Application of Thermal Remote Sensing in Study on Surface Temperature Distribution of Ho Chi Minh City

Tran Thi VAN, Le Van TRUNG, Hoang Thai LAN, Vietnam

Key words: land surface emissivity, land surface temperature, NDVI, surface heat island, thermal remote sensing

SUMMARY

Land surface temperature (LST) is an important factor for a wide variety of applications such as: hydrological, agricultural, biogeochemical and climate change,... LST is strongly influenced by the ability of the surface emission. Therefore, calculating LST with the high accuracy has been one of the biggest preoccupations of scientists. Thermal infrared remote sensing potentially measures the earth surface radiation for retrieving surface temperature values in the whole study area by pixel. The paper presents the results of study on methodology to determinate the surface temperature of urban areas in Ho Chi Minh City considered surface emissivity factor from NDVI method. The experiment was carried out on Landsat and Aster satellite images that are suitable for studies on heat processes in urban areas. The results showed that the average bias of LST calculation is about 2oC in compared with the in-situ measurements. It presented the advantage of the new technology in comparison with the traditional measurement method from the meteorological observation stations.

Application of Thermal Remote Sensing in Study on Surface Temperature Distribution of Ho Chi Minh City

Tran Thi VAN, Le Van TRUNG, Hoang Thai LAN, Vietnam

1. INTRODUCTION

In the electro-magnetic wavelength region of 3-35µm, called thermal-infrared region in terrestrial remote sensing, radiation emitted by the earth due to its thermal state are far more intense than the solar reflected radiation. Of this range, the useful spectral bands are limited by the intensity of radiation emitted and the atmospheric windows. An excellent atmospheric window lies between 8 and 14µm., in which most remote sensors set up to detect the thermal radiative properties of the ground materials (Gupta, 1991).

In thermal remote sensing, radiations emitted by the ground objects are measured for temperature estimation. Past studies of land surface temperatures and thermal remote sensing of urban areas have been conducted primarily by using NOAA AVHRR data (Gallo, 1998; Roth et al., 1993; Streutker, 2002). However, for all of these studies, the 1.1km spatial resolution of AVHRR data was found suitable only for macro-scale urban temperature mapping, not for establishing accurate and meaningful relationships between image-derived values and those measured on the ground. Medium resolution thermal infrared imagery, such as from Landsat TM/ETM+, Aster have been extensively employed to study intra-urban temperature variations and to related them to surface cover characteristics (Weng et al., 2006).

Land surface temperature (LST) is a good indicator of energy balance at the Earth's surface. Due to the earth surface heterogeneity LST estimation is much more complicated. Apart from the attenuation in the transmitted radiance caused by the atmosphere, the problem is also complicated by the highly variable land surface emissivity (LSE). But in the case of land surface, the emissivity dynamics has a wider range and can vary over short distances. Moreover, a proper LST validation is also difficult because the derived LST is representative for the whole pixel, while point temperature measurements can vary over short distances. Hence, a field validation is possible only for homogeneous areas such as dense vegetation (Dash et al., 2002). The main problem is that it is not possible to obtain separately the temperature and the emissivity from passive radiometry, because the number of unknowns is always larger than the number of measurements (Becker, 1980). For the case of a sensor with N spectral channels, we have N equations (one per channel) for solving a problem with N + 1 unknowns (the N emissivities plus the surface temperature). Thus the system of equations is indeterminate, and we always need some hypothesis to solve the problem (Valor et al., 1996).

Some approaches that try to solve the N+1 unknowns problem have been proposed. However, as LSE is less variable in space and time than LST, it is reasonable to estimate LSE first and then calculate LST. Most of these approaches calculate the LSE from the thermal infrared bands (TIR) such as normalized-emissivity (NOR) method (Gillespie, 1985), the spectral-ratio method (Watson, 1992), the temperature-emissivity separation (TES) method (Gillespie et al., 1998) or the temperature independent thermal infrared spectral indices (TISI) method (Becker et al., 1990). Therefore the calculated LST will have the same TIR band resolution that is usually coarser than visible and infrared bands. The NDVI method (Van de Griend, 1993; Valor et al., 1996) will improve the spatial resolution of calculated emissivity and temperature by resolution of the visible and infrared bands.

