Towards a global geomorphometric atlas using Google Earth Engine

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Abstract—**Attempts towards a global geomorphometric atlas have been done in the past when computational power was less evolved than nowadays. In this study, we present a possible way to create a global geomorphometric atlas by taking advantage of the Google Earth Engine (GEE) computational capabilities. To exemplify how accessible, efficient and fast GEE works in geomorphometric analysis we globally derive popular land-surface variables (e.g. slope, aspect, multiple curvatures, and surface roughness) and perform a hierarchical pixel-based classification of topography on three levels of details. The scale of analysis can easily be adjusted to meet the user needs. Performing large-scale morphometric analysis with GEE has the potential to become an important milestone in Geomorphometry and can lead towards generating a global geomorphometric atlas.**

I. INTRODUCTION

The idea of a global geomorphometric atlas has emerged more than a decade ago [1-3]. At that time, the availability of high-quality digital elevation models (DEM) and, even more important, of limited computational capabilities raised multiple challenges. Guth [1] and Reuter and Nelson [2] used the 90 m Shuttle Radar Topography Mission (SRTM) DEM for the derivation of a number of global land-surface variables (LSVs) and their statistics while facing the above-mentioned issues.

Nowadays, cloud computing has become universally available and is playing an important role in storing, analyzing and sharing geospatial data and results. One important cloud-based platform is Google Earth Engine (GEE), which provides access to petabytes of data, algorithms and powerful computation services [4]. GEE is gaining popularity in the remote sensing community. However, to our knowledge, there is no attempt to use the GEE resources in providing global morphometric analysis at a glance.

In this study, we present a solution to tackling one of the most challenging issues in the global analysis of DEMs, namely the demand for computational resources, by using GEE capabilities. Using the SRTM DEM dataset [5], we derive LSVs and perform a classification of topography proposed by Drăguţ and Eisank [6]. A global geomorphometric atlas is envisaged and expected to fill an important gap while becoming an important resource in decision-making processes dealing with surface measurements [2,3].

II. MATERIALS AND METHODS

A. *Google Earth Engine*

GEE offers the opportunity to perform global-scale geospatial analysis at no cost. Besides many satellite imagery collections, GEE offers ready-to-use topography datasets, like SRTM v4 3 arc-seconds, SRTM 1 arc-second, GTOPO30 elevation, USGS National Elevation Dataset at 1/3 arc-second and Australian DEM at 5m, just to name a few [4]. Using Google's massive computational capabilities, GEE has already implemented a relatively high number of algorithms and the development is ongoing [4]. However, the analysis of DEMs lacks available algorithms, except for derivation of slope, aspect, and hillshade using 4-connected neighbors of each pixel.

The most convenient way to use GEE is through its web-based code editor for interactive algorithm development based on Earth Engine JavaScript API. Outside of the web-based code editor, one can use the Earth Engine API in Python and JavaScript, using the power of Google's cloud for planetary-scale data analysis [4]. This can lead to ways of using already available functionalities from other GIS software for performing geospatial analysis.

The scale of analysis in GEE is determined as a function of the output, rather than of the input, as common in many geospatial software packages. Specifically, the user specifies the scale at which the data should be analyzed or the scale is determined by the zoom level in the interactive window and all the computations are made on-the-fly. This is possible due to the pyramiding policy of storing images at multiple scales in

