# THE EFFECTS OF POLARIZATION ON FRACTAL DIMENSION MAPS ESTIMATED FROM SAR DATA

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## ABSTRACT

In this paper the innovative SAR image processing technique developed by the authors and aimed to provide a map of the point by point fractal dimension of a single (amplitude) SAR image is applied to a data-set of COSMO-SkyMed images. The considered images were acquired with different polarizations in different days of August 2011 (i.e., the data set is not fully polarimetric). The main objective of the paper is to explore the potential dependence on polarization of the fractal dimension maps estimated on natural and urban scenarios. The comparison of the obtained maps is performed investigating the statistical behavior of the fractal dimension maps in homogeneous areas. The obtained results demonstrate the independence of the maps from the considered polarization channel.

## 1. INTRODUCTION

The necessity of developing tools for the extraction of value-added information from high resolution SAR data is a very relevant question in the remote sensing community. As a matter of fact, a huge amount of SAR images is currently available, provided by many space and airborne high resolution SAR sensors, but these data are not yet ready for standardized, massive use from non-expert SAR scientists. As a matter of fact, SAR products end-users are mostly interested in monitoring physical parameters characterized by a clear and precise meaning within their scientific area, and generally prefer data provided in easy-to-use formats. Therefore, the use of SAR images is severely limited to radar sensor experts since it requires supervised analysis to support any major image application.

Within this framework, the authors developed an innovative SAR image processing technique which, working on a single (amplitude) SAR image, provides the map of the point by point fractal dimension of the scene observed by the sensor [1], [2]. The fractal dimension is a meaningful and effective parameter for the description of the roughness of natural surfaces. Moreover, it allows to distinguish areas different from a geomorphologic viewpoint and recognize geodynamic processes accountable for natural structures formation [3]-[5]. The fractal dimension of natural areas, due to the fact that it is related only to the roughness of the observed surface, shows a very interesting behavior: it is one of the few parameters which we expect to be very stable whenever illumination and radar conditions change. However, when the fractal estimation is performed in presence of man-made objects, non-fractal characteristics appear on the fractal maps [6]: these characteristics are mainly related to the strong signature and to the significant geometrical distortions present on SAR data when built-up areas are imaged. Hence, these non-fractal characteristics can be heavily modified whenever a change in the acquisition parameters of the sensor (e.g. view angle, resolution) occurs. This exceptional properties have been discussed and verified by the authors w.r.t. changes in the sensor look angle and local incidence angle in [7]-[9].

In this paper the fractal dimension maps generated using this innovative technique on a set of images acquired by the same sensor and relevant to the same area, but with different polarizations, are analyzed and compared for the first time. For the analysis we employ a set of Cosmo-SkyMed stripmap SAR images relevant to the area of Naples and its surroundings, including part of the urban area and the natural area relevant to the Somma-Vesuvius volcanic complex: resolution is in any case 3x3 $m^2$, while the polarization varies in the different images. In particular, all the four polarization cases (HH, VV, HV, VH) are considered. Note that the data set used in the present paper is not fully-polarimetric, since the considered images were acquired in different days of August 2011. The fractal dimension maps are estimated all over each SAR image, independently if natural or man-made features are present. Our analysis is aimed at exploring potential dependencies of the obtained maps on data polarization.

The paper is organized as follows. In Section 2 the used estimation algorithm is briefly described, while Section 3 is devoted to the presentation and discussion of the obtained results. Finally, in Section 4 some concluding remarks are provided.

