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Snake Model for the Extraction of Loess Shoulder-line from DEMs

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Abstract: Shoulder lines are the most important landform demarcations for geographical analysis, soil erosion modeling and land use planning in the Loess Plateau area of China. This paper proposes an automatic, effective and accurate method of determining loess shoulder line from DEMs by integrating a hydrological D8 algorithm and a snake model. The watershed boundary line is adopted as the initial contour which evolves to identify the exact position of loess shoulder-line by the guidance of an external force of snake model from DEMs. Experiments show that the method overcomes the difficulties in both threshold selection for edge detection and the disconnecting issues in former extraction approaches. The accuracy evaluation of shoulder-line maps from the two test sites of the loess plateau area show obvious improvements in the extraction. The average contour matching distance of the new method is 12.0 m on 5 m resolution DEM, and shows improvement in the accuracy and continuity. The comparisons of accuracy evaluations of the two test sites show that the snake model method performs better in the loess plain area than in the area with high gully density.

Keywords: Snake model; DEM; loess shoulder-line

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Introduction

Loess shoulder-line is a significant line and indispensable indicator in characterizing results of surface processes in the Loess Plateau of China (Zheng et al. 1998; Qin et al. 2010; Qin et al. 2010). The loess shoulder-line could be defined according to morphological variation in the loess landforms. Figure 1 illustrates a hypothetical profile representing the point of morphological variation between the inner-gully area (AC) and the inter-gully area (BC) between the loess positive and negative terrains (P–N terrains) (Zhou et al. 2010). The average surface slope is usually lower than 25 degrees; while in the inner-gully area, the slope suddenly gets steep over 35 degrees (Zhu et al. 2003). Figure 2 shows the loess shoulder-line overlaid against the real loess landscape.

For decades, researchers have been dedicated to automatic extraction of loess shoulder-line from different aspects and invented different algorithms. Lu et al. (1998) designed a 3 ×3 filter to detect loess shoulder–line by variation of slope. It is complex and sensitive to the noises produced in the process. Zhu et al. (2003), Liu et al. (2006), Li et al. (2008) and Zhou et al. (2009) comprehensively considered the terrain variables derived by a 3×3 window, i.e.

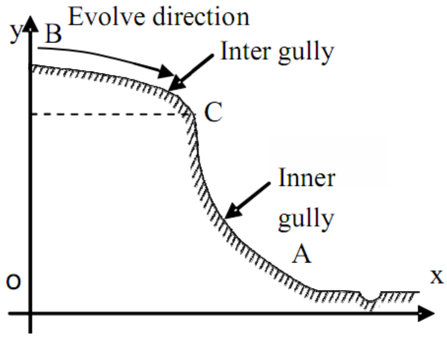

Figure 1 Illustration of loess shoulder-line profile.

Figure 2 Illustration of loess shoulder-lines on surface.

profile curvature, slope variation, height variation and gully density in the extraction of the loess shoulder-lines. Xiao et al. (2007) used a two-step algorithm by linking candidate points to an integrated line. Recently, the slope or height variation can be detected by the edge detectors. Yan et al. (2011) compared the performance of four edge detectors in extraction of loess shoulder-lines and found that the LoG detector can extract loess shoulder-lines accurately and effectively. However, there are still some drawbacks in the mentioned methods to be solved. Firstly, in order to produce a continuous and integrated shoulder-line, a global method must be invented to overcome local noises. Secondly, the hydrological and morphological processes should be taken into account to achieve more accurate results. Finally, quantitative factors should be employed to evaluate the availability of the method.

The paper proposes a combined method to extract the loess shoulder-line. It adopts the snake model and D8 algorithm (Wilson. et al. 2008) respectively. The method is able to overcoming these drawbacks. The snake model is capable of extracting object contour extraction in computer vision, medical imaging and remote sensing image processing. There are many applications using the snake model, such as edge detection (Hoch et al. 1996), object recognition and tracking (Wang et al. 2004; Barnard et al. 2002), road network extraction and updating (Mayer et al. 1998; Zhang et al. 2004; Butenuth et al. 2008; Li 2009). Inspired by the snake model, this paper employs Gradient Vector Flow (GVF) to help the snake involve to their final destination. It uses an external force proposed by Xu et al. (1997, 1998 and 2000) to overcome difficulties of contour initiation and concave contour detection in loess shoulder-line extraction. The paper firstly adopts hydrological water flow routine algorithm to extract stream boundary lines by simulating the water flow direction in a local neighborhood. For simplicity, the paper chooses the D8 algorithm to extract the watershed boundary automatically (Wilson. et al. 2008). Then the snake model extracts the shoulder-line automatically by the initial watershed boundary. Finally, the contour matching method is employed (Tao et al. 2007) to evaluate the accuracy of the snake model.