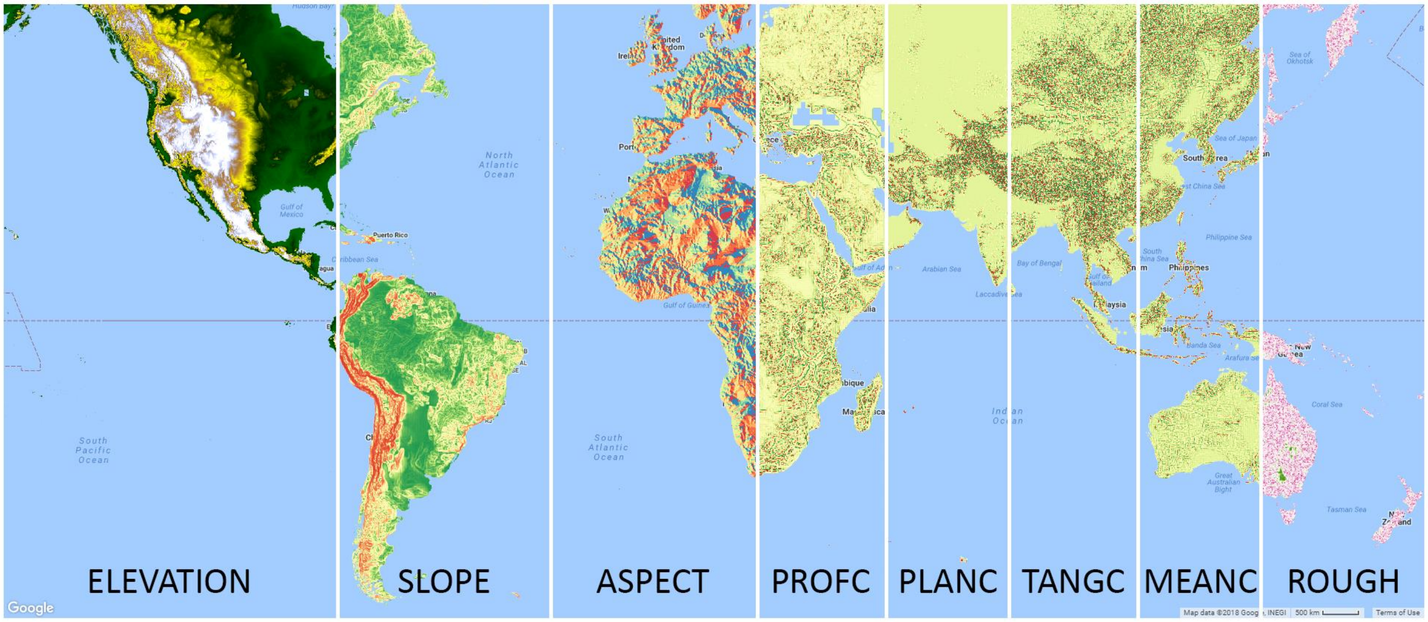

Figure 1. Subsets of the globally derived land surface variables from SRTM v4 3 arc-seconds: elevation, slope, aspect, profile curvature (profc), plan curvature (planc), tangential curvature (tangc), mean curvature (meanc) and surface roughness factor (rough). At this scale, the results are aggregated into pixels of 20km resolution.

GEE [4]. The same applies for projections, which are determined by the map's zoom and view bounds of the interactive map or can be specified using the *reproject()* method. The SRTM data [5] utilized in this paper has a geographic coordinate system with the WGS84 datum.

B. Land surface variables

In the current implementation, we included the following LSVs: elevation, slope, aspect, profile curvature, plan, tangential, mean curvature and surface roughness factor, using a neighborhood of 3x3 pixels (Figure 1). Other related LSVs and their statistical parameters could be derived as well. We tested multiple scales of analysis, from 90m to 1km using the analysis-ready SRTM v4 in GEE (Figure 2). These basic LSVs were derived using the formulas available in Olaya [7].

C. Classification of topography

Drăguţ and Eisank [6] proposed an object-based workflow to automatically classify topography from SRTM data at three scale levels of complexity. To test the suitability of GEE in performing global classifications, we followed the same classification rules proposed by the authors, based on the average elevation and the average standard deviation of elevation to perform a pixel-based classification of topography. This results in three levels of complexity, with the most detailed one (Level 3) comprising 8 classes: high mountains, low mountains, high hills, tablelands, rough low hills, smooth low hills, high plains and low plains (Figure 3). Again, the scale of analysis varies with the zoom level, and we tested fixed resolution, ranging from 90m to 1km.

