Study on SDE Distribution of Forest Vegetation in China Based on Trapezoidal Grid Segmentation

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Abstract. The trapezoidal grid segmentation of China was carried out at a scale of 1:10000 to form a grid system covering the Chinese mainland. Based on the standard deviation ellipse (SDE) distribution theory, seven major categories and 53 sub-categories of Chinese forest vegetation were studied respectively. The SDE distribution was obtained and the average area distribution rate of 51.75% major-category vegetation was also obtained. Broad-leaved forests and sparse forests accounted for the largest proportion in China, with a proportion of 68.11%, the deviation rate of the average was 31.61%, and the dispersion was 0.097; the average distribution rate of sub-category vegetation was 9.38%, and the temperate subalpine evergreen coniferous forests accounted for the largest proportion in China, with a distribution rate of 30.23% and a dispersion of 0.032. The spatial distribution pattern of vegetation is mostly "southwest-northeast", but the elliptical center of the major-category vegetation moves more; while in terms of the direction of sub-category vegetation, there were nine categories of vegetation with three long-axis azimuths [<45 degrees], 27 categories of vegetation with long-axis azimuth [27° ≤90°], and 27 categories of vegetation with long-axis azimuth [90°].

1. Introduction

The theory of grid can be traced back to the "nine-square system" in primitive society. After the Han Dynasty, Zhang Heng (78-139) put forward the idea of "calculating the world by networking it", which is also the embryonic form of rectangular grid. After the nine-square system, the "Cartographic Hexahedron", a method of drawing maps on a scale, proposed by Pei Xiu of Jin Dynasty divides the plane into two-level coordinates and azimuth. The "Map of China and Overseas", compiled by Jia Dan (730-805), and it is also an application model of grid map. Based on this map, an engraved stone "Yuji Map" was made. Luo Hongxian (1504-1564) used Zhu Siben (1273-1332), a predecessor of the previous dynasty, to draw the "Yudi Map", and then drew “Yutian Map”. For the first time, it used the Atlas to express the practical significance of grid theory. Chen Shupeing carried out a series of innovative research on grid theory by using the functions of geospatial analysis and geographic comprehensive analysis; The discussion of the general and narrow spatial information grid system and grid GIS is proposed and researched by scientists such as Li Deren and Wang Jiayao in China. It has been verified by application in Wuhan and other places with good effect. From a foreign perspective, Eratosthenes (275 BC - 193 BC) built a latitude-longitude network system, and Hipparchus (140 BC) first divided the circle into 360° and tried to the topographic surface into a plane and put forward the theory of locating the spatial position by latitude and longitude. Ptolemy (90-168) used a new latitude-longitude network to draw the map. Mercator (1512-1594) used Atlas as a professional term to
representatlas, this innovative approach ended the Ptolemaic era.

With the support of current global and national grid theories, many grid systems have emerged, including classical longitude-latitude coordinate system, grid coordinate system and rectangular coordinate system, and various grid models constructed by modern geographic information system. The Platonic Solids global grid model has become the most widely used model, while other grid models have corresponding uses, such as the idea of studying global grid models based on triangle (QTM), diamond or polygon segmentation (Goodchild, Fekete, Tobler & Chen, etc.). The research of Yang Shiren’s grid system can be seen in China by using triangle to divide the earth’s surface, while Chen Jun uses Voronoi algorithm to calculate the model after dividing the earth's surface and transforming the coordinates. Zhao Xuesheng et al. proposed a grid system scheme hierarchically by using triangular space analysis, and Yuan Wen et al. proposed to establish a new sphere with equiangular proportional projection so as to study the gridded earth surface. Zhou Chenghu et al. proposed a Cumulative algorithm to study the rasterization of vector data in GIS. The World Geographic Reference System constructed by the U.S. military is based on a longitude-latitude framework segmentation method, in which, the Earth is circumferentially cut into 24 zones in the longitude and latitude direction, with an angle of 15°. At this time, the Earth's surface is divided into 24*12 grid elements, which constitute the first-level division of the grid system. The span of each element is 15°×15°. The quadrilateral at the ends of the pole converges into a triangle. For a single grid cell, it continues to cut the grid into 1° sub-cells and completely cover the Earth's surface with a 1° × 1° secondary grid. The secondary grid continues to be subdivided by 1°×1°, and its subdivision unit size is 1′, thus forming a global 1′×1′ three-level grid system. Some scholars have proposed a hexagonal grid based on a regular hexagon, which has higher coverage efficiency and angular resolution than quadrilateral and triangle. Therefore, single-resolution hexagonal grids exist widely and are applied to various industries, especially in the fields of meteorology and environment.

