COOLING EFFECT RANGE ASSESSMENT OF PADDY FIELDS IN URBAN NEIGHBORHOOD BY LANDSAT THERMAL IMAGERY

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ABSTRACT: Rice is the staple and vital food crop for the people in Asia and is also the major production crop in Taiwan. The paddy irrigated mainly by flooding the field, which consumes more water than the other crops. The planting cycle of paddy in general includes four periods: pounding, growth, strain of corn and after reap. Two of the four cycles, pounding and growth, must be irrigated in order for the paddy to grow up. Because of the irrigation water, the heat in air and land can be significantly absorbed, produce lower temperature in ambient of paddy, that is called the cooling effect. The cooling effect of paddy field is more significant in the urban neighborhood and can be one of the nature solutions to the global warming.

There were few studies of the cooling effect of paddy field since it is difficult to get the temperature around the paddy field in large area. As the development of remote sensing technology, remotely sensed data have the attribute of instantaneous and wide range of views. Remote sensing data can be used more extensively and save more time and labor compare to the traditional measurement.

This study utilized the thermal bands of Landsat-7 satellite dated from 2005 to 2010 and match with the different planting cycle of paddy, to analyze and estimate the range of cooling effect. The study area located in Taoyuan, where paddy fields were next to metro areas, providing environment to analyze and estimate the influence distance of the cooling effect. Land surface temperatures (LST) were derived from the thermal and optical bands of the Landsat-7. The LST in each of the buffer areas from the center line of paddy and metro area were estimated and the turning point at the LST-distance curve was considered the affected range of the phenomenon. Results indicated that the average range of cooling effects were 110, 90, 105and 80 meters for active growth, transplant seedling, and after harvested periods, respectively. It indicated that the lands covered with water are more effective to cool the temperature in residential areas.

1. INTRODUCTION

Due to the quick development at many cities in Taiwan, as well as the excessive use of air conditioners, the environmental temperature increased rapidly. The temperature in urban area, due to high percentage of concrete land pavement and exhausts discharged from automobiles and factories, excess heat from air-conditioning of modern buildings, raised to a uncomfortable degree for people who living in the area.

The cultivation of rice paddy plays an indispensable role in sustaining human life and in maintaining the balance of the entire ecosystem in monsoon Asia. In fact, the paddy is justifiably the most suitable form of agriculture for the soil, weather and other geographical conditions in this area. The cultivation of rice paddy takes large amount of irrigation water, especially during sprouting, transplanting, and nutrient growth periods. The fields of rice paddy keep 3 to 6 centimeter of pounding water on the land surface for most of the growing season. The transpiration of rice plants and evaporation from paddy fields consumes significant amount of heat. As a result, the temperature usually feels cooler in areas surrounded with large paddy fields. The cultivation area of paddy rice decreased from 783,600ha in 1956 to 398,400ha in 2010 in Taiwan. In the mean time, the temperature increased significantly as many agricultural land use developed to urban. However, the actual degree of increase is difficult to demonstrate over an extended area mainly due to the lack of records of regional temperature. The temperature at the meteorological station represents point temperature or, at most, temperature of very limited surrounding area. Since the beginning of thermal remote sensing from satellites, remotely sensed observations of the land surface have provided another source of data for examining the heat characteristics over land surfaces. This study utilized the thermal bands of Landsat-7 satellite dated from 2005 to 2010 and match with the different planting cycle of paddy, to analyze and estimate the range of cooling effect. The study area located in Taoyuan, where paddy fields were next to metro areas, providing environment to analyze and estimate the influence distance of the cooling effect.

2. MATERIALS AND METHODOLOGY

2.1 Thermal Remote Sensing

The earth surface can be thought to be a physical system which is periodically excited by the sun and which responds in two ways. First, the earth re -emits, by reflection, a portion of the energy that it receives from the sun, mainly in the visible and near infrared part of the electromagnetic spectrum. This part of the radiation, in principle, is the representation of the surface characteristics of the earth which are useful in determining vegetation varieties and conditions, delineating water body and coast lines, discriminating soil and rock types, etc. Secondly, it receives part of the solar energy and emits directly in the thermal infrared portion of the electromagnetic spectrum. This emitted radiation is strongly related to the surface temperature and the emmissivity can be used to infer the energy exchanges in the earth-atmospheric boundary. All objects with temperatures above absolute zero emit electromagnetic (EM) energy. The magnitude and spectral distribution of this energy can be defined by Plank's equation for a perfect radiator

