A Method for Automated Extraction of Martian Talus Slopes – Case Studies of Nanedi Valles and West Candor Chasma, Mars

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1. Introduction

Terrestrial talus (or scree) slopes are common features in mountainous environments. Their geomorphic form is determined by their constituting material, scree or similar loose, often poorly sorted material. The angle of repose of this type of material defines more or less the surface slope of these forms. On Earth they are sometimes slightly vegetated, therefore they might become slightly oversteepened and metastable.

Martian talus slopes are governed by differing environmental conditions: lower gravity (ca. 38% of the terrestrial), largely available loose material (often windblown), the lack of (present) fluvial erosion and typical large escarpments make the talus slopes more important areomorphic feature on Mars than on Earth.

Our previous approach to outline terrestrial talus surfaces in the Eastern Alps in an automated way (Székely and Podobnikar 2008) has been successful in finding certain types of talus surfaces. On the other hand the method has been found to be somewhat sensitive to the resolution of the applied DTM. Here we apply a similar technique to two Martian DTMs derived from High Resolution Stereo Camera (HRSC) imagery on board of ESA Mars Express (Jaumann et al. 2007).

Our main aim is to separate and outline the talus surface areas from other slopes (like escarpments, impact rims, etc.) in the study areas of Nanedi Valles and West Candor Chasma in order to analyse the spatial distribution of this phenomenon, in craters, along escarpments, and, especially, in the area of vallis sides.

2. Data and Methods

The 50 m resolution DTMs (Heipke et al. 2007) of the two test areas of Nanedi Valles (ca. 4.9°N, 49°W; orbit No. 1235) and West Candor Chasma (6.6°S, 70.9°W; orbits No. 805, 902, 927) derived from HRSC images have been used for the morphometric analysis. Since the DTMs have limited accuracy due to the automated matching procedure of relatively featureless plateau areas, 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 provide unique details of the

Martian surface like dunes in the bottom of valles, terraces and spurs of former thalwegs, that were necessary for the visual classification of areomorphic features.

The concept of the recognition is based on the idea that a talus slope has a certain slope angle, but also ends on a low-lying, typically horizontal, subhorizontal surface. So if we calculate the local relief on a basis of local moving window analysis, the talus slopes can be characterised by the property that there is much relief area above them and not much relief are below them. On the other hand, the talus itself may cover some relief as well.

For the automated recognition of talus surfaces development of significant and, as much as possible independent, DTM-derivative spatial variables are necessary, that are converted to indicator variables by applying threshold values. Beside of the independence of the variables the idea on improvement of the initial approximation of the talus slopes step-by-step is important (Podobnikar 2005). The modelling starts with the most coarse estimations and continue using increasingly finer variables that improve the quality of the modelling until the changes are within the certain threshold.

A two-phase data processing has been carried out. The slope distribution was analysed first in order to find appropriate threshold values for the second phase. Then, the indicator variables have been computed and, finally, the indicator variables are integrated to one category by simple summation. If the sum reaches a preset number (on a pixel by pixel basis), the pixel in question will be categorized as classified to the respective group.

In the latter phase a novel visibility simulation technique has been applied. Here the pixels of the DTM are considered successively as central points of a sequence of visibility test as follows:

1. Calculate visibility (visible: 1, not visible: 0) from a central point of the particular grid cell in the DTM using a specific zenith angle θ (Fig. 1).

2. Repeat the visibility calculation for every grid-point of the DTM to produce a derivative binary grid B_φ applying certain parameters.

3. To certify the isotropic processing continue calculation of the derivative binary grids B_φ by a sequence of azimuths φ (applying an appropriate azimuth interval δ), sum up B_φ to produce continuous grids according to upper views U_θ, and lower views L_θ as $\Sigma(B_\varphi)$, where $\varphi = \{0°, \delta, 2\delta, 3\delta, \ldots, 360° - \delta\}$, $n = 360/i$ times and where θ is carefully chosen.

