Research Article **AJGRR (2018) 1:9**

American Journal of Geographical Research and Reviews
(ISSN:2577-4433)

A Verification Method of Thermo- infrared Remote Sensing Temperature Retrieval Algorithm with a CFD Model

Yong Zhang[1,*], Zhiqiang Yao[1], Yingbao Yang[2], Leqin Zhang[1], Xin Pan[2]

[1]College of Natural Resources and Environment, Chizhou University, No.199 Muzhi Road,Chizhou 247000, China
[2]School of Earth Science and Engineering, Hohai University, 8 Buddha CityWest Road, Nanjing 210098,China

ABSTRACT

Due to the thermal infrared remote sensing inversion of surface corresponds to the surface temperature of the image pixels is planar, the inversion algorithm of authentication, rarely considering the reference temperature data and inversion of surface temperature on like yuan scale problems.ENVI - met based on the CFD model to simulate the nanjing jiangning district land surface temperature, and by the methods of measurement of analog temperature verification, proved ENVI - met the error of the model to simulate the surface temperature of 0.6 ^{0}C, meet the verification accuracy of temperature inversion algorithm. Using ENVI - met model of Landsat8 data.

Keywords: land surface temperature; CFD; ENVI-met; cross validation

***Correspondence to Author:**
Yong Zhang
College of Natural Resources and Environment, Chizhou University, No.199 Muzhi Road,Chizhou 247000, China

How to cite this article:
Yong Zhang,Zhiqiang Yao,Yingbao Yang,Leqin Zhang,Xin Pan. A Verification Method of Thermo - infrared Remote Sensing Temperature Retrieval Algorithm with a CFD Model. American Journal of Geographical Research and Reviews, 2018; 1:9.

eSciPub LLC, Houston, TX USA.
Website: http://escipub.com/

1. Introduction

In recent years, the inversion of land surface temperature algorithms of many thermal infrared sensors have been validated, such as Landsat TM / ETM +, ASTER, AVHRR, AATSR, MODIS and SEVIRI data. The pixels of the surface temperature image obtained by the thermal infrared remote sensing inversion have a surface shape, It is very rare to consider the reference temperature data and the inversion of surface temperature at the pixel scale in the verification of the inversion algorithm. From its verification method, it can be divided into three categories: temperature-based verification method, Radiation-based verification method and cross validation method.

The temperature-based verification method is a direct comparison of the remote sensing inversion of the surface temperature and the satellite transit time in the study area measured by the surface temperature. However, the measured temperature at the time of satellite transit is a very difficult and complex task. Because of the satellite scale problem, usually the thermal infrared remote sensing spatial resolution is meters or even kilometers. Take MODIS (thermal infrared band spatial resolution of 1000m) as an example, if we want to verify the temperature of a pixel, it is necessary that we must select some points to measure the temperature in the study area 1000m × 1000m evenly at the satellite transit time, and then the average value of these temperature values is the reference temperature of the cell temperature. Surface temperature verification requires verification of multiple pixels, which is bound to require a large number of personnel and equipment.

Radiation-based verification method is an improved method of verifying surface temperature. This method does not require surface temperature data, but relies on the surface emissivity and the atmospheric contour data of satellite transit time[1]. The surface emissivity can be measured by field measurements or based on surface coverage types, can also be obtained through other ancillary data.[2] The verification method assumes that the surface temperature and the above-mentioned surface emissivity and atmospheric contour data are known and as an atmospheric model input parameters to simulate the satellite transit time on the star heat radiation (the thermal radiation intensity already contains the influence of the atmosphere).[3] And then use the thermal radiation intensity to calculate the brightness temperature; and then use the brightness temperature and the assumed surface ratio of radiation rate into the inversion algorithm to be verified LST; Finally, the difference between the LST and the assumed LST is compared, and the accuracy of the temperature inversion algorithm can be determined. Radiation-based verification method does not require surface temperature observation data. This method can be applied to the field where the surface temperature is difficult to be measured and extended to the surface uniform and non-isothermal surface. However, there are some difficulties in the measurement and estimation of the surface emissivity at the pixel scale, and the actual atmospheric contour data at the time of satellite transit are generally more difficult to obtain and the measured cost is more expensive.[4] There are also studies using models to simulate the atmospheric profile at a time, but the model's atmospheric contours can not be well replaced by the true atmospheric contours of satellite transit moments, with greater errors.[4] Therefore, how to obtain the cellular scale of the surface than the emissivity and atmospheric contours is the difficulty of the method.