This paper presents the results of study of method to determine LST in urban level corrected by surface emissivity with simple calculation procedure, enable to apply for any satellite images independent on the number of thermal bands and improve the spatial resolution of the final result maps. In addition, the study results were verified with the in-situ observed LST measures for accuracy assessment. Landsat and Aster images were used in this study.

2. METHOD

2.1. Method of Determining LST

Satellite thermal infrared sensors measure radiances at the top of the atmosphere, from which brightness temperatures T_B (also known as blackbody temperatures) can be derived by using Plank's law (Markham et al., 1986):

$$T_B = \left(\frac{hc}{k\lambda}\right)\left(\frac{1}{\ln\left(\left(2hc^2\lambda^{-5}\right)/B_\lambda + 1\right)}\right) \tag{1}$$

Where h is Planck's constant (6.62×10^{-34} J-sec), c – velocity of light (2.998×10^{8} m sec^{-1}), λ – wavelength of emitted radiance (m), B_λ – blackbody radiance (Wm^{-2} μm^{-1}).

With the known LSE, the emissivity-corrected LST (T_S) can be calculated by the Stefan Boltzmann law (Gupta, 1991):

$$B = \varepsilon\sigma T_S^{\;4} = \sigma T_B^{\;4} \tag{2}$$

Therefore,

$$T_S = \frac{1}{\varepsilon^{1/4}} T_B \tag{3}$$

where σ is the Stefan Boltzmann constant (5.67×10^{-8} Wm^{-2} K^{-4}), B – total amount of radiation emitted (Wm^{2-}), T_S – surface temperature (K), T_B – brightness temperature (K), ε – land surface emissivity varied between 0 and 1.

In order to determine an actual surface temperature it is necessary to carry out atmospheric correction and know the emissivity of the surface land cover. Atmospheric correction is necessary for bands which are to take part in determining the LST. In the first, DN value in those bands should be converted to reflectance value for visible (VIS) and near infrared (NIR) data and radiance value for TIR data at satellite sensor. After that to carry out the conversion them to the surface value with the suitable method: dark object subtract (DOS) is applied for VIS and NIR data, In-Scene Atmospheric Compensation (ISAC) algorithm for TIR data.

2.2. NDVI method for emissivity correction

Pixels representing the land surface are usually mixed pixels of surfaces-types such as vegetation and soil. The effective emissivity of a pixel can be estimated by summing up the contributions from its surface-types. Van de Griend and Owe (1993) found a high correlation between measured emissivity and NDVI, which measured from visible and near-infrared spectral reflectance. They gave the following relation:

$$\varepsilon = 1.0094 + 0.047*\ln(\mathrm{NDVI}) \qquad (4)$$

But this is only valid for areas with a large patches covered by vegetation or soil. Valor and Caselles (1996) proposed an operational model of determining the effective emissivity that is applicable to areas with several soil and vegetation types and changing vegetation cover:

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s (1 - P_v) \qquad (5)$$

where ε_v, ε_s are the emissivity of the full vegetation and bare soil, and P_v is the vegetation cover fraction. ε_v, ε_s can be obtained from the formula (4) where the patches of vegetation and soil are selected so that they are a lot bigger than a pixel. P_v is derived according to Carlson and Ripley (1997), from:

$$P_v = \left(\frac{\mathrm{NDVI} - \mathrm{NDVI}_s}{\mathrm{NDVI}_v - \mathrm{NDVI}_s} \right)^2 \qquad (6)$$

The scheme to determinate thermal remote sensing LST is described in Figure 1.

