

CALCULATION AND DISCUSSION ON CORRECTING MODEL OF THE POTENTIAL TEMPERATURE ABOVE COMPLEX TERRAIN BASED ON NOAA/AVHRR AND DEM

DAN Shang-ming^{1,2,3}, DAN Bo⁴, XU Hui-xi⁵, CHEN Gang-yi^{1,6}, AN Hai-feng⁶

¹ Key Laboratory of Atmospheric Sounding, China Meteorological Administration, Chengdu 610225, P.R.China;

² Sichuan Academy of Environmental Science, Chengdu 610041, P.R.China;

³ Sichuan Province Agrimeteorological Center, Chengdu 610072, P.R.China;

⁴ Sichuan Provincial Meteorological Observatory, Chengdu 610072, P.R.China;

⁵ Sichuan College of Architecture Technology, Deyang, 618000, P.R.China;

⁶ Chengdu University of Information Technology, Chengdu 610225, P.R.China-
dancsqx@163.com

Commission VIII, WG VIII /3

KEY WORDS: NOAA/AVHRR, DEM, Black-body Temperature, Potential Temperature, Complex Terrain, Correction Model

ABSTRACT:

This paper analyzed factors which affects the mountain temperature. Taking Chongqing in China as an example, the black-body temperature (TBB) retrieved from NOAA/AVHRR data was converted into the potential temperature, referring the concept of the potential temperature and confirming a height base. These results show that characteristic of the potential temperature field distinctly changes than before calculation. Then, this paper found the revised coefficient for γ (the lapse rate of temperature) through analysis about terrain factors, which can afford idea and method to protect the mountain environment and make full use of climate resources.

1. INTRODUCTION

Temperature is an important factor of mountain environment. It is important for estimation and exploitation of mountain resources and protecting environment to calculate mountain temperature field.

The spatial distributions of mountain temperature is related with geographic location, altitude, terrain (slope, aspect, shadow), under surface nature, meteorological condition (wind speed, wind direction, humidity, radiation), four seasons and diurnal variation and so on [1]. At the same latitude, the influence from altitude and terrain conditions is the most significant. Usually, the mountain temperature in southern brae is higher than that in northern brae; the temperature difference has the maximum in the winter and the minimum in summer in different aspect [2]. In different regions, the altitude affects the air temperature to significantly different extent. Many researches prove these results. In the northeast of the Yunnan Province in China, the lapse rate of temperature of mean annual temperature shows 0.45-0.77°C/100m, that of the northern brae is lower than that of the southern brae, and the correlation between mean annual temperature and latitude is obvious [3]. The results of the Huanggang Mountain in Fujian Province in China showed that annual mean temperature had a significant linear relationship with altitudinal gradient with a lapse rate of 0.43°C/100m, the highest in September is 0.56°C/100m [4]. The average air temperature in Fujian Province in China had a exponential relationship with altitude, the extent of the lapse rate of temperature is 0.41-0.81°C/100m, and the annual mean temperature is 0.57°C/100m [5]. The extent of the lapse rate of temperature on the Lushan and the Taishan in China is 0.402-

0.656°C/100m, and that of the Emeishan is 0.485-0.604°C/100m [6].

In recent years, GIS was widely used, which promote the process of mountain temperature research. For example, ZHANG Hong-liang et al. [7] brought forward Topography Adjusted Model (TASM), which corrects the mountain temperature based on Conventional Statistical Model (CSM) by using the topographic factors (slope and aspect) on the small scale. CHENG Lu et al. [8] found mountain temperature distribution model based on meteorological observation data, considering many factors, such as solar radiation, altitude, terrain, and so on.

In order to facilitate analysis of air temperature on the different air pressure (or altitude), in meteorology, air block usually will be raised or depressed on the standard air pressure (1000hPa) by Static Atmosphere State Equation in accordance with the insulation process. At this time, the temperature of the gas block is known as the potential temperature. This paper analysed the factors affecting ground temperature and retrieved the black-body temperature (TBB) from NOAA/AVHRR data. Taking Chongqing in China as an example, TBB was converted into the potential temperature, referring the concept of the potential temperature and confirming a height base. Then, comparatively analysed the potential temperature and TBB. Further, correction model for terrain impact on the potential temperature was discussed.