## 2. FRACTAL DIMENSION ESTIMATION

The retrieving of the fractal dimension is performed through spectral analysis of the amplitude SAR data, whose full details are presented in [2]. In particular, the Capon spectral estimator is used, due to its effectiveness in the estimation of power-law spectra. However, in order to obtain a point-by-point map of the fractal dimension the spectral estimation is performed using a window sliding over the whole SAR image: the window

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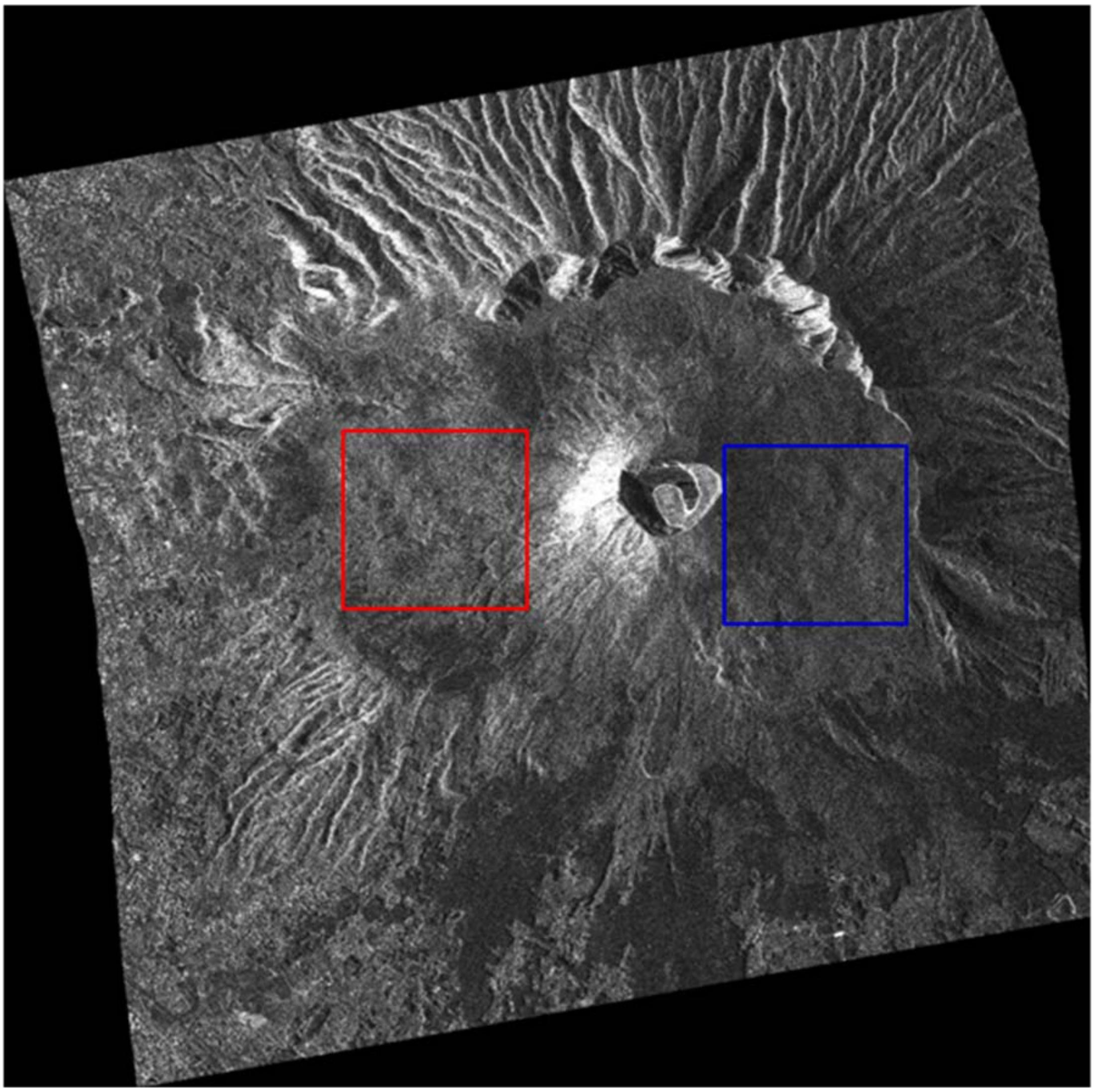
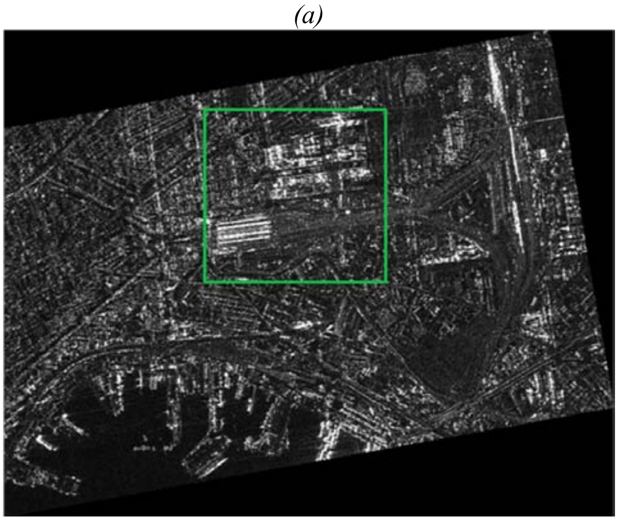


