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ORIGINAL ARTICLE

Analysis of Impact Factor of Lightning Density in Hunan Province

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Abstract: In this paper, information from Hunan Province lightning monitoring and warning system platform is used and 14 sample points are selected, to analyze its average annual lightning density, and establish PLS model for statistical analysis to research the complex relationship formed between lightning density and altitude, aspect and geological structures. The results show that thunderstorms path, altitude, aspect, and shade have significant effects on lightning density distribution. Soil resistivity has a certain influence on this but overall it has relatively lesser effect.

Keywords: Light density; Impact factor monitoring; Early warning; Relevance

Introduction

Hunan Province is located at the South-central part of China, which is belonging to the transition zone of Yunnan-Guizhou Plateau and Yangtze Plain, located at the second stair of the three plateaus, with complex topographic structures. The unique geographical location and topography cause the formation of complex and varied lightning distribution structure in China. In recent years, with the development in lightning monitoring and warning services, the analysis and estimation of spatial distribution of lighting is getting more and more important to the meaning and value of the guideline in lightning warning forecast. By using the regression analysis to establish relational equation of the elements and spatial variables, topography, and geological factors of lightning density distribution. This method quantitatively reflects that in the spatial distribution of lightning density in real topography, a more accurate mathematical model of the factor affecting can be obtained.

1. Determination of factor and analysis

The study area is the Hunan Province. By using the information from the Hunan Province's lightning monitoring and warning system platform, one sample point is taken from the chosen area of each cities and states, with a total of 14 sample points, to calculate average annual lightning density of 5 years, which is from 2008 to 2012 (since the lightning location system was not stable in 2008, the data for the year is not used). The study area is over 210,000 km^2, and within the territory there are many mountains, mountain plain, plain, lake, and hills, with complex topography. The overall body has a special characteristic of horseshoe shaped in the north opening, which is beneficial towards the flow of warm air to the central province in the northeast and northern area. The airflow is blocked by mountains and

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hysteresis effect and causing the formation of complex correlation between lightning density and altitude, slope aspectand geological structures in the inner region. In order to reveal this correlation, this paper using the PLS statistical method to establish the relationship between geological and topographic factor, thunderstorm pathway and lightning density distribution. Therefore, a survey point is set as the center of a 5 x 5km region, and establish the lightning density function, in which is the factor of thunderstorm pathway; h as the altitude factor; as the slope aspect factor; k as the shielding degree factor; p as the soil resistivity factor, ε as the other factors that affecting the lightning density. By using the residual ε in regression analysis shows that estimated formula of lightning density under the effect of the climate, topography, and geology is $N = f_0 + f_1\varphi + f_2h + f_3\beta + f_4k + f_5\rho + \varepsilon$ (1). The f_o is the constant while, f_1 to f_4 is the coefficient of each factor.

The underlying data source:

(a) Thunderstorm path factor φ: The conclusion from the statistical analysis of information in section 3.1 of this article, such that a survey point in north east and northern area is significantly affected by thunderstorm pathway, the thunderstorm path φ is equal to the percentage of the thunderstorm pathway in north east and northern area.

(b) Altitude factor h: The altitude is obtained by using GPS or mobile phone software by surveyor.

(c) Slope aspect factor β: When the slope angle is same as the thunderstorm pathway or the angle between them is smaller, the thunderstorm will be uplifted significantly, causing more significant convection. When the positive and negative ions separation movement is more intense in the atmosphere, it will cause the lightning activity to be more frequent. As shown in the figure below, a three-dimensional Cartesian coordinate system is established, x is the east direction, y axis is the direction of true north, z is the vertical direction, surface abcd as slope surface, o as the center of slope, on is perpendicular to the slope surface abcd. Vectors on xy plane are projected as o'n', o'n' and the angle β on x axis is the slope angle. The slope aspect factor in the computing application shall be corresponding to the direction of thunderstorm pathway in the region.

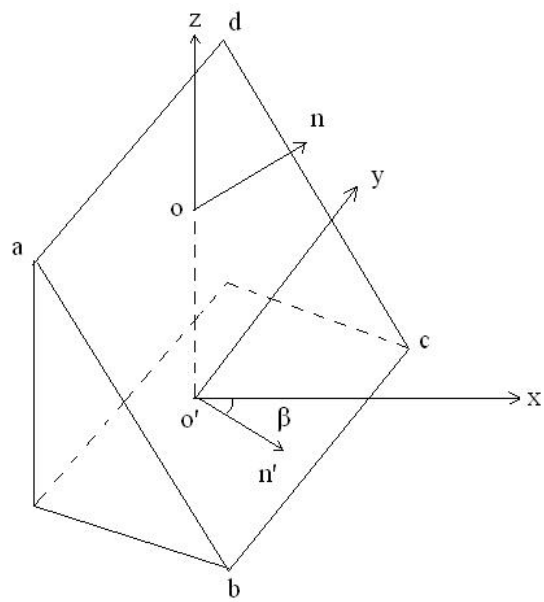

Figure 1. Schematic diagram of slope aspect.

(d) Shielding degree factor k: The lightning density is not only related to altitude, the surrounding altitude also has direct effect on the regional lightning density. Since lightning density chosen in this paper is 5km x 5km grid, so when choosing the degree of shielding an integer multiple of the 5km x 5km grid is selected, this is 25km x 25km, in order to facilitate the calculation and statistics. The shielding degree is within the range of 25km x 25km, with an average altitude higher than center of the grid of 5km x 5km. if the average altitude and the center height of the other 5km x 5km grid have height difference within the range of 5%, it will not be included as shielding point.

(e) Other factors affecting the lightning density ε: Other than the above mentioned factor, they may be other influencing factors such as the degree of air pollution in a place will affect the quantity of positive and negative ions in the atmosphere, water or shore. But this factor is difficult to be simulated using mathematical model, therefore there will be summarized as a total impact factor.

For the calculation of the size of each of the coefficients, by contacting the Lightning Protection Centre of each city, the biography of each of the region is obtained, a total of 14 sample values, as follows:

Table 1 Lightning density sample analysis table.

Location	**Lightning Density**	**Lightning Path φ**	**Slope Aspect Factor λ**	**Altitude h**	**Shielding Factor k**	**Soil Resistivity β**
Yuelu Shanjiao, Chang Sha	1.76	25%	12°	0.184km	5	196Ω·m
Yueyang Lake District	1.32	18%	0	0.032km	7	47 Ω·m
Xiangtan City Hill	1.47	25%	134°	0.064km	13	129 Ω·m
Zhuzhou City Riverside	1.52	25%	-165°	0.043km	18	59 Ω·m
Changde District Plain	1.81	18%	0	0.041km	14	133 Ω·m
Yiyang City West Hill	3.87	44%	56°	0.092km	7	203 Ω·m
West Loudi City Low Mountain	4.21	44%	146°	0.256km	9	272 Ω·m
Zhangjiajie Scenic Area	4.76	36%	157°	0.721km	3	487 Ω·m
Western Aizhai Bridge	4.08	33%	-24°	0.571km	5	3600 Ω·m
HuaiHua Valley	3.82	33%	-12°	0.249km	19	189 Ω·m
Yongzhou District Riverside	2.59	25%	37°	0.121km	21	69 Ω·m
Central Shaoyang Hill	4.37	18%	19°	0.089km	15	152 Ω·m
Hengyang Basin	4.61	18%	0	0.057km	13	163 Ω·m

2. PLS modeling and error analysis

The main component is extracted by using the multivariate PLS regression model as shown in *Table 2*. Firstly, extract the component of linear combination independent variables t_1 from independent vector X. t_1 has the maximum variation in variable X and because of this characteristic; a simple relationship can be established. Expected value of $Y = Bt_1$, when the degree of association between the two variables t_1 and Y reached the maximum value, regress Y on t_1, to obtain $Y = B_{PLS1}t_1 + e_Y$, and lastly carry out the cross validation test. To check whether it can achieve the application effective precision, the accuracy test of the equation would be check. If it cannot achieve it, continue the analysis of calculation and extraction on the residual information e_x and e_y of t_1, till a satisfying degree of accuracy is achieved. The estimated value $? \sum_{i=1}^{m} \mathrm{B}_{PLSi} t_i$, regress it on the equation $Y = \mathrm{B}_{PLS} X + e_{PLS}$ to complete the PLS regression model.

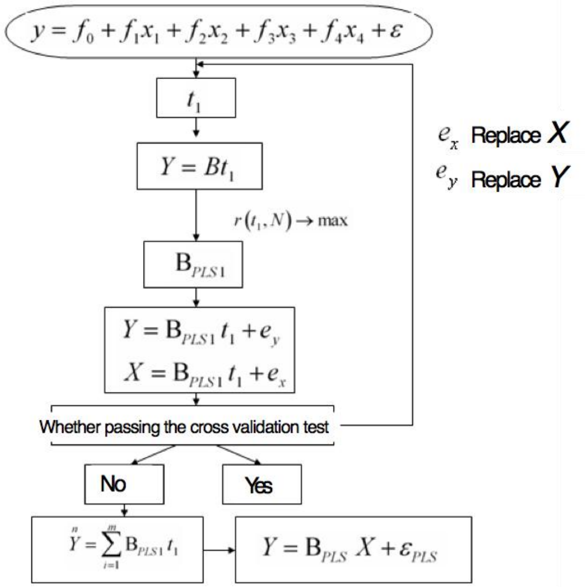

Figure 2. The flow chart of PLS regression model.

Using equation (1), according to the method of regression modeling, the relationship between the Hunan Province's lightning density and its impact factors is obtained. Positive and negatives values indicate its positive and negative impact of its relation respectively.

Table 2. Estimation model of Hunan Province's lightning density.

Constant f_0	**Coefficient of Thunderstorm pathway f_1**	**Altitude f_2**	**Slope Aspect f_3**	**Shielding Degree f_4**	**Soil Resistivity f_5**
-90.79	768.70	6.74	68.42	-3.86	-0.45

Table 2 shows that the thunderstorm pathway, altitude, slope aspect and shielding degree have significant effect on lightning density distribution. Soil resistivity has a certain effect but overall its effect is relatively smaller.

3. Test results and analysis

By using the accurate evaluation of PLS regression model, the results calibration analysis on the predicted lightning density and actual lightning density of each cities and states is carried out, and results are showing in *Table 3*. In the table, the RY is squared of correlation coefficient of the prediction model and actual lightning density. Q^2 is reflecting the cross validation (i.e., equation (1)) to determine the regression predictability of regression model on precipitation. For the model which $Q^2 < 0.36$ with short solid lines as replacement, lower Q^2 value represent a lower predictive ability and poor explanation, which are those omitted closed models in *Table 3*. As seen from the table, most of the models can explain 70% of the variation of variables, causes the correlation coefficient of predicted and actual precipitation reaches above 0.84 (i.e.017), highest value reached 0194, which is in the Northwest area. The predictability of each model of precipitation passed the cross validation test; among them the north-western area reaches 82%, which its predictability is more significant. In contrast, the models in Xiangxi Autonomous Prefecture, Shaoyang and ChenZhou are poorer (not listed in the table) because the area is the widest, and its topography is complex. A characteristic of lightning density distribution is difficult to be clearly reflected under the effects of different weather, geology, and topography.

Table 3. Accuracy Evaluation of the Partial Least Squares Regression Model of Survey Points of each cities and states.

	Changsha	Qiu yang	Xiangtan	Zhu zhou	Changde	Yi yang	Loudi	Zhang jiajie	Huai hua	Yong zhou	Heng yang
RY (R2)	0.87	0.94	0.88	0.82	0.88	0.81	0.78	0.86	0.78	0.76	0.84
Q2	0.83	0.91	0.82	0.80	0.87	0.74	0.73	0.75	0.71	0.70	0.79

Conclusion

Through the analysis of the impacts of thunderstorm pathway, altitude, slope aspect, shielding degree, soil resistivity and other factors to lightning density distribution, the results show that the characteristics of the lightning density of Hunan Province are formed from the combined effect of multiple factors. Among them the effect from thunderstorms pathway, shielding degree, altitude and slope aspect are more significant, while the effect of soil resistivity and other factors are relatively less significant. This result can better explain the lightning density distribution of Hunan Province under the unique climate and topographic conditions.

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