Generation of triangulated irregular networks for distributed hydrological modelling

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Abstract Taking slope, topographic and wetness index as the key criteria to select nodes, we generate triangulated irregular networks (TINs) that integrate multiple landscape properties. Also, comparison between two different interpolation methods is presented. The results indicate that for the same TIN, spatial variability of terrain is better depicted by using 5-degree polynomial interpolation than linear interpolation, and TIN can account for basin terrain and other landscape properties with fewer nodes while keeping the similar precision compared to a regular grid and hence can lead to the higher computation efficiency when applied to distributed hydrological modelling, especially for the large-scale watersheds.

Key words TIN; Grid; topographic index; slope; hydrological model

INTRODUCTION

Grid and TIN (triangulated irregular network) are two common ways used to reflect the spatial variability of topography, distribution of land use, etc. TINs are a series of triangles, which can represent terrain features as well as other properties of the surface, while grids are a series of points ranked in a matrix format, and the value of a point shows the surface information of the location. The data storage of TINs contains nodes of triangular mesh and their relationship, which is more complex than that of grids. TIN nodes can be distributed irregularly, bringing more flexibility of multiple resolutions.

In general, watershed boundary as well as special points and lines can be depicted more precisely by TINs than grids. With the same degree of precise presentation, the number of TIN meshes can be far smaller than that of grids. TINs are usually generated by selecting important nodes to capture the terrain variability. For example, a certain number of points on contour lines, generated by grid DEM, are selected as nodes of triangular mesh. Traditional TIN generation methods generally do not account for criteria other than the preservation of critical slopes, and TIN meshes have varying size and density. Vivoni *et al.* (2004) mentioned that traditional techniques ignore hydrographic and landscape features that are desirable within hydrological model domains and proposed an approach of the use of multiple resolution TIN meshes to represent surface terrain in a watershed model. Vazquez *et al.* (2007) analysed the effects of DEM gridding on the prediction of basin runoff. In this study, TIN and grid are compared as two ways to represent surface spatial characteristics. Terrain slope and topographic index are used as principal criteria to generate TINs, while spatial characteristics such as land use, soil type, hydrogeology, etc. are also considered. The resulting TINs can reflect both terrain variety and watershed hydrological features with fewer meshes, and are more applicable to hydrological modelling.

GENERATION OF TINS

Computation of slope and topographic index

Beven & Kirkby (1979) first proposed a topographic index in TOPMODEL. It is considered that runoff is mainly affected by terrain and landscape and it is concluded that areas with the same topographic index and soil features have hydrological response similarity. Distribution of the calculated topographic index over the whole watershed macroscopically indicates the change of runoff generation areas and the degree of saturation or wetness. Thus topographic index is usually used as an important parameter of physically based distributed hydrological models (Yang *et al.*, 2000). Therefore topographic index, as an index representing runoff generation features, is chosen as a significant factor in TIN generation. The topographic index is calculated as:

$$\lambda = \ln\left(\frac{\alpha}{\tan\beta}\right) \tag{1}$$

where α is pixel contributing area per unit width; $\tan\beta$ is local pixel slope.

Various methods to calculate topographic index have been proposed. In practice, the single flow direction algorithm (Kong *et al.*, 2003) and the D8 based multiple flow direction algorithm proposed by Quinn *et al.* (1991) are widely used. In this study, we used the single flow direction algorithm to compute topographic index with little amendment. In the calculation, the slope of one point is taken as the steepest slope along its neighboring eight directions, and it is assumed that effective length of contour line is equal to that of a grid cell or the diagonal one that is normal to the flow direction. The calculation is conducted with the aid of ArcInfo (Mike & Tom, 2005). Then the formula to calculate topographic index becomes:

$$\lambda = \ln\left(\frac{(A_{cc}+1)\cdot L^2}{L_e \tan\beta}\right) \tag{2}$$

where A_{cc} is the number of cells that flow into the point; L is the length of grid cell; and L_e is equal to L or $\sqrt{2}L$ depending on D8 flow direction.

The upper portion of the Qin River basin was chosen as the study area, which has an area of 1352 km^2, with the outlet of the basin located at the Kongjiapo hydrological station. The data used in this study are 100-m resolution grid DEM, which are based on SRTM 30-m DEM provided by NASA, and revised via GTOPO30 data and 1:250 000 contour lines of the Yellow River basin. If the slope of the point in the riverway is 0, we use the minimal slope of its neighbouring eight points instead to avoid the denominator being 0. Figure 1 illustrates the results of flow convergence calculation and the topographic index distribution.

