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Towards the automated geomorphometric extraction of talus slopes in Martian landscapes

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ABSTRACT

Terrestrial talus slopes are a common feature of mountainous environments. Their geomorphic form is determined by their being constituted of scree, or similar loose and often poorly sorted material. Martian talus slopes are governed by the different nature of the Martian environment, namely: weaker gravity, the wide availability of loose material, the lack of fluvial erosion and the typicality of large escarpments; all these factors make talus slopes a more striking areomorphic feature on Mars than on Earth. This paper concerns the development of a numerical geomorphometric analysis, parameterization and detection of the talus slopes method. We design inventive variables, a multidirectional visibility index (MVI) and a relief above (RA) and propose two techniques of talus slope extraction: ISOcluster and progressive Boolean overlay. Our Martian digital terrain model (DTM) was derived from the ESA Mars Express HRSC imagery, with a resolution of 50 m. The method was tested in the study areas of Nanedi Valles and West Candor Chasma. The major challenge concerned the quality of the DTM. The selection of robust variables was therefore crucial. Our final model is to a certain degree DTM-error tolerant. The results show that the method is selective concerning those slopes that can be considered to constitute a talus slopes area, according to the visual interpretation of HRSC images. Based on an analysis of the DTM, it is possible to infer various geological properties and geophysical processes of the Martian and terrestrial environments; this has a range of applications, such as natural hazard risk management.

1. Introduction

Terrestrial talus slopes (or cones and fans) are a common feature of mountainous environments. Their geomorphic form is determined by their being constituted of scree, or similar loose and often poorly sorted material. Together with certain supporting factors, the angle of repose of the material determines the angles of the surface slope of these forms. On Earth, talus slopes are sometimes slightly vegetated and therefore may become somewhat over-steepened and metastable. Martian talus slopes are governed by quite different environmental conditions: a weaker gravitational force (approx. 38% of the terrestrial); the wide availability of loose material (often windblown); the absence of fluvial erosion; and typically large escarpments that make the talus slopes a more conspicuous areomorphic feature of the Martian landscape than that of Earth. Due to the absence of fluvial erosion on Mars, the various geomorphic processes active in the various time intervals have been partly preserved and, consequently, it can be said that the present surface retains a 'memory' of its geomorphologic history. In this context, the formation of talus and their later dissection, by the incision of gullies (cf. Reiss et al., 2009), are an important means of estimating the age of the surface, or the existence (or lack thereof) of talus cover. A general outlining of talus surfaces is therefore advantageous.

The goal of our paper is to present two methods of robustly separating and detecting Martian talus surface areas from other non-talus slopes of the natural environment (such as escarpments or impact rims). In advancing these methods, our procedures use only digital terrain models (DTMs) as their input.

Besides remotely-sensed multichannel imagery, DTMs represent important input data for geomorphic evaluation. It is often possible to infer certain geological properties and geophysical processes based on their evaluation. In the case of planetary science studies, this is especially important because only remote sensing data is available, and it is not possible to obtain in situ ground verification. In terms of methodology, comparing the well-known characteristics of Earth's geomorphological surface with the characteristics of the planet studied is an important step. Even

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if the data acquisition and the DTM-generation techniques were the same or comparable, the physical, geophysical, geological, and consequently geomorphological circumstances, are so considerably different that such comparisons are useful.

By studying the selected geomorphic forms on the surfaces of both planets, we seek to better understand the interplay of processes on Mars and Earth. Studying the properties of talus slopes on Mars has a number of beneficial applications on Earth, such as natural hazard risk management (Sodnik et al., 2013).

We propose two automated recognition techniques, applied to Martian DTMs derived from High Resolution Stereo Camera (HRSC) imagery on board the ESA Mars Express (Jaumann et al., 2007). Both geomorphometric techniques make use of the specific geometric properties of the talus slopes, together with the spatial distribution of elevations in the immediate vicinity of the spot to be analyzed. In order to automatize it the processing to the maximum possible extent, we will avoid geomorphometric studies that involve arbitrary decision-making in the quantification of their concepts (Mark, 1975; MacMillan and Shary, 2009). In addition to the automated manner of processing, the resulting procedure should be robust enough to tolerate certain types of inaccuracies in the DTM.