III. Results and Discussions

The most striking aspect in using GEE is related to the speed of computation. Deriving the LSVs is a matter of seconds, and the time increases when the analyzed area is larger and resolution is finer. At fine resolution (e.g. 90m), the zoom level needs to focus on smaller regions, for faster visualization of results. Furthermore, analysis-ready DEM datasets are available or a user can upload their own, either public or private, which can reduce the cost of owning and maintaining hardware. In this way, performing global geomorphometric analysis has never been easier. One possible limitation for using GEE in the future is related to the fact that this is a commercial platform from Google and the risk of changing the license conditions can occur.

The current implementation of LSVs is easily adjustable to perform at different spatial resolutions or DEM datasets (Figure 2). There is a long debate about which LSVs express better the surface characteristics. Many LSVs show collinearity [8] and

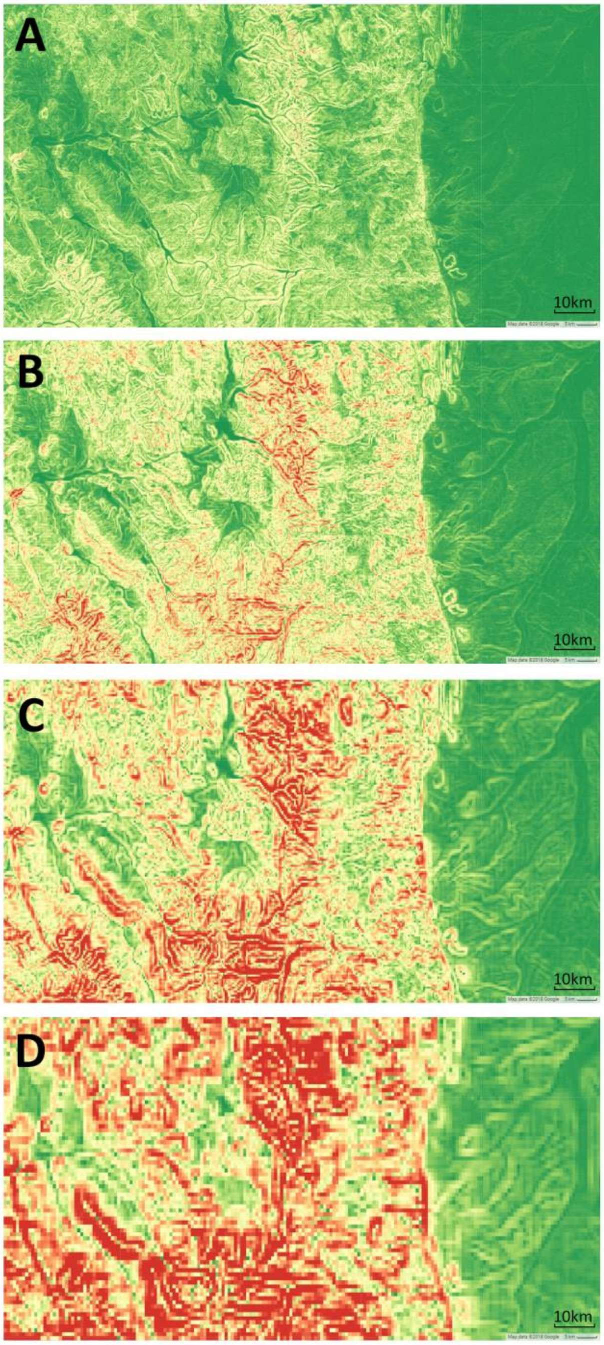

Figure 2. Slope derivation in degrees (0-90°) at 4 different spatial resolution: at 90m (A), 250m (B), 500m (C) and 1km (D), for an area west of the city of Boulder, Colorado, USA. Computational time is kept within seconds and increases with the increase in spatial resolution and extent of the area analyzed.

Evans [9] states that the first and second derivatives of a DEM are enough in most cases. Extending the current approach to a multi-scale geomorphometric characterization as that proposed by Wood [10] is currently under investigation.

