COSMO-SKYMED AO PROJECTS – EXPLOITATION OF FRACTAL SCATTERING MODELS FOR COSMO-SKYMED IMAGES INTERPRETATION

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ABSTRACT

In this paper the analysis of fractal dimension maps extracted from Cosmo-SkyMed amplitude-only SAR data is considered. The focus is on the Somma-Vesuvius volcanic complex, whose study allows to draw significant comments on the behavior of the fractal maps. In particular, the dependence of the fractal maps on geometrical and geomorphologic characteristics of the imaged surface is investigated. Preliminary results regarding the different behavior of the fractal dimension evaluated on the Gran Cono and on the Mt. Somma are presented.

Index Terms— Synthetic Aperture Radar (SAR), fractals, geophysics

1. INTRODUCTION

In the last years an important part of the activity of the remote sensing community has been focused on the development of processing techniques able to provide data which can be readily interpreted also by non-expert users. These value added products should provide detailed information on specific physical or geometrical parameters of the scene under survey. However, the development and the inversion of new models relating the SAR image to the parameters of interest are necessary in order to implement the extraction procedure.

In this paper the focus is on the analysis of amplitude-only Cosmo-SkyMed SAR images of natural areas modeled as realizations of fractional Brownian motion (fBm) fractal surfaces [1]-[2], which have been acquired in the framework of the AO Cosmo-SkyMed project id. 1200. The authors developed a model which allows the retrieving of the fractal dimension of the observed surface [3], which is a significant geophysical parameter of natural surfaces, dictating the distribution of the roughness over different spatial scales [2], [4]. In particular, the fractal dimension of volcanic structures has been related to the specific nature of the lava flows and of the materials present in the area [5]-[8]. Hence, the possibility to estimate the fractal dimension from a single amplitude-only SAR image is of fundamental importance for the geophysical analysis and characterization of volcanoes and, moreover, can be of great aid for the monitoring and crisis management in case of eruptions and other similar natural hazards [8]-[9].

The models and techniques introduced by the authors in [3] allow the extraction of the point-by-point fractal dimension of the observed scene. In fact, the output product of the proposed procedure is a map of the fractal dimension of the area of interest. 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 can be observed on the fractal map [10]: 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.

In this paper the extraction of the fractal dimension is performed on a Cosmo-SkyMed image of the Somma-Vesuvius volcanic complex. The behavior of the map is analyzed: the distribution of the obtained fractal dimension values is investigated on different zones of the maps. In particular, it is verified that the fore-slope and back-slope areas of the image share a very similar fractal dimension distribution. Furthermore, the obtained fractal dimension can be related to geomorphologic properties of the volcanic surface.

In this context, for the specific case of active stratovolcanoes such as the Somma-Vesuvius volcanic complex, the performed methodology could be an effective tool in the quantitative geomorphology analysis. In particular, we investigate if the fractal dimension analysis is able to discriminate the region of volcano edifices affected by different geodynamic processes that have acted in different spatial and temporal scales. More specifically, our analysis is addressed at the definition of the fractal dimension of the active Vesuvius center. Analyzing the fractal map (see, Fig. 1), we investigate the differences between the fractal dimension of the Gran Cono with respect to the oldest Mt. Somma caldera structure, whose current morphology is resulting by action of different processes as the long-term gravity tectonic deformation process, eruptive mechanisms and subsequent erosion processes.

The paper is organized as follows. In Section 2 the rationale of the fractal dimension estimation is presented. In Section 3 results regarding the analysis of the fractal map of the Vesuvius are reported and discussed. Finally, in Section 3 significant conclusions are drawn.

2. FRACTAL DIMENSION ESTIMATION

The retrieving of the fractal dimension is performed through spectral analysis of the amplitude SAR data, whose details are presented in [3]. In particular, the Capon spectral estimator is used, due to its effectiveness in the estimation of power-law spectra [11]. 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 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 parameter of interest. For example, in order to distinguish different types of lava flows present on the scene a good accuracy (which implies a lower resolution) can be necessary; on the other side, when the identification of small features (e.g. non-fractal features due to man-made objects) is of interest a high resolution (which implies a lower accuracy) is required.

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.

TABLE I
STATISTICS OF THE SUBSETS

	D_{min}	D_{max}	D_{mean}	D_{stdev}
Fore-slope	2.11	2.58	2.31	0.07
Back-slope	2.04	2.53	2.30	0.07

3. ANALYSIS OF THE FRACTAL MAPS

A Cosmo-SkyMed amplitude image of the Somma-Vesuvius volcanic complex is considered here as a case study. The image is acquired in stripmap mode with a view angle of 31° and presents a resolution of about 3x3 m^2. In Fig. 1 both the considered image and the obtained fractal dimension map - whose range of values is [0, 2.7] - are shown: note that the allowed values of fractal dimension for a fractal object are between 2 and 3 [1]-[2]. Values in the map lower than 2 are due to the presence of non-natural features on the scene [10].