TIN generation method

The nodes of TINs are generally selected from points of the grid DEM by a certain algorithm. For example, they are chosen from points on some elevation interval contours. This method has higher resolution along rugged hillslopes since the terrain variability is high, but flat regions, especially the river course where contours are sparse, are poorly resolved. In contrast, the analysis of topographic index indicates that topographic index isolines automatically remain dense within regions that frequently saturate. If only based on slope-preserving or topographic index, TINs will have excessively dense distribution in the hillslopes or plains, but attributes such as stream networks, land-use, etc. spatially couple with slope and topographic index. As a result, when we construct the TIN mesh, lots of information about basin landscape is synthetically considered. The main principles are as follows: (1) topographic index isolines are dominant near the valleys; (2) slope

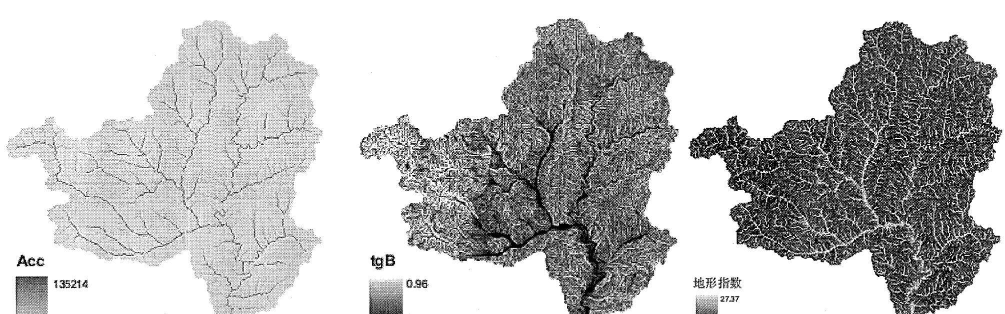

Fig. 1 Flow accumulation, slope and topographic index distribution.

isolines are dominant close to hillslopes and ridges; and (3) incorporate all the information on stream networks, sub-basins, land use, soil and Thiessen polygons formed by precipitation stations, and add TINs in some local areas where high spatial variability exists but meshes are sparse according to the above two criteria.

Depiction accuracy of topography based on different discretization forms of land surface

TIN meshes generated contain about 7000 triangles. TIN elevation error distribution compared with original high-resolution DEM (255 000 100-m grids, referred to as Grid in figures and tables) is shown in Fig. 2, which illustrates that the ratio of grids whose relative errors are within ±5% is over 95%, which means high precision, and if we use 5-degree polynomial interpolation, this ratio increases to 98%. In order to further study the depiction accuracy of topography by TINs, we utilized 500-m grids (referred to as Grid 500 in figures and tables) transformed from 100-m grids as a comparison, the number of which is about 10 000. The computed frequency distribution of the elevation error, slope and topographic index are shown in Fig. 2 and Table 1, Fig. 3 and Table 2, and Fig. 4 and Table 3, respectively. TIN1 stands for the TINs using linear interpolation, and TIN5 for the TINs using 5-degree polynomial interpolation, the original DEM (100-m) is indicated as grid and the coarsening DEM (500-m) as grid 500. The elevation error is based on the elevation values of 100-m grids. To account for the changes in size of grids, the number of units, the location of the centre of units, the distribution of upper stream catchment area of the unit (A_{cc}) and the pixel contribution area per unit width (α) are calculated and shown in Table 4 and Fig. 5.

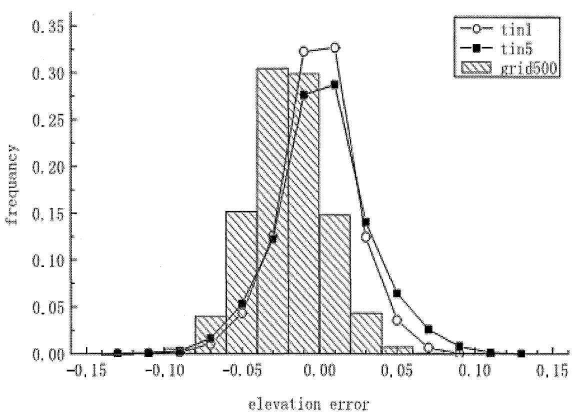

Fig. 2 Comparison of frequency distribution of elevation error.

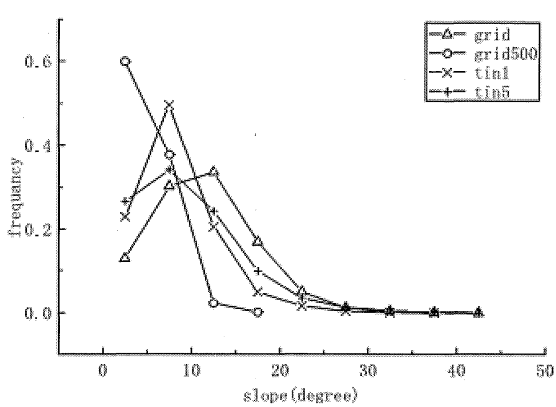

Fig. 3 Comparison of frequency distribution of slope.