(a)



(b)

*Figure 1. Geocoded version of the VV amplitude image of the Vesuvius (a) and of the urban area (b). The windows used for the statistical comparison are overlaid on the images.*

*Table 1. Statistics of the areas marked in red.*

| Fore-Slope | $D_{min}$ | $D_{max}$ | $D_{mean}$ | *Stddev* |
|---|---|---|---|---|
| HH | 2.14 | 2.46 | 2.31 | 0.05 |
| VV | 2.13 | 2.48 | 2.30 | 0.05 |
| HV | 2.14 | 2.52 | 2.34 | 0.05 |
| VH | 2.15 | 2.50 | 2.34 | 0.05 |

*Table 2. Statistics of the areas marked in blue.*

| Back-Slope | $D_{min}$ | $D_{max}$ | $D_{mean}$ | *Stddev* |
|---|---|---|---|---|
| HH | 2.15 | 2.52 | 2.34 | 0.05 |
| VV | 2.15 | 2.51 | 2.35 | 0.05 |
| HV | 2.19 | 2.54 | 2.37 | 0.05 |
| VH | 2.20 | 2.55 | 2.37 | 0.05 |

*Table 3. Statistics of the areas marked in green.*

| Urban Area | $D_{min}$ | $D_{max}$ | $D_{mean}$ | *Stddev* |
|---|---|---|---|---|
| HH | 1.58 | 2.48 | 2.14 | 0.11 |
| VV | 1.59 | 2.58 | 2.15 | 0.11 |
| HV | 1.60 | 2.53 | 2.19 | 0.12 |
| VH | 1.68 | 2.52 | 2.19 | 0.12 |

encloses small portions of the image that are supposed to share the same fractal parameters and a unique value of fractal dimension is assigned to the center pixel of each window.

The dimension of the sliding window results from a trade-off between the accuracy of the estimation and the resolution required for the generated fractal maps. It is evident that an appropriate choice of the sliding window dimension is of key importance whenever the analysis and interpretation of the fractal maps is in order. In fact, accuracy and resolution of the obtained maps can play different roles according to the particular application of interest.

In the following a sliding window of 51x51 pixels is considered: in fact, this size represents a good compromise between accuracy and resolution, at least for the analyses presented here. As a matter of fact, it allows identifying with good accuracy significant geophysical characteristics of the scene under survey.

## 3. ANALYSIS OF THE FRACTAL MAPS

A set of four COSMO-SkyMed stripmap images, with 3m x 3m resolution, relevant to the area of Naples and surroundings and including both urban areas (the business district of Naples) and natural ones (the Somma-Vesuvius volcanic complex), was considered for the experimental set up. The images were acquired in four different days of August 2011: each image acquisition is relevant to a different polarization (HH, VV, HV, VH).