2. Material and methods

The geomorphometric analysis is based on the 50 m resolution DTMs (Heipke et al., 2007) derived from HRSC images (see Fig. 1) of the two test areas: Nanedi Valles (approx. 4.9°N, 49°W; orbit no. 1235; an area of 97 × 70 km) and West Candor Chasma (6.6°S, 70.9°W; orbits no. 805, 902, 927; an area of 105 × 75 km). The DTMs have been created from an automated photogrammetric matching procedure of relatively featureless plateau areas. In some cases, the automated matching resulted in less plausible geometric forms. In order to check the results and to identify instances of improbable landforms, a Context Camera (CTX; on board of Mars Reconnaissance Orbiter, MRO), HiRISE (High Resolution Imaging Science Experiment, also on board of MRO), and anaglyph HRSC images were used for visual control. The HRSC SRC (Super Resolution Channel) data provides unique details of the Martian surface, such as dunes at the bottom of valles and terraces and spurs of former thalwegs, which also proved necessary for the visual classification of areomorphic features.

Since the quality of the processed DTM is not comparable to that of the contemporaneous terrestrial DTMs, which usually have a higher resolution and greater accuracy, we designed robust variables and methods for the talus slopes (Székely and Podobnikar, 2009).

We applied two calculation methods in order to outline the talus areas. The ISOcluster unsupervised classification method has already been published by Székely (2001) in terms of a general context, and in terms of a terrestrial context (the evaluation of the geomorphometry of the European Eastern Alps) by Székely et al. (2002), and this was later applied to other areas, such as Corsica (Székely et al., 2004). However, the aforementioned studies considered the surface as a juxtaposition of certain types of similar elements (clusters) so that the DTM is actually an image, and the procedure is a segmentation problem. In the context of talus detection, we are looking for a single or a small number of clusters in the result that can be identified as correlating highly with the talus areas.

The second method is a progressive Boolean overlay on the basis of the sum of the binary indicator variables derived from various geomorphometric indices, including classic variables and a newly introduced variable, termed as the multidirectional visibility index (hereafter referred to as MVI). For the general context and for indicator variable elements, the next section describes the necessary geomorphometric variables.

Our combined detection method of talus surfaces makes use of the studied digital geomorphological properties of talus slopes. Thus, based on both empirical results and some heuristic considerations, a specific geomorphometric analysis of the various DTMs led us to calculate the DTM derivatives discussed below.

2.1. *Calculated derivative variables for the composite filter to detect talus slopes*

In selecting optimally designed variables, our primary consideration was the characteristic slope angle of the talus surfaces. Clearly, we can expect the derivatives used to be significant and independent as far as possible. However, these principles are not necessarily true for all kinds of derivatives: interdependence may to some extent be permitted if two interdependent variables are found to be selective enough to filter out those cases that appear to mimic a talus surface, but which are in fact the result of other geomorphological processes.

Generally speaking, detection is based on the idea that a talus slope has a certain slope angle. However, the talus surface typically ends on a low-lying, horizontal or sub-horizontal surface, characterized by a considerably lower slope angle. Furthermore, in certain cases of topographic evolution, these surfaces may be subject to the erosional dissection that creates gullies or other quasi-linear features that modify the general slope distribution properties of the primordial talus surface. Such cases have been considered by Székely et al. (2014) with regard to ignimbrite surfaces, although talus slopes are, at least partially, conical, so the robust plain fitting is in many cases not suitable. Another issue concerns the potential presence of local errors in the DTM that may result in some extreme slope values. Some specific methods of calculation, such as the application of an annular window instead of a circular one, are intended to filter out these problematic cases.

The following morphometric variables were used:

A: slope angle
B: relief above RA
C: quasi slope QS_θ

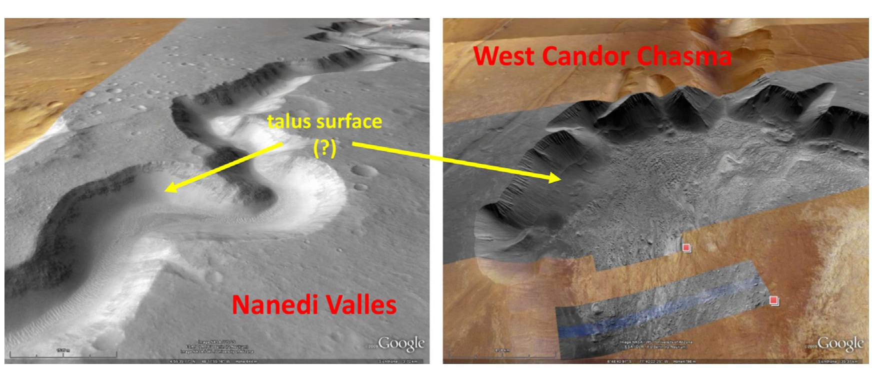

Fig. 1. The study area: Nanedi Valles (4.9°N, 49°W; an area of 97 × 70 km) and West Candor Chasma (6.6°S, 70.9°W; an area of 105 × 75 km); Google Earth.