2. Standard Deviation Elliptic Distribution Model

(1) Elliptic Distribution Function

The anisotropy of a variable can be described quantitatively by an ellipse, as the ellipse shown in Figure 1, with a long semi-axis length of 1, a short semi-axis length of b (b ≤ 1), and b is an anisotropy ratio. α is the angle between the long axis and the x coordinate axis (forward) of the ellipse, which is called the long axis azimuth (0° ≤ α ≤ 180°). Then the distance \( \rho(\theta, \alpha, b) \) from the point \( P \) in the θ direction of the ellipse to the center of the ellipse can be used as a standard measure of anisotropy in this direction.

\[
\rho(\theta, \alpha, b) = \frac{b}{\sqrt{b^2 \cos^2(\theta - \alpha) + \sin^2(\theta - \alpha)}}.
\]

The function \( \rho(\theta, \alpha, b) \) is called an elliptic distribution function, also known as a standard
deviation elliptic distribution model. It can also be considered as an equivalent ellipse describing the spatial variation of a variable.

(2) Mathematical Model of Spatial Variation Function

According to the general model of the function, the mathematical function of the spatial variogram \( \gamma(h_{i,j}) \) of the random variables \( Z(x_i, y_i) \) and \( Z(x_j, y_j) \) can be recorded as:

\[
\gamma(h_{i,j}) = c_0(\theta_{i,j}) + c(\theta_{i,j}) f\left( \frac{h_{i,j}}{\alpha(\theta_{i,j})} \right) \tag{2}
\]

Wherein, \( \theta_{i,j} \) is the vector azimuth from point \((x_i, y_i)\) to point \((x_j, y_j)\). \( c_0(\theta_{i,j}) \) is the nugget value; \( c(\theta_{i,j}) \) is the arch height; \( \alpha(\theta_{i,j}) \) is a range. It can be seen from the function that when the nugget value \( c_0(\theta_{i,j}) \), the arch height \( c(\theta_{i,j}) \) and the range \( \alpha(\theta_{i,j}) \) are anisotropic, the variation function \( \gamma(h_{i,j}) \) is very complex and not suitable for practical calculation. For simplicity, it is assumed that only one of the above values is anisotropic, while the other values are isotropic. Usually, nugget value \( c_0(\theta_{i,j}) \) is used to distinguish observation errors and spatial variations, which is more subtle and is considered to be a subtle variation in large-scale calculations. Generally, it can be regarded as. So it can be assumed that \( c_0(\theta_{i,j}) = c_0 \), and then we can get:

\[
\gamma(h_{i,j}) = c_0 + c(\theta_{i,j}) f\left( \frac{h_{i,j}}{\alpha(\theta_{i,j})} \right) \tag{3}
\]

1) A-E Model

If the function is further simplified, it can be assumed that \( c(\theta_{i,j}) \) is also isotropic, that is to say, \( c(\theta_{i,j}) = c_m \) only \( \alpha(\theta) \) obeys the elliptic distribution, and there is \( \alpha(\theta_{i,j}) = \alpha_m \rho(\theta_{i,j}, \alpha, b) \), it can be further obtained that:

\[
\gamma(h_{i,j}) = c_0 + c_m f\left( \frac{h_{i,j}}{\alpha_m \rho(\theta_{i,j}, \alpha, b)} \right) \tag{4}
\]

The mathematical model of spatial variogram function with range anisotropy is obtained. However, the model only considers that the range \( \alpha(\theta_{i,j}) \) obeys the elliptic distribution A-Ellipse and is mathematically called the A-E model. This model is a mathematical model that is more common and widely used in geostatistical theory. At the same time, according to the difference of the function \( f\left( \frac{h_{i,j}}{\alpha_m \rho(\theta_{i,j}, \alpha, b)} \right) \), many different types of mathematical models can be derived.