4. Calculate continuous derivative grids that simulate a sort of relative relief: $RR_\theta = U_\theta - L_\theta$

These channels serve then as input for the summation.

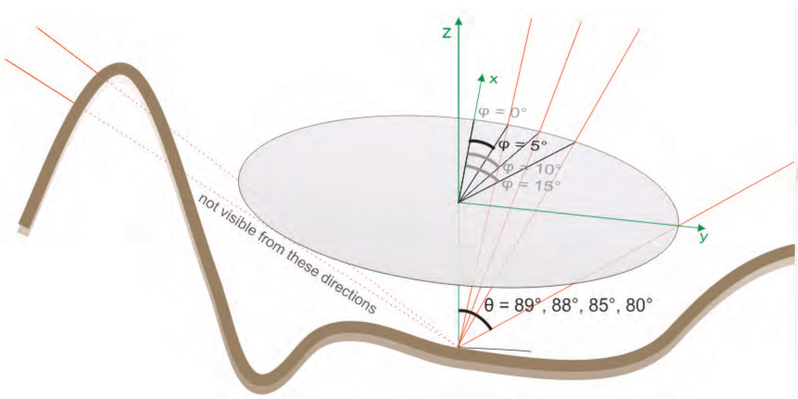

Figure 1. Principle of visibility simulation with definitions of φ (azimuths) and θ (zenith angles).

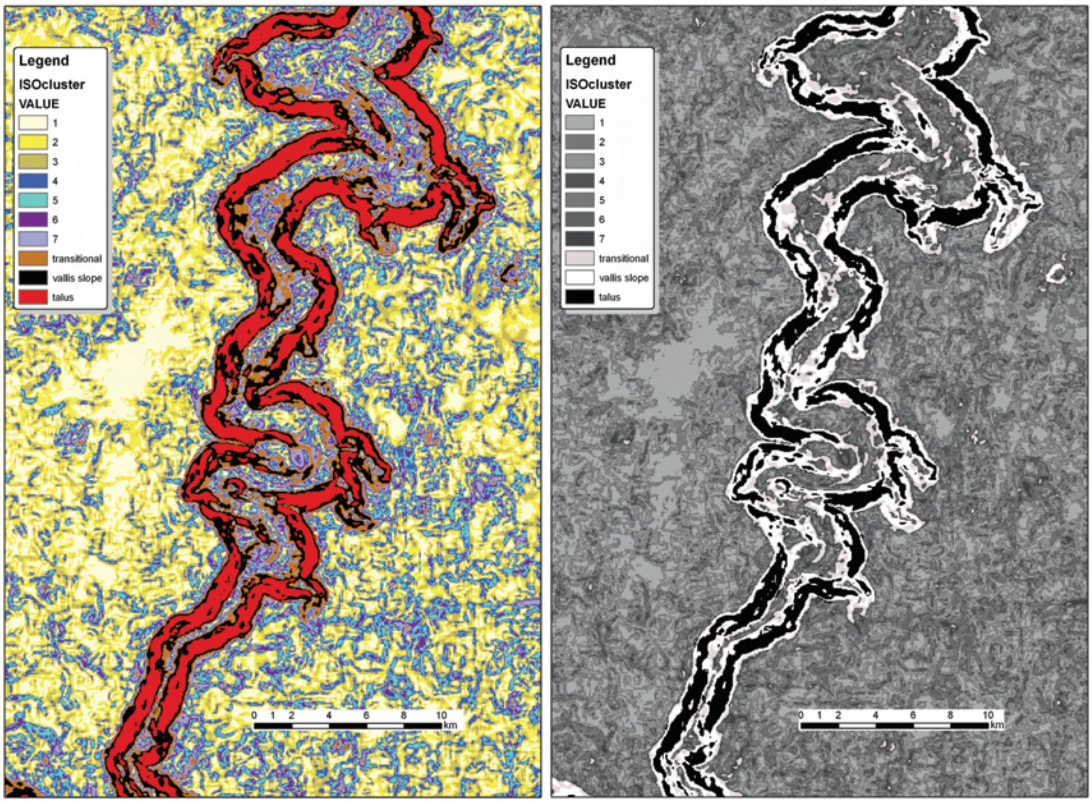

Figure 2. Result of the pre-processing step outlining the candidate pixels of talus (left: in colour). Clusters 1-3 are characteristic for the planation surface, clusters 4-7 representing the smaller dissecting forms, while the transitional cluster is situated mostly in the valley bottom but also forms a band at the rim of the vallis. The vallis sides are mostly falling into the cluster that is expected to represent the talus surface.

