the same height for $z_0 = 1.6$ (curve at the left side of the figure).

Satellite data allow the mapping of the aerodynamic roughness, through land cover and land use mapping. Usually, classification of optical data is used for land use mapping and attribution of roughness length to classes (Hasager 1997). A good source for this land cover mapping is the CORINE Land Cover for all the European countries. But the scale of these data (1/100 000) is often not relevant for a good modeling of the land use influence on wind flows.

2 SAR AND AERODYNAMIC ROUGHNESS LENGTH $Z_0$

Obstacle impacts on the air fluxes are linked to their structure. Depending on their shape, the disturbances on the air fluxes of an object extend vertically above three times its height and horizontally until forty times its height downstream (Troen and Petersen, 1989). The aerodynamic roughness impacts on the vertical profile of the horizontal mean wind speed as (Monin and Yaglom, 1971):

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

where $u^*$ is the friction speed, $K$ is the Von Karman’s constant, $z$ the altitude, and $z_0$ the aerodynamic roughness length corresponding to the height above the displacement plane at altitude $z_d$ at which the mean wind $U(z)$ becomes zero when extrapolating the logarithmic wind speed profile downward to the surface layer.

SAR sensor delivers a backscattering coefficient $\sigma_0$. This coefficient is strongly affected by the composition of the ground cell and by its structure. Both $z_0$ and $\sigma_0$ are dependent on topographic roughness at the sub-meter scale (Greeley and Blumberg, 1995). Hence, the measurement provided by a SAR is strongly related to the roughness of the area (Basly, 2000; SARScape Project, Le Hégaret-Mascle et al. 2003). A methodology is proposed based on this observation.
3 METHODOLOGY FOR AERODYNAMIC ROUGHNESS LENGTH EXTRACTION

The following scheme presents the methodology for the estimation of the aerodynamic roughness length from SAR images. The first step is the combination of a set of SAR images in order to reduce the influence of atmospheric conditions on the representation of structures. This multi-temporal image is processed in order to model the structures and to enhance their properties. Then a classification process is applied to the data set comprising the multi temporal SAR image, and the modelling of the structures. The classes determined through the supervised classification process are affected to roughness length, based on the corresponding tables determined from the European Wind Atlas (Troen and Petersen, 1989).

![Diagram showing the methodology](image)

Figure 2. Methodology for the estimation of aerodynamic roughness from SAR images.

3.1 Multi-temporal processing of SAR images

Multi-temporal processing of SAR images is often used to reduce the speckle effects. In addition to this noise reduction, applying a multi-temporal processing to the SAR images allows the production of a resulting image with a reduce dependence to meteorological effects. The meteorological effects such as wind or humidity change the behaviour of the backscattering coefficient. Hence by applying a multi-temporal mean to the set of images, these effects are reduced. The backscattering coefficient is than more representative of the structures of the area of interest.

After the calibration of the original images, a precise registration is applied to the images. Then the mean image is computed.

3.2 Structures modelling

The association of the wavelet transform and the multiresolution analysis leads to a powerful and comprehensive analysis and processing of remotely sensed images. The concept of multiresolution analysis introduced by Mallat (1989) derives from the Laplacian pyramids (Burt, Adelson, 1983).

Figure 3 is a very convenient description of the multiresolution analysis and more generally of pyramidal algorithms.

The basis of the pyramid is the original image. Each level of the pyramid is an approximation of the original image computed from the original one. When climbing the pyramid, the successive approximations have coarser and coarser spatial resolutions. The theoretical limit of a multiresolution analysis is one pixel representing the mean of the original image. Due to some physical constraints
this limit is never reached. The basis of the pyramid can also be considered as an approximation of
the landscape measured by the sensor.

Associated to the multiresolution analysis, the wavelet transform allows the description of the
differences existing between two successive approximations of the same image i.e., of two successive
levels of the pyramid, by its wavelet coefficients. If the process of the multiresolution analysis is
inverted, the original image can be exactly reconstructed, from one approximation and from the
different wavelet coefficients. These tools allow a hierarchical description and modelling of the
information contained in the image. Ranchin and Wald (1993) proposed some potentialities of these
tools in the field of Earth Observation. A small presentation of these tools and of two algorithms
in the context of remote sensing is proposed in Ranchin (1997). In the proposed method, the used
algorithm is the “à trous” algorithm (Dutilleux, 1987). For each iteration, one context image and
one wavelet coefficient image are computed. They have the same number of pixels as the original
one, and can be compared pixel by pixel to the original one. The wavelet coefficient image represents
the characteristic scales of the original image with no privileged direction.

The wavelet coefficients images always have histograms, which are centred at zero and present
a very sharp distribution. Figure 4 is a typical example of the histogram of the wavelet coefficients
image for a natural image. This histogram which is a representation of the probability density
function (pdf) of the image can be adjusted to a theoretical pdf obeying a Laplacian or a Gaussian

Figure 3. Pyramid representing the multiresolution analysis combined with the wavelet transform.

Figure 4. Typical histogram of the wavelet coefficients image representing the information at a given
scale (here between one and two meters) for a natural image.
law. Following Antonini et al. (1992), the best results were achieved by fitting the histogram to a generalized Gaussian law.

The contents of the histogram can be interpreted as follows:

- the values close to zero (central peak of the histogram) represent noise or very small variation of the image,
- the high values of the histogram (left and right parts of the histogram) represent the strong variations of the image i.e. well-marked structures as borders between different elements.

In this work, we considered that all the obstacles that are within a distance of 100 m influence the roughness of an object. The data set is composed of Precision Images (PRI), at 12.5 m, we will represent the structures using the three first wavelet coefficients images produced by the application of an “à trous” algorithm (Dutilleux, 1987).

3.3 Classification process

The classification process is a supervised approach based on a hierarchical descending approach (Benzecri, 1973) called mediancut (Albuisson, 1995). The inputs of the classification process are the mean image and the three wavelets coefficients images as described previously.

4 CONCLUSION

The resulting image is proposed in Figure 2. The first analysis of the resulting classification is interesting. The roughness classes seem to be in accordance with the ground truth and some quantitative evaluation should be conducted.

This paper presents the methodology for estimation of the aerodynamic roughness through the use of a set of SAR images. The repetitiveness of the methodology is easy, but need some skills in the interpretation of the resulting classification. The evaluation of the process will be under take by Risoe and an independent research and engineering French institute, the CSTB. This evaluation comprises a global evaluation of the resulting classification, but also a comparison to ground-measured aerodynamic roughness length.

REFERENCES


