Analysis of the Relationship between Urban Heat Island and Vegetation Cover through Landsat ETM+:A Case Study of Shenyang

Shouzhen LIANG[1,2,3],Ping SHI[1]

1. Yantai Institute of Coastal Zone Research for Sustainable Development, CAS, Yantai, China, 264003, Pshi@yic.ac.cn

2.South China Sea institute of Oceanology, CAS, Guangzhou, China, 510301 , Liangshzh0816@163.com

3. Graduate University of Chinese Academy of Sciences, Beijing, China, 100039

Abstract—**Urban heat island is a phenomenon that the temperature of urban area is higher than surrounding rural area or suburban area, which is considered as one of major problems in the 21st century posed to human beings. With the extension of urban area, the phenomenon shows an increasing trend. So we must find the critical factor and analyze the relationship between them in order to resolve the problem of urban heat island. In this paper the heat island in Shenyang and the relation between urban heat island and vegetation were analyzed based on Landsat ETM+ data. After correcting the data using the 6s radiative transfer code and atmospheric correction tool developed by Barsi et al, the land surface temperature was derived from thermal infrared data according to Planck function and vegetation index (NDVI) was derived according to the ratio visible band and near infrared band. The results show that the temperature difference is large so that the urban heat island effect is obvious in Shenyang city and there is a strong linearly negative correlation between land surface temperature and NDVI. This is probably due to the ecological function of vegetation in cooling down the surface from high evapotranspiration. Though the urban heat island is complex and the vegetation is only an influential factor, the result of this study can be useful for policy-makers, planners, and the general public to understand urban heat island and realize what kinds of urban heat land mitigation strategies are available.**

I. INTRODUCTION

With the rapid development of economics, more and more people enter into city, which causes the urban area to expand. Urbanization improves our material lives, but it also induces many problems, such as global warming, industrial waste, and air pollution. A major phenomenon is observed in large cities as compared to its surroundings: a higher temperature or heat content called Urban Heat Island and it is considered as the most typical characteristic of urban thermal environment, meanwhile it is also one of major problems in the 21st century [1]. The urban heat island effect has been the subject of numerous studies in recent decades and is exhibited by many major cities around the world [2-7]. There are many factors causing urban heat island. The basic reason is the unbalance between energy gains and losses of region. When the energy entering into city is larger than the energy city releases, the urban temperature will rise. Conversely it will fall. In general the reasons are as follows. The most significant reason is the difference of thermal properties of the surfaces. In city, the buildings have higher albedo than vegetation, water, wet soil and the construction material including concrete, brick, tar and asphalt are better conductor than the vegetation of the rural area. Moreover, the surfaces in city are impervious, which make runoff greater than rural area. And the lack of surface water and vegetation makes evapotranspiration decrease in the urban environment. Thus more heat energy entering into air in urban area makes the temperature rise rapidly, while in rural areas, the solar energy absorbed near the ground evaporates water from the vegetation and soil during the day. Thus, while there is a net solar energy gain, this is compensated by evaporative cooling to some extent. The second reason is the building structure. The canyon structure that tall buildings create enhances the warming. During the day, solar energy is trapped by multiple reflections of the buildings while the infrared heat losses are reduced by absorption. And high roughness structure is also problem of urban area, which reduces the convective heat removal and transfer by wind. The anthropogenic heat released from vehicle, power plant, air-conditioner, and other heat resources is also an important factor that contributes to the relative warmth of cities [8]. It is also believed that air pollutants, particularly aerosols that are abundant over polluted urban areas, can absorb and re-radiate long wave radiation and inhibit the corresponding radiative surface cooling producing a pseudo-greenhouse effect, which is also responsible for urban heat island effect.