2. STUDY AREA

Chongqing city is located in the southeast of the Sichuan basin. It is subtropics monsoon climate. It is hot in winter and warm in

summer. The wind speed is slow. The mean annual air temperature is 17.8°C and the annual air temperature difference is 20.9°C. The annual average precipitation is 1150mm. The annual average relative humidity is 79%. The annual average wind velocity is 3m/s and the rate of no-wind is 33%.

The width of the study area (Fig.1.) is approximate 30km from the east to the west and 37km from the south to the north and it's area about 1100 km². It's geographical environment complex. Chongqing city is located in middle of the study area. The altitude of the Zhongliang Mountain which lies in the west of the city is from 500 to 650 meters, and the altitude of the Nan Mountain which lies in the southeast of the city is from 400 to 600 meters. The distance is from 16 to 20 kilometres between the Zhongliang Mountain and the Nan Mountain. The altitude of the Yangtze River and the Jialing River are below 200m. The Yangtze River flows through the east of the city from southwest to northeast, and the Jialing River ran across the city from north to south and east, surrounding the east of the Zhongliang Mountain. Because of impact of the terrain, in recent ten years, the city expanded toward the south and north. The size of the city significantly expanded, the functional areas became more obvious.

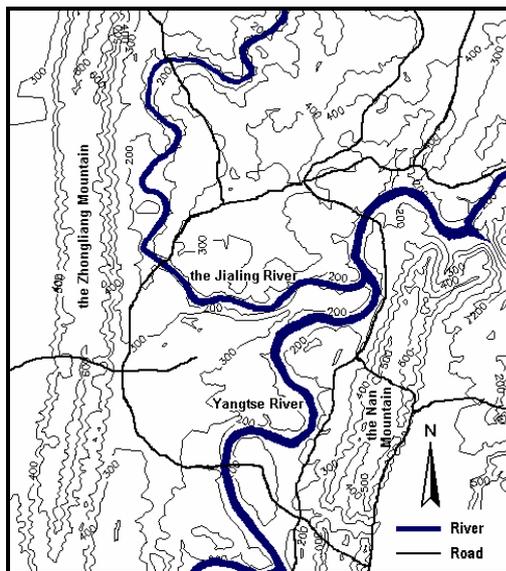


Figure 1. The terrain, river and primary road

3. DATA AND METHODOLOGY

3.1 TBB and DEM

In this paper, the black-body temperature(TBB) was analyzed based on radiant temperature for AVHRR thermal band 4, which was calculated from emitted spectral radiance (R) using Planck's equation [9]:

$$B(\nu, T) = \frac{c_1 \nu^3}{e^{c_2 \nu / T} - 1} \quad (1)$$

Where T is the radiant temperature in Kelvin for the pixel, C₁ the calibration constant (1.1910659 × 10⁻⁵ mWm⁻² s r⁻¹ cm⁴), C₂ the calibration constant (1.438833 cm K), ν the central wave number for each band, R is the corrected spectral radiance for

the pixel. The temperature scale (K) was converted into to Celsius (°C), according to the equation: t=T-273.15.

Digital Elevation Model (DEM) was generated from topographic contour in support of GIS software. The TBB image was registered to DEM image and resample with methods of bilinear interpolation.

3.2 Factors affecting temperature

The temperature of the air mass is related with its height in the atmospheric thermal force field of the earth. Usually, the temperature decreases with increase of altitude. The lapse rate of temperature in the free air is 0.98 °C/100m, and that in troposphere is 0.65 °C/100m. In most cases, mountain surface temperature also decreases with increase of altitude. Factors which affect the temperature are more complex due to surface roughness. There is obvious difference in different regions and in different seasons [10]. In the inland, the following are main factors which affect the temperature: solar radiation, altitude, latitude, terrain, weather condition, dryness/wetness conditions and so on. So, the temperature (T_{x,y}) of some ground spot is expressed as :

$$T_{x,y} = f_{x,y}(I, \phi, h, \alpha, \beta, \eta, \mu, C, \delta) \quad (2)$$

Where I is solar radiation; φ is latitude; h is altitude; α is aspect; β is slope; η is shadow; μ is Surface roughness; C is under surface nature; δ is other factor.

Solar radiation (I) is fundamental factor which determines the temperature of the earth. But in some region of which the scope is smaller, temperature differences caused by solar radiation can be ignored.