1 Study Area

The study area is located in the loess plateau north-west China. Two representative sites are selected in this study, located in the loess tableland and loess hill-gully area respectively. The general information of these two sites is shown in Figure 3. The test areas are covered with data of 5 m resolution produced by contours of 1:10,000 scale topography maps. These data are the highest resolution terrain data available in this region. In addition, the corresponding DOM data with 1 m resolution of the same area is used for manual interpretation and mapping of the loess shoulder-lines which will be applied as ground truth for accuracy evaluation of our algorithm. Table 1 lists statistical information of data sources in these two sites.

The main topography of the test area is characterized by a complex combination of loess tableland, loess ridge, loess hill as well as the transitional form between them. The site 1 locates in the loess tableland area, and the site 2 is in the loess hill area. There are distinguished characteristics between the positive and negative terrains and the loess shoulder line could be manually extracted on a DOM image. Careful rectification is done to validate the accuracy both in laboratory and field investigation. The morphological feature of the test sites are shown in Table 2.

2 Method

2.1 Snake model

The snake model is a recent achievement used to extract or track the edge of objects. The snakes,

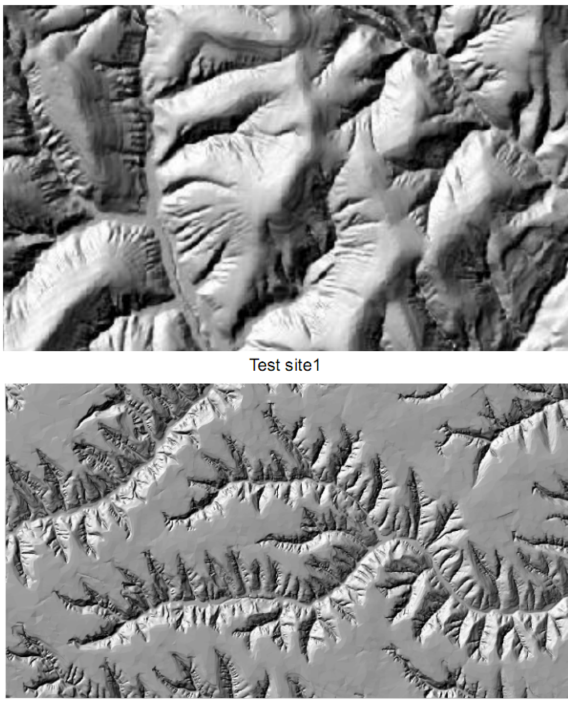

Figure 3 Hillshade of the two test area.

or active contours, firstly proposed by Kass and Terzopolulos in 1987, are one or a series of deformable curves which could move under the guidance of a combined influence of internal forces from the curve itself and external forces from the background image. It is capable of extracting an integrated contour line even though there are weak edges with weak visual characteristics. So the snake model is widely used in many applications including subjective contours tracking, stereo matching, motion tracking and road extraction et al. After an overall investigation on the existing two active contour models, parametric active contour and geometric active contour, this paper chooses the former one in the experiment for its efficiency and accuracy. In the parametric model, Curve evolves against the background image under the energy of itself and stops at the edges on the conditions of minimal total energy.