Urban heat island studies are generally conducted in two ways. one is measuring air temperature through the use of automobile transects and weather station network, and the other is measuring surface (or skin) temperature through the use of airborne or satellite remote sensing [9] .At the beginning, the urban heat island is found and researched using the data of observation station [10]. To date, the vast majority

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of climatologic studies of UHI's have been performed using in situ data, which have the advantage of a high temporal resolution and a long data record, but which also have poor spatial resolution. So it is inappropriate when to observe a large area. Lack of simultaneity is also a disadvantage. And not all points can be observed with observation station, then the data need be obtained through interpolation which will introduce error. Remotely sensed temperature measurement from satellites, on the other hand, has higher spatial coverage and can be carried on simultaneously. Satellite thermal data can effectively depict the patterns of the thermal environment of extensive urban areas. The advent of satellite remote sensing makes it possible to study urban heat island on continental or global scale [11]. But these data have not been frequently used in urban climatology applications due to the complexity of the interactions of thermal infrared radiations with the atmosphere and urban surfaces. In recent years, with the advance of the study on algorithm and the improvement of sensor, remotely sensed data began to be used in the field of urban climate and urban heat island [12, 13, 14]. These studies ,employing medium scale sensors (Landsat TM, NOAA AVHRR), give a spatially continuous view of the surface UHI over large urban areas than is feasible using data from meteorological station networks and recognize the correlation between land surface temperature and land cover using land cover maps of the study area extracted from satellite data (SPOT HRV,Landsat TM, Landsat MSS).

Research on land surface temperature shows that the partitioning of sensible and latent heat fluxes and thus surface radiant temperature response is a function of varying surface soil water content and vegetation cover [15].This finding encourages more research focusing on the correlation between land surface temperature and vegetation. And the study on the relation between vegetation and land surface temperature is very significant, especially to large cities which suffer heat island. In this paper Landsat ETM+ thermal data is used to derive the land surface temperature of Shenyang, The aim is to find the spatial distribution of land surface temperature and analyze the relation between land surface temperature and land cover , especially vegetation .In this study, NDVI , which can indicate the vegetation abundance to some extent, is also derived

II. DATA AND METHODS

A. Study area

Shenyang city, the capital of Liaoning province, is chosen as the study area. Shenyang city is the largest city and the center of economy, communication, finance and commerce in the Northeast China. Shenyang city is also a typical heavy industry city and has a population of more than 4,000,000 in urban areas. Shenyang is located in the southern of northeast China, in the middle of Liaoning province. The range of temperature is -29℃ to 36℃.Due to the large population and heavy industry, the urban heat effect is very obvious.

B. Data

In this study the data used include Landsat ETM+ image acquired on August 19, 2004, vector data of study area, and land cover data. Thermal infrared data with 60m resolution was utilized to derive the land surface temperature. NDVI was derived using Red band and NIR band data. According to meteorological material, the date of data acquired has a highly clear atmospheric condition.

Figure1. The location of study area

C. Image preprocessing

In order to derive land surface temperature and NDVI, the data must be preprocessed. The processes are as follows.

1) Calibration: After transmitting the atmosphere, the signal energy received by sensor will be converted to digital number (DN) of the image. Namely the image is recorded using DN, not energy .These DNs must be converted to spectral radiances when data are used to analyze or derive the properties of object qualificationally .Generally the following equation is used to convert DN back to spectral radiance or top-of-atmosphereic(TOA) radiance measured by the sensor instrument[16].

$$L_\lambda = gain * \mathrm{QCAL} + offset \quad (1)$$

which is also expressed as:

$$L_\lambda = \frac{LMAX - LMIN}{QCALMAX - QCALMIN} * (QCAL - QCALMIN) + LMIN \quad (2)$$

where L_λ is the spectral radiance at the sensor's aperture in w/ (m^2 sr μm).These parameters are different with different sensor. To Landsat7 ETM+ data, these parameters can be acquired from Landsat 7 Science Data User's Handbook

