The use of remotely sensed data to estimate the heat island effect in the central part of Taiwan

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Abstract: It is our goal to obtain a better scientific understanding of how to define the nature and role of remotely sensed land surface parameters and energy fluxes in the heat island phenomena, and local and regional weather and climate. By using the TRMM (Tropical Rainfall Measuring Mission) visible and thermal imagery data and analyzing the surface energy flux images associated with the change of the landcover and land use in the study area, we present how significant is the magnitude of the heat island heat effect and its relation with the surface parameters and the energy fluxes in the Taichung area of Taiwan. We used the energy budget components such as net radiation, soil heat flux, sensible heat flux, and latent heat flux in the study area of interest derived form remotely sensed data to understand the island heat effect in Taichung. The results show that water is the most important component to decrease the temperature, and the more the consumed net radiation to latent heat, the lower the urban surface temperature.

Keywords: heat island, remote sensing, energy budget, evaporation, evapotranspiration

1. Introduction

Thousands of human lives were claimed by the heat wave in Europe in Summer 2003. The strength of the heat wave is manifested as the environment of the residential areas favors the heat island effect. Knowledge on the pattern and strength of the heat island effect is crucial to reduce, if not to prevent human beings from, the threat of the heat wave.

The heat island is usually produced and pronounced as the man-made structures and constructions are increased such as buildings and roads, primarily made of asphalt and concrete. The man-made structures and constructions change not only the landscape, but also the state of the land surface characteristics and energy balance by influencing the surface albedo, thermal capacity, heat conduction ..etc. In another word, the urban heat island effect may be examined through accessing the land surface characteristics and energy balance components.

In this paper, we present a direct method to analyze the magnitude of the heat island effect by examining the distributions of temperature and evapotranspiration in the study area. Three major steps are proceeded to achieve our goal: 1) retrieve the ground temperature, 2) estimate the vegetation index and the surface heat fluxes such as the sensible heat and latent heat fluxes, and 3) analyze the relationship between the ground temperature and those energy fluxes and parameters.

2. Satellite data and methodology

1) TRMM data

The VIRS channels of TRMM data were used to estimate the energy fluxes, and the channels 1, 2, and 4 were used to retrieve the energy components. The time of this study is at 9:00 a.m. (local time) July 10, 2003.

Table 1. VIRS Channels of TRMM

Channel	Spectral Region	Wavelength (μm)
1	Visible (R)	0.63
2	Near Infrared (NIR)	1.60
3	Near Infrared	3.75
4	Infrared	10.8
5	Infrared	12.0
Spatial Resolution：2.4 km		
Swath Width ：833 km		
Pixels/Scan：261		

2) Methodology

The methodology is based on the Simplified Surface Energy Balance Index model to retrieve the surface heat fluxes by using TRMM data [1]. The energy balance equation at the land-air interface may be written as

$$R_n = G_0 + H + ëE \qquad (1)$$

where:
R_n = net radiation [W/m^2]
G_0 = soil heat flux [W/m^2]
H = sensible heat flux [W/m^2]
ëE = latent heat flux [W/m^2].

That is, the net radiation term is a balance among all incoming and outgoing shortwave and longwave radiation, as well as energy conducted into the ground, some of which can be measured directly by the remote sensing techniques. The soil heat flux is derived with an empirical relationship between the vegetation and surface characteristics. The sensible and latent heat fluxes are not calculated as separate parameters, but linked to each other through the evaporative fraction, Ë, which is determined as:

$$\Lambda = \frac{lE}{lE + H} = \frac{lE}{R_n - G_0} \qquad (2)$$

Among the energy budget components, sensible and latent heat fluxes are generally partitioned from the net energy through the evaporation and radiation controlled analysis. When the surface is wet or heavily vegetated, the net energy is mainly used to consume water in soil and vegetation through evaporation and evapotranspiration (namely, evaporation controlled). That is, most net radiation is converted to latent heat flux. On the other hand, when the surface is rather dry, few of the latent heat flux will be consumed, most net radiation is converted to sensible heat flux for heating the surface and this case is called radiation controlled. A schematic representation of S-SEBI is given in Fig. 1. By using the reflectance-to-temperature relationships, we can determine the sensible and latent heat fluxes.

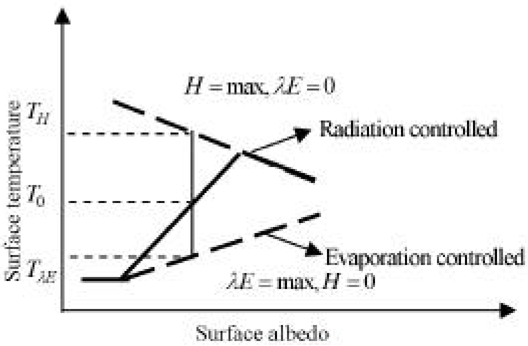

Fig.1. Schematic representation of the relationship between surface reflectance and temperature together with the basic principles of S-SEBI.

3. Results

1) Land-cover classification images from SPOT

We used a supervised method to classify the land cover in the Taichung area as shown in Fig. 2. Forest is in dark green, park is in light green, and the buildings are in red. After classification, it is found the range of the Taichung city and the source of anthropogenic heat.

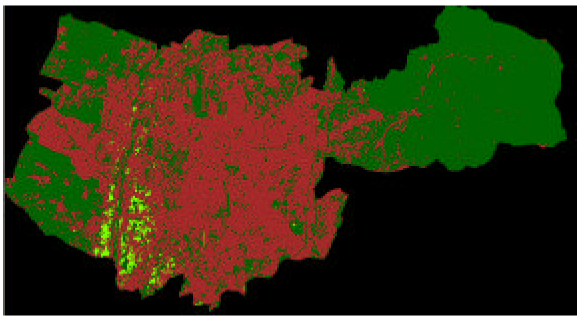

Fig.2. Land cover classification of Taichung area

2) Surface temperature

Images acquired at channel 4 (10.8 ì m) of VIRS of TRMM are used to infer the radiative surface temperature through a linear regression between the surface brightness temperature and ground temperatures observed at the meteorological stations as shown in Fig. 3.

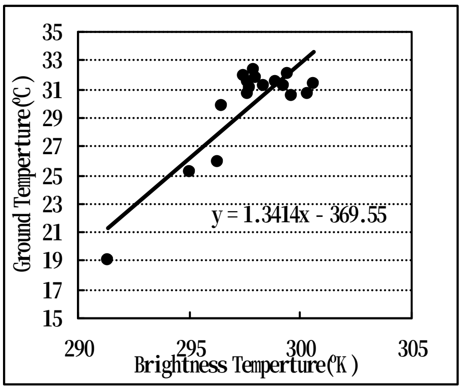

Fig.3. Relationship between the brightness temperature and ground temperature.

3) Retrieve the surface heat fluxes

According to the surface energy balance equation, the net radiation is first derived

$$R_n = K^{\downarrow} - K^{\uparrow} + L^{\downarrow} - L^{\uparrow} \quad (3)$$

$$R_n = (1 - r_0) K^{\downarrow} + L^{\downarrow} - L^{\uparrow} \quad (4)$$

where the incoming shortwave radiation, K , is measured in the field. The reflected shortwave radiation, $K^{\uparrow}$, is defined by the surface albedo, and the emitted longwave radiation L is defined by the surface temperature (Stefan Boltzmann equation), and $L^{\downarrow}$ is the long wave radiation coming from the sky [2].

The soil heat flux, G_0, is determined by the thermal conductivity of the soil and the temperature gradient of the topsoil. We used an empirical equation established by Bastiannssen(1995)[3] to estimate the G_0:

$$G_0 = Ã^* R_n \quad (5)$$

$$\Gamma = T_0 (0.0032 + 0.0062 r_0)(1 - 0.978 NDVI^4) \quad (6)$$

where *To* is the measured surface temperature, and the Normalized Difference Vegetation Index, NDVI, is defined as:

NDVI=(NIR-VIR)/(NIR+VIR) (7)

After estimating the soil heat fluxes from the net radiation, we used the surface energy balance concept to retrieve the sensible and latent heat fluxes as shown in Fig.4.

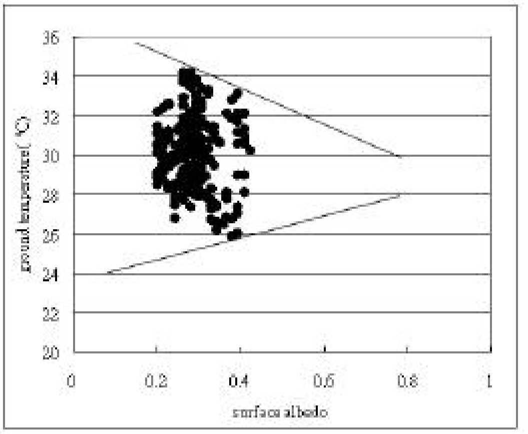

Fig.4. Schematic representation of the relationship between surface reflectance and temperature of Taichung on July 10, 2003.

4) Relationship between the ground temperature and surface characteristic

The surface parameters (NDVI and sensible and latent heat fluxes) are compared with the urban surface temperature as shown in Fig. 5, 6, and 7 because these components are linked to the presence of water body, and the urban temperature effect of water [4].

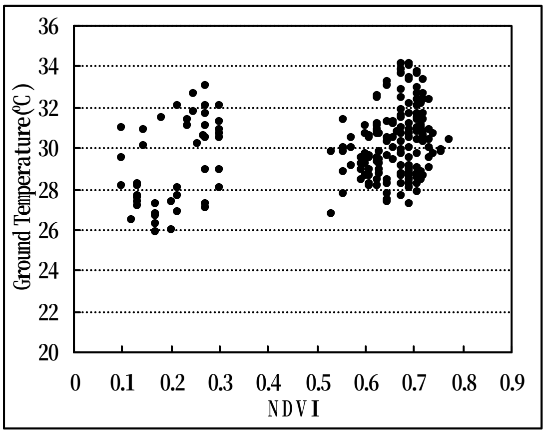

Fig.5. Relationship between the NDVI and ground temperature.

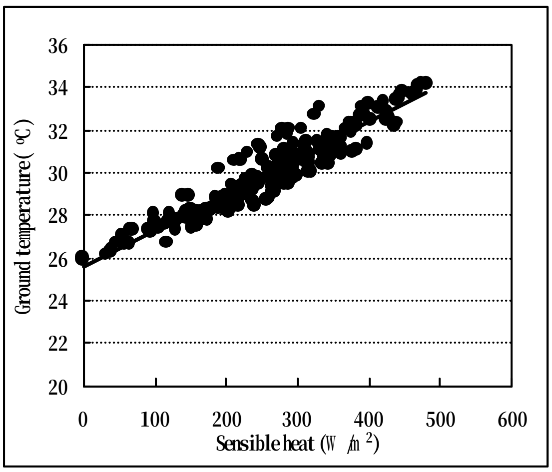

Fig.6. Relationship between the sensible heat and ground temperature.

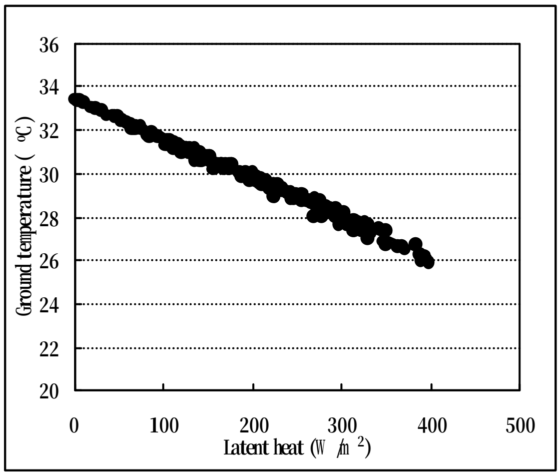

Fig.7. Relationship between the latent heat and ground temperature.

According to Fig. 5, 6, and 7, the ground temperature is shown to be most correlated with latent heat with correlation reaching 0.9.

3. Conclusions

This study shows that the urban surface is rather dry as most net radiation is converted to sensible heat flux for heating the surface. That is, the higher is the sensible heat, the higher becomes the urban ground temperature. However, in the areas of wet surface, most net radiation is converted to latent heat flux. This means that water in soil and vegetation is consumed by the evaporation and evapotranspiration. Finally, it is shown that evapotranspiration is most correlated with ground temperature compared to sensible heat and NDVI. That is, an estimate of evapotranspiration is an indicator of the strength of urban heat island effect.

Acknowledgment

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