3.3 Calculation of the potential temperature

3.3.1 Confirming benchmark altitude: Firstly, in study area, confirm a benchmark altitude as a base altitude surface for the potential temperature field. Usually, take the average altitude in study region as benchmark altitude, and convert the temperature on other altitude to the benchmark altitude. The altitude extent of this study area is from 180m to 698m, and it's average altitude is 320m. The altitude extent of district of the city is from 220m to 400m. At last, benchmark altitude is confirmed 300m.

3.3.2 Calculation of the potential temperature: When only considering influence from altitude and the lapse rate of temperature, the model of the potential temperature is expressed as:

$$\theta = f(T_0, h, \gamma) \quad (3)$$

Where T₀ is the average temperature on the benchmark altitude; h is altitude; γ is the lapse rate of temperature.

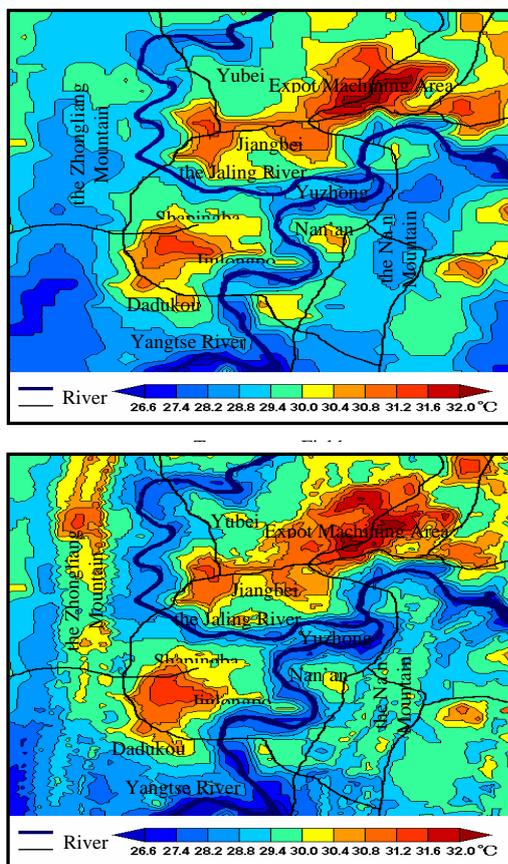
The following is calculation equation for the potential temperature of any spot(x, y) in study area.

$$\theta_{x,y} = T_{300} + (h_{x,y} - 300) \cdot \gamma \quad (4)$$

Where $h_{x,y}$ is the altitude of any spot(x, y);300 is the benchmark altitude; T_{300} is the benchmark temperature; γ is the average of the lapse rate of temperature in study area.

4. RESULTS ANALYSIS AND DISCUSSION

The value of the γ (the lapse rate of temperature) is $0.57^{\circ}\text{C}/100\text{m}$, referring the results of the Emeishan district at the same latitude[6]. According to Eq. (4), the TBB field figure (Fig.2.a) and the potential temperature field figure (Fig.2.b) can be gained using NOAA/AVHRR data obtained at 11:40 AM, on Sep 1, 2006.



b. Potential Temperature Field
Figure2.Contrast between temperature field and

4.1 Analysis

Before and after calculation, there is no great change of the general pattern of the temperature field, but three types obviously changing are the following: the mountains, the valleys and the part of the city.

The first style lies in the Zhongliang Mountain and the Nan Mountain before calculation, the lower-temperature areas locate in the valley, but after calculation, the temperature where the valley locates rise.Furhermore, the trend of the potential temperature field in the north part of the Zhongliang Mountain

is obviously consistent with the mountain, but in the south part of the Zhongliang Mountain, the trend of the potential temperature field is not obvious. The reason to these results is that the vegetation in the south part is better than that in the north part, which proves the vegetation can cool the surface temperature. And the same result appears in the Nan Mountain.

The second style lies in the valley between the Yangtze River and the Jialing River. In these regions, the temperature of the valley falls at large after calculation. Especially in the extent from the Shapingba to the Yuzhong district, before calculation the temperature field $29.5\sim 30.0^{\circ}\text{C}$ hardly become the linked belt between the south high-temperature-zone and the north high-temperature-zone. After calculation, the high-temperature-zones of the city are distinctly divided into the south and the north parts, which show that water has inhibitory effect on the high-temperature field of the city.

The third style lies near the exports processing district in the north of the Chongqing City. After calculation, the temperature field obviously changes. The extent of the high temperature zone($30.4\sim 31.2^{\circ}\text{C}$) expands. The form of the temperature contours(31.2°C)changes from mirror writing “Y”, which tilts towards the right, to “C” whose “mouth” opens towards the left. The temperature field of the southwest part of the city slightly expands and enhances.