The parametric curve can be defined by:

$$v(s) = \{x(s), y(s)\} \tag{1}$$

where $s \in [0,1]$ (s denotes the normalized length of the curve, v are the points. x, y are their coordinates). The goal energy function of snake model E_{Snake} can be expressed as:

$$E_{\text{Snake}} = \int [E_{\text{int}}(v(s)) + E_{\text{ext}}(v(s))]ds \tag{2}$$

where E_{int} stands for the internal energy. It is only inherited by shape of the curve. The energy will force the snake to move. E_{int} could be defined as:

$$E_{\text{int}} = \frac{1}{2}(\alpha |v'(s)|^2 + \beta |v''(s)|^2) \tag{3}$$

where $v'(s)$ and $v''(s)$ stand for the first and the second order derivative of v to the curve s respectively. The first-order parameter α is a constant coefficient in describing the curve's tension, which makes the snakes act like a membrane so as to gradually touch the edge of the object. The second-order term β makes the snake curve perform like a thin plate and is a parameter to characterize rigidity of the snake curve. Through adjusting the values of α and β, the relative importance of the membrane and thin-plate terms could be

Table 1 Topographic parameters of the test sites

Test site	Area (km²)	Average slope (°)	Landform type	Gully density (km/km²)	Average height (m)
Site 1	5.4	30.6	Loess hill gully	10.9	996.0
Site 2	40.2	20.7	Loess tableland	4.7	961.6

Table 2 Characteristics of positive and negative terrains on DOM and DEM

Terrain Types	Texture complexity	Color tone	Average slope (°)	Land use type
Positive Terrain	Simple	Bright	≤25	Agriculture
Negative Terrain	Complex	Dark	≥35	Wild

controlled.

For the extraction of loess shoulder-lines, the external energy E_{ext} represents the height information of each cell and it could be derived from the DEMs. The position independent force could be used to identify the obvious loess shoulder-line candidates with apparent height variation.

2.2 Extraction of initial contour line

The paper adopts an improved snake model by using the watershed boundary line as the initial contour extracted by D8 water flow routing algorithm. The watershed boundary line will finally evolve to the obvious candidate points for the loess shoulder-lines. The snake model could keep the weak edges between the candidates connected. Thus, an integrated loess shoulder-line could be achieved.

The procedure of the algorithm is shown in Figure 4. The process can be divided into two parts. The first is to identify the initial contour lines by D8 algorithm shown in the upper dash box. It includes processes of sink filling, flow direction, flow accumulation calculation and watershed boundary extraction (Easterbrook et al. 1999; Jia 2010). The D8 water flow routing algorithm could be departed into three steps. (1) Filling. This step is used to remove sinks in real terrain depicted by DEM data to keep water flows to the outlets. (2) Flow direction. In this step a 3 by 3 neighborhood is defined. The water flow direction of the central unit of the neighborhood is judged by flowing to its steepest neighbors. (3) Flow accumulation. It will accumulate to all the units to outlets of the watershed. More details could be found in the literature of Wilson et al. (2008). The threshold parameter used for watershed extraction in these experiments is 300,000 (1000×600/2) units, which is calculated based on the area of the study site. The second part implements an edge detection process, in which the watershed boundary line is employed as the initial contour line until it touches the destined position. After calculating the external force E_{ext} with the DEM data, this paper adjust the parameters α and β iteratively to control the evolving speeds until it pursuits the global optimization when the snake curve evolves to the loess shoulder-line. Figure 5 shows nine stages during the evolution of the initial contour in one of the test sites.

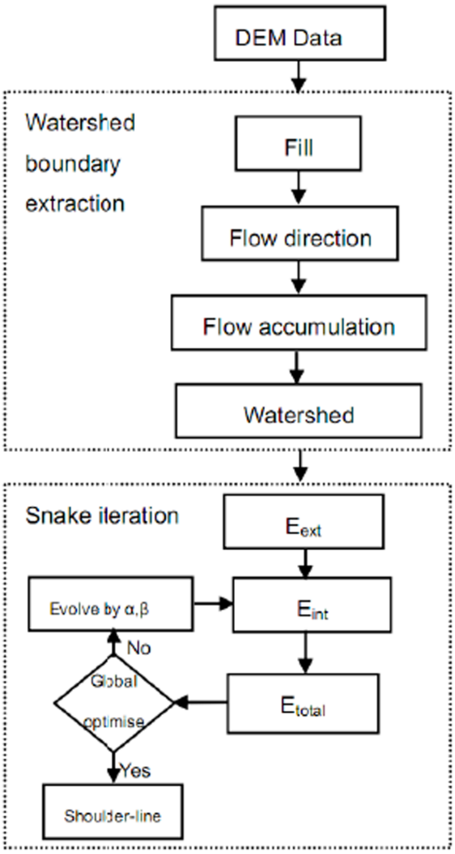

Figure 4 Pipeline of loess shoulder-line extraction.

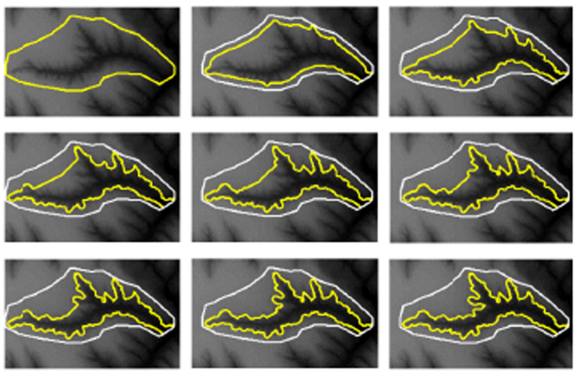

Figure 5 Nine stages of the evolving of the snake contours (The white line is the initial snake curve, the yellow line is the evolving contours).

3 Results and Discussion

3.1 Results

In the experiment, the snake contour evolves to the position of loess shoulder-line after 60 times of iterations by the interactive guidance of internal and external forces. Experiments show that 0.5 is suitable for the parameters of α and β. It means the snake curve evolves equally in both directions. The paper sets these two parameters ranging from 0.1 to 1 and finds that the equal value of the two parameters would keep a balance on involving in the normal and tangential directions of each snake point. A series of experiments are implemented in the two different test areas based on the aforementioned settings.

The loess shoulder-line extracted by snake model in another test site is shown in Figure 6. Because the 5 m resolution DEM is still too rough for the extraction of loess shoulder-line, the paper does not down sample the data to investigate scale effects of these parameters, either the scale effects of the snake based method.

For comparison, this paper accomplishes the results achieved by (Yan et al. 2011). It adopts the first and second order edge detectors to extract the loess shoulder-line. Figure 7 shows a group of derivatives from six detectors. Figure A, B and C are derived from the first order detectors, named Sobel, Prewitt and Robert respectively. There appear disorderly for their sensibility to the local noise and disturbance. Thus the edges are not easy to process with a uniform rule by which the segments at weak edges could be connected to an integrated line. The second order detectors with enlarged moving analysis window will overcome the drawback. The neighborhood algorithm keeps the edge lines more integrated. As is shown in Figure D and E, LoG detector performs better than canny does according to their continuity and accuracy, but errors are still apparent compared with the true data. Hence, all the results derived by edge detectors are far from mature and a more efficient and accurate method is expected.

Figure 8 shows the cumulative frequency curves of the two test sites, in which the x and y axis represent for the error and its corresponding percentages. It shows a comparison of the final curve extracted via snake model, LOG detector and manually extracted true lines.

3.2 Accuracy evaluation

The matching ratio method is used to evaluate the quality of the loess shoulder-line extracted per

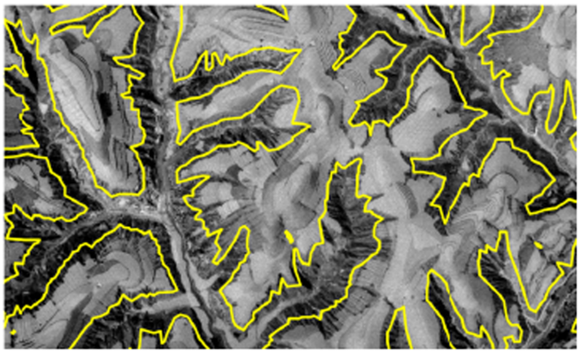

Figure 6 The snake model based loess shoulder-line overlaid with DOM in test site 1.

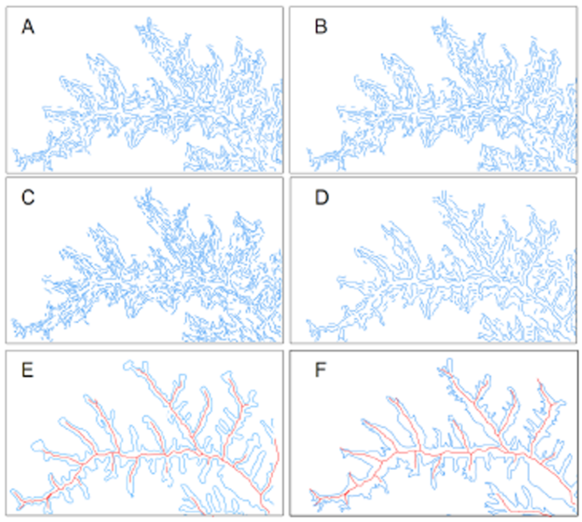

Figure 7 Lines by (A) Sobel, (B) Prewitt, (C) Roberts, (D) Canny, (E) LOG, (F) manual.

