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Study on Surface Temperature Characteristics of Chengdu Based on Multi-temporal Landsat Data

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***Abstract*—By studying the multi-year surface temperature (LST) phenomenon in the center area of Chengdu, the characteristics of surface temperature in the context of population (POP), gross domestic product (GDP), and building index (NDBI) reflecting the state of urban economic development are analyzed. The relationship between ground temperature and various factors, and the possible causes of the formation of geothermal phenomena. The exploratory regression, Ordinary Least Square model (OLS), Geographic Weighted Regression model (GWR), and frequency ratio method were used to evaluate the correlation and differentiation characteristics of the ground temperature and each factor after using the atmospheric correction method to obtain the ground temperature data. It is determined that there is a significant correlation between the variables and the LST, and the factors are dependability; The LST overall level showed a decreasing trend, The area of the high temperature area shows a growing trend, There are slow cooling zones in the study area; Different economic intensity ranges contribute to the slow temperature drop zone. The index of the "FR" that is quoted is quantified to give the degree of a slow cooling zone, which makes it more intuitive in the text. At the same time, GWR model supplemented the local masking of OLS model in correlation analysis and the model performs better.**

Keywords*—land surface temperature; relevance; Socio-economic; the slow cooling zone; variability

I. INTRODUCTION

Metropolitan centers temperatures are often higher than in the peripheral area of about 5℃, resulting in reduced air pressure, changes in local atmospheric contaminants reflux pattern, formed the greenhouse effect [1]. The research results of domestic and foreign scholars show that the study of urban surface temperature is mostly concentrated in ecological environment[2-3], Landscape pattern field[4-5], but research on urban socio-economic field is not much; in the socio-economic field, changes in surface temperature are affected by socio-economic drivers[6]; The relationship between urban development intensity and surface temperature is that the change of artificial building cover changes the distribution of surface temperature[7]; the surface temperature of urban impervious surface is significantly higher than that of river as the representative temperature[8]; Thus, Human activities can affect changes in surface temperature, such as urban population density and economic development, are part of the reason for the rise in temperature[9-10]. Therefore, This text mainly explores the characteristics of ground temperature differentiation under local socio-economic conditions.

Land Surface Temperature reflected in the application of thermal infrared remote sensing has the characteristics of high spatial sensitivity and large scale spatial-temporal differentiation. The raster were used to make statistics for population activities and socio-economic behaviors on the surface from a macro perspective, extracting the characteristic area. The surface characteristics are refined to discuss the dynamic performance of surface temperature under vividly economic intensities. Based on the distribution of the socio-economic effects of the LST, it is a reference to the surface temperature management.

II. STUDY AREA OVERVIEW

The study area is the central area of Chengdu defined by the government in 2017(103° 41' 8.22" E-104° 29' 30.35" E, 30° 13' 46.46" N - 30° 58' 2.27" N), area total area of 566 km^2, including 11 administrative region: Jinjiang District, Qingyang District, Jinniu District, Wuhou District, Chenghua District, Xindu District, Pidu District, Wenjiang District, Shuangliu District, Longquanyi District and Qingbaijiang District; 2 straight Pipeline functional area: Chengdu High-tech District, Tianfu New District (Figure 1).

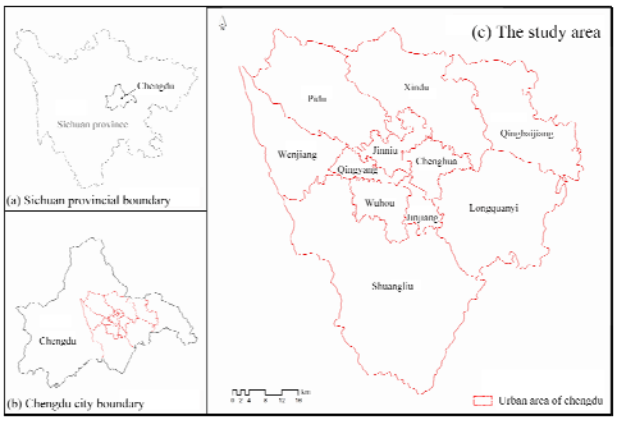

FIGURE I. RESEARCH LOCATION MAP

The Landsat data used in the study area were downloaded from the Geospatial Data Cloud for 8 periods (2000-2017). Socio-economic class data obtained from the use of resources

and environmental data and Chinese Academy of Sciences, Chengdu and affiliated counties Bureau.