3. STUDY AREA AND DATA SETS

3.1. Study area

Ho Chi Minh City is located in the South of Vietnam and has a diversified landscape from the northern to the southern part. The urban areas are mainly concentrated in the centre of the city. The northern part is agricultural land; the southern one is low-lying land with dense mangrove forests. Population density has increased from 552 persons/km^2 in 1985 to 3067 persons/km^2 in 2006 (in urban areas about 10 905 persons/km^2, in rural areas about 648 persons/km^2). Population growth has caused urban encroachment into the adjacent agricultural and rural regions, especially in the northern part of the city due to the advantages of the landscape and relative high topography (Figure 2).

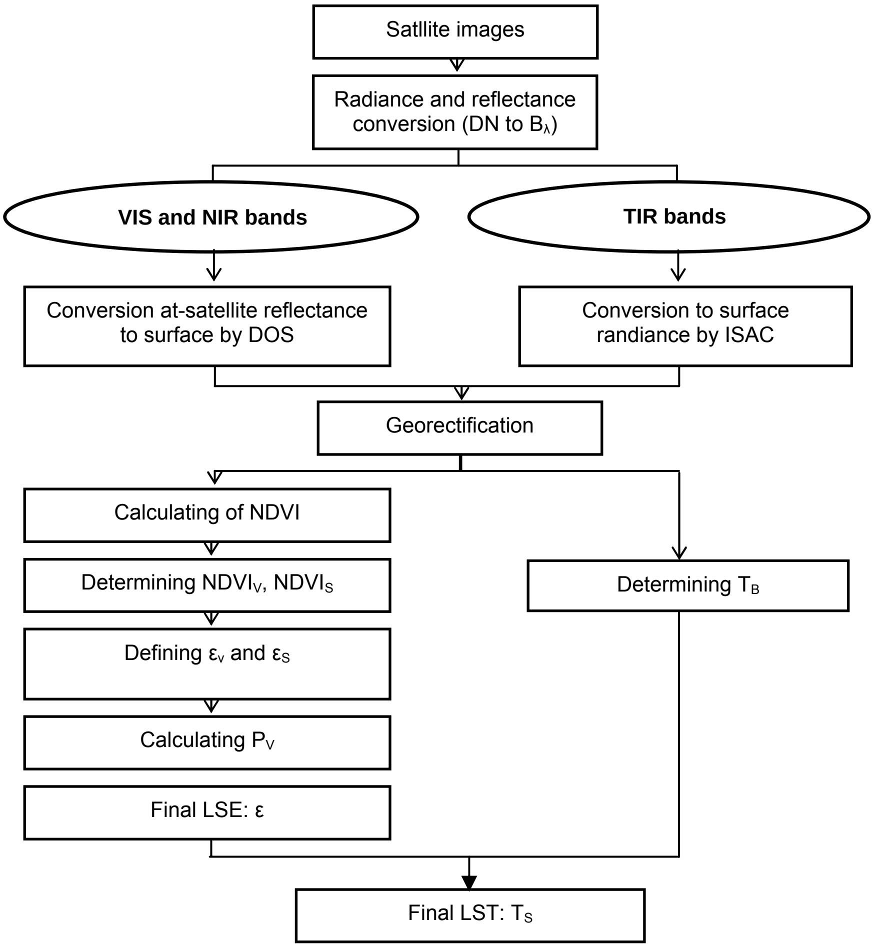


Figure 1. The scheme to determinate thermal remote sensing LST

Figure 2 The study area - Ho Chi Minh City

3.2. Data sets

Landsat Thematic Mapper (TM) and Aster images were used in this research. Landsat ETM image have eight bands, included six reflective bands in visible, near- and mid-infrared spectral regions with 30-m pixel size, one panchromatic band with 15-m pixel size, and 1 thermal infrared band with 60-m pixel size in spectral regions of 10.4-12.5µm, acquired on 16 February, 2002. Aster image acquired on 25 December, 2006 has 14 bands with different spatial resolutions: three visible-near-infrared bands with 15-m pixel size, six shortwave infrared bands with 30-m pixel size, and five thermal infrared bands with 90-m pixel size in spectral region of 8.125-11.65µm, in which bands 13 and 14 have spectral regions 10.25-11.65µm.