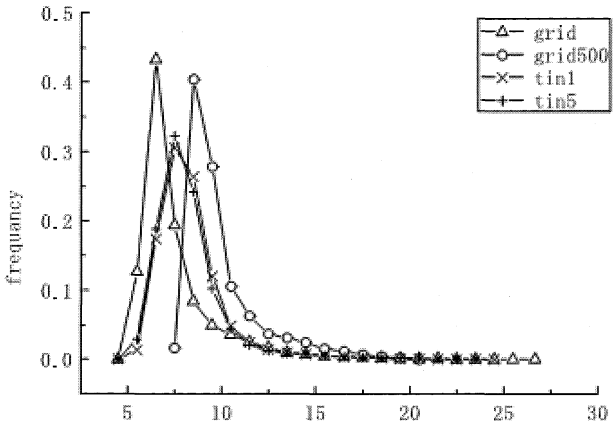

Fig. 4 Comparison of frequency distribution of topographic index.

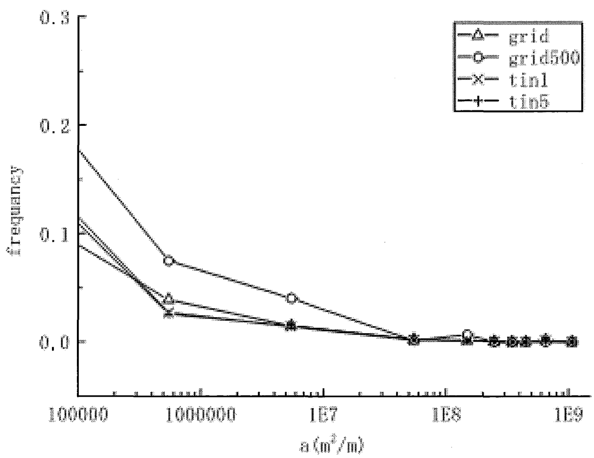

Fig. 5 Comparison of frequency distribution of α.

Table 1 Comparison of depiction accuracy of elevation.

Item	Grid	Grid500	TIN1	TIN5
Ratio of relative error within ±5%	–	0.95	0.98	0.94
Maximum (m)	2516	2490	2516	2516
Minimum (m)	999	999	999	999
Mean (m)	1445	1445	1441	1446
Standard deviation (m)	229	228	230	231

Table 2 Comparison of depiction accuracy of slope.

Item	Grid	Grid500	TIN1	TIN5
Maximum	43.92	17.78	37.56	42.39
Minimum	0	0.06	0.01	0.01
Mean	11.19	4.62	8.04	9.15
Standard deviation	5.56	2.27	4.44	5.85

Table 3 Comparison of depiction accuracy of topographic index.

Item	Grid	Grid500	TIN1	TIN5
Maximum	27.37	20.23	24.67	23.17
Minimum	4.82	7.44	4.93	4.77
Mean	7.53	9.91	8.35	8.24
Standard deviation	2.16	2.01	1.90	1.96

Table 4 Comparison of depiction accuracy of A_{cc}.

Item	Grid	Grid500	TIN1	TIN5
Maximum (hm^2)	135 214	134 075	134 813	134 750
Minimum (hm^2)	0	0	0	0
Mean (hm^2)	392	1586	338	356
Standard deviation(hm^2)	5474	10 607	5025	5214

The comparison results indicate that: (1) Both TINs and coarsening grids can depict the elevation well, but the former have a little higher precision. (2) Compared with original high-resolution grids, the TIN method depicts the steep regions well, yet smoothes the gentle slope. (3) Both the values and distribution of flow accumulation area per unit width are in good agreement for TINs using different interpolations and a 100-m grid model, while the results of 500-m grids differ from those of 100-m grids in the source areas far away from the river and are similar to those of TINs near the river where the flow accumulation area is large. (4) Regions near the watershed division become homogeneous when the mesh size is large. TINs have less impact than homogeneous 500-m grids. If we use 5-degree polynomial interpolation, the results improve a little, but ensemble distributions by the two interpolations differ very little.

CONCLUSIONS

- TIN mesh system, which is based on slope and topographic index and incorporates various kinds of hydrological information, has several advantages compared with the grid method of the spatial discretization of the land surface.
- TIN method, which uses continuous polylines to capture the curved borderlines, can handle watershed boundaries easily, while the grid method can only use serrated borders to approach actual ones.
- TIN method can accurately represent local details with fewer units when dealing with multi-scale data due to its inherent characteristic of variable resolution, while in grids, the number of nodes is in significant contradiction with accuracy for the single spatial resolution.
- TINs can incorporate multiple known landscape information in the process of constructing TIN mesh. Therefore, the mesh themselves contain a lot of basin hydrological information. While raster grids depend on the smallest scale of all the information and can only use points to depict information other than lines and surfaces, which leads to less accuracy.
- TINs are flexible to include additional discretization units in local areas to account for higher spatial variability, which makes it more effective than the grid method.

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