In this study, we have used the SRTM v4 DEM dataset. However, we are aware of the issues related to this dataset. New and enhanced DEM datasets have recently been proposed, out of which the MERIT DEM [11] seems very promising for geomorphometric analysis.

The classification example we provided is just one of the multiple global classifications of topography (Figure 3). Other popular or promising global classifications include those of Iwahashi and Pike [12] and Iwahashi, *et al.* [13]. The massive computing power of GEE makes now possible to perform global classifications of topography at a finer scale than achieved before and with a higher degree of automation.

IV. Conclusions

In this study, we draw the attention of the current cloud-computing development of Google Earth Engine and its implication for geomorphometric analysis. To support the benefits of using GEE in DEM analysis, we derived basic LSVs and performed a global classification of topography, which could be seen as possible parts of a future geomorphometric atlas.

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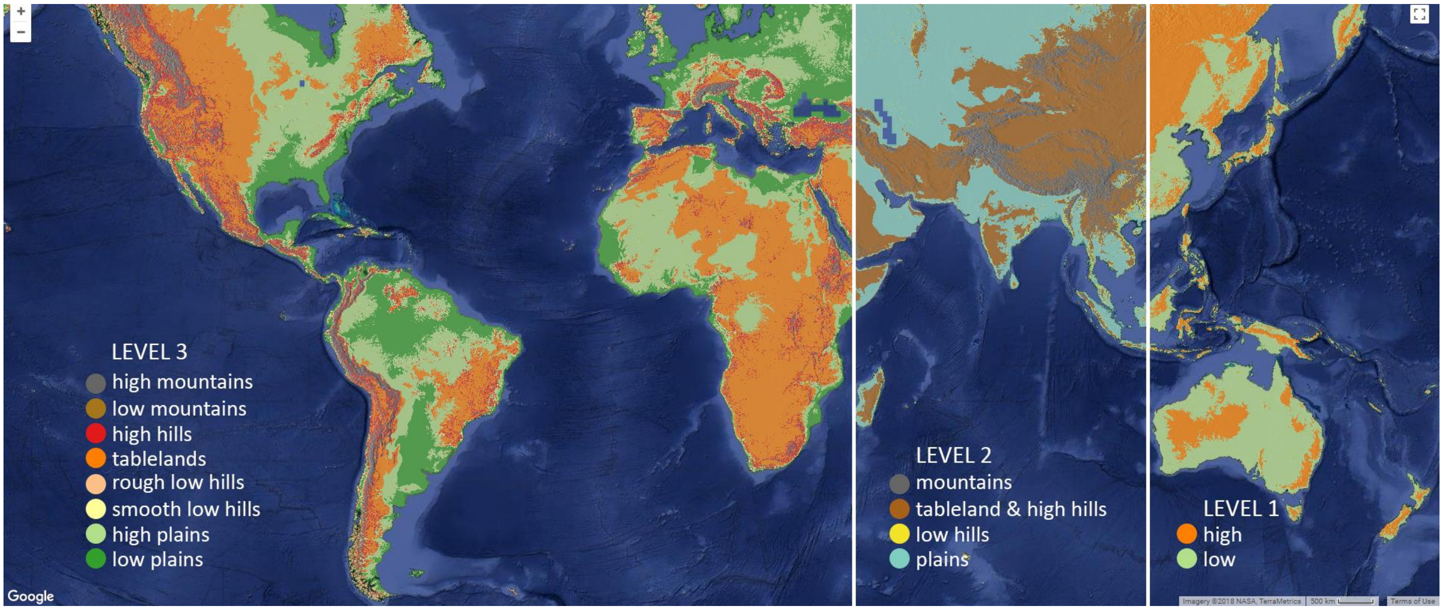

Figure 3. Pixel-based global classification of SRTM DEM at Level 1, Level 2 and Level 3, following the procedure described by Drăguţ and Eisank [6] for an object-based classification of topography. At this scale of visualization, the results are aggregated into pixels of 20km resolution.

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