$$M_{\lambda} = \pi B_{\lambda}(T) = \frac{2\pi hc^{2}}{\lambda^{5}\exp(\frac{hc}{\lambda KT} - 1)} \tag{1}$$

where B_{λ} is Planck's function; M_{λ} is the spectral radiant emission, in $Wm^{-2}m^{-1}$; h is Plank's constant, c is the speed of light, λ is the wavelength, in m; k is the Boltzmann constant; and T is the temperature in degree Kelvin. This equation describes the spectral emission of an object per unit area per wavelength. Since natural objects are not perfect blackbodies, the above equation needs to be corrected by multiplying by the emission ε for different materials. The total radiant emission from a surface at a given temperature can then be determined by integrating M_{λ} with respect to wavelength for all wavelengths and resulted in:

$$M(T) = \int_{0}^{\infty} \varepsilon M_{\lambda}\, d\lambda = \int_{0}^{\infty} \frac{2\pi\varepsilon hc^{2}}{\lambda^{5}}\left[\exp(\frac{hc}{\lambda KT} - 1)\right]^{-1} d\lambda \tag{2}$$

where M is the radiant emission in W/m^2.

2.2 Surface Emissivity Estimation

The surface temperature estimation is complicated with the determination of surface emissivity within an area mixed with many different land covers. In this study we adopted and modified the theoretical model that relates the emissivity to the NDVI (normalized difference vegetation index) of a given surface and explains the experimental behavior observed by van de Griend and Owe and Juan et.al (van de Griend and Owe, 1993 and Valor and Caselles, 1996, Juan et. al, 2006) as:

$$\varepsilon_i = \varepsilon_{vi} P_V + (1 - P_V)\varepsilon_{si} \tag{3}$$

where ε_{vi} and ε_{si} are band emissivity values for vegetation and bare soil, respectively, and P_V is the proportion of vegetation or fractional vegetation cover. P_V can be obtained from NDVI values according to (Carlson & Ripley, 1997):

$$P_V = \left(\frac{NDVI - NDVI_s}{NDVI_v - NDVI_s}\right)^2 \tag{4}$$

where $NDVI_v$ and $NDVI_s$ are the NDVI values of full vegetation cover (P_V=1) and bare soil (P_V=0), respectively, which can be obtained from the NDVI histogram.

The results were with good relationship in the agricultural areas yet with less satisfactory results in the areas of land cover mixed with water, such as paddy fields and wetlands due to the extreme low NDVI of water surface. Therefore, we modified the fractional vegetation cover by the fractional water cover and then first determine the type of land cover and apply the proper fractional cover and then the emissivity value.

$$P_W = \left(\frac{NDMI - NDMI_w}{NDMI_v - NDMI_w}\right)^2 \tag{5}$$

$$\varepsilon_i = \varepsilon_{wi} P_W + (1 - P_W)\varepsilon_{vi} \quad (6)$$

where ε_{wi} and ε_{vi} are band emissivity values for water and vegetation, respectively, and P_W is the proportion of water cover (Eq. 5).

2.3 Study Area

The study area located in a quick developing Taoyuan area, where paddy fields, urban, small scale industries scattered in the tableland. The Taoyuan Tableland lies between the northern border of the Ling-Kou Tableland (23°05'N, 121°17'E) and the southern border of the Hu-Kou Tableland (22°55'N, 121°05'E); it borders the town of Yinge in the east (22°56'N, 121°20'E) and the Taiwan Strait in the west (22°75'N, 120°99'E) (Department of Land Administration 2003). It sits at elevations from sea level to 400 m and is composed of tableland up to 303 m and hills with sloping gradients from 303 to 400 m. It runs in a southeast-to-northwest trend, abutting mountains in the southeastern corner and the shore of the Taiwan Strait at the far end. With a high average humidity of 89%, the tableland is located in a subtropical monsoon region with humid winters and warm summers. January temperatures average 13 °C, and July temperatures average 28 °C. Annual average precipitation ranges from 1,500 to 2,000 mm.