2) C-E Model

Again, when \( \alpha(\theta_{i,j}) \) is assumed to be isotropic, ie \( \alpha(\theta_{i,j}) = \alpha_m \), and \( c(\theta_{i,j}) \) is anisotropic, and \( \frac{1}{c(\theta_{i,j})} \) obeys elliptic distribution, and it is assumed \( c(\theta_{i,j}) = \frac{c_m}{\rho(\theta_{i,j}, \alpha, b)} \), then:

\[
\gamma(h_{i,j}) = c_0 + c_m \left( \frac{1}{\rho(\theta_{i,j}, \alpha, b)} \right) f\left( \frac{h_{i,j}}{\alpha_m} \right) \tag{5}
\]

Because it only considers the reciprocal of elliptic arch height, that is, \( \frac{1}{c(\theta_{i,j})} \) obeys the elliptic distribution, it is recorded as the C-E model.
By introducing \( \gamma_0(h_{i,j}) = f\left(\frac{h_{i,j}}{\alpha_m \rho(\theta_{i,j}, \alpha, b)}\right) \) and \( \gamma'_0(h_{i,j}) = \left(\frac{1}{\rho(\theta_{i,j}, \alpha, b)}\right)f\left(\frac{h_{i,j}}{\alpha_m}\right) \) into Formulas (130) and (1-31), the general expression of variation function is obtained as follows:

\[
\gamma(h_{i,j}) = c_0 + c_m \gamma_0(h_{i,j})
\]

In which, \( \gamma_0(h_{i,j}) \) is called a standardized variation function.

The standard variance function of A-E model is obtained.

\[
\gamma(h_{i,j}) = c_0 + c_m f\left(\frac{h_{i,j}}{\alpha_m \rho(\theta_{i,j}, \alpha, b)}\right)
\]

The standardized variation function of C-E Model is as follows:

\[
\gamma(h_{i,j}) = c_0 + c_m \left(\frac{1}{\rho(\theta_{i,j}, \alpha, b)}\right)f\left(\frac{h_{i,j}}{\alpha_m}\right)
\]

(3) Standard Deviation Ellipse

Whether A-E model or C-E model, the overall direction of ellipse is proposed. In order to further analyze the spatial magnitude, SDE (The Standard Deviation Ellipse) method is also used in the field of geo-statistics. In the SDE method, the gravity, azimuth and standard distance of ellipse are proposed. The standard deviation elliptical SDE parameters mainly have the average center, azimuth and the standard deviation of each direction, which are calculated by the following formulas:

**Average center:**

\[
\bar{X}_w = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}, \quad \bar{Y}_w = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i}
\]

**The azimuth:**

\[
\tan \theta = -\sqrt{\frac{\sum_{i=1}^{n} w_i x_i^2 - \sum_{i=1}^{n} w_i y_i^2}{\sum_{i=1}^{n} w_i x_i^2 - \sum_{i=1}^{n} w_i y_i^2 + 2\sum_{i=1}^{n} w_i x_i y_i}}
\]

**The standard deviation of x-axis:**

\[
\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} \left( w_i \bar{x}_i \cos \theta - w_i \bar{y}_i \sin \theta \right)^2}{\sum_{i=1}^{n} w_i^2}}
\]

**The standard deviation of y-axis:**

\[
\sigma_y = \sqrt{\frac{\sum_{i=1}^{n} \left( w_i \bar{y}_i \sin \theta - w_i \bar{x}_i \cos \theta \right)^2}{\sum_{i=1}^{n} w_i^2}}
\]

In which,

- \((x_i, y_i)\) —— Spatial location coordinates;
- \(w_i\) —— Weight;
- \((\bar{X}_w, \bar{Y}_w)\) —— Weighted average center coordinates;
- \(\theta\) —— Elliptical azimuth;
The coordinate deviation between the location coordinates and the average center of each research object:
\( (\tilde{x}, \tilde{y}) \) —— The coordinate deviation between the location coordinates and the average center of each research object;
\( \sigma_x, \sigma_y \) —— The standard deviation along the x-direction and the y-direction.

3. Data Sources

Based on the national DEM data and SRTM remote sensing images, the research area covers the mainland of China (including Hainan and Taiwan provinces). The longitude is 75°-135° and the longitude difference is 60°. It is divided into 10 6° zones, latitude is 20°-55°, latitude difference is 35°, and it is divided into 8 4° sub-zones. The corresponding 1:1 million scale is divided into 80 rectangular grids, the corresponding 1:100,000 scale is divided into 11,520 grids, the corresponding 1:10000 scale is divided into 737,280 grids, forming a grid system covering the Chinese mainland (including Hainan Province and Taiwan Province) and package it in a grid.

The 1:1 scale is divided into 11,520 grids, corresponding to 1:1,280 scales. Form a grid system covering the Chinese mainland (including Hainan Province and Taiwan Province) with a grid package.

Figure 2  Trapezoidal grid graph

It contains a number of attribute data, including geographical coordinates, topography, meteorology, soil, forest vegetation and so on.

4. Results and Analysis

The trend of measuring geographic elements such as a group of points and surfaces is generally to calculate the standard distances of the elements in the direction of \((x, y)\) (referring to ArcGIS 10 help document). Element class is mainly concentrated in an elliptic domain class. According to the principle of statistics, when the range of 1-fold standard deviation (default value) covers 68% of the statistical elements, the range of 2-fold standard deviation covers 95% of the statistical elements, and the range of 3-fold standard deviation covers the centroid of 99% of the total elements. The ellipse is the Standard Deviational Ellipse (SDE), and the GIS toolbox can obtain the statistical distribution of the research elements by SDE analysis. Comparatively speaking, such a distribution analysis makes the distribution analysis of spatial variable elements more credible, and eliminates the keynote of simple division and generalization of forest vegetation distribution, making the large-scale multi-factor extraction analysis feasible.

4.1 Standard Deviation Ellipse (SDE) Analysis of Forest Vegetation

The FM-SOTER (F-Forest and Plants Forest Vegetation, M-Meteorology, SO-Soil, TER-Terrain) database was established by using the research results. Seven major forest vegetation areas were first generated in Arc GIS 10, and the standard deviation ellipse distribution in Figure 3 was obtained. Through further information extraction, the quantitative indicators of SDE distribution of seven forest
vegetation were obtained, and the parameters of their long wheel base, short wheel base, central coordinates and the proportion of forest vegetation area to the national area were obtained.

According to the needs of this study, 53 sub-category forest vegetation types are generated in Arc GIS 10 by using FM-SOTER database, and their SDE distribution maps are obtained. Through further information extraction, the SDE indices of 53 sub-category forest vegetation types are obtained, and the parameters such as their long wheel base, short wheel base, central coordinates and the coordinates of the standard deviation ellipse are used to calculate the ellipse distribution of seven major-category forest vegetation types in China.

4.2 Dispersion of Forest Vegetation Categories

From the analysis of major-category forest vegetation, except for desert forest vegetation, which is the minimum distribution rate of 0.56%, and the average distribution rate of other six forest vegetation categories is 51.75%. Broad-leaved forest and sparse forest account for the largest proportion in the country, which is 68.11%. The deviation rate from the average is 31.61%, and its dispersion is 0.097.

According to the analysis of 52 sub-category forest vegetation, the average distribution rate of sub-category forest vegetation is 9.38%, and the proportion of temperate subalpine evergreen coniferous forest is the largest in China, with the distribution rate of 30.23%, and its dispersion is 0.032.

5. Conclusions

The SDE was used to calculate the ellipse distribution of major-category forest vegetation and the standard deviation ellipse distribution of seven major-category forest vegetation types in China.

(1) The elliptical center of coniferous forests is distributed in Xin'an County, Luoyang City, Henan Province (112° 2.114' E, 35° 41.891' N), with a long semi-axis of 1804283.6m, a short semi-axis of 1047661.3m and an azimuth of 23.77°. The overall spatial distribution pattern of coniferous forests is "southwest-northeast". The main spatial distribution is in the middle and lower reaches and the south of the Yellow River.

(2) The elliptical center of cultivated forest vegetation is located in Baofeng County, Pingdingshan City, Henan Province (113° 42.526' E, 34° 11.688' N). The long semi-axis is 118387.7m, the short semi-axis is 997228.8m, and the azimuth angle is 23.49°. The overall spatial distribution pattern is "southwest-northeast", and the main spatial distribution is in the middle and lower reaches of the Yellow River.