Aster image was obtained in 1B level, where the radiometric calibration and geometric resampling were carried out. It has radiance value in $Wm^{-2}\mu m^{-1}$. Landsat ETM had digital number value in all 8 bands ranging in 0-255. In image pre-processing stage, it is necessary to convert digital number value to radiance for Landsat ETM data. The 2006 Aster image was then georeferenced in Universal Tranverse Mercator projection based on the topographical map with root mean square (RMS) error less than 0.5 pixel. All Aster bands were resampled at 15m. An image-to-image registration was conducted between the Aster image and the ETM images in order to keep registration errors to less than a pixel. The 15-m resampled interval was carried out for all bands of the ETM image.

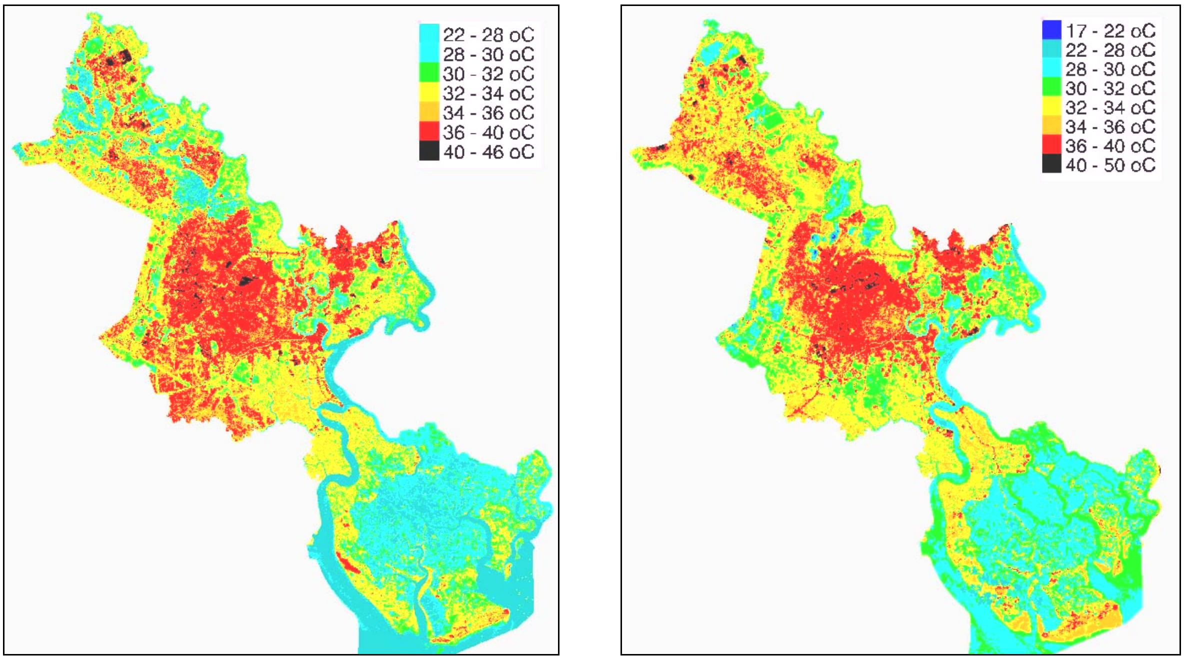
4. EXPERIMENT AND RESULTS

Because approximately 80% of the energy thermal sensors received in the 10.4–12.5µm wavelength region is emitted by the land surface (Czajkowski *et al*., 2004), maximum LST is usually obtained in this region (French *et al*., 2008). Landsat ETM with one thermal band 6 in the atmosphere window of 10.4–12.5µm was used for deriving the LST. Aster has five thermal bands from 10 to 14 in the window 8.125–11.25µm, but two bands 13 and 14 with the same window as that from Landsat, so they were used for calculating LST. The maximum of those 2 temperatures is considered to be the land surface temperature (Li et al., 1999). The remote sensing results gave the spatial distribution of LST for the whole study area.

4.1. Distribution of LST

From the above NDVI method procedure, $NDVI_s$ and $NDVI_v$ defined on bare land and full vegetation patches for 2002-Landsat data were 0.107 and 0.676 correlative to $\varepsilon_s = 0.904$ and $\varepsilon_v = 0.991$, for 2006-Aster data were 0.106 and 0.725, correlative to $\varepsilon_s = 0{,}904$ and $\varepsilon_v = 0{,}994$. The LSE is related to the land cover state, therefore, the results have shown that the vegetation areas had the LSE higher than 0.92, particularly the fully vegetated areas LSE was above 0.95. They were found in forest, agricultural land or green park. In the urban areas, built-up land and bare land LSE were lowest in 0.90-0.91. Water on river and lake had LSE in range of 0.91 and 0.92 depending on the vegetation content.

The LST was determinated from the LSE and brightness temperature. The retrieved LST maps show the picture of LST distribution in an area. The maps in Figure 3 were produced to show the spatial distribution of emissivity-corrected LST in 2002 and 2006. The statistics of LST in Table 1 indicate that maximum temperatures are 45.9°C in 2002 and 49.4°C in 2006, mean values are 31°C in 2002 and 33.3°C in 2006. These are only instantaneous results at the time of image acquisition. But if it is considered that the 2006 image was recorded in the cool period of December, the 2002 image in the hot period of February, it is reasonable to infer that the temperature had increased over time.



a) Landsat 13-02-2002 b) ASTER 25-12-2006

Figure 3. Distribution of LST in 2 types of images Landsat and Aster

The digital remote sensing method provides not only a measure of the magnitude of surface temperatures for the entire city area, but also the spatial extent of the surface heat island (SHI) effects. The SHI was found in some hot spots of the entire study area. In the LST map, the most extensive hot spot was found in the centre of HCM city where the urban area is located. A second SHI was developed in the north of the city in Cu Chi district. The third one was found in Thu Duc district of the eastern part. The highest LSTs (greater than 45°C) were found in the industrial zones, where high temperatures were caused by production activities as well as solar radiance. The urban areas have experienced maximum temperatures ranging between within 36°C and 40°C. In addition, wind circulation in urban areas is limited by the building geometry. So, with these temperatures, human bodies experience discomfort and require air cooling. More air conditioners are used, more heat is released and temperatures increased further. On the contrary, in suburban and rural areas where forest and agricultural land still remain with full vegetation cover, the LSTs are usually lower. They found in Can Gio district in south of the city with mangrove forest and in Cu Chi district in northern part of the city, where are the agricultural land and rubber tree plantation. In the 2002-LST map compared with the 2006-LST one, the fourth SHI was detected in the west-south of the central urban area, located in the Binh Chanh district. This area is covered by agricultural land, so hot spot was existed here in the bare land after crop. From this distribution of the LST value, we obviously get the idea that the distribution of LST and land cover has spatial relationship by the thermal properties of the surface objects. Finally, the LST product derived from the thermal remote sensing data will be useful for detecting land cover as well as for evaluating change detection in researching urbanization through the impervious surfaces.

Table 1. LST statistics from satellite images (^oC)

Satellite image	Min	Max	Mean	Stdev
Landsat data in 13 Feb 2002	23.2	45.9	31.0	2.4
Aster data in 25 Dec 2006	17.4	49.4	33.3	2.8

4.2. Accuracy assessment

To check the accuracy of the satellite LST retrieval results, 10 observation points were set up and daily surface temperatures were measured in December, 2006. Measurements were carried out at 10:30 a.m. when the Terra/Aster satellite passed over the area. Therefore, the Aster image LST value was used to compare with these *in-situ* measurements at the 10 observation points. For closer conclusion we also carried out the calculate the LST from other methods on the same 2006-Aster image. Two methods were as following:

(1) calculating the LST with NOR method (Li et al., 1999) that the LSE value was selected by maximum value of LSE of the NDVI method and was considered as a constant
(2) calculating the LST from the method of Artis and Carnahan (1982) with the LSE of the NDVI method

In addition, we obtained the AST08 product, which is the LST images retrieved from the TES method particularly for only Aster data (Gillespie et al., 1998).

In order to assess the accuracy of the methods, the mean difference between the values estimated with each method and the ones measured in-situ 10-established points. The value are shown in Table 2. It showed that the bias of NDVI-method estimated values and *in-situ* measurements was less than 2^oC. The bias from AST08 product derived from TES method gave the best results with value less than 1^oC. Other methods had the bias higher than of the NDVI one.

Table 2. Comparison between LST estimated from different methods

Method	Bias (^oC)
TES – AST08	0.81
NDVI method	1.95
Method of Artis and Carnahan	2.01
NOR	6.83
uncorrected ε (T_B)	7.24

There is one thing need to be considered that although the estimated LST from TES method has the lowest error, but this result is quantified on the field of view (FOV) 90mx90m for Aster TIR images. Meanwhile, NDVI method uses properties of the reflectance bands with a higher spatial resolution for VIS and NIR (15-30m) than TIR bands (60-90m), so higher the spatial resolution emissivity map can be obtained. In this case, LSE map has the spatial resolution 15m for Aster data and 30m for Landsat data. The spatial resolution of the final LST map will be the same as the LSE one. Concurrently, TES method has the complicated algorithm and requires the input data fully corrected by atmospheric effects. This is difficult to realize. The NDVI method can be applied even to sensors with only one thermal band, provided that these sensors have red and near infrared bands, whereas TES method needs at least four thermal bands. Finally, the TES method was developed for only the Aster data. As a results, the method to retrieve the LST from this research will be the optimal solution.

5. CONCLUSION

In this paper we applied thermal remote sensing to study the LST distribution in Ho Chi Minh City. Distribution picture of LST of HCM City has shown that the LST gradient pulled from the central urban areas to the rural one related to the land cover, formed the SHI on the city.

We reviewed the NDVI method for estimating the emissivity-corrected LST checked errors by the field in-situ observation established points to show the optimality of the method. The results have shown that the bias of estimated value compared with the field in-situ measured one less than 2^{o}C. This has simple calculation procedure, enable to apply for any satellite images independent on the number of thermal bands and improve the spatial resolution of the final result maps.

LST measurements from the meteorological stations have the higher temporal resolution, but are recorded at only a few sites from sparse stations. Therefore, they cannot tell us the temperature for all required locations. The digital remote sensing method can provide these data. The retrieved LST maps show the picture of LST distribution in an area. The in-situ measured LST from each point definitely is different to remote sensing estimated one. However, we can not to measure the LST of each object in the whole area in reality, because it requires a vast human labor with very high field survey cost and needs a lot of measured instruments. In addition, one can not to increase the dense of the meteorological stations because of the high establishment cost. Therefore, the remote sensing solution in estimating the LST will be preferred.

REFERENCES

Artis, D.A. and Carnahan, W.H. (1982), Survey of emissivity variability in thermography of urban areas, *Remote Sensing of Environment*, *12*, 313-329

Becker, F. (1980), In *Remote sensing application in agricultural and hydrology* (G. Fraysse, Ed.), Balkema.

Becker, F. and Li, Z.L. (1990), Temperature-independent spectral indices in thermal infrared bands, *Remote Sensing of Environment, 32,* 17-33

Carlson, T.N. and Ripley, D.A. (1997), On the relation between NDVI, fractional vegetation cover and leaf area index, *Remote Sensing of Environment, 62*, 241-252

Czajkowski, K.P., Goward, S.N., Mulhern, T, Goetz, S.J., Walz, A., Shirey, D., Stadler, S., Prince, S.D. and Dubayah, R.O. (2004), Estimating environmental variables using thermal remote sensing, in *Thermal Remote Sensing in Land Surface Processes,* CRC Press

Dash, P., Göttsche, F.-M., Olesen, F.-S., Fischer, H. (2002), Land surface temperature and emissivity estimation from passive sensor data: theory and practice-current trends, *International Journal of Remote Sensing, 23*, 2563-2594

French, A.N., Schmugge, T.J., Ritchie, J.C., Hsu, A., Jacob, F. and Ogawa, K. (2007), Detecting land cover change at the Jornada Experimental Range, New Mexico with ASTER emissivities, *Remote Sensing of Environment*, doi: 10.1016/j.rse.2007.08.020 (in press)

ITT Visual Information Solutions (2004), *ENVI user's guide*

Gallo, K.P. and Owen, T.W. (1998), Assessment of urban heat island: A multi-sensor perspective for the Dallas-Ft, Worth, USA region, *Geocarto International, 13(4)*, 35-41

Gillespie, A.R. (1985), Lithologic mapping of silicate rocks using TIMS, Proceedings TIMS Data User's Workshop, *(JPL Pub. 86-38, Jet Propulsion Laboratory, Pasadena, CA)*, 29-44

Gillespie, A. R., Rokugawa, S., Hook, S., Matsunaga, T., & Kahle, A. B. (1998), A temperature and emissivity separation algorithm for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images. *IEEE Transactions on Geoscience and Remote Sensing, 36,* 1113−1126

Gillespie, A.R., Rokugawa, S., Hook, S.J., Matsunaga, T. and Kahle, A. (1999), *Temperature / Emissivity separation algorithm theoretical basis document, version 2.4*, ATBD-AST-05-08, Prepared under NASA contract NAS5-31372

Gupta, R.P. (1991), *Remote Sensing Geology*, Springer-Verlag Berlin Heidelberg, Germany

Li, Z.L., Becker, F., Stall, M.P. and Want, Z. (1999), Evaluation of Six Methods for Extracting Relative Emissivity Spectra from Thermal Infrared Images, *Remote Sensing of Environment, 69*, 197-214

Markham, B.L. and Barkewr, J.L. (1986), *Landsat MSS and TM Post Calibration Dynamic Ranges, Exoatmospheric Reflectance and at-satellite Temperatures.* EOSAT Landsat Technical Notes 1, 3–8.

Roth, M., Oke, T.R. and Emery, W.J. (1989), Satellite derived urban heat islands from three coastal cities and the utilization of such data in urban climatology, *International Journal of Remote Sensing, 10,* 1699-1720

Streutker, D.R. (2002), A remote sensing study of the urban heat island of Houston, Texas, *International Journal of Remote Sensing, 23(13),* 2595-2608.
Valor, E. and Caselles, V. (1996), Mapping Land Surface Emissivity from NDVI: Application to European, African, and South American Areas, *Remote Sensing of Environment*, *57*, 167-184
Van De Griend, A. A. and Owe, M. (1993), On the relationship between thermal emissivity and the normalized difference vegetation index for natural surfaces, *International Journal of Remote Sensing*, *14(6),* 1119 – 1131
Watson, K. (1992), Spectral ratio method for measuring emissivity, *Remote sensing of Environment, 42,* 113-116
Weng, Q. and Quattrochi, D.A. (2006), Thermal remote sensing of urban areas: An introduction to the special issue, *Remote Sensing of Environment, 104,* 119-122

CONTACTS

Mrs. Tran Thi Van
Institute for Environment and Resources, Vietnam National University Ho Chi Minh City
142 To Hien Thanh St., Dist. 10
Ho Chi Minh City
VIETNAM
Tel. +84.8.38651132
Fax + 84.8.38655670
Email: tranthivan@hcmier.edu.vn