III. RESEARCH TECHNIQUE

A. Surface Temperature Inversion

According to the Planck's law, the actual temperature can be obtained by inverse inversion under the condition that the radiation intensity and wavelength of the object are known. Firstly, the radiation brightness value of the blackbody with temperature of TS in the thermal infrared band was obtained. Then, according to the inverse function of Planck's formula, the real surface temperature TS was calculated through formula 1 and formula 2. In formula 2, the surface specific emissivity is calculated by calculating the surface vegetation coverage.

$$T_S = \frac{K_2}{ln\left(K_1 / B\left(T_S\right)+1\right)} \tag{1}$$

$$B\left(T_S\right) = \frac{L\lambda - L\uparrow - \tau\cdot\left(1-\varepsilon\right)L\downarrow}{\tau} \bullet \varepsilon \tag{2}$$

Where, K1 and K2 are constants, K1 = 607.76w /(m^2* m*sr), K2 = 1260.56k; εis the surface specific emissivity, TS is the actual surface temperature, B(TS) is the thermal radiance of black body in TS, which is pushed by Planck's law, and the permeability of atmospheric in thermal infrared band.

The specific emissivity of the surface is calculated by using the following equation (3-4):

$$\varepsilon_{surface} = 0.9625 + 0.0614\,F_V - 0.0461\,F_{V2} \tag{3}$$

$$\varepsilon_{building} = 0.9589 + 0.086\,F_V - 0.0671\,F_{V2} \tag{4}$$

Where, and respectively represent the specific emissivity of natural surface pixel and urban pixel.

Fv is obtained by using the mixed pixel decomposition method, and the land types of the image are divided into water bodies, vegetation and buildings. The specific calculation formula is as follows (5) :

$$F_V = \frac{NDVI - NDVI_S}{NDVI_V - NDVI_S} \tag{5}$$

Where, is the normalized difference vegetation index; NDVI is the normalized vegetation index; Take = 0.70 and = 0.00, when the NDVI> of a pixel is 0.70, the value is 1;When NDVI<0.00, the value is 0.

B. Frequency Ratio Method

The frequency ratio method (FRM) is used to analyze the characteristics of disaster causing factors[11]. By analyzing the proportion of the slow cooling area of surface temperature in the region of economic variability level, the interference degree of the slow cooling area in the region of different levels can be determined (6).

$$FR = \frac{\left(Ni/N\right)}{\left(Si/S\right)} \tag{6}$$

Where, FR is represents the frequency ratio; Ni represents the number of cells in the LST slow cooling zone within the economic factor level; N represents the number of pixels in the range of economic factor levels; Si represents the total number of pixels occupied by the slow surface temperature; S represents the total number of pixels in the downtown area of Chengdu. The larger the FR value, the larger the area occupied by the surface temperature in the area, indicating that the surface temperature in the area is affected by a certain range of factors.

IV. INVERSION PRECISION EVALUATION AND CORRELATION ANALYSIS

Evaluation of surface temperature inversion accuracy: the inversion accuracy was verified by using field measurement data provided by Sichuan meteorological station. By comparing the inversion values extracted from the base stations of Wenjiang meteorological station (30.7489, 103.8611) in 2004, the inversion error in 2004 was 0.27 (Tab I), and the correlation coefficient between the surface temperature inversion results over the years and the measured data was 0.93 ($p<0.001$), indicating the reliability of the inversion results.

Correlation analysis of surface temperature and various factors: There are differences among the data in the study area, in order to reduce errors, increase accuracy, and uniformly normalize. Then use the OLS model and the GWR model for correlation analysis[12-13]. According to Significant summary result, the significant correlation is 100% between population and surface temperature, The area about 25% is negatively correlated, and The area about 75% is positively correlated. The significance of GDP as an explanatory variable is 75%, and it is negatively correlated with LST 100%. NDBI and TLS showed 100% positive correlation, and the significance was 100% (Tab III)；In the OLS model's result, the regression accuracy p value of each factor is 0.00000, and the regression coefficients of each factor have extremely significant statistical significance($p < 0.001$) (Tab II)；Results of residual analysis showed that there was no obvious rule of residuals, indicating that residuals were normally distributed. Meanwhile, The spatial autocorrelation analysis showed that Moran's I value was 0.4468, Z value was 23.3288(Z value >0), and P value was 0.00000. It shows that the clustering of this model is less than 1% and the residual distribution is reliable. This shows that the OLS model has reliability, and LST have extremely significant statistical significance with NDBI, POP, and GDP.

