Estimating Land Surface Temperature from Landsat-8 Images Based on a Cloud-Based Automated Processing Service

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Abstract. As the biggest city in Vietnam, Ho Chi Minh City (HCMC) usually suffers from a number of environmental issues such as traffic jam, subsidence and inundation, river and air pollution, high temperature, etc. Therefore, a hazard maps system helps the city government and population understand well environmental risks. The main data sources for such system is a combination of in-situ measurements in ground and remotely sensed images from space. Popular satellite data products available and free of charge are used to environmental monitoring, consisting of Sentinel, Landsat, and Terra/Aqua MODIS. In this paper, we focus on estimating land surface temperature (LST) from Landsat-8 images based on a cloud-based automated processing service. The LST image is computed from red, near-infrared and thermal infrared bands. The service can be integrated as a part of a hazard map system when its data are collected from different sources.

Keywords: Lansat · LST · Cloud-based service · HCMC

1 Introduction

During the 30 last years, urbanization significantly increases in major cities in Asia, e.g. Tokyo, Japan; Chongqing, China; Mumbai, India; Kuala Lumpur, Malaysia; Taipei, Taiwan; Singapore, Singapore; and Ho Chi Minh, Vietnam [1,2]. Most of the cities focus on large investments in urban infrastructure development such as water supply, electric supply, roads, railways, ports, and airports to promote their economic growth [2]. This causes shrinking green urban space, increasing imperious area, vehicle, the amount of waste, etc. and then, urban environment has been affected seriously, e.g. increased emission and noise, or polluted air and water resources. Therein, urban heat is one of negative

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impacts on human health. Thus, providing a state of land surface temperature (LST) in cities as a hazard map to their citizen is necessary.

Since the 1960s, remote sensing technique has been developed to observe natural resources and environment from space, e.g. GOES, NOAA, METEOSAT, TERRA, AQUA, Landsat satellite missions. These missions also provide basic data sources for an analysis of LST at global scales, e.g. AVHRR and MODIS images, and regional scales, e.g. TM and TIR images. Particularly, the TM, ETM and TIR sensors of the Landsat satellite program has provided continuously thermal images in the 10.5–12.5 µm wavelength bands with moderate spatial resolution since 1982 [3]. They are suitable for studying urban heat.

Ho Chi Minh City (HCMC) is the biggest city of Vietnam in a term of socioeconomic development. During the last three decades, urban expansion and industrialization have occurred significantly. These lead many issues of urban environment, and meanwhile an increase of LST in HCMC's urban area occurs. The city government would like to develop a hazard map system to provide environmental information to the citizen, e.g. temperature, water and air quality, as a website. The urban heat is one of indicators of the system where its input data is a combination of in-situ ground measurements and satellite images. At present, available satellite thermal images free of charge, consisting of MODIS and Landsat, are suitable for urban heat monitoring. Here this paper focus on exploiting Landsat-8 images to estimating LST as an indicator in the hazard map system in HCMC, where a cloud-based service is developed to automatically download and process Landsat data.

The rest of the paper is organized as follows. Section 2 introduces the study area, fundamental background of Landsat data as well as the approach to estimate LST and Emissivity used in the paper. We present our cloud-based service for automatically download and process data in Sect. 3. The experimental results used to validate the approach are shown in Section 4. Finally, Sect. 5 concludes our paper.

2 Study Area and Method

In this section, we present our study area as well as the remote sensing image source which are used for our service. We also discuss the method used to estimate the LST of HCMC.

2.1 Study Area

HCMC is one of densely urban areas of Vietnam, occupying the total area of approximately 2,095.01 km^2 and the population of about 8.6 million people. It includes 19 urban and 5 rural districts, enclosed by Binh Duong in the north, Tay Ninh in the north-west, Dong Nai in the east, Ba Ria - Vung Tau in the south-east, Tien Giang in the south-west and Long An in the west, as described in Fig. 1 [4]. This region has a tropical climate with two wet and dry seasons.

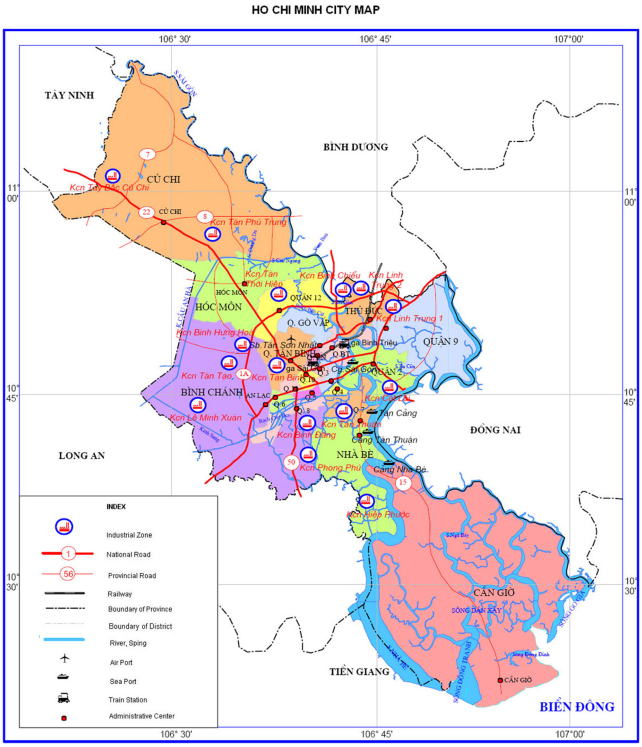

Fig. 1. The administrative map of Ho Chi Minh City, Vietnam

The rainy or wet season from May to November, with a precipitation of approximately 159 rainy days per year while the sunny or dry season from December to consecutive April, with a sunshine of average 2,490 h per year. The average humidity is 75% and the average temperature is 28 0C with little variation throughout the year [4].

2.2 Landsat Images

Landsat-8 is the latest satellite of the Landsat program of the National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS), launched in February, 11th 2013. The key mission of this satellite program is to collect multispectral imagery in medium spatial resolution, thereby distributing for public users to bring benefits for many sectors such as agriculture, science, government and so much more [5]. The Landsat-8 data is acquired from two sensors, including The Operational Land Imager (OLI) providing 9 visible, near infrared, and shortwave-infrared band images with 30-m spatial solution, and the Thermal Infrared Sensor (TIRS) providing 2 thermal band images with 100-m spatial resolution. The temporal resolution is 16 days.

Landsat-8 datasets are available and free of charge in the USGS Earth Explorer website [6].

In this study, to cover the whole HCMC, we need to collect three censes at the Path-Row locations of 125-052, 125-053, and 124-053. The two scenes in Path 125 are captured nearly while the scene in the Path 124 is captured before 4 days from the path 125. Figure 2 shows the locations of three Landsat scenes and the composite color image in HCMC after atmospheric calibration and mosaicking.

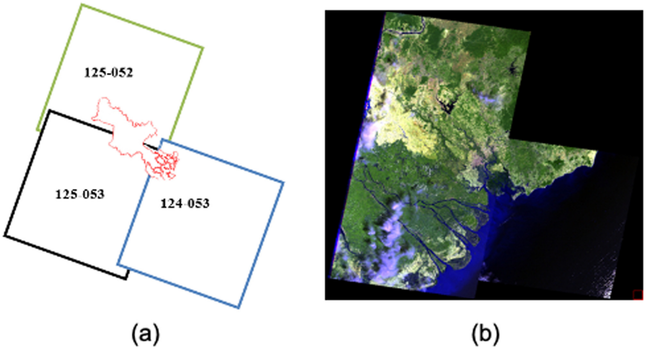

Fig. 2. (a) The locations of three Landsat scenes to cover the whole HCMC, and (b) the composite color image after mosaicking three Landsat scenes

2.3 Derivation of LST from Landsat Images

The derivation of LST requires main steps as described in Fig. 3, where LST is determined from TIR band-10 and OLI band-4, 5 band images. The steps of Landsat-8 image processing referred to the Landsat-8 data users handbook [8].

Processing Landsat-8 TIRS Images. *At Sensor Radiance:* Convert the Digital Number (DN) to Top-of-Atmospheric (ToA) Spectral Radiance. Typically, the standard product pixel values of Landsat-8 data are represented in 16-bit unsigned integer format, which is range from 0 and 65536. We need to convert those value to the ToA Spectral Radiance and/or Reflectance to quantize and calibrate for high-accuracy in processing. The Landsat-8 product metadata file (MTL) provides a bunch of parameters and coefficients used for describing band images. In this process, we leverage the radiometric rescaling coefficients to convert the DN values to ToA Spectral Radiance, as described in Eq. 1.

$$L_\lambda = M_L \times Q_{cal} + A_L \tag{1}$$

where, L_λ is the ToA Spectral Radiance in W/m^2 srad μm, Q_{cal} is the DN value of Band 10 or Band 11 Image, M_L is the Band-specific multiplicative rescaling

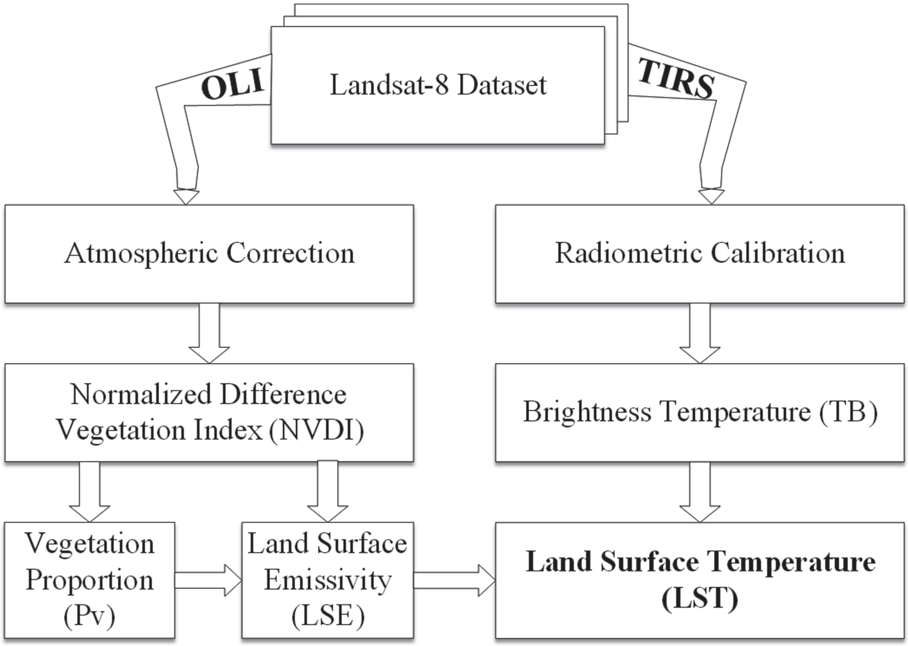

Fig. 3. Land surface temperature

factor from MTL, and A_L is the Band-specific additive rescaling factor from MTL.
Brightness Temperature: Convert the ToA Spectral Radiance to Brightness Temperature. Once having the ToA Spectral Radiance for TIRS band data, we can conduct the ToA Brightness Temperature by using Eq. 2.

$$T_B = \frac{K2}{ln(\frac{K1}{L_\lambda + 1})} \quad (2)$$

where, T is the ToA Brightness Temperature in Kelvin, K_1 and K_2 are the Thermal Conversion Constant and 2 from MTL.

Then, to convert from Kelvin unit to Celsius unit, we apply the following equation (Eq. 3).

$$T_B {}^\circ C = T_B - 273 \quad (3)$$

Processing Landsat-8 OLIRS Images. *Land Surface Reflectance:* Convert the DN values to ToA Spectral Reflectance and ToA Spectral Reflectance with the sun angle correction, and then apply the MODTRAN atmospheric calibration module to receive Spectral Reflectance in land surface. We convert the DN values to ToA Spectral Reflectance, using Eq. 4.

$$\rho'_\lambda = M_\rho \times Q_{cal} + A_\rho \quad (4)$$

where, $\rho_{\lambda'}$ is ToA Spectral Reflectance; M_ρ is Band-specific multiplicative rescaling factor from MTL file; Q_{cal} is DN value of OLI Bands Image; and A_ρ is Band-specific additive rescaling factor from MTL file.

Then, the Eq. 5 is used to correct for the sun angle of ToA Reflectance:

$$\rho_\lambda = \frac{\rho_{\lambda'}}{cos(\theta_{SZ})} \tag{5}$$

where, ρ_λ is the ToA Spectral Reflectance with a correction for the sun angle, and θ_{SZ} is the local solar zenith angle from MTL.

Normalized Different Vegetation Index (NDVI): The value of NDVI is used to evaluate the density of vegetation on land surface by observing visible and near-infrared solar radiance reflectance. NDVI is calculated in Eq. 6.

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \tag{6}$$

where, ρ_{NIR} and ρ_{RED} are the Land Surface Reflectance of the Near-Infrared Band (Band 5) and the Visible Red Band (Band 4).

Vegetation Proportion (P_v): P_v is the fraction of vegetation in each pixel of satellite imagery, which is used to examine the role of vegetation in mixed land over. The Pv estimation is done by applying Eq. 7.

$$P_v = (\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}})^2 \tag{7}$$

where, $NDVI_{max} = 0.5$ and $NDVI_{min} = 0.2$ are the maximum (dense vegetation) and minimum (bare land) NDVI values, respectively [7].

Land Surface Emissivity (ϵ): Land surface emission ϵ is seen as the key factor in the process of retrieving land surface temperature, using Eq. 8 [7]. The land surface emission affects the accuracy of the LST estimation. The value ranges from 0 to 1 representing perfect reflector and perfect emitter, respectively. It means that the lower emission value is, the colder temperature the land surface has, and inversely the higher the emissivity, the more heat was emitted or absorbed.

$$\epsilon = \epsilon_v P_v + \epsilon_s(1 - P_v) \tag{8}$$

where, ϵ_v, and ϵ_s are the emissivity of homogenous pixels of vegetation and bare soil, respectively.

Determining Land Surface Temperature (LST): At final stage, the retrieval of LST value from Landsat-8 imagery is based on the following expression:

$$LST = \frac{T_B}{1 + (\frac{\lambda(T_B)}{\rho})ln\epsilon} \tag{9}$$

where, λ is the wavelength of emitted radiance, and $\rho = h \times c/\sigma$ while $\sigma = 1.38 \times 10^{23} J/K$ is the Stefan Boltzmann's constant; $h = 6.626 \times 10^{34} J.s$ is the Plank's constant; and $c = 2.998 \times 108 m/s$ is the speed of light.

As a result, Fig. 4 presents the NDVI and LST images, derived from Landsat-8 image captured on 19/01/2019.

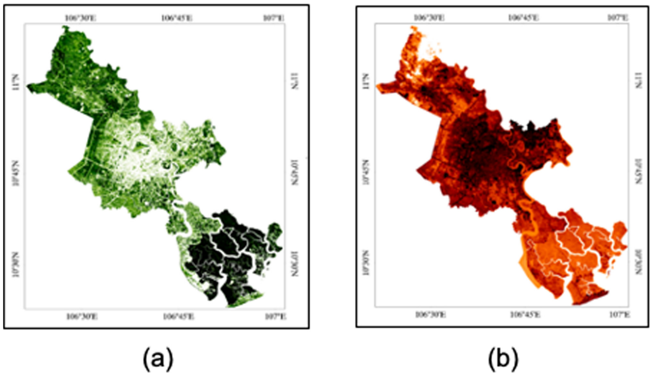

Fig. 4. (a) NDVI and (b) LST images derived from the Landsat-8 image, captured on 19/01/2019.

3 Cloud-Based Service for Estimating LST and Emissivity in HCMC

In this section, we present a cloud-based automated processing system for remote sensing satellites data. The innovative idea of our system is to apply state-of-the-art IT technologies to bring intuitive and visuality for monitoring environmental issues as aforementioned.

3.1 Overview of the Remote Image Processing Service

Figure 5 depicts an overview of our system, which composes of three main sides described as follows.

- *Satellite Imagery Providers:* provide remote sensing of Landsat-8 and MODIS data for the cloud server. Both of the data sources are freely available to find and download.
- *Image Processing Cloud Server:* provides the ability to automatically search and download up-to-date imagery data from providers in associated with fast and reliable data processing in retrieving LST, AOT
- *Client Applications*: provide user-friendly interfaces such as dashboard website or mobile applications with the integration with...from the cloud server.

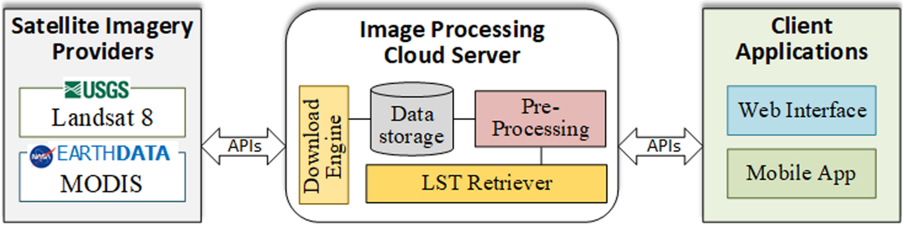

Fig. 5. Cloud-based automated processing system for satellites imagery

3.2 Design and Implementation

The key features of our processing system is to provide an automated mechanism for searching and bulk downloading up-to-date satellite data, and apply fast and reliable processing tasks to retrieve important factors that cause change in temperature of the Earth's surface. Our system is designed and implemented using Python programming language and a wide range of utilize libraries for handling satellite data. The workflow of main classes in the implementation is depicted as Fig. 6.

Download Engine: We design and implement a download engine to acquire images from Landsat-8 and MODIS satellites. The engine is responsible for finding the latest imagery sources, and download to a temporary storage in the cloud server if available. Typically, the Landsat-8 satellites captures the entire of Earth's surface once every two weeks, while MODIS does the same task every 1 to 2 days.

For processing purpose, we check the data source from providers instantaneously every 16 days to get up-to-date satellite images. We use the APIs provided by USGS's Earth Explorer [9] to work with Landsat-8 data, and leverage NASA EarthData Search APIs [10] to download MODIS land data products. All imagery will be converted into the GeoTiff, which is a popular format for satellite images.

Pre-Processing and LST Retriever: Once the Download Engine updates a new imagery, the LST Retriever will be acknowledged to process the data to derive land surface temperature. If the imagery is captured from Landsat-8, it has to be extracted into two type of bands (i.e. OLI and TIRS) to apply the Atmospheric Correction and Radiometric Calibration processes first. Those processes are encapsulated in a *MetadataReader* and *CalibrateLandsatBand* classes as shown in Fig. 6. Otherwise, if the server receives MODIS images, it will extract the LST values from Land Surface Temperature/Emissivity (MOD11) products.

The LST Retriever then calculate land surface temperature using the retrieval algorithm described in above sections. The results in this process will be packaged and provided for end-user applications which can be web interfaces or mobile applications.

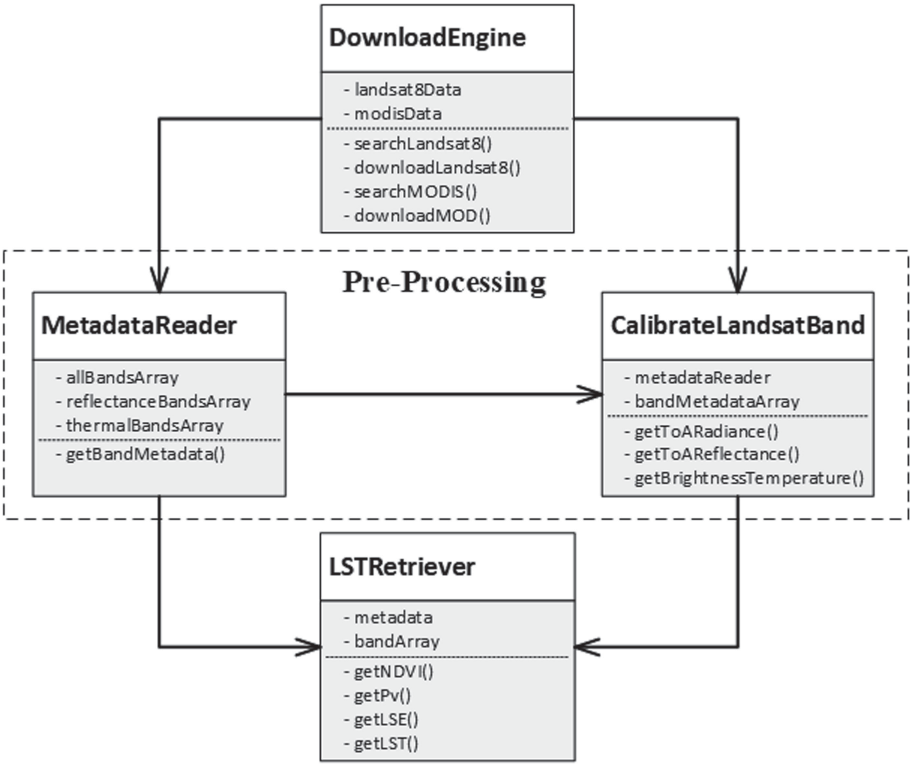

Fig. 6. The class diagram of image processing cloud server

4 Experimental Results

In this section, we present our experiments to estimate LST of HCMC. The LST measurements were performed with the 30 s interval in a range of approximately

Fig. 7. The samples A on the road and B on the grass

Table 1. The estimation of LST at the impermeable surface A and B the method in this paper

Date	Start	End	LST Landsat (^oC)	Surface
02 Oct., 2019	10:25	10:55	42.2	A
18 Oct., 2019	10:20	10:55	41.6	A
03 Nov., 2019	10:25	10:55	33.8	B
19 Nov., 2019	10:25	10:50	31.3	B

30 min, corresponding to the Landsat and Terra satellite acquisitions at local time 10.00 AM and 10.30 AM, respectively. In this case, the samples A and B are located at (106039′25.70″ N, 10046′19.70″ E) on the road and (106039′33.65″ N, 10046′21.55″ E) on the grass, as presented in Fig. 7. The comparison results of the two locations are shown in Table 1.

5 Conclusion

In this paper, we presented our approach to estimate the LST and Emissivity of Ho Chi Minh City using two data sources, Landsat and MODIS images. We developed a cloud-based service to automatically download and process data. The estimated values are compared to values collected a thermometer device. The comparison results show that the model we used provide good results. The service can be integrated into a hazard maps system where different sources of data can be collect to provide comprehensive information related to environmental issues in Ho Chi Minh City.

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