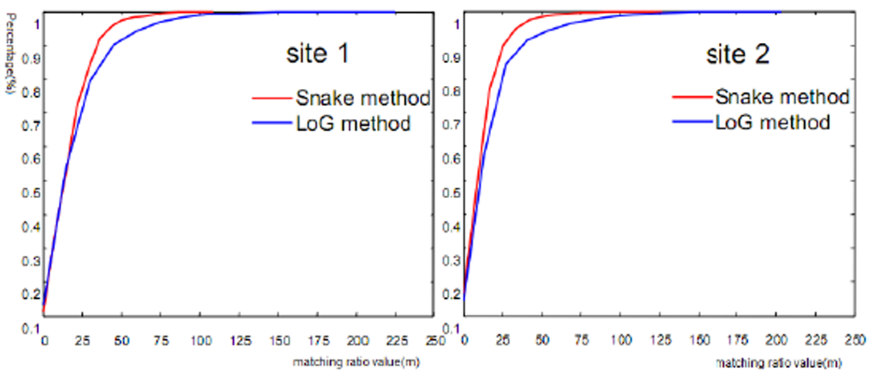

Figure 8 The cumulative frequency curve of the matching ratio result.

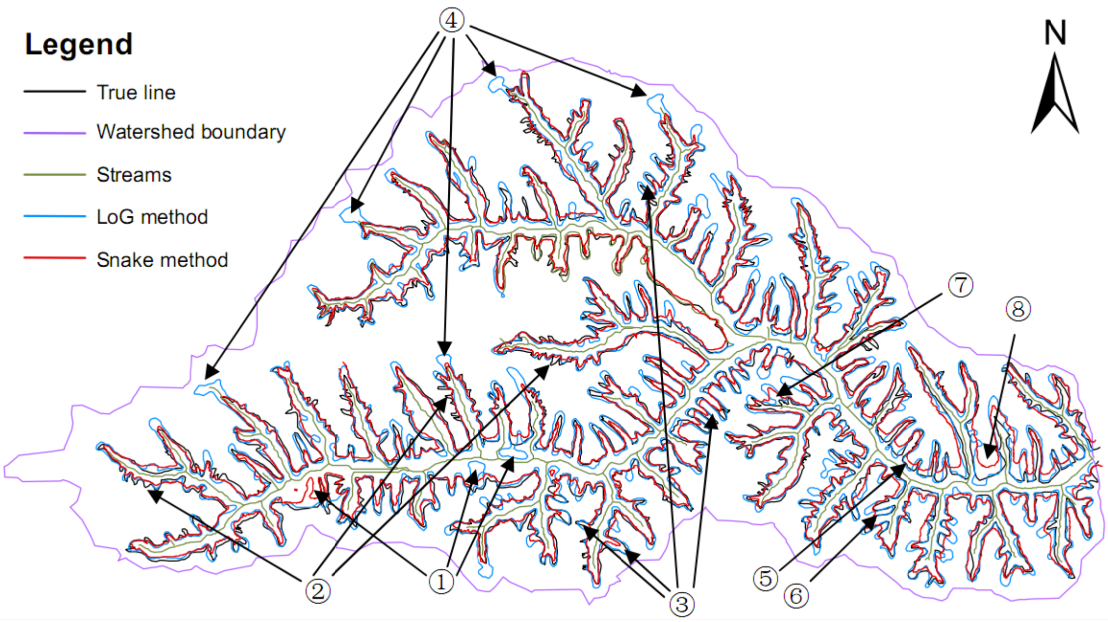

Figure 9 Comparisons between standard loess shoulder-line and line should line by LoG edge detector and snake method in site 2.

measuring the vertical length of difference to the true line proposed by Tao et al. 2007. The evaluation is carried out by the point to point distance in two different parts.