Through further analysis found that GWR model good improved OLS model for the local characteristics of cover. Statistical GWR model as a result, the Local R2 value up to 86.12%, Akaike information criterion (AICc) decreased to 1200.605692, the results model for superior performance. According to the load of the load R2, each factor can co-explain 86.12% surface temperature in the area (Figure III).

TABLE I. MULTIPHASE SURFACE TEMPERATURE DATA AND FIELD DETECTION DATA

Date	Detection of geothermal	Inversion of geothermal	The inversion error	Wenjiang District			
				Max	***Min***	***Ave***	***SD***
20041207	7.2	7.47	0.27	8.46	-0.78	7.39	0.52

TABLE II. RESULTS OF OLS MODEL ARE SUMMARIZED

variate	Coefficient	SD	Statistics	Probability	Robust_SE	Robust_t	Robust_Pr	VIF(c)
intercept	-1.2035	0.01180	-101.97293	0.00000*	0.0117	-102.7791	0.00000*	-
NDBI	7.7950	0.33278	23.4240	0.00000*	0.3534	22.0554	0.00000*	1.0350
POP	0.1849	0.04531	4.0815	0.00005*	0.0421	4.3959	0.00002*	2.0244
GDP	-0.2544	0.0762	-3.3353	0.00089*	0.0698	-3.6452	0.00029*	1.9759

*Statistically significant p value（p<0.01）

TABLE III. EXPLAIN VARIABLE SIGNIFICANCE SUMMARY

Variate	Remarkable(%)	Minus(%)	Positive(%)
NDBI	100.00	0.00	100.00
POP	100.00	25.00	75.00
GDP	75.00	100.00	0.00

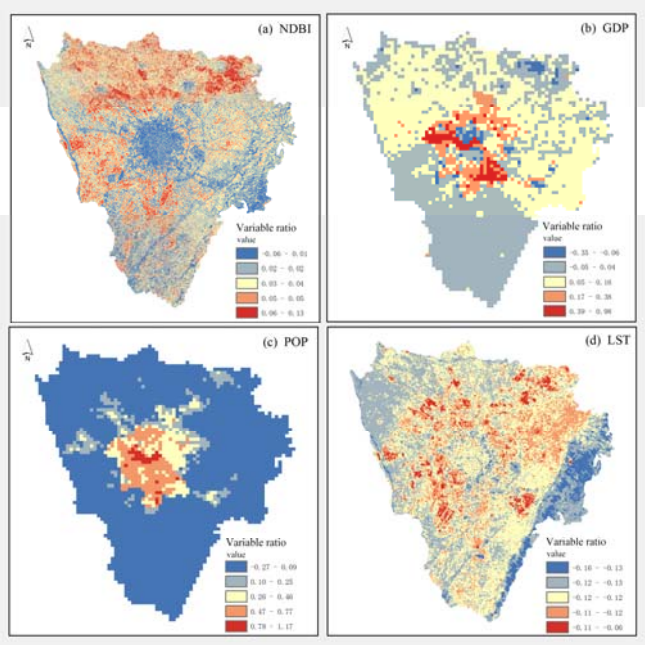

FIGURE II. EXPLAIN THE SPATIAL DISTRIBUTION OF VARIABLE RATE

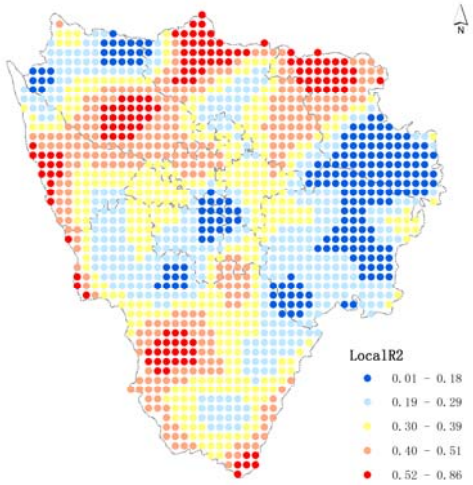

FIGURE III. THE LOCAL R2 VALUE OF THE GEOGRAPHICALLY WEIGHTED REGRESSION MODEL

V. RESEARCH AND ANALYSIS

The surface temperature in the study area is obtained by inversion, by fully considering the background of the standard deviation classification[14] will ground temperature according to the order from low to high divided into levels Ⅰ - Ⅶ (Tab IV).