3. Data Processing

In order to analyze the slope distribution, a preprocessing step has been carried out to outline the potential areas for talus slopes (Fig. 2). The slope angle and the standard deviation of the slope angle (as a measure for the variability) have been used as input. This two-channel data set has been processed by ISOcluster classification. (ISOcluster was used here to keep the possibility of extension. In case of a more complex slope distribution other derivatives can be integrated as third, fourth, etc. channel in the same scheme.) The number of target clusters has been defined to be 10, because of the expected classes: Beside of the plateau and terrace areas (#1-#3) and the incision(?) features (#4-#7) the internal slopes of craters and valles may need to be separated. The "bedrock" areas (scarp surface) are expected to fall in an individual category. Toe areas of mass movements can also be present.

The resulting clusters showed promising separation (Fig. 2). The classified variable should cover the talus surfaces in their entirety, e.g. an interval between the minimum and maximum of the values characteristic for fans was defined, and the area encompassed thus represent an area that is likely can be identified as talus.

A number of variables have been tested to provide similar results as the ISOcluster output. The most successful (estimated as the most significant) variables were those that are based on the relative relief based on innovative visibility simulation technique discussed above. A further group of potentially useful variables are based on the relief above function by applying focal operations with annular window. These masks combined with the restrictions on slope angles (derived from the ISOcluster procedure) effectively separated the horizontal, subhorizontal areas, as well as terraces (that can be found in Nanedi Valles) and the rock escarpments as well. The latter features may remain in the selection under certain conditions.

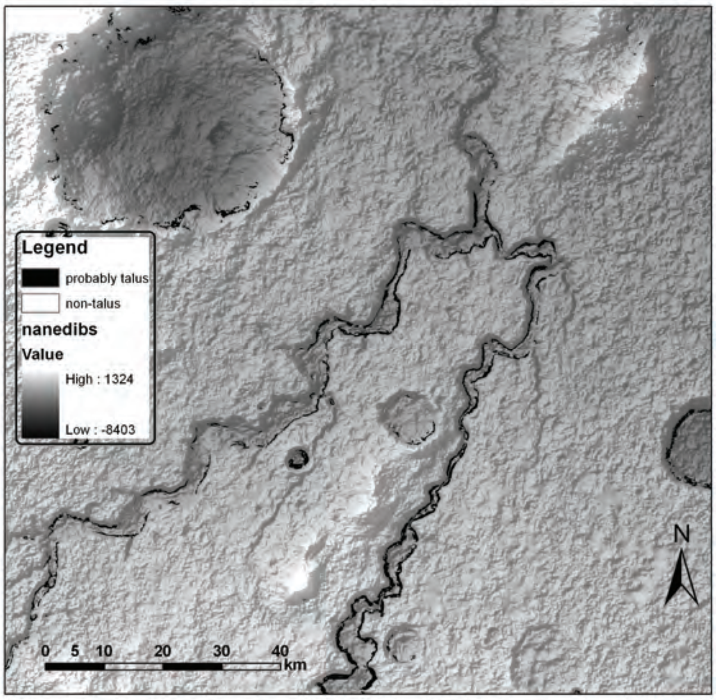

Figure 3. Example of Nanedi Valles area, the result of the processing (probably talus category) is depicted in black. Note the spatial distribution of the talus pixels also around the rims of craters.

4. Results and Discussion

Fig. 3. shows a larger area outlining the results of masking. It is important to note that for both areas of Nanedi Valles and West Candor Chasma (Fig. 4) the same processing has been applied (including all parameter selections). Although the relief that is partly covered in the two test areas are rather different, the success of recognition of the appropriate pixel groups is the same.

The vallis sides of Nanedi Valles are often comparable with the sides of larger craters where talus slopes are also occur, consequently the fluvial features are less probably present in the valles; the mass wasting processes have already reshaped these slopes. The same applies to West Candor Chasma, where larger slopes, exceeding 2 km in relief, are also showing these properties. However, in this area the remnants of larger landslides also occur, where talus is not observable.

Although the DTM has some errors that can be revealed by comparison with the SRC channel imagery, the processing remained robust and uninfluenced by some gross errors, most probably because the slope distribution of Martian surface features is persistent in this scale.

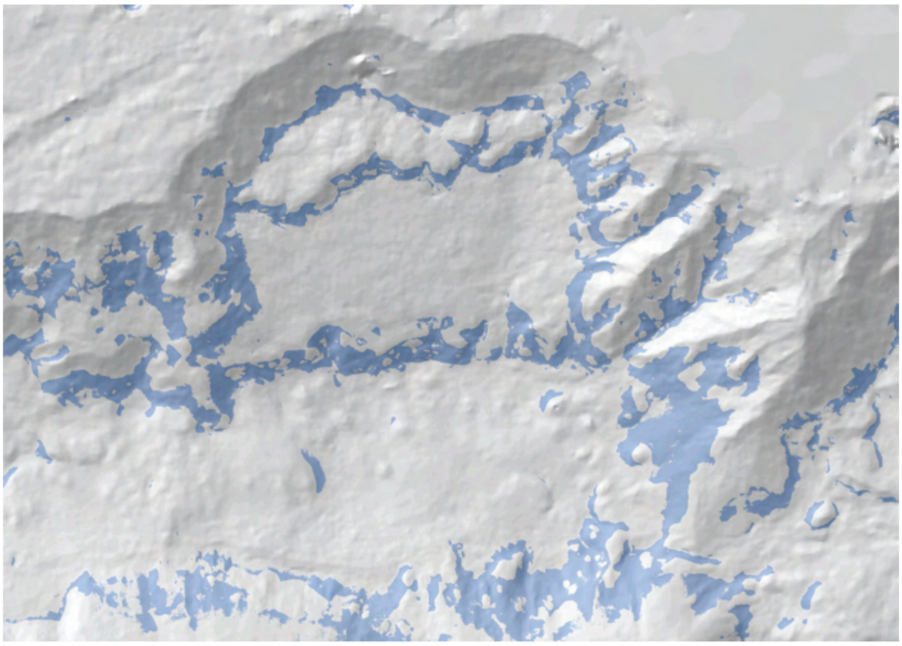

Figure 4. Example of West Candor Chasma, the result of the processing (probably talus category) is in light blue (dark grey in greyscale). The horizontal size of the image is ca. 50 km, north is to the top. Note that despite of the staircase-like setting, at the foot of each escarpment a belt of talus is recognized. This pattern is different within the incising valleys on the right.

Carrying out a thorough visual checking of the identified features, it is found that the majority of the areas that can be visually classified as talus surface are identified also by the automated processing. This result paves the way towards the analysis of multi-resolution DTMs as well in the lack of high-resolution DTM.

5. Conclusions

An automated recognition method has been developed for 50 m resolution Martian DTMs derived from HRSC imagery. The processing scheme has been found robust in two different Martian areomorphic settings, that may indicate that the technique can be applicable in generally for high-resolution Martian DTMs. The procedure is somewhat DTM-error tolerant. However, the verification of the results yet can be of qualitative nature only. Due to the known accuracy problems in the DTM generation a quantitative in-depth analysis of DTM and its derivatives is not suitable, therefore the visual checking remains as the only option for the verification: the original imagery has still somewhat better resolution and characterised by higher information content.

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