(3) The elliptical centers of broad-leaved and sparse forests are located in Jingxing County, Shijiazhuang City, Hebei Province (114° 11.520' E, 38° 16.694' N), with 193,2478.4m long semi-axis, 1077113.7m short axis and 37.23° azimuth. The overall spatial distribution pattern of broad-leaved and sparse forests is "southwest-northeast", the main spatial distribution is in the North China Plain, its northeast reaches the edge of Heilongjiang Province, southwest to Guizhou, and it belongs to the most widely distributed forest vegetation in China.

The standard deviation ellipse method is used to calculate the ellipse distribution of sub-category forest vegetation, and the 52 standard deviations of forest vegetation in China (Fig. 6-2). In which, the obtained ellipse centers and direction trends can be divided into three categories:

(1) The long-axis azimuth of the standard deviation ellipse is less than or equal to 45°, a forest vegetation with remarkable latitudinal zonality. There are 9 main categories: subtropical deciduous coniferous evergreen forest (40.11°), tropical deciduous forest (38.81°), temperate deciduous forest (38.82°), temperate deciduous forest (29.35°), temperate deciduous forest (5.91°), tropical mangroves (37.83°), grasses, weed grassland (29.67°).

(2) The long-axis azimuth of the standard deviation ellipse (SDE) is greater than 45° and less than or equal to 90°. This is a forest vegetation with apparent two-way effects of latitude zonality and longitude zonality. There are mainly 27 categories: subtropical, tropical subalpine evergreen coniferous forest (80.65°),...
deciduous-evergreen broad-leaved mixed forest of acid yellow-brown soil in subtropical mountainous areas (58.92°), subtropical evergreen oak forest (87.01°), subtropical evergreen coniferous forests and shrubs (including bamboo forests) (77.64°), subtropical evergreen broad-leaved mixed forest (85.29°), weed grasses and grassland (87.81°), double-season rice and continuous cropping for warm winter crops and tropical economic forest, fruit trees (66.82°), cold temperate deciduous coniferous forests (75.08°), warm temperate evergreen coniferous forest (38.81°), water-drought, double cropping a year and transitional tropical defoliation, evergreen fruit trees (67.36°), desert (86.67°), temperate, warm temperate desert riverbank salinized meadow soil deciduous leaflet sparse forest (87.87°), temperate, warm temperate deciduous shrub (38.82°), temperate, warm temperate deciduous broad-leaved forest (29.35°), temperate one-crop-one-year crop (73.7°), temperate neutral meadow and marsh (60.26°), temperate subalpine evergreen coniferous forest (85.88°), temperate salty meadow (87.08°), temperate grassland sandy deciduous leafless sparse forest (32.97°), tropical evergreen broad-leaved rainforest (89.98°), tropical limestone semi-evergreen broad-leaved rainforest (84.63°), tropical mangroves (37.83°), grasses, weedy grassland (29.67°), one-crop-a-year crop in alpine region (55.64°), alpine grasslands (79.38°), high mountain top crushed stone (88.45°), alpine deciduous shrubs (80.74°).

(3) The long-axis azimuth of the standard deviation ellipse [>90°] is a forest vegetation with obvious reverse bidirectional effects of longitude zonality and latitude zonality. There are 27 major categories, namely: clumpy dwarf grass, dwarf semi-shrub, shrub grassland (92.59°), two-year three-crop or two-crop-a-year or warm temperate deciduous fruit trees (94.37°), subtropical, tropical evergreen, deciduous shrub and sparse forests (98.27°), subtropical limestone deciduous broad-leaved- evergreen broad-leaved mixed forest (99.3°), subalpine evergreen leathery leaf shrub (92.06°), glacier snow quiet (129.61°), semi-arbor desert, (111.55°), juicy dwarf semi-shrub salty desert (96.21°), Gobi Desert (105.02°), temperate grassland sandy evergreen coniferous sparse forest (169.88°), temperate deciduous broadleaf-coniferous mixed forest (124.4°), shrubs, semi-shrub deserts and oak deserts (94.44°), shrubs, semi-shrub deserts and oak deserts + semi-arbor deserts (120.56°), tropical acid brick-red soil semi-evergreen rainforest (102.77°), dwarf semi-shrub low mountain and sorghum desert (93.62°), sparse shrub grassland (114.81°), transitional tropical evergreen broad-leaved forest (90.26°), alpine, creeping low semi-shrub gravel desert (104.53°), alpine meadow (132.03°), alpine padded forest vegetation (96.97°), and alpine shrub tundra (96.97°).

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