4.2 Discussion

The research results show that altitude has distinct effect on the temperature field and the potential temperature has applied significance. From the TBB field figure (Fig.2.a), we can see only the south and the north high-temperature-zone and scattered high-temperature-spot appear in the south part of the city. From Fig.2.b, we can see the potential temperature of the north part of the Zhongliang Mountain is obvious higher than that of the surrounding area, where the air can freely convect and diffuse. But, in the valley between the Yangtze River and the Jialing River, the air can easily settle and cumulate, which don't benefit low-level air pollutants diffuse, because the potential temperature is lower and thermal convection relatively is weak. So, the potential temperature field can be regard as judge means for the diffusion of the air, which has value for spatial analysis of city's atmospheric environment on complex terrain.

This paper is different from the same research based on DEM.For example, ZHANG Hong-liang et al. [7] and CHENG Lu et al. [8] simulated spatial distribution of the average temperature on mountain surface using scattered meteorological observation data in support of DEM, which can afford basis for thematic application of the air temperatures resources. This paper found mathematical model. In order to mutually compare thermal conditions on different location, this paper convert the black-body temperature (TBB) retrieved from NOAA/AVHRR data into the potential temperature in support of DEM.

5. DISCUSSION ON CORRECTING MODEL FOR TERRAIN FACTORS

In the free air, few factors are related with calculation of the potential temperature.But,the surface temperature above complex terrain is affected by many factors, the calculation process of the potential temperature is more complicated. In different spot, the value of the γ (the lapse rate of

temperature) is different because of terrain, so the calculation results need to be corrected. To adopt revised coefficient for γ is the correcting method to the potential temperature.

5.1 Slope

Fig.3.a and Fig.3.b show that the angle relationship between slope and solar injection. Where β is angle of the slope, Z is zenith direction, I is solar injection direction, ω is angle of zenith. In sunshine day, the equation of revised coefficient (A_β) for slope is expressed as:

$$A_\beta = \begin{cases} \sin(\frac{\pi}{2} + \beta - \omega) & \text{Sunny slope} \\ \sin(\frac{\pi}{2} - \beta - \omega) & \text{Shade slope: } \frac{\pi}{2} - \beta > \omega \\ 0 & \text{Shade slope: } \frac{\pi}{2} - \beta \leq \omega \end{cases} \quad (5)$$

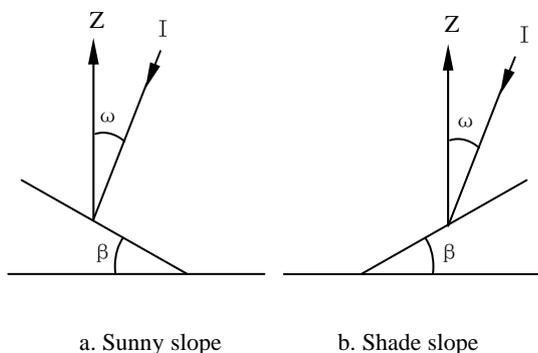


Figure3. the angle relationship between slope and solar injection

5.2 Aspect

Fig.4. shows that the angle relationship between aspect and solar injection. Where P is aspect; N is the north direction, α is the angle between aspect and the north direction, I is solar injection direction, Ω is azimuth of the sun. The equation of revised coefficient (A_α) for aspect is expressed as:

$$A_\alpha = \begin{cases} \cos(\Omega - \alpha) & -\frac{\pi}{2} < \Omega - \alpha < \frac{\pi}{2} \\ 0. & \Omega - \alpha \leq -\frac{\pi}{2} \text{ or } \Omega - \alpha \geq \frac{\pi}{2} \end{cases} \quad (6)$$

5.3 Terrain shadow

There are both cases for revised coefficient (A_{η}) for shadow. when terrain is shadowed, $A_{\eta}=0$; or, $A_{\eta}=1$. To sum up, the revised coefficient ($k_{x,y}$) for γ (the lapse rate of temperature) due to influence of terrain is expressed as:

$$k_{x,y} = \begin{cases} b_1 + a_1 \cdot (A_\alpha \cdot A_\beta \cdot A_\eta)_{x,y} & -\frac{\pi}{2} < \Omega - \alpha < \frac{\pi}{2} \\ b_2 + a_2 \cdot [(A_\alpha + A_\beta) \cdot A_\eta]_{x,y} & \Omega - \alpha \leq -\frac{\pi}{2} \text{ or } \Omega - \alpha \geq \frac{\pi}{2} \end{cases} \quad (7)$$

Where a_1 、 a_2 、 b_1 、 b_2 are regression coefficients, which can be gained from tests. Usually, $k_{x,y} > 1$, when the surface is affected by solar radiation; $k_{x,y} \leq 1$, when the surface is shadowed by terrain. Eq. (4) is revised as the following:

$$\theta'_{x,y} = T_{300} + (h_{x,y} - 300) \cdot \gamma \cdot k_{x,y} \quad (8)$$

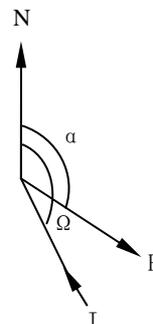


Figure4. the angle relationship between aspect and solar injection

6. THE END

This paper found the calculation model for the mountain potential temperature based on TBB and DEM, after analyzing factors which affects the temperature above ground surface. The research achieved some practical results, which can afford idea and method to protect the mountain environment and make full use of climate resources.

The research looks forward to improving, because the lapse rate of temperature above complex terrain is related with many factors, such as surface roughness, under surface nature, diurnal variation. For example, usually, surface roughness is bigger above complex terrain, water and gas is abundant in the south mountain in China. Mostly, calculation the potential temperature should belong to non-adiabatic process; impact which latitude difference has on the temperature field should be considered, if the latitude expands widely in the study area. Therefore, more tests and researches need to be done so as to the simulating results of the potential temperature can be close to the actual situation.

REFERENCES

[1] WENG Du-ming, LUO Zhe-xian. Mountain Area Geography Weather [M]. Beijing: China Meteorological Press, 1990:144.

[2] FU Bao-pu, Yu Jing-ming, LU Qi-yao. Resources and Development Exploitation of the Mountainous Country Weather [M]. Nanjing: Nanjing University Press, 1996:165-179.

[3] HUANG Zhong-yan. Mountain Climate Features of Northeast Yunnan [J]. Journal of Mountain Science, 1994, 12(1):32-38.

[4] ZHENG Cheng-yang, FANG Jing-yun. Changes in Air Temperature Variables along Altitudinal Gradient in Mt.

HUANGGANG, CHINA[J], *Acta Meteorological Sinica*, 2004, V62:251-255.

[5] MA Zhi-guo, CHEN Hui, CAI Wen-hua, et al. Analysis of Average Temperature and Geography Factor are Related to Statistics Characteristic in FUJIAN[C]. China Meteorological Society, The Proceeding of the National Agricultural-Meteorological and Ecological Environment Academic Meeting, Nanchang, Jiangxi, 2006:433-436.

[6] ZHANG Jia-cheng, LIN Zhi-guang. *China Climate* [M]. Shanghai: Shanghai Science & Technology Press, 1985:79-89.

[7] ZHANG Hong-liang, NI Shao-xiang, DENG Zi-wang, et al. A Method of Spatial Simulating of Temperature Based Digital Elevation Model (DEM) in Mountain Area [J]. *Journal of mountain science*, 2002, 20(3):360-364.

[8] CHENG Lu, QIU Xin-fa. Spatial Distribution of Temperature in QINLING Mountain based on GIS [J], *Journal of SHANXI Meteorology*, 2006, (6):1-4.

[9] Tran H., Daisuke U., Shiro O., Yoshifumi Y., "Assessment with satellite data of the urban heat island effects in Asian mega

cities", *International Journal of Applied Earth Observation and Geoinformation* Vol.8, pp.34-48, 2006

[10] WENG Du-ming, Sun Zhi-an. A Preliminary Study of the Lapse rate of Surface air Temperature over Mountainous Regions of CHINA [J]. *Geographical Research*, 1984, 3(2):24-34.

ACKNOWLEDGEMENTS

The authors acknowledge the financial supported by "The open fund of the Key Laboratory of Atmospheric Sounding, China Meteorological Administration (Contract No.KLAS200703)" and "The plan for application base research in Sichuan province (Contract No.2006J13-007-1).

APPENDIX A. INTRODUCTION TO AUTHOR

DAN Shang-ming (1952.2—), Male, Senior Engineer, Research Field: Remote Sensing and It's Application. E-mail: danscq@163.com.