2. Study Area

Nanjing (31°14″–32°37″ N,118°22″–119°14″ E) is the capital of Jiangsu Province, and is in one of the largest economic zones in China, the Yangtze River Delta.[5] Nanjing covers seven districts and a total area of 6587 km2. It has a humid subtropical climate, which is influenced by the East Asian monsoon. The annual average rainfall and air temperature in Nanjing are 979 mm and 15.9 ℃,respectively. July and August are the hottest and the most humid months, in which the average maximum air temperature is 32 ℃.[6] Accordingly, LST peaks in the hot summer. The experimental area is a subset of Nanjing City based on the land use and land cover map in 2010. The area,which is characterized by heterogeneous urban landscape patterns, has four main land cover types,namely, water, vegetation, bare soil, and impervious surfaces.

3. Methods

The ENVI-met model as the CFD model is adopted to examine the impact of greenspace patterns on land surface temperature.[7] It employs the non-hydrostatic incompressible Navier-Stokes equations for the wind field, the k-epsilon turbulence model and a combined advection-diffusion equation with the alternating directly implicit solution technique to simulate the interaction between microclimate and urban surfaces, such as walls, soil and vegetation.[8] This model requires two main input files, including the configuration file containing settings for initialization values and timings and the 3D model file designing the spatial location, height of buildings, vegetation and soils based on a cell in the simulated area.[9,10] The four steps are described below:

(1) Constructing a 3D model of the study area based on LiDAR data and IKONOS images;

(2) Initializing the CFD model by field survey and defining basic settings, including temperature at 1.5 m above ground: 299 K; wind speed (at 10 m above ground): 1.6 m/s; wind direction: south to north; RH: 84%; roughness length in 10 m: 0.1; total simulation: 24 h;

(3) Calibrating the CFD model: comparing simulated temperature with measured temperature and adjusting the inputted parameters to make the simulation stable and the errors reduce;

(4) Outputting the simulated temperature: simulating the temperatures of different scenarios based on systematic verification and reliability analysis of the ENVI-met model after inputting the two main files .

3.1 ENVI-met model validation

In order to simulate the thermal environment problem in the mesoscale region, it is necessary to establish a more realistic three - dimensional model. This paper mainly combines the LiDAR data and high resolution airstrip, and establishes the 3d model of the experimental area manually in the Eddi module of the micro-climate model ENVI - met. In order to build a three-dimensional model, it is necessary to obtain the height information and layout of the study area. In this paper, we use the height information of LiDAR point cloud data and using high resolution aerial slice obtain the layout information, and then establish the 3D model of experimental area in Eddi module of ENVI-met. The specific idea is: First, the experimental area of high-resolution aerial as a base map into the ENVI-met modeling module Eddi,and the height information for the building and vegetation is obtained through the LiDAR point cloud data. Second, the ENVI-met initial boundary condition is set by the measured and meteorological data. Finally, run the ENVI-met software to simulate the surface temperature of the study area and evaluate the reliability of ENVI-met by comparing the measured data in the experimental area.

3.1.1 Field measurement

In order to verify the reliability of the surface temperature simulated by the ENVI-met of the microclimate model, a small area of Nanjing was selected as the experimental area. The aerial image with high spatial resolution of the experimental area is used as the base image of

ENVI-met and the LiDAR data is used as the building height information input when ENVI-met is modeled. The reliability of the model is verified by combining the field measured data with the established surface temperature simulated by the three-dimensional model of the residential area.

Figure 1. Experimental area:(a) Experimental area aerial imagery;(b) Two - dimensional model.

For the ENVI-met model, simulations of microclimate require the input of initial meteorological data such as atmospheric temperature, relative humidity, wind speed, and wind direction in the initial state. These meteorological data can be obtained from the weather website. The validation of the ENVI-met model requires field-measured surface temperature data. The surface temperature observation time for the June 12, 2013 10:00. The study shows that the ENVI-met simulation runs for 24 hours and the best temperature field is obtained. Therefore, the meteorological data at 10:00 on June 11, 2013 as the initial input parameters, the micro-climate simulation of the region, and in accordance with the actual seven observation points of the spatial distribution of the establishment of the model in the process of setting the corresponding seven monitoring (Receptors), record the detection of the surface temperature of the simulation data.

(1) Observation point selection

The actual surface temperature of the seven monitoring points was observed in the experimental area, as shown in Figure 2. The location of the observation site covers a representative point, such as the building periphery, between the two buildings, roads, open areas, grass and so on.

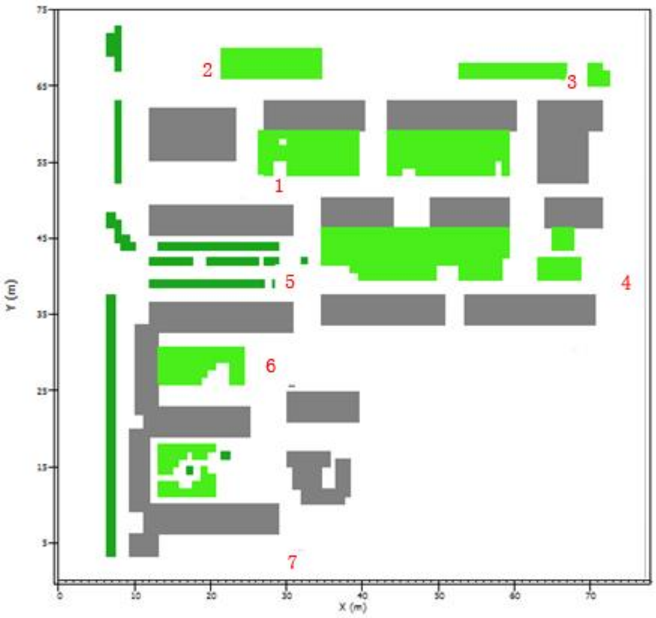

Figure 2. Study area two-dimensional map (gray for the building; green for the vegetation; red figures for the monitoring point)

(2) Observation instrument

Thermal infrared imager for observing surface temperature. Thermal infrared imager, is directly on the surface of the shooting, access to surface temperature. We observe the time is June 12, 2013 10 o'clock, with a thermal infrared imager to select the pre-selected monitoring point of its temperature image. The thermal image of the seven infrared observations taken by the thermal infrared imager is shown in Figure 3:

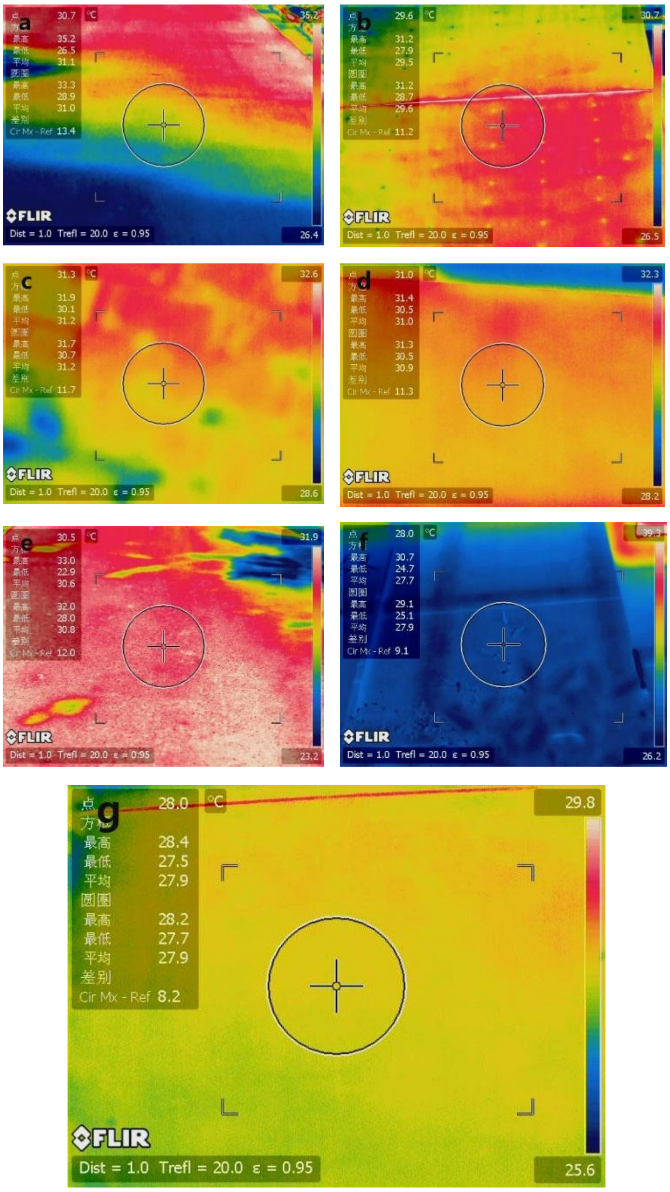

Figure 3. Test area monitoring point measured temperature:(a) No. 1 monitoring point; (b) No. 2 monitoring point; (c) No.3 monitoring point; (d) No. 4 monitoring point; (e) No. 5 monitoring point; (f) No.6 monitoring point; (g) No. 7 monitoring point.

3.1.2 ENVI-met modeling

Firstly, the high resolution aerial data of the experimental area is introduced into the Eddi module of ENVI-met as the base map to establish the 3D model of the study area. The height of the building is obtained through the study area LiDAR data. ENVI-met software model is based on the form of two-dimensional plane grid nodes to achieve the modeling process, the first need to set the experimental area of the grid area and size of the experimental area and latitude and longitude information, Type to establish the corresponding model. In this experiment, considering the simulation performance is limited by the performance of the computer, set the modeling range of 78 * 75, X, Y direction of the grid size of 2m * 2m, Z direction grid size is set to 2m. Location: Longitude 118.77, Latitude: 32.05. Reference time zone is GMT + 8; reference longitude is 120 ° east longitude.

ENVI-met in the Eddi module to build the building model manually: the height of the building information, through the interface input parameters to set the height of the way. Taking into account the complexity of the simulation simulation, the need to establish the model to be properly simplified, that is, so that the model can meet the 2m* 2m modulus, and is a regular cube, both quickly build the model, but also smooth the value simulation.

Similarly, the establishment of vegetation model: According to the observation of the site to observe the vertical distribution of vegetation, the establishment of the actual distribution of vegetation, due to the study area of vegetation for the low lawn. The model is 2D and 3D displays as shown in Figures 4 and 5:

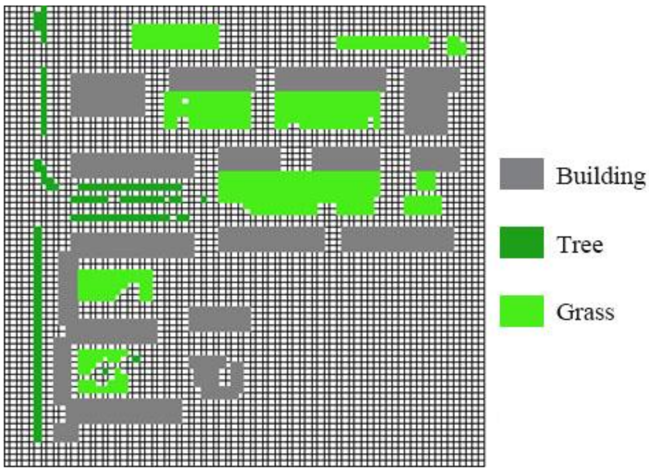

Figure 4. Two - Dimensional Display of Study Area Model.

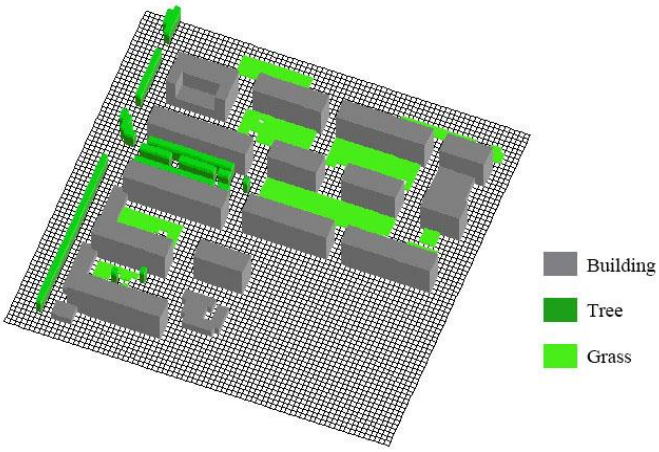

Figure 5. Three - dimensional display of study area model.

3.1.2 Contrast with measured data

Through the establishment of the above model, after the boundary condition is set, simulate the surface temperature of the experimental area in the Run Model module and derive the temperature data of the experimental area monitoring point. The simulation results of the surface temperature of the experimental area are shown in Figures 6:

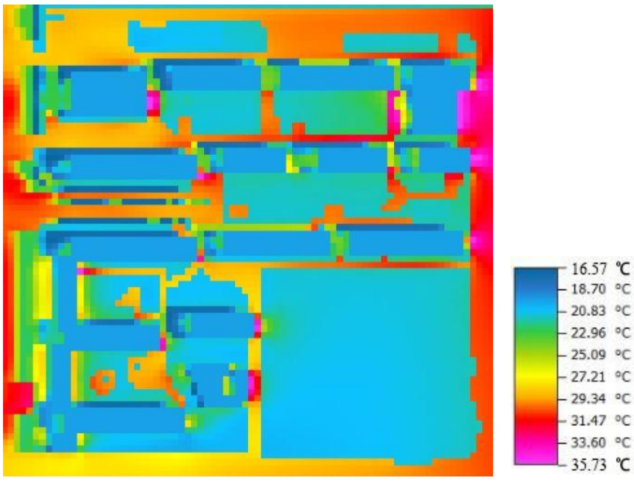

Figure 6. The experimental area simulates the temperature.

The temperature data of the monitoring site from the exported experimental area are compared with the measured temperature data, the comparison result and the absolute error are shown in Table 1, and the measured temperature and simulated temperature are shown in Figures 7.

Table1. Monitoring point error statistics

Monitoring points	1	2	3	4	5	6	7
Measured temperature（℃）	30.7	29.6	31.3	31	30.5	28	28
Simulated temperature（℃）	30.2	28.9	30.5	31.6	30.2	28.9	28.4
Absolute error（℃）	0.5	0.7	0.8	0.6	0.3	0.9	0.4

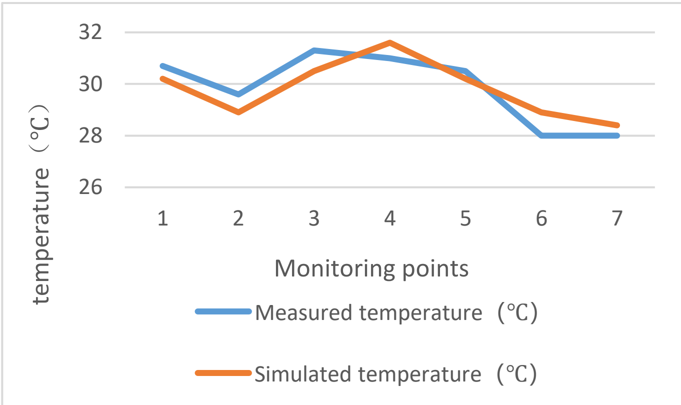

Figure 7. Comparison of measured and simulated temperature.

From Table 4 and Fig 7, it can be concluded that the simulated temperature of ENVI-met is almost the same as that of thermal infrared imager. The average error is 0.6 ℃. Therefore, ENVI-met simulation surface temperature can be regarded as temperature inversion The reference temperature is reliable and effective.

3.2 CFD cross validation

Landsat 8 thermal infrared band spatial resolution of 100m, high resolution aerial resolution of 0.3m, that is, Landsat8 a cell equivalent to 334 × 334 aerial pixels. Five sample points were selected on the Landsat8 temperature image. Theoretically, the corresponding five 334 × 334 pixel image areas (actual range of 100m × 100m) were cut out on the aerial plane as the base map for ENVI-met modeling. Then, for the five 334 × 334 pixel regions, the surface temperature was modeled with ENVI-met, and the average temperature of the region was the standard temperature of Landsat8 corresponding to the pixel. The modeling range is set to 60 × 60 grid, X, Y direction of the grid size of 2 * 2, in meters, Z direction grid size of 2 meters. Location: Longitude 118.77, latitude 32.05, reference time zone GMT + 8, reference longitude east longitude 120 °. Since the aerial and LiDAR data are data of the Jiangning area, we removed the Jiangning area of the Landsat8 data separately and selected five sample points. The sample pixel coordinates are shown in Table 2. The surface temperature is retrieved by the splitting window algorithm proposed in Chapter 3, and the inversion results are verified by ENVI-met simulation. Figure 4.8 shows the pseudo-color image of the 432 band combination after the Landsat8 data in the Jiangning area and the full color band, and Figure 4.9 shows the spatial image of the temperature image and the sample point retrieved in this region.

Table.2 Sample point pixel coordinates

Sample point	1	2	3	4	5
Row	8	4	16	39	41
Column	27	47	12	44	21

Figure 8. Landsat8 Jiangning fusion image.

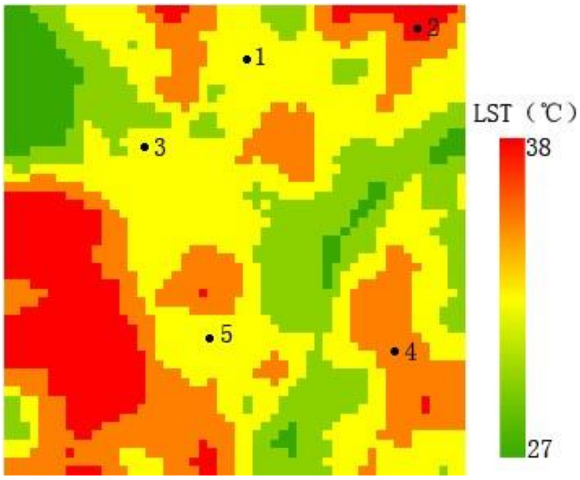

Figure 9. Jiangning LST image.

In Fig. 10, a~e is the five image regions on the aerial image of five temperature images corresponding to Landsat8 inversion.

Figure 10. Aerial sample area

After the model is built in the Eddi module of ENVI-met, the boundary condition is set in the Configuration Editor module, and then the surface temperature of each model is simulated by Run model. The surface temperature of the sample area is displayed by LEONARDO module. Extract ENVI-met Data The temperature of the regional temperature field is obtained by averaging Landsat8, which is averaged. Figure 11 for the ENVI-met simulated Landsat8 transit time 5 sample area of the surface temperature map.

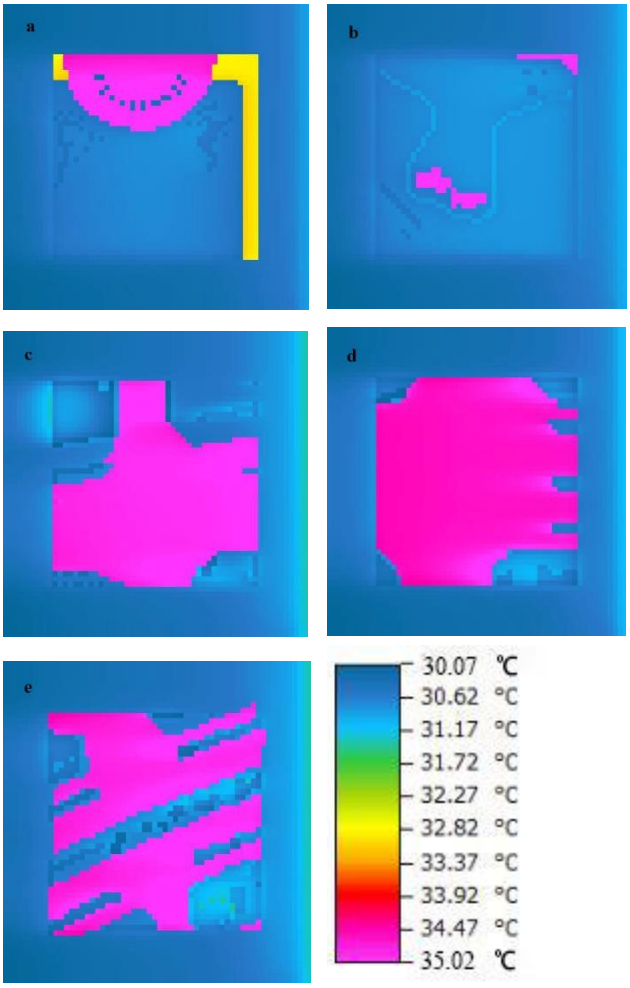

Figure 11. Simulated surface temperature map

4. Results

The average temperature of each sample simulated by ENVI-met represents the temperature of one pixel on the LST image retrieved by Landsat8. Table 3 lists the LST retrieved by the Landsat8 splitting window algorithm and the regional mean temperature simulated by ENVI-met and the error between them.

Table.3 Comparison of simulated temperature and inversion temperature

Sample point	1	2	3	4	5
Simulated temperature (℃)	32.26	31.25	32.59	33.26	32.51
Inversion temperature (℃)	32.77	34.43	32.21	34.39	33.1
Absolute error (℃)	0.51	3.18	0.38	1.13	0.59

Figure 12. Regional panorama

5. Discussion

It can be concluded from Table. 5 that the CFD model ENVI-met simulates the surface temperature as the validation data of the Landsat8 surface temperature inversion algorithm, the absolute error fluctuation range is large, the absolute errors of the sampling points 2 and 4 are relatively large, Especially the No. 2 sample point, the absolute error has reached 3.183 ℃. Figures 4.16 and 4.17 are panorama of sample points 2 and 4, and it can be found that buildings 2 and 4 are located next to the building, especially No. 2 closer to the building. Because of the actual range of each pixel in the image (100m * 100m), it can not build the model of the building when modeling, ignoring the influence of the surrounding building on the surrounding temperature. In addition, because ENVI-met is based on surface energy balance to simulate the surface temperature, without taking into account the human heat (such as human production life, car activities, etc.) on the surface temperature, and thermal infrared remote sensing is recorded at the time of the satellite transit surface Of the true thermal radiation intensity (subject to the impact of human heat). Because of this, the surface temperature simulated by ENVI-met is lower than the LST inversion. In this paper, the mean error of LST inversion is 1.158 ℃, and the average temperature error is 0.65 ℃ if the influence of the surrounding buildings is not affected by the Landsat8 splitting window algorithm. Therefore, for the Landsat8 two thermal infrared band split window algorithm used to invert LST can achieve reliable accuracy.

6. Conclusions

In summary, it is feasible to use CFD to simulate the surface temperature to verify the accuracy of the temperature inversion algorithm. However, when selecting the sample point, it is necessary to select the ground that is relatively empty and less affected by anthropogenic heat. point. This is because the ENVI-met simulated surface temperature is affected by the surrounding environment, and ENVI-met simulates the surface temperature from the building, the underlying surface, the vegetation and water interaction, the energy balance angle to calculate the temperature, To the impact of human heat. The surface temperature obtained by inversion of thermal infrared remote sensing is the true temperature (including the effect of human heat) at the time of satellite transit, so the temperature obtained by inversion is higher than the simulated temperature.

Acknowledgments: This study is supported by the Anhui Provincial Universities Natural Science Research Project (No. KJ2011B113), by the Provincial Quality Project of Colleges and Universities in Anhui Province (No. 2015zy071), by the Chizhou College Natural Science Research Project (No. 2016ZR016).

Author Contributions: Yong Zhang proposed the main idea, offered invaluable suggestions for data analysis,and revised the manuscript thoroughly and wrote this paper. Zhiqiang Yao performed the experiments and made careful data analysis. Yingbao Yang designed the experiments. Leqin Zhang also conceived the experiments and contributed analysis tools. Xin Pan made some comments on the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Pan X, Liu Y, Fan X. Comparative assessment of satellite-retrieved surface net radiation: An examination on CERES and SRB datasets in China[J]. Remote Sensing, 2015, 7(4): 4899-4918.
2. Pan X, Liu Y, Fan X. Satellite retrieval of surface evapotranspiration with nonparametric approach: Accuracy assessment over a semiarid region[J]. Advances in Meteorology, 2016, 2016.
3. Pan X, Liu Y, Gan G, et al. Estimation of Evapotranspiration Using a Nonparametric Approach Under All Sky: Accuracy Evaluation and Error Analysis[J]. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2017, 10(6): 2528-2539.
4. Li Z L, Tang B H, Wu H, et al. Satellite-derived land surface temperature: Current status and perspectives[J]. Remote Sensing of Environment, 2013, 131: 14-37.
5. Yang Y, Yao L. The influence of urban design factors on urban heat environment in urban residential area with remote sensing[C]//MIPPR 2009: Remote Sensing and GIS Data Processing and Other Applications. International Society for Optics and Photonics, 2009, 7498: 74984K.
6. Tang C S, Shi B, Gao L, et al. Urbanization effect on soil temperature in Nanjing, China[J]. Energy and Buildings, 2011, 43(11): 3090-3098.
7. Su W, Zhang Y, Yang Y, et al. Examining the impact of greenspace patterns on land surface temperature by coupling LiDAR data with a CFD model[J]. Sustainability, 2014, 6(10): 6799-6814.
8. Fahmy M, Hathway A, Pattacini L, et al. Environmental thermal impact assessment of regenerated urban form: A case study in Sheffield[C]//World Renewable Energy Congress-Sweden; 8-13 May; 2011; Linköping;

Sweden. Linköping University Electronic Press, 2011 (057): 3201-3208.

9. Yang Y, Zhang X, Lu X, et al. Effects of Building Design Elements on Residential Thermal Environment[J]. Sustainability, 2017, 10(1): 57.
10. Cheng L, Gong J, Li M, et al. 3D building model reconstruction from multi-view aerial imagery and lidar data[J]. Photogrammetric Engineering & Remote Sensing, 2011, 77(2): 125-139.