The linear regression analysis of the area at various levels, the regression coefficient of VII is 0.0005, which is greater than 0, and the overall trend is increasing. the area ratio is the highest at 2.8291% in 2011, and then decreases year by year. The area coefficients of VI, V and IV are respectively -0.0004, -0.0005, -0.0052, all less than 0, The three-level area showed a decreasing trend, with the IV-level area decreasing the most. Ⅳ-level area accounts for 39.7583%, than the poor much more drastic changes. The remaining Level Correlation coefficients were greater than 0, as a whole to rise. In 2011, the III-Level peaked and then began to decrease; in 2014, II-Level reached its highest value; the I-Level area continued to increase. In general, the area change of each temperature zone is polarized, and the area of ordinary temperature zone (IV-level) changes drastically.

TABLE IV. 2000-2017 AREA PROPORTION OF SURFACE TEMPERATURE AREA(%)

Range of levels	2000	2004	2006	2009
I	0.01	0.06	0.19	0.15
II	2.22	0.36	0.04	1.97
III	25.04	10.06	16.37	25.55
IV	37.83	73.73	59.20	39.02
V	24.54	13.70	23.04	24.41
VI	8.03	1.87	1.12	7.22
VII	2.32	0.23	0.02	1.69
Range of levels	**2011**	**2013**	**2014**	**2017**
I	0.29	0.37	0.94	1.48
II	2.46	4.15	3.67	2.41
III	25.61	25.01	22.01	22.76
IV	46.55	42.93	46.04	46.80
V	17.76	20.66	21.40	20.45
VI	4.50	4.81	3.94	4.51
VII	2.83	2.06	2.00	1.59