The first is to compare the manual based true lines with snake model based loess shoulder-lines shown in Figure 9. The other is to compare that with line generated by LoG. For a better understanding of data distribution of the matching ratio, the cumulative frequency of matching ratio is aggregately calculated with increasing error levels shown is Figure 7. Nearly 90% of the errors from the snake model are within 25 m, while about 70% by LoG method. This implies that the snake model based method could get a better result. The improvements could also be observed by comparing the increasing speed of cumulative frequency curve in these two sites.

Table 3 Comparisons of accuracy statistics for snake and LoG based loess shoulder-line (Unit: m)

Sites	Method	Min	Max	Mean	Std dev
Site 1	LOG	0	224.6	19.5	22.1
	Snake	0	108.2	16.5	14.0
Site 2	LOG	0	203.0	16.7	21.0
	Snake	0	126.2	12.0	12.3

Table 3 shows a group of quantitative statistics for the matching ratio results in these two test sites. The mean matching differences in these two sites are 16.5 m and 12.0 m respectively. From the table, the snake model method exceeds the LoG one in both test sites and it performs better in site 2 than in site 1.

3.3 Discussions

Comparisons show that the shoulder-line extracted by the snake model generally preserve the closer distance and high spatial correspondence with true line compared with other methods.

The error behaves in a specific spatial pattern and varies in different landform units. In the flat and wide stream labeled by ① in Figure 9, the error increases in their number and magnitude. The reason might be that the strength of driving force in such areas is rather low, causing decreases in the accuracy. It is stressed that the snake model may evolve to a more accurate level if the number of curve evolving times increases.

While small errors are usually located around the straight parts as is pointed out by ② in Figure 9, and vice versa. The true line zigzags more complexly than the snake based derivatives. It seems that the snake model is not sensitive to concaves of small gullies. Figure 9 also shows that big errors usually appear at the narrow gullies labeled with ③ for it is difficult for the snake to converge in the head of narrow gullies.

As is labeled by ④, the snake model contributes a lot to the improvements of the gully head area .The loess shoulder-line extracted by the new method locates closer to the standard one than by the LoG detector. The mean, max and standard deviation of the matching difference are improved from 377.5 m, 17.0 m and 37.8 m to 334.7 m, 12.1 m and 13.1m. As is shown by label ⑤, on the steep slopes near the streams, bigger distance can be found between the loess shoulder-line and the true line, the snake one occupies the upper position, while the LoG detector line is depressed near the streams.

The worst result appears at the location labeled with ⑥, ⑦ and ⑧, where a series of multi-period shoulder-line form a rather complex case. The manual extraction and the LoG detector tend to find out the most obvious loess shoulder-line candidate points. But the snake model tends to be closer to the positive terrain area; this edge is not easy to be identified by the edge detector or naked eyes. Based on the quantified analyses in Figure 8-9, the result of site 1 also confirms the high accuracy of snake model. The improvements could be reflected on two aspects. On the one hand, the snake model preserves higher percentages than the LoG based method with the same error level for both of these sites. On the other hand, the error of the snake model is lower than that of the LoG based method at the same level of cumulative frequency. The improvements could also be achieved by analyzing the statistics of length differences in these two sites in Table 3. The table also implies that the snake model behaves better in the tableland area (site 2) than in the hill and gully area (site 1). The difference may be caused because of the difference of morphological attributes of the two test sites. In addition, the high dense gully in test site 1 would limit the performance of the snake model in calculation.

4 Conclusions

A new method based on the D8 water routine and snake model for extracting loess shoulder-lines from DEMs is put forward in this paper. Based on a series of experiments, the paper draws following conclusions:

(1) The model is capable of extracting an integrated loess shoulder-line, with a higher accuracy and continuity than the other methods. Nearly 90% of the loess shoulder-lines are located within 25 m to the true lines in two test sites. Especially in the gully head area, the new method improves the accuracy of loess shoulder-line compared with the LoG edge detector.

(2) The accuracy of snake model based loess shoulder-line extraction method varies in different landform areas. It can achieve better results in the loess tableland area than in the loess hill-gully area.

(3) The errors are obviously related to landform locations. In either the plain or broad stream area, the errors increase due to the limited ability of concaving convergence of the snake model.

(4) The paper only used 5 m resolution DEM, Higher resolution DEM and the scale effects of parameters for snake mode are expected to achieve better results.

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