Two sub-images were cropped from each of the original images for analysis purposes: the first one encloses an area of few square kilometers around the Somma-Vesuvius volcanic complex and the second one is relevant to the Naples business district. Therefore, the former one is made up mainly of natural elements, while the latter of man-made ones. For all the sub-images the fractal dimension maps were estimated and geocoded using the SRTM DEM of the area of interest. The geocoded versions of the VV amplitude sub-image of the Vesuvius and of the urban area are presented in Fig. 1 (a) and (b), respectively. The four estimated fractal dimension maps (one for each polarization) relevant to the Vesuvius case are shown in Fig. 2, while those relevant to the urban area are presented in Fig. 3. Note that in the fractal maps in Fig. 3 the black spots are related to the presence on the scene of man-made objects [6], such as buildings, which provide estimated values outside of the allowed range for fractal objects, whose fractal dimension is constrained to hold values ranging in ]2,3[. In Fig. 2 this happens also for the layover areas, which are mainly located close to the Vesuvius cone top and on the Mt. Somma slopes area in the North [9], [10].

The obtained maps are compared in a statistical sense: as a matter of fact, from an application viewpoint we are mainly interested in the values assumed by the fractal dimension on homogeneous areas, rather than on punctual characteristics related to the statistical behavior of single image pixels [9]. This consideration justify the implemented comparison set up. In particular, three windows of dimension 200x200 pixels were considered on the maps: two on the Vesuvius sub-image (in order to account for both fore-slope and back-slope regions [9]) and only one on the urban area. These three windows are marked in red, blue and green on the images in Fig.1, as well as on the maps in Figs. 2 and 3. For the values enclosed in the windows meaningful statistical parameters were evaluated. The numerical values of the computed statistics are reported in Tab. 1, 2 and 3 for the red, blue and green windows respectively, while in Fig. 4 the corresponding pdfs are shown.

The statistics and the histograms of the fractal dimension estimated over natural areas are almost coincident for the HH and VV channels. As expected, the same behavior is presented by the cross-polarized channels, but with slightly larger values of the average estimated fractal dimension. This can be attributed to the lower signal to noise ratio present in the SAR images for HV and VH channels. Anyway, we note that in all the considered cases (both natural and urban ones) the average fractal dimension estimated on the cross-polarized channel is precisely the same, in accordance to the fact that this channels should be equal, apart from the noise component and from potential temporal variations occurred between the acquisition times.

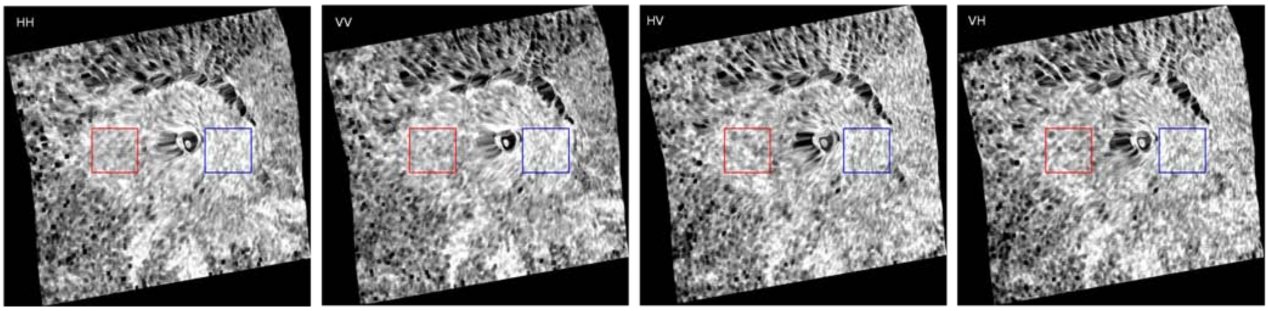



*Figure 2. Geocoded fractal dimension maps relevant to the area shown in Fig. 1 (a). The windows used for the statistical comparison are overlaid on the maps.*