Visual inspection of Fig. 1 allows some preliminary comments. The dark spots in the fractal map (which present values of fractal dimension outside the allowed fractal range) are related to the presence of man-made objects or layover zones on the observed scene.

Then, both the image and the fractal dimension map have been geocoded and orthorectified using the SRTM DEM of the area of interest. The geocoded versions of the images presented in Fig. 1 are shown in Fig. 2, as superimposed to a Google Earth optical image of the zone. As a matter of fact, the geocoding step introduced significant artifacts in the fractal dimension maps, which are visible in Fig. 2 as circular smearing regions due to rotation and interpolation. Apart from these effects, which are particularly strong close to layover areas, it is possible to note that the zones of the volcano located in fore-slope and those located in back-slope show very similar distributions for the values of the fractal dimension. This behavior is due to the fact that the fractal dimension D depends only on the roughness of the considered surface, which is the same in the fore-slope and in the back-slope regions. This observation is confirmed by the numerical values - reported in Tab. I - of the statistics relevant to subsets cropped from the geocoded image, one in the fore-slope and the other in the back-slope region. Moreover in Fig. 3 the two plots of the histograms corresponding to the two subsets are reported and compared. From the figure, a very high degree of agreement between the two curves can be appreciated.

The following step consisted in the identification of different behaviors of the fractal dimension in areas presenting different geomorphologic properties. In particular, our attention focused on the occurrence of different statistics of the fractal maps in the zone of the Gran Cono, i. e. the higher part of the volcanic complex, and in the zone of the Mt. Somma, i. e. the northern older part of the whole complex. Indeed, a different behaviors is present in the two zones, which can be partly appreciated also

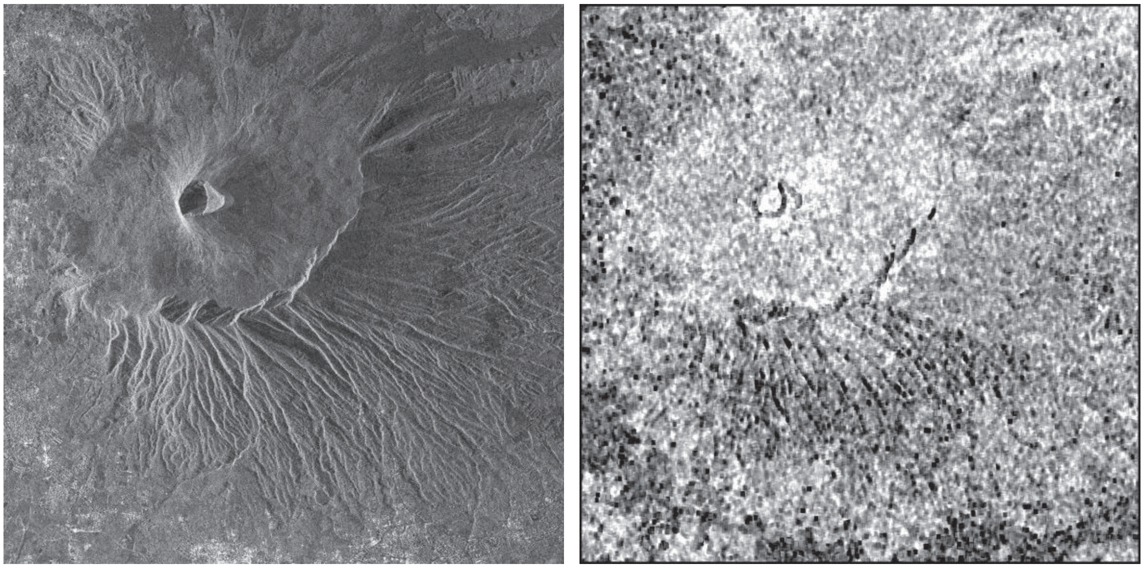

Fig. 1 Cosmo-SkyMed amplitude image of the Vesuvius (left) and the relevant fractal dimension map (right). Near range is on the left.

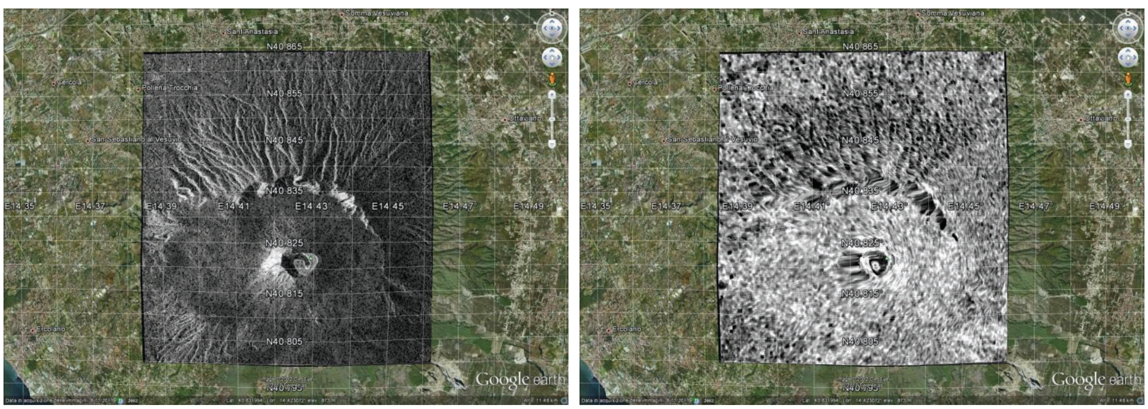

Fig. 2 Geocoded version of the images presented in Fig. 1 superimposed on Google Earth optical image.