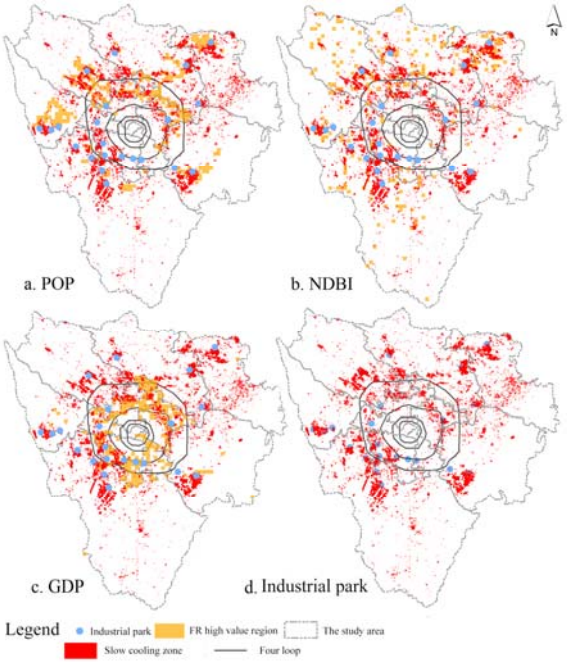

FIGURE IV. THE SPATIAL DIFFERENTIATION CHARACTERISTICS OF SLOW COOLING ZONE AND EACH FACTOR

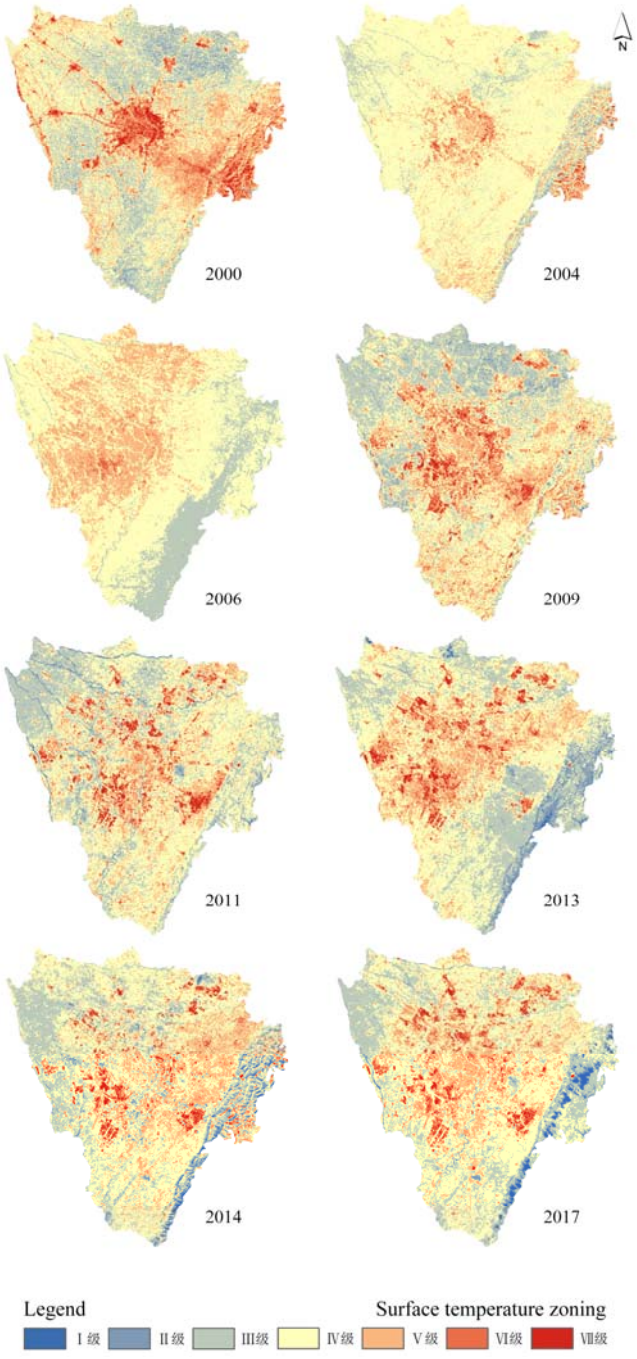

FIGURE V. SURFACE TEMPERATURE AND TEMPERATURE DISTRIBUTION

TABLE V. FR INDEX OF SLOW COOLING ZONE IN DIFFERENT GRADE RANGE OF FACTORS

	Range division	t2	t3	t1	T	t3/t2	t1/T	FR
POP	-0.2696-0.0926	3237841	237994	356536	4025446	0.074	0.089	0.830
	0.0926-0.2510	270980	50720	356536	4025446	0.187	0.089	2.113
	0.2510-0.4604	246391	34912	356536	4025446	0.142	0.089	1.600
	0.4604-0.7659	233306	30785	356536	4025446	0.132	0.089	1.490

	0.7659-1.1733	34450	957	356536	4025446	0.028	0.089	0.314
GDP	-0.3493--0.0579	90008	14285	356536	4025446	0.159	0.089	1.792
	-0.0579-0.0409	1804301	118767	356536	4025446	0.066	0.089	0.743
	0.0409-0.1554	1768073	172313	356536	4025446	0.097	0.089	1.100
	0.1554-0.3791	254268	43579	356536	4025446	0.171	0.089	1.935
	0.3791-0.9774	108796	6525	356536	4025446	0.060	0.089	0.677
NDBI	0.0544-0.0960	261446	60320	356536	4025446	0.231	0.089	2.605
	0.0371-0.0544	804680	95238	356536	4025446	0.118	0.089	1.336
	0.0232-0.0371	1283725	105041	356536	4025446	0.082	0.089	0.924
	0.0094-0.0232	1170266	64687	356536	4025446	0.055	0.089	0.668
	-0.0302-0.0094	504153	29817	356536	4025446	0.059	0.089	0.624

From 2000 to 2017, the LST spatial distribution map (Figure V) can be visually found that the VII and VI levels are concentrated in the urban building agglomeration area, The two levels changed from shifted from the concentration distribution of 2000 to the point-plane distribution in the outer urban area in 2017. The value is found to be less than 0 (Figure II(d)) by calculation of the LST grid change rate during 17 years, indicating that it is generally at a drop level. Using the Jenks that is the largest of its kin[15] to classify the variability, it is found that the variability[16]in the building agglomeration area is consistent with the LST distribution characteristics. In order to explain this phenomenon, the LST variability is extracted in the urban building agglomeration area according to the classification result, and named as the slow cooling zone. At the same time, FRM is used to calculate the FR value of the slow cooling zone distribution of the surface temperature under each economic factor in different grade (Tab V), so as to obtain the contribution of the city's socio-economic development to the slow cooling zone of LST.