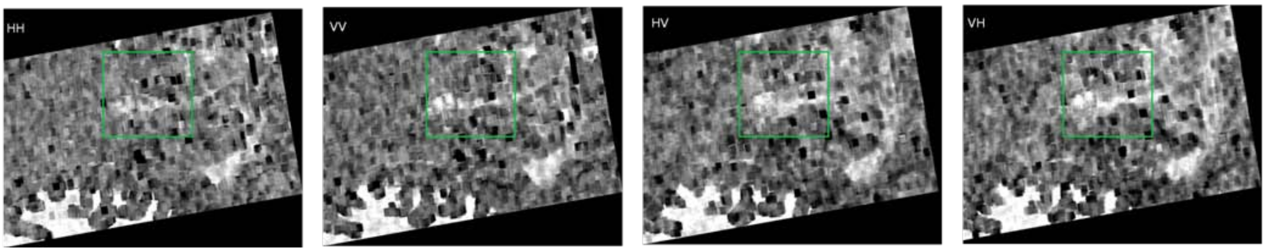
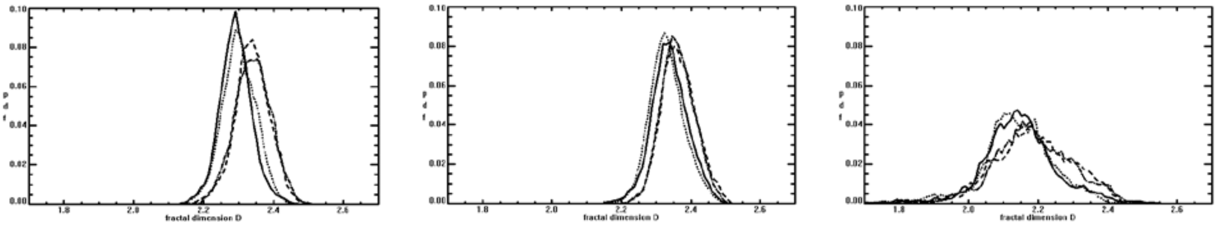



*Figure 3. Geocoded fractal dimension maps relevant to the area shown in Fig. 1 (b). The windows used for the statistical comparison are overlaid on the maps.*




(a) (b) (c)

*Figure 4. Measured pdf of the 200 x 200 pixel areas marked in red (a), in blue (b) and in green (c) on the fractal maps in Figs. 2 and 3. Solid line: VV; dotted line: HH; dashed line: VH; dot-dashed line: HV.*

Approximately the same behavior is experienced on urban areas. However, it is worth noting that the behaviors of the fractal dimension maps estimated over natural and urban areas are significantly different. In particular, on natural areas (in absence of buildings or of any man-made object), the estimated fractal dimension keeps completely in the fractality range ]2,3[. Conversely, the histograms and the statistics of the fractal maps relevant to the urban area present minimum values which are lower than 2 and a standard deviation which is much higher w.r.t. the natural area case. In this case the histograms in Fig. 4 (c) present very irregular and asymmetric shapes, with values of standard deviation more than doubled with respect to the natural areas ones. As a matter of fact, the shape of these histograms is typical of urban areas and can be related to the particular spectral signature of man-made objects [6], [9].

## 4. CONCLUSIONS

In this paper we presented the analysis of the fractal dimension maps estimated on multi-polarization Cosmo-SkyMed data acquired over the Naples area in Italy. The obtained results effectively illustrate the behavior of the fractal dimension maps estimated on natural and urban areas for different polarizations. In particular, it was demonstrated that the estimated value of the fractal dimension does not dependent on polarization, apart from variations only among the co and cross-polarized channels. However, these variations can be related to the lower signal to noise ratio typical of the cross-polarized channels.

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