2) Atmospheric correction: After calibration, the next step is to remove the atmospheric effect. The signal received is perturbed by the atmosphere when transmitting from solar to earth to sensor and from earth to sensor.The signal received on the sensor may include other information in addition to the surface information. To reflection band, the atmospheric effect includes absorption and scattering, which can add or attenuate signal. While to emission band, the main effect is absorption and emission, especially water vapor.In order to acquire the actual signal of surface,removing the influence of the atmosphere is a critical preprocessing step. This is so-called atmospheric correction.There are many researches to contribute to eliminate atmospheric effects from the satellite data. An atmospheric correction tool developed by Barsi et al[17] and available at(http://atmcorr.gsfc.nasa.gov/) for the thermal band of Landsat sensors was applied.The tool uses the MODTRAN radiative transfer code and a suite of integration algorithms to estimate three parameters: atmospheric transmission and upwelling and downwelling radiance.Thus the surface radiance can be calculate using the following equation:

$$L_T = \frac{L_\lambda - L_\mu - \tau(1-\varepsilon)L_d}{\tau\varepsilon} \tag{3}$$

where L_T is the radiance of a blackbody target of kinetic temperature *T*, L_λ is the TOA radiance , L_μ is upwelling radiance, L_d is the downwelling radiance, τ is the atmospheric transmission ,and ε is the emissivity of surface.

In this study to emissivity only three land cover were considered including water, vegetation and built-up land and these emissivities were assumed to be fixed values. Actually the emissivites of land surfaces such as soil, sands and vegetation canopies vary with viewing angle, components, surface condition and so on, but there are little such spectral, angular emissivity data available. Therefore, many researchers assume that land surfaces are Lambertian, and emissivity is independent of viewing angle. To Landsat, the viewing angle is small so the error will not too much.

To the reflection band, the atmospheric correction is different. The emissivity of surface is not considered. The main effect in these bands is atmosphere intrinsic radiance, environment radiance and gas absorption. The data except the thermal infrared band were corrected atmospherically using 6s (Second Simulation of a Satellite Signal in the Solar Spectrum) radiative transfer code. The code predicts a satellite signal between 0.25 and 0.40 um assuming cloudless atmosphere. The apparent reflectance at the satellite level for Lambertian surface can be written

$$\rho'(\theta_s,\theta_v,\phi_v) = t_g(\theta_s,\theta_v)\left\{\rho_a(\theta_s,\theta_v,\phi_v) + \frac{T(\theta_s)}{1-\langle\rho(M)\rangle S}\left[\rho_c(M)e^{-\tau/\mu_v} + \langle\rho(M)\rangle t_d(\theta_v)\right]\right\} \tag{4}$$

The description of these parameters can be acquired from 6s manual.6s radiative transfer code takes into account the main atmospheric effects, gaseous absorption by H_2O, O_2, CO_2 and O_3, scattering by molecules and aerosols and a ground surface. The aerosol data needed during atmospheric correction come from MODIS04 product. Landsat ETM+ 3rd and 4th band were correction in order to derive NDVI.The selected aerosol model was continental model and the atmosphere optical depth required in 6s radiative transfer code came from MODIS aerosol product. Midlatitude summer was adopted as the atmospheric profile.

D. Derivation of Land Surface Temperature and NDVI

After calibration and atmospheric correction, the radiance and reflectivity can represent the actual properties of the surface. Here, these data can be utilized to derive the surface information. Landsat ETM+ thermal infrared imagery can be converted from spectral radiance to brightness temperature (blackbody temperature) using the Landsat specific estimate of the Planck curve under an assumption of unity emissivity [18]

$$T_\lambda = \frac{K_2}{\ln(\frac{K_1}{L_\lambda}+1)} \tag{5}$$

where T_λ is the temperature in Kelvin (K), K_1 is the pre-launch calibration constant 1 in W/ (m^2 sr μm) and K_2 is the pre-launch calibration constant 2 in Kelvin. For Landsat 7ETM+ data, K_1=666.09 W/ (m^2 sr μm) and K_2=1282.71 K.

Note that T_λ is actual temperature of the surface because L_T has been corrected for spectral emissivity of different land cover, but the temperature is only skin temperature (about the depth of 50um). And subpixel temperature is not considered, however the temperature calculated is only the average temperature of mixed pixel.

In order to analyze the relationship between urban heat island and surface characteristics, the urban vegetation cover information was extracted from ETM+ data. Though many vegetation indices including NDVI, RVI, SAVI, DVI, MSAVI have be developed to represent vegetation cover, the normalized different vegetation index (NDVI) from red band and near infrared was adopted in this study. NDVI has been used extensively since developed .It is the best indicator of vegetation cover degree .It is written as follows

$$NDVI = \frac{R_{NIR} - R_{\mathrm{Re}d}}{R_{NIR} + R_{\mathrm{Re}d}} \tag{6}$$

Where R_{NIR} and $R_{\mathrm{Re}d}$ are the spectral reflectance in the ETM+ near-infrared band and red band.

The range of NDVI is -1 to 1.The positive values indicate vegetation areas and bare soil, while the negative values indicate non-vegetation surface such as water, snow and cloud.

III. RESULT AND DISCUSSION

A. The Distibution of Land Surface Temperature

Fig.2 shows the distribution of land surface temperature in Shenyang. The range of temperature is 294-312K.It is very obvious that the urban temperature is higher than suburban area and rural area. The higher regions include urban areas, road, and residential district. The highest temperature located in central district of Shenyang. The hot spots also occurred in

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the suburban area because these areas are the county seat where many manufactories and large population located. The areas with the lowest temperature mainly include water and forest. The general principle is that the temperature gradually lowers from the city center to suburban or rural areas except water. Certainly there are several plots where the temperature is low, for example Shenyang Imperial Palace. Based on statistics, the average temperature of the whole study area is 298.67k, while the average temperature of urban area is 303.4K and the average temperature of rural area is 298.08.The difference between urban area and rural area is 5K, so the urban heat island effect is obvious in Shenyang city.

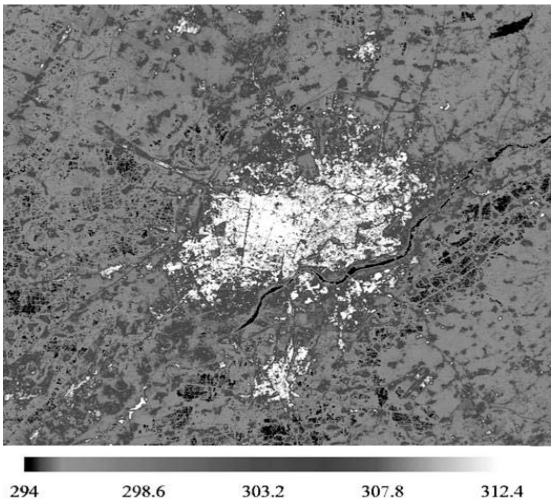

Figure 2 Distribution of land surface temperature

B NDVI

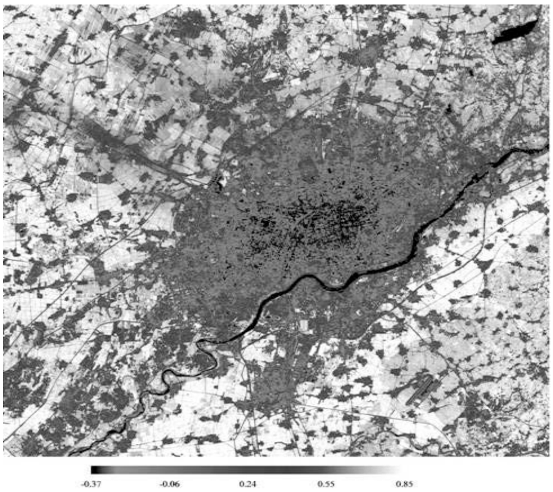

Figure 3 NDVI of the study area

NDVI can reflect the amount and the nature of vegetation cover .In this study the NDVI was derived based on Landsat ETM+ data. Figure shows the distribution of NDVI in Shenyang city. The range of NDVI is -0.37 to 0.85. Except of water, the lowest value located in central district, and the highest value located on the east and south of Shenyang where the vegetation is the densest. In general the object with NDVI between 0 and 0.15 is identified as building or bare soil. But due to the influence of vegetation in urban areas, the NDVI of building is 0 to 0.2.In central district there are some plots, mainly parks, where the NDVI is high.

C. Relation between Land Surface Temperature and NDVI

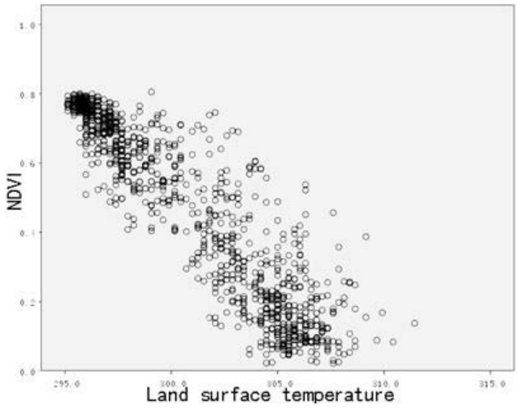

Figure 4 Scattering plot

According to Fig.2 and Fig.3, there is a phenomenon found. The urban areas where the NDVI is lower have higher land surface temperature, while suburban or rural areas where NDVI is higher have lower land surface temperature. In order to study the correlation between them, 927 points were randomly sampled to determine the correlation in this study. Based on these points, scattering plot between land surface temperature and NDVI was plotted (Figure 4). According to the relation derived form scattering plot, It can be supposed that there is a negative linear relation between NDVI and land surface temperature (water excepted).Whether the relation can be depicted with a function? After statistical analysis, the relation can be represented using the function:

$$y = -0.056x + 17.413 \quad (7)$$

Where y is NDVI value, x is land surface temperature. The correlation coefficient is -0.906, which is rather high. So the supposition can be accepted.

In the urban areas, the vegetation is little and the land surface temperature is high while it is contrary in rural areas. Urban heat island is obvious in Shenyang. According to the result, the amount of vegetation can affect land surface temperature. The reason may be the ecological function of vegetation in cooling down the surface from high evapotranspiration. To reduce urban heat island effect, increasing the vegetation cover can be a very good method for Shenyang city. In fact there are many factors affecting land surface temperature, the vegetation is only one of factors influencing land surface temperature. The vegetation abundance can not determine the land surface temperature. So the function may be unuseful when utilized to other city. Especially there is a contrary phenomenon on the boundary between Egypt and Israel. The temperature of bare soil is lower than vegetation areas. Thus the vegetation cover is not

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a dominant factor. There must be more important influencing factors determining the land surface temperature.

IV. CONCLUSIONS

Urban heat island has been a well-known problem .In order to reduce the effect it is very important to find influential factors. Vegetation abundance is one of the most influential factors to control land surface temperature through partitioning solar radiation into fluxes of sensible and latent heat .Based on Landsat ETM+ thermal infrared data, this study investigated the relation between land surface temperature and vegetation cover. In this study NDVI was adopted to as an indicator of vegetation cover or abundance .Using ETM+ data the land surface temperature and NDVI were derived. And the relation between them was constructed. Result shows that land surface temperature of urban areas in Shenyang city is greater than the temperature of suburban and rural areas, which indicates the urban heat island effect is very important. And there is a negative correlation between land surface temperature and NDVI. The higher NDVI is, the lower the land surface temperature is .This may give us some illumination. To resolve the problem of urban heat island, it may be a good method to increase vegetation cover. But it is very difficult to implement the method. The city with dense population, a large quantity of factories and business has little land to increase vegetation. Nonetheless, this is also a useful try, which can help administrators realize the problem and the solution method when planning the city construction. But the relation may be only useful to Shenyang city. Urban heat island is very complex problem .To other cities, the relation can change.

Generally using remotely sensed data to derive land surface temperature is a good study method in large scale. But there are some limitations .Land surface temperature is affected by many factors including emissivity, atmospheric effect, landscape characteristics and stage. In this study the emissivity is considered, however, it is only simply grouped into vegetation, water and building, which is not enough. And the 0.01error of emissivity estimated will lead to 1K error of temperature. The resolution of Landsat ETM+ thermal infrared data is 60meter.Mixed pixel including several objects which have different emissivity and temperature is also a disturbed factor. So land surface temperature derived from remotely sensed data is uncertain. Meanwhile NDVI is influenced by many factors including the plant leaf, soil background, and differences in row direction and spacing in the case of agricultural crops [19].Sometimes it can not reflect the vegetation cover information well and truly.Future research is needed to consider more factors and reduce the uncertainty. Moreover the impact of each element to land surface temperature should be researched

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