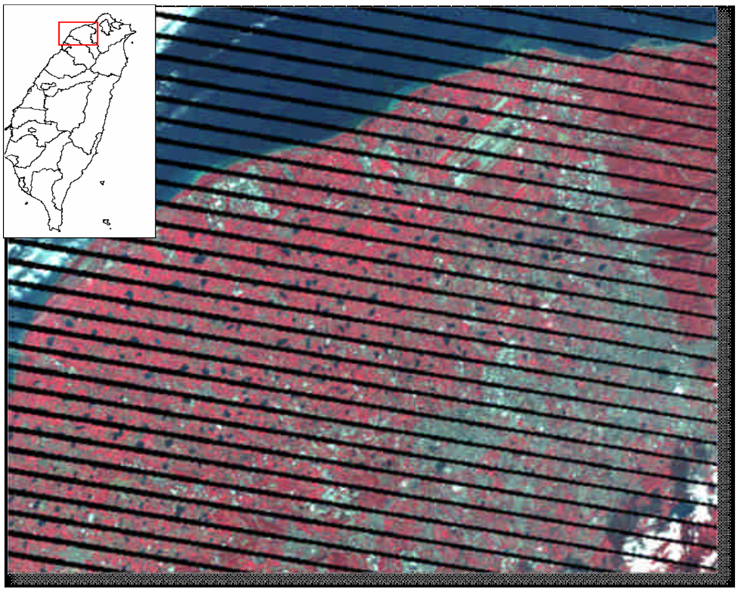

Figure 1. Landsat 7 ETM+ image of the study area of Taoyuan county. The stripes were due to SLC-off of the Landsat 7 ETM+

2.4 Zonal Surface Temperature Calculation

To determine the range of cooling effect from the surface temperature images, the zonal average surface temperature was calculated as the following procedures: (Figure 2)

(1) Identify the paddy and residential area boundary from the classified Landsat 7 images.
(2) Use multiple ring buffer function to create buffer lines every 15 m.
(3) Calculate the average surface temperatures from center boundary toward residential zone and paddy zone every 15 m.
(4) Plot the zonal surface temperatures and determine the inflection point.
(5) The range of cooling effect was the distance of the boundary of paddy field and residential area to the inflection points on the surface temperature plot.

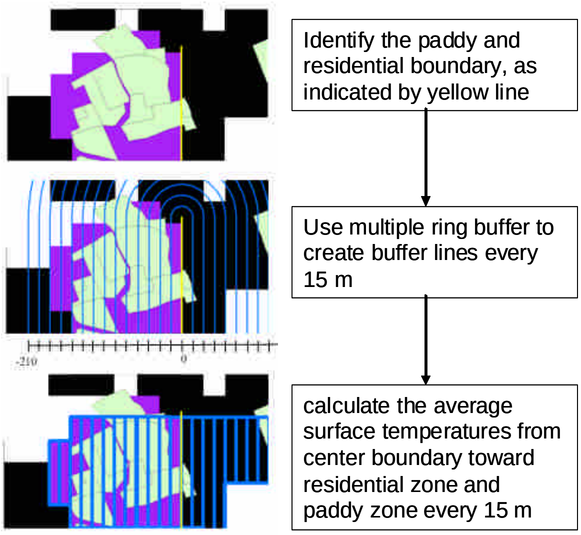

Figure 2. Procedures to determine the range of cooling effect from the surface temperature images.

The range of cooling effect was determined by the distance of paddy field and residential area boundary to the inflection points on the surface temperature plot. It is due to the effective cooling potential, cool air current may be effective to a distance and gradually reduce its influence and resulted in an inflection point on the surface temperature curve.

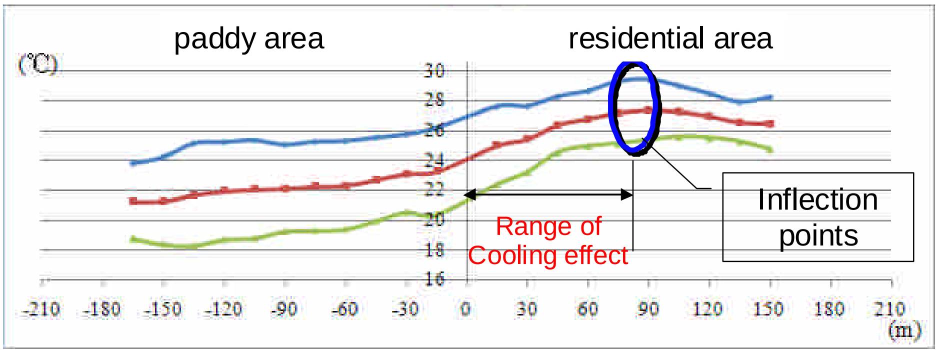

Figure 3. Surface temperature curve with upper and lower confidence levels. The range of cooling effect was determined by the distance of paddy field and residential area boundary to the inflection points.