POP and LST: The population variability ranged from 0.0926 to 0.2510. The slowest temperature reduction zone had the highest proportion of 2.113, indicating that population growth has the greatest contribution to LST at this level of intensity. It is mainly distributed in the residential areas of Wenjiang District, Qidu District, Qingbaijiang District, Longquanyi District and industrial workshops, as well as areas outside the Third Ring Road at the junction of Wenjiang District, Jinniu District and Xindu District (Figure IV(a)). In the central area of the 3rd ring, the population increase rate is the largest, but the contribution to the surface temperature is minimal, indicating that the population cannot be the main influencing factor in this area. The negative correlation of 25% in the previous section may exist in these areas.

GDP and LST: The maximum contribution of GDP to surface temperature is 0.1554-0.3791, and the FR value is 1.935. The main area of this range is distributed between the third ring and the fourth ring, the south part of the south of the fourth ring, and the industrial plant area of the outer 6 area. (Figure IV(c)). The highest GDP growth rate is distributed in the Qingyang District and Jinjiang District in the central region, but the FEW is the lowest, and the region has the lowest contribution to LST. The geothermal phenomenon persists in Longquanyi District and Shuangliu District, and there is the strongest contribution area, which is mostly distributed in the industrial plant area.

NDBI and LST: It can be seen by that value of FR that the increase of NDBI index is synchronized with the increase of FR value in the intensity range of each NDBI. It shows that the change of building density is proportional to the ground surface temperature. The contribution to the LST phenomenon is greatest in the range of 0.05442-0.096, and the FR value is 2.605. The area is mainly distributed in the outer 5 areas of Wenjiang District, Qidu District, Xindu District, Qingbaijiang District and Shuangliu District, which are scattered (Figure IV(b)). In combination with NDBI variogram and industrial park distribution graph (Figure IV(c)), the area growth of external multi-zone cities is obvious in the recent decade, and the appearance of building agglomeration area contributes greatly to the surface temperature phenomenon. It can thus be seen that that surface temperature is affect by the outward expansion of the city, which is migrated from the interior of the city to the outside and has the presence of phenomena around the major parks.

VI. CONCLUSION

Based on the analysis of LST from 2000 to 2017, the following conclusions can be drawn: The surface temperature has a significant correlation with each factor ($p<0.001$). The GWR model can explain 86.21% of the LST phenomenon, and the model performance is excellent. The surface temperature is generally decreasing in Chengdu, but the extremely high temperature area (VII) is increasing. The slow cooling zone is consistent with the high temperature zone of the surface temperature, and it is mostly concentrated outside the three rings, near the four rings, and outside the four rings in the towns. The factors contribute differently to the formation of the slow-down temperature-zone in the surface temperature. The changes in local NDBI and GDP have the most significant impact on LST changes.

By studying the correlation between local socioeconomic factors and surface temperatures, the social economic factors contribute to the formation of the surface temperatures. In the research on the extraction and analysis of the characteristic area

of surface temperature, it is found that the slow cooling is mostly distributed in industrial plants, roads, residential areas and other impervious water areas. The extent of the social economic contribution has been distributed around the circle, indicating that the road has an advantage for the social economy development, and the change of surface temperature is influenced by the contribution of social activities around the road to different degrees. In the analysis of surface temperature, it is found that the normalization of raster data can effectively reduce errors. Analysis of the surface temperature found that the raster data is normalized to reduce errors. In multi-model correlation analysis, the GWR model performs better. Compared with the traditional linear regression analysis, it can highlight the local feature information and effectively reduce the interference of individual data with the results. FRW is the result of spatial data quantification, which can effectively analyze the contribution of evaluation factors to surface temperature. Since the surface temperature is affected by many factors, the subsequent consideration will be given to the addition of multi-faceted evaluation factors for comprehensive and more accurate study of ground temperature differentiation characteristics.

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