Comparison of several methods for multi-scale DEM generalization in different landform areas

Qiao Wan
School of Resource and Environment Science
Wuhan university
Wuhan, China
wanqiao@whu.edu.cn

Yumin Chen
School of Resource and Environment Science
Wuhan university
Wuhan, China
ymchen@whu.edu.cn

Abstract—**There are various landforms in real word and numerous methods proposed previously for DEM generalization. When use different methods to generalize a DEM, the results vary greatly. Therefore, in order to get a most proper method to implement the generalization, we need taking topographic information into consideration. This paper tested four methods widely used in DEM generalization and compared their performances in different landform areas. The results show the compound method delivered the best results among those algorithms. However, the four methods all have its advantages and disadvantages. Thus we can select the most proper one in different practical applications according to their different characteristics.**

INTRODUCTION

With the wide use of multi-scale DEMs, it is necessary to study the DEM generalization method further. There are numerous DEM generalization methods proposed before [1,2]. And those can be categorized into three groups, including raster DEM method, restructuring the grid-based DEM using a triangulated irregular network (TIN) method, and generalizing using a drainage-constrained TIN method.

In most generalizations of DEMs, the influence of topography feature is usually ignored. Generally speaking, the most proper method for generalization in different areas which have different topography features and for different practical applications varies greatly. Therefore, how to choose the best method to implement the generalization in different landform areas is a problem should be solved.

This paper classifies landform types into several classes, using a quantitative approach proposed before [3]. The principal objective of this paper is to find the proper method for multi-scale DEM generalization in different landform areas. Therefore this paper tested a lot of samples, and selected some examples from them which belong to the different landform types. Then implemented DEM generalizations using the selected four methods and compared their performances in different landform tests. The four methods are, the resample method [4], the maximum z-tolerance algorithm [5], the compound method [6], the ANUDEM algorithm [7].

METHODOLGY

There are eight major classes of landforms [3], and those classes of landforms are River Alluvial Plain(RP), Piedmont Plains(PD), Gravelly Fans(GF), Plateaux and Upper Terraces (TR), Hill(H), Mountains(M), Lowlands (LL),Flood Plains(FP). According to their similarity in terrain feature, we merged them into six types. After merging, the results are Plain (P), Gravelly Fans (GF), Plateaux and Upper Terraces (TR), Hill (H), Mountains (M), Lowlands (LL). This paper classified all landforms into six types by their elevation rang and slope(TABLE I).

TABLE I. THE STANDARD OF FIRST CLASSIFICATION

Landform	Slope range (%)	Elevation rang (m) Max-Min elevation
P	0-5%	[0,150)
GF	0-5%	[150,250)
TR	0-12%	[250,500)
H	8-25%	(50,500)
M	Over 25%	[500,1500)
LL	Less than 1	<0

In the paper, the original data are some 30 m DEMs, which was generalized to generate DEMs with different resolutions respectively, including 50, 100, 150, and 250 m spatial resolutions. All the original DEMs were clipped to1,001×1.001 grid cells, in order to keep their size same.

Therefore, after the classification, we tested the four methods we selected in DEM generalization of different landforms and compared the performances of the selected four methods in different landform types. The resample method is one of the most widely used method for DEM generalization, which requires averaging the neighboring cells of a high-resolution, square-grid DEM into a series of lower-resolution data sets. The maximum z-tolerance algorithm is an example of methods using TIN to generalize DEM, which extracting more points in areas where the terrain are more complicated, so it has superiority in retaining the terrain feature. And the compound method is a drainage-constrained TIN method for DEM generalizations. The difference between the maximum z-tolerance method and the compound method is, the maximum z-tolerance method use only significant points and the compound method take the streamline of DEM into account when structure the TIN. The ANUDEM method is a interpolation method taking the drainage network into consideration.

For the resample method, we chose the nearest neighbor method to carry out the sampling. And for the ANUDEM and the compound method, they used the same significant point and drainage network to get a fair comparison result. For the maximum z-tolerance algorithm, it used the same significant point as the compound method's to restructure a TIN.

When we set the z-tolerance value using the z-tolerance algorithm to extract the significant point, the six landforms can merged into less three types by their similarities in terrain feature (TABLE II).

TABLE II. THE STANDARD OF SECOND CLASSIFICATION

Type	Inclusive landforms
Flats	P, LL, TR
Hills	GF, H
Mountains	M

The USGS DEM data accuracy standard in which a RMSE of one-half contour interval is the maximum permitted guided the specification of z-tolerance values at different scales in different landforms (TABLE III).

TABLE III. THE SPATIAL RESOLUTION AND CORRESPONDING Z-TOLERANCE VALUES IN DIFFERENT LANDFORMS

Resolution(m)		50	100	250	500
Z-tolerance Value (m)	Flats	5	10	25	45
	Hills	15	30	30	90
	Mountains	30	60	125	180

And we use the simple "D8" flow routine algorithms [8] to extract the streamline of the DEM. We set the threshold of this algorithm by taking the grid number of DEMs into consideration, result in a coarser DEM with a smaller threshold value.

