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Landscape according to surface roughness: experimenting in the Taklimakan Desert

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Abstract—**Surface roughness, interpreted in the wide sense of surface texture, is a generic term referring to a variety of aspects and scales of the spatial variability structure of surface morphology. Even when the interest is limited to short-range roughness, relative to the resolution considered, various aspects of surface roughness can be characterized, such as omnidirectional roughness and roughness anisotropy. Adopting smoothing and/or upscaling approaches it is possible to perform a multiscale analysis of the selected roughness indexes. In this case study, a simplified geostatistical-based algorithm for surface/image texture analysis is adopted for the multiscale analysis. The proposed roughness algorithm is designed to offer a balance between the flexibility and complexity of geostatistical approaches, providing an easy yet informative approach for roughness analysis. Differently from conventional geostatistical approaches, it bypasses the detrending step to reduce at a minimum the user selected computational parameters. The algorithm is capable to partition roughness according to specific lag distances and to roughness anisotropy; moreover, ad hoc roughness indexes can be developed from the basic implementation. The multiscale analysis is based on a simple iterative approach, according to which the short-range roughness indexes are calculated from multiple upscaled versions of a source DEM. The DEM adopted is the 30 m resolution Copernicus DEM, representing a portion of the Taklimakan Desert, China. Despite the simplicity of the approach, the informative content extraction potential is very high, as confirmed by the unsupervised clustering of the landscape based on multiscale roughness indexes.**

I. INTRODUCTION

This case study explores the potentialities of a simplified geostatistical algorithm for the multiscale analysis of surface roughness or, more generally, surface texture. The algorithm [1] is designed for the analysis of surface roughness and image texture, with some basic implementations coded in R as well as in Python for ArcMap [2]. The algorithm has been devised to provide an easy to use yet powerful geostatistical approach for the spatial variability analysis, reducing at a minimum level the user-dependent choices. Differently from conventional geostatistical approaches ([3], [4]), it bypasses the detrending procedure; the effect of local slope is filtered out exploiting the geostatistical approach based on increments of order k [5]. The algorithm permits to calculate short-range roughness indexes, where short-range means that the spatial variability of surface is computed considering differences in elevation or in band intensity, in the case of imagery, comparing locations at a small distance (e.g., lags of 1 or 2 pixels). The current implementation, which can be easily modified to compute ad hoc roughness indexes [6], permits to calculate two key factors of short-range roughness: omnidirectional roughness and roughness anisotropy (strength and direction). With this kind of algorithm, it is possible to perform a multiscale analysis of roughness indexes by means of a simple approach based on DEM/image upscaling ([7]-[11]). It should be highlighted that the present implementation is conceived for the analysis of DEMs and imagery on a projected system. For working in geographical coordinates systems custom kernels can be defined, if one wants to derive the roughness considering lags with projected distances.

II. METHODS

A. Study area and Digital Elevation Model

In order to highlight the potential of the approach, the Taklimakan Desert (Fig. 1) China has been selected as study site. This kind of landscape is well suited to outline the potential of the proposed approach. In fact, it is characterized by the widespread presence of complex morphological features ([12] [13]), with multiple wavelengths and anisotropies (Fig. 2), such as in correspondence of the network of complex/compound mega dunes. The analysis is performed on a digital elevation model

(DEM) at 30 m resolution (5000 x 5000 pixels), derived by means of UTM projection of the Copernicus DEM, at 1 arc-second resolution [14]. For supporting the morphological interpretation, Sentinel 2 imagery at 10 m resolution (ESA, Copernicus) has been considered; however, the absence of vegetation and of anthropic land cover enhance the correlation between image texture and surface roughness (e.g., Fig. 2).

B. The multiscale approach

The multiscale approach followed is relatively simple: the short-range roughness analysis is performed iteratively on multiple coarser resolution versions of the original DEM. It is an approach that exploits the dispersion variance and sampling frequency to filter out specific wavelengths [7].

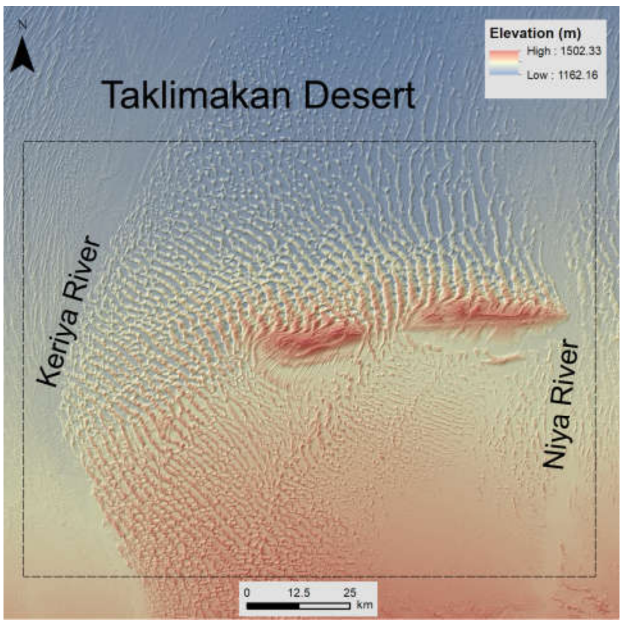

Figure 1. Study site location highlighting the morphology of the portion of the Taklimakan desert considered.

The short-range roughness is analyzed considering the MAD (Median Absolute Differences) estimator of spatial variability [6], which represents a robust version of the usual geostatistical estimators such as the variogram and the madogram [5]. The adopted geostatistical approach bypasses the detrending step considering differences of differences (i.e. increments of order 2); the implemented algorithm permits to compute roughness for lag distances of 0.5, 1 and 2 pixels. For this case study a lag distance of 2 pixels has been considered both to highlight better the anisotropy as well as to filter out some fine-grain noise of the DEM. A circular search window with a 3-pixel radius has been used for MAD estimations. Two basic short-range roughness indexes have been selected: omnidirectional roughness (units in m) and anisotropy strength (ranging from 0, isotropy, to 1, maximum anisotropy). The anisotropy direction (a further index provided by the algorithm) has not been considered for the landscape classification, being here interested in rotation invariant metrics.

The coarsening of the original DEM resolution has been conducted via simple pixel aggregation, using the mean as estimator. The following coarsening factors of the original pixel (30 m) have been selected: 1, 2, 4, 8, 16, 32. Accordingly the DEMs' resolution ranges from 30 m to 960 m (further referred as levels L1-L32) and the lag distance from 60 m to 1920 m. Clearly a smoother transition and a narrower/wider range of variation can be selected. For each of the 6 levels L1-L32 the short-range roughness indexes, omnidirectional roughness (Fig. 3) and anisotropy (Fig. 4), have been calculated and then resampled via bilinear interpolation to the original resolution at 30 m.

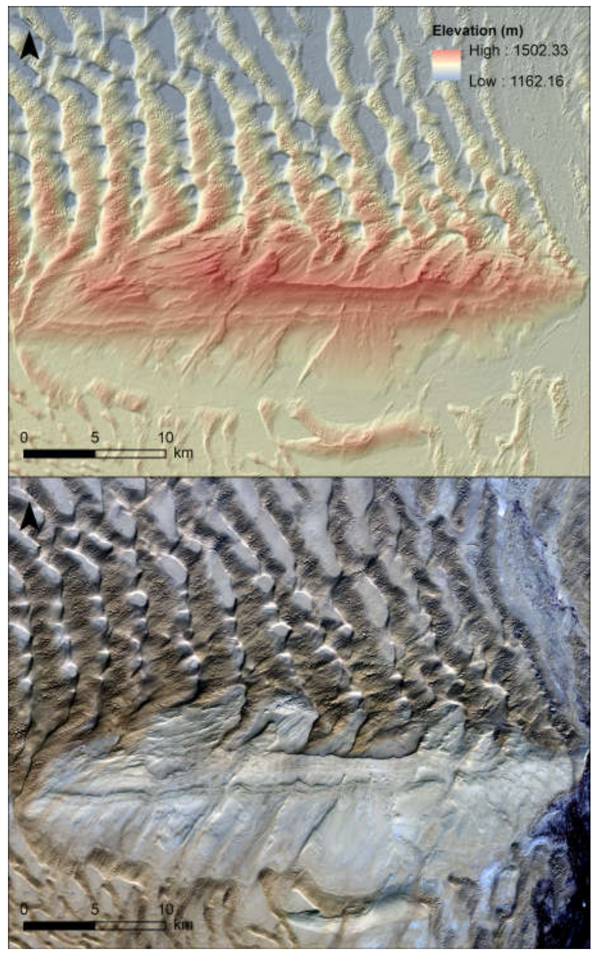

Figure 2. A detail of the study area: top, Copernicus DEM at 30 m resolution (ESA - Copernicus); bottom, Sentinel 2 imagery at 10 m resolution (Sentinel 2 color composite, ESA - Copernicus). It is evident the transition between the complex sand dune system and the mountain area with outcropping bedrock.

Most of the computations have been computed in the R statistical programming environment. Saga Gis 8.3 has been adopted for the classification of landscape according to roughness indexes by means of the Isodata clustering method. Arcmap 10.8.2 (Esri) has been deployed for data management and the creation of the maps presented here.

III. RESULTS

The landscape classification (Fig.5), for a portion of COP DEM tile, has been conducted with the Isodata method (variables normalized, number of clusters tested from 5 to 16), using the 12 multiscale roughness indexes computed above (6 omnidirectional roughness indexes and 6 anisotropy indexes). This should be considered a preliminary classification and a more in-depth analysis on the classification approaches and selection of input features should be carried out. Nevertheless, the derived 8-clusters classification is satisfactory for providing a glance of the rich informative content of the basic short-range roughness indexes computed. The spatial assemblage of clusters (Fig. 5, left) and the mean values of roughness indexes for clusters centers (Fig. 5, right) are quite distinctive of the different morphologies.

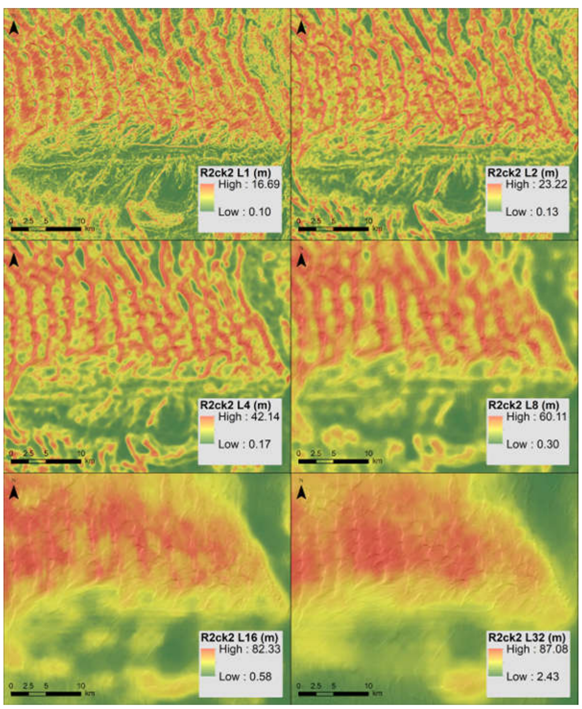

Figure 3. For the area of Fig. 2, short-range omnidirectional roughness computed on the multiresolution DEMs (levels L1-L32, from 30 to 960 m resolution). Increasing the pixel size, longer wavelengths contribute to the computed roughness indexes. The separation between the desert, the mountain with shallow bedrock and the alluvial deposits is particularly evident at levels L16 and L32. Color scales histogram equalized.

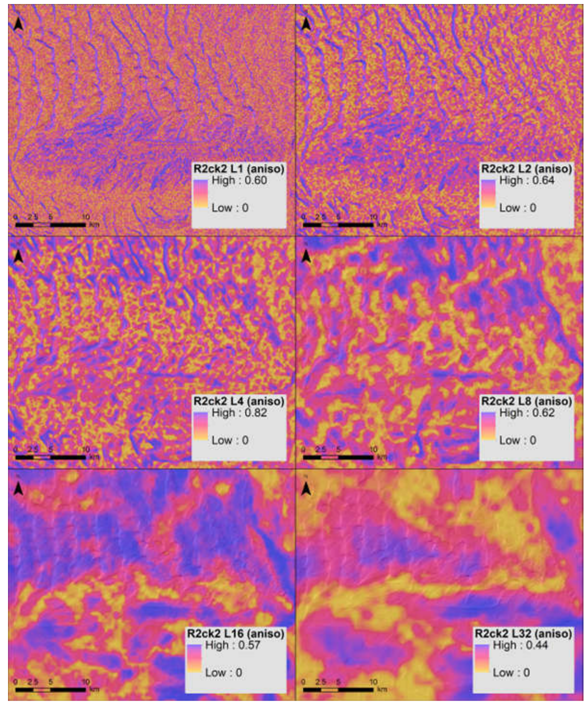

Figure 4. For the area of Fig. 2, short-range roughness anisotropy computed on the multiresolution DEMs (levels L1-L32, from 30 to 960 m resolution). Increasing the pixel size the roughness anisotropy related to longer wavelengths is enhanced. Color scales histogram equalized.

For example, the classes 3 (yellow), 7 (orange) and 8 (red) distinguish specific morphologies of the complex dunal system. Class 3 is characterized by low omnidirectional roughness at levels L1 and L2, but very high, as class 7, at levels L16 and L32; it has a relatively high anisotropy at levels L4, L8 and L16. This class essentially represents long wavelength dunal system with a smooth surface in the short-range. Class 7 is like class 3, but it is characterized by a higher roughness at levels L1 and L2, indicating a rougher morphology at short range, related to presence of short wavelength dunes. Class 8 is different, because it is characterized by the highest omnidirectional roughness at all scales and the highest anisotropy in the levels L1, L2 and L4. Class 8 essentially detects the steep scarps of mega-dunes facing south-west direction. The assemblage of clusters changes evidently in the two central mountains, where the bedrock is shallow or outcropping and there are some elongated ghost dunes, with a prevalence of classes 2 (green), 4 (pink) and 5 (dark green). Class 4 is characterized by low anisotropy at all scales and often represents areas with star shaped dunes. Class 5, with the lowest omnidirectional roughness at all scales, is representative of the alluvial deposits of Keriya and Niya rivers and interdunal flat and smooth surfaces.

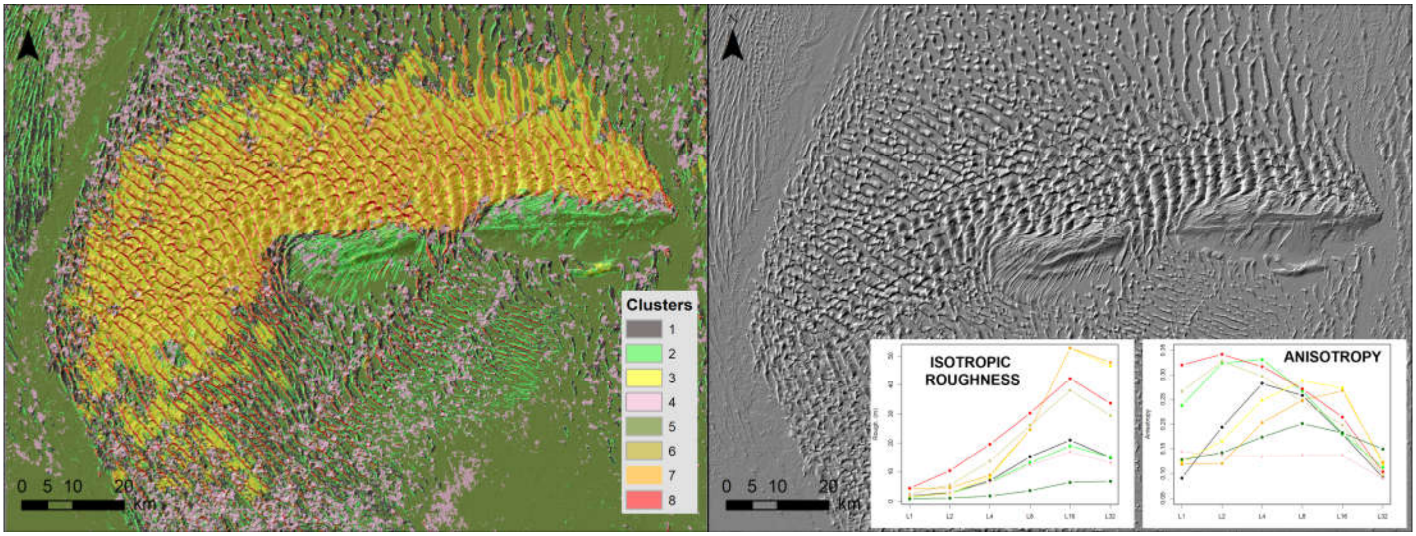

Figure 5. Isodata classification according to surface roughness indexes (on the left) and clusters centers in terms of omnidirectional roughness and anisotropy (on the right, hillshade on the background).

From the graphs of cluster centers (Fig. 5) it is also evident that anisotropy is a distinctive feature. For example, classes 1, 2 and 4 (black, light green and pink) have almost identical omnidirectional roughness at all scales and their differences are mainly related to anisotropy.

IV. Conclusions

The results of this explorative analysis are promising and demonstrate the applicability of the approach. Notwithstanding, multiple aspects require further investigation, both from the perspective of the computational details as well as from the interpretative point of view. Regarding the geomorphological interpretation it should be admitted that the study site has been selected as a "toy example", and the interpretation of computed indexes is quite naïve from the geomorphological and geological point of view. The interpretation of this kind of analysis from the perspective of geomorphic processes analysis and modelling is promising (e.g., [12] and [13]). Accordingly, collaboration with experts on the Taklimakan desert geology and geomorphology would be surely an added value.

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