looking at Fig. 2, where the western and eastern zones of the fractal map present higher values of the fractal dimension with respect to the northern zone. This fact can be better appreciated also looking at the 3D map shown in Fig. 4, where the fractal dimension map has been superimposed to the DEM of the zone. Furthermore, in order to better highlight this phenomenon we generated a quantized version of the fractal map in Fig. 2, where the values of fractal dimension were grouped in significant classes, as specified in the legend of Fig. 5, where the result of the quantization is again shown as superimposed to the DEM of the scene. From the presented figure it is evident that the Gran Cono, which is mostly represented in red, can be separated from the Mt. Somma, which is represented mostly in blue, through their fractal dimension. Anyway, further investigations will be necessary in order to gain a better insight into the geophysical reasons of this different behavior.

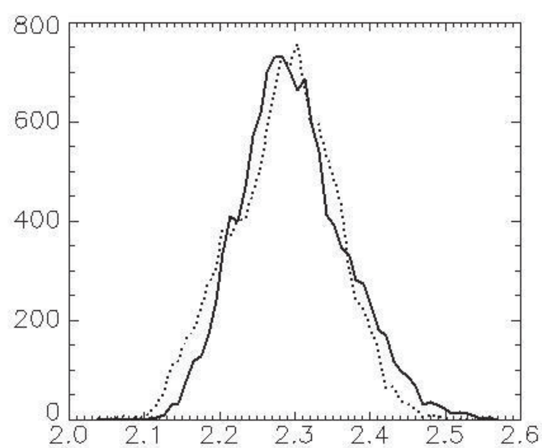

Fig. 3 Histograms relevant to the fore-slope (solid line) and back-slope (dotted line) subsets, whose statistics are reported in Tab. I.

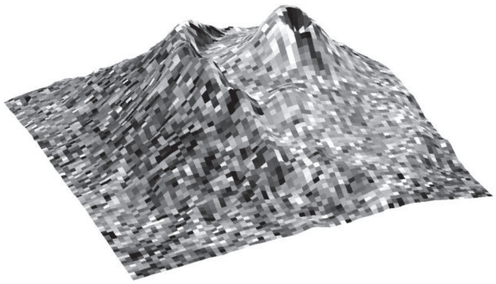

Fig. 4 Fractal dimension map superimposed on the DEM.

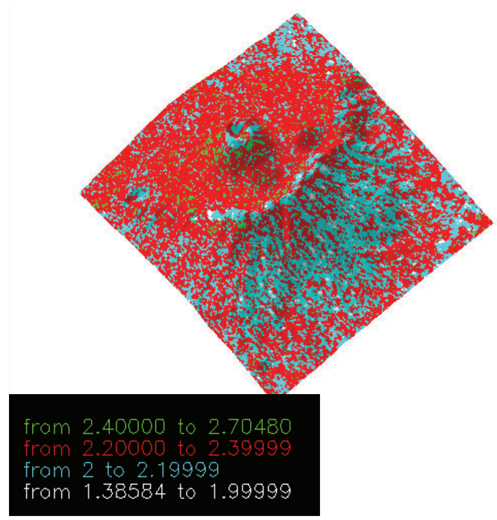

Fig. 5 Quantized fractal dimension map superimposed on the DEM. The false colors legend is reported on the bottom.

4. CONCLUSIONS

In this paper the framework developed by the authors for the retrieving of the fractal dimension map from amplitude-only SAR data is applied on a Cosmo-SkyMed image relevant to the Somma-Vesuvius volcanic complex. The obtained maps are analyzed, using both statistical and geophysical concepts. The provided results, though preliminary, highlight the potentialities of this kind of high level SAR product. In particular, the fractal dimension has proved to depend only on the roughness of the observed scene, being independent from sensor parameters. Finally, interesting preliminary results concerning the different fractal behavior of the Gran Cono and of the Mt. Somma has been demonstrated. In particular, it has been verified that the fractal dimension of volcanic cone is typically included in the range [2.2, 2.4[. This result confirms that the shape of volcanoes represents a natural equilibrium profile; as a matter of fact, the decrease of the fractal dimension retrieved values is systematically associated with secondary geomorphologic phenomena as the case of flank erosion or to anthropic artifacts. In this context, similarly to the fragmentation processes [12] the fractal dimension could be seen as an index of the evolution degree of the volcanic edifices.

5. REFERENCES

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