This paper classified all landform type areas into those types and tested the four methods we selected and compared their performances. In order to get a credible result of comparison, we used four representative parameters widely used in DEM generalization, including the root mean square errors (RMSE), the mean slope value, the mean roughness value and the streamline matching rate (SMR) [6].

The root mean square errors (RMSE) were compared to measure the accuracy of the original and generalized elevation surfaces. It can be specified as followed:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Z_i' - Z_i)^2}{n}} \quad (1)$$

The mean slope ($\overline{S}$) and surface roughness (K) are good measures to compare the generalized DEMs created at varying scales. Their computational formulas are:

$$\overline{S} = \frac{\sum_{i=1}^{n} S_i \times A_i}{\sum_{i=1}^{n} A_i} \quad (2)$$

$$K = \frac{A'}{A} = \frac{\sum_{i=1}^{n} A_i \sec S_i}{\sum_{i=1}^{n} A_i} \quad (3)$$

Where S denotes the slope, A denotes the projected area; A' denotes the surface area, i denotes the ith nit; and n denotes the total number of units.

The streamline matching rate (SMR) [6] was computed to test the effectiveness of retaining drainage features. In this paper, the threshold value of 'streamline buffers' is as same as the resolution of the generalized DEM. The computational formula is:

$$SMR = \frac{L'}{L} \times 100 \quad (4)$$

Where L' denotes the length of streamlines that fell into the corresponding stream buffer zones, L is the total length of the streamlines.

RESULT AND DISCUSSION

In this paper, we classified landform types into several classes, and compared the performance of four methods for DEM generalization. The DEMs were all clipped, so composed of the same 1,001×1.001 grid cells. We take a sample of the Mountains (M) type as an example to show the comparison (Fig. 1).

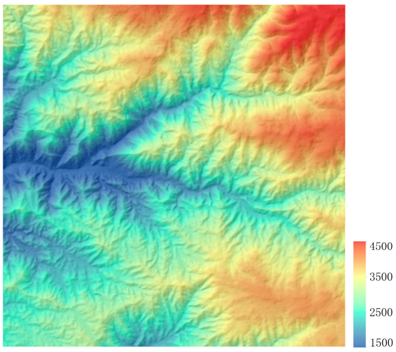

Fig.1 The sample DEM

The basic geographic information of the original DEM is shown in the TABLE IV.

TABLE IV. THE BASIC GROGRAPHIC INFORMATION OF ORIGINAL DEM

Mean Elevation (m)	Maximum elevation (m)	Minimum elevation (m)	Mean slope(°)	Mean roughness
3135.33	4457	1448	21.58	1.0981

The z-tolerance values used in different resolutions (only for the maximum z-tolerance method and the compound method) is shown in TABLE V.

TABLE V. THE Z-TOLERANCE VALUES IN THE SAMPLE GENERALIZATION

Resolution(m)	50	100	250	500
Z-tolerance Value (m)	30	60	125	180

And the threshold values when we extracting the drainage network from the original DEM represent in TABLE VI.

TABLE VI. THE THRESHOLD VALUES FOR EXTRACTING THE DRAINAGE NETWORK

Resolution(m)	50	100	250	500
threshold value	600	1000	1500	2000

The following several tables is the results of the generalization.

TABLE VII. RMSEs (m)

	50m	100m	250m	500m
Compound	22.33	30.47	51.39	113.75
ANUDEM	27.83	34.81	72.60	146.94
Z-tolerance	28.68	35.67	80.94	163.11
Resample	18.86	29.84	53.10	108.47

TABLE VIII. THE MEAN SLOPE VALUES (°)

(21.58)	50	100	250	500
Compound	21.25	18.71	15.99	8.92
ANUDEM	22.25	18.52	14.10	7.64
Z-tolerance	22.61	17.86	14.86	8.01
Resample	21.20	18.52	16.34	8.59

*The 21.58° is the mean slope value of original DEM.

TABLE IX. THE MEAN ROUGHNESS VALUES

(1.0981)	50	100	250	500
Compound	1.0986	1.0751	1.0518	1.0247
ANUDEM	1.1069	1.0610	1.0409	1.0102
Z-tolerance	1.1075	1.0628	1.0412	1.0109
Resample	1.0953	1.0773	1.0539	1.0215

TABLE X. THE SMR VALUES (%)

	50	100	250	500
Compound	60.14	71.92	97.33	85.16
ANUDEM	64.34	65.81	69.10	63.27
Z-tolerance	60.23	68.45	87.22	41.23
Resample	76.99	80.45	87.22	51.34

The results show that the resample method had an effective performance in the generalization, the RMSE, mean slope value, mean roughness values of the resample method are all fine, but it can not keep a excellent streamline than the compound method or ANUDEM method. Compared with the resample method and maximum z-tolerance algorithm, the ANUDEM algorithm and the compound method performed much better in preserving the key morphological and hydrological features. However, the compound method is better than the ANUDEM algorithm in retaining terrain details.

Totally speaking, the compound method delivered the best results among those algorithms. But in practical applications, selecting proper method must take some other factors into account, such as the size of the DEM data after generalized and the priorities of parameters retaining. For example, in a hydrological model, the best method for DEM generalization will be the compound method. But in some applications which demand rapid results and less accuracy, the resample method maybe best choice.

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