3. RESULTS AND DISCUSSIONS

The Landsat 7 ETM+ images were classified to 7 land surface categories, namely paddy fields, forest, water bodies, high-density residential, low-density residential, bare soil and others, using the supervised classification module in ERDAS IMAGINE software package. The accuracy statistics of the four classified images were listed in Table 1.

Table 1. The accuracy statistics of the four classified Landsat ETM+ images

Statistics / Date	Overall accuracy	Kappa
2010/02/11	0.90	0.89
2008/04/26	0.94	0.93
2007/08/30	0.87	0.85
2005/06/05	0.90	0.89

The surface temperature maps were calculated using Equations 1 and 2, with the surface emissivity determined by Equations 3 to 6. Figure 4 and 5 illustrated the surface temperature maps of 2010/02/11, and 2008/04/26 respectively, in degree C.

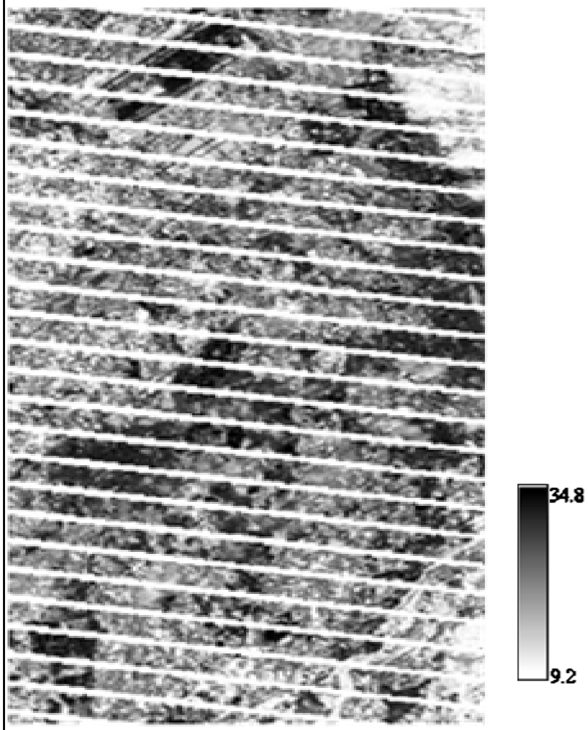

Figure 4. Surface temperature map of 2010/02/11, in degree C

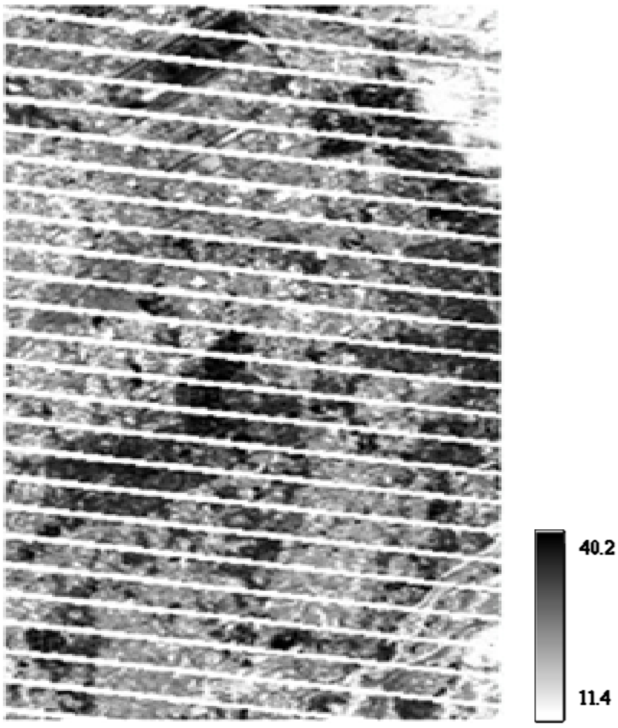

Figure 5. Surface temperature map of 2008/04/26, in degree C

The ranges of cooling effect were 100 m for low density residential area, while it decreased to 90 m for high density residential. The average affected distances were 110, 90, 105and 80 meters for active growth, transplant seedling, and after harvested periods, respectively as listed in Table 2 and 3.

Table 2. Effective range of cooling effect for paