

HOW CLOSE ARE MARTIAN VALLEY NETWORKS TO OPTIMAL CONFIGURATION? IMPLICATIONS FOR EARLY MARS CLIMATE. X. Cang¹, W. Luo^{2,1} University of Maryland, Baltimore County (xuezhicang@gmail.com), ²Northern Illinois University (wluo@niu.edu).

Introduction: The widespread presence of valley networks (VNs) on Mars strongly suggests past water activity [e.g. 1-2]. However, the details of the processes involved, their duration, and the climatic conditions under which they operated are still being debated among researchers [e.g., 1-3]. Earlier works have generally recognized the lower density and immature look of the Martian VNs compared to terrestrial streams [4-5]. More recent mapping efforts based on higher resolution data [6-8] have revealed VNs are much more similar to terrestrial streams than previously thought. Quantitative measure of how similar they are can offer new insights into our understanding of the duration of fluvial processes and the climatic conditions on early Mars. Here we present a novel approach to measure landform maturity at basin scale by computing the ratio of energy dissipation along simulated optimal channel network (OCN) and that along real network (on Earth and Mars) [e.g. 9].

Method: OCNs are dendritic networks that drain a given area with minimum total energy expenditure [10]. OCNs can be obtained by starting with an initial network draining an area and randomly switching flow directions of different pixels, keeping only the directions that yield a lower energy dissipation; the process is iterated until the minimum total energy expenditure is reached [10]. The energy dissipation H is computed based on upstream contribution area A_i of cell i in a grid (a surrogate for discharge) as follows (more details of the derivation can be found in [9]):

$$H = \sum A_i^\gamma$$

where γ is the exponent. In general, larger γ values produces straighter OCNs (Figure 1).

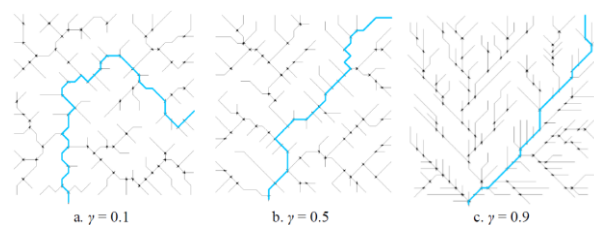


Figure 1. OCN under different γ values.

It has been shown that many of properties of the natural river networks (e.g., Horton's laws) can be well reproduced by OCNs [11], suggesting that the dendritic hierarchy of natural networks is the result of self-organization of fluvial processes that minimizes energy

dissipation [9]. Thus the ratio of energy dissipation (R_{ed}) shown below offers a quantitative measure of the degree to which the real network approaches OCN and we can interpret this ratio as a measure of the maturity of watershed:

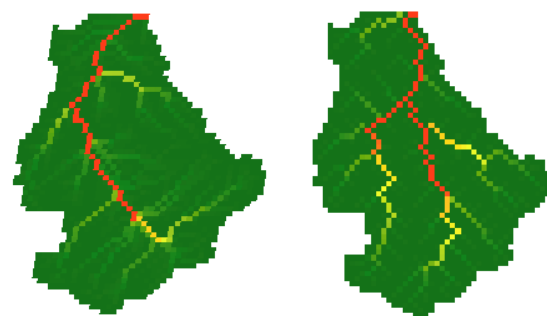
$$R_{ed} = H_{OCN} / H_{real} \quad (1)$$

where H_{OCN} is the energy dissipation along OCN and H_{real} is that long real network within a watershed. Theoretically, $H_{OCN} \leq H_{real}$, $0 < R_{ed} \leq 1$. For OCN, $R_{ed} = 1$. The higher R_{ed} value (closer to 1) of a watershed is interpreted to mean that the watershed has been eroded by fluvial processes for a long time and its streams have self-organized to approach OCN.

Before calculating R_{ed} , we first need to delineate watershed boundary based on topography. For this, we followed the standard watershed delineation procedure [12]: 1) filling the small sinks to make the terrain drainable, 2) determining the flow direction of each cell, 3) calculating the flow accumulation of each cell and thresholding accumulation to be streams, 4) labeling each stream, and 5) delineating the watershed boundary of each stream.

To obtain OCN within a watershed, the exhaustion search method can be applied, but it is inefficient and prohibitively time-consuming [9]. We adopted the simulated annealing algorithm [13], which is more effective and the approximate optimal solution of OCN well. However, it only generates OCN in a rectangular area, so we modified it to work for any shape watershed by recording the ID of elevation cells inside the watershed and skipping those outside.

Results: Figure 2 shows one example basin in the dense VNs belt on Mars with $\gamma = 0.5$. The R_{ed} of this example is 0.86.



Figures 2. Left: flow accumulation based on DEM. Right: flow accumulation based on simulated OCN. $\gamma = 0.5$ for both cases.

We computed R_{ed} for a total of 3,420 watersheds randomly selected from the conterminous US HUC10 polygons (with average size of 539 km²) that span across different climatic zones and geologic units (Table 1). The result shows that terrestrial watersheds generally have high R_{ed} values (close to 1), consistent with high maturity from fluvial erosion. A total of 3,326 Martian watersheds are selected (with average size of 361 km²) and their R_{ed} values calculated (Table 2). The result shows that Martian watershed has lower R_{ed} values than their terrestrial counterparts, suggesting that Martian watersheds are less mature, which is consistent with previous research [e.g., 3, 14-15].

Table 1. Statistics of terrestrial watershed R_{ed}

	$\gamma = 0.3$	$\gamma = 0.5$	$\gamma = 0.7$
Average	0.93	0.90	0.87
Median	0.93	0.90	0.88
SD	0.03	0.04	0.05

Table 2. Statistics of Martian watershed R_{ed}

	$\gamma = 0.3$	$\gamma = 0.5$	$\gamma = 0.7$
Average	0.90	0.87	0.87
Median	0.90	0.88	0.87
SD	0.04	0.05	0.05

However, when examining the spatial distribution of large VN systems with $R_{ed} > 0.82$ (the lower boundary of two-sigma range of terrestrial watershed maturity when $\gamma = 0.5$), we observe that they are widely distributed on Martian surface (Figure 3). This suggests that, although Martian watersheds are not as mature as terrestrial counterparts, long-term and widespread fluvial activities, and by inference, warm and wet climatic conditions, are necessary to produce such wide spatial distribution.

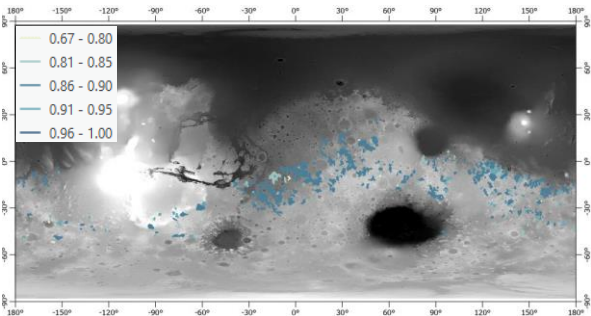


Figure 3. Spatial distribution of large VN systems with $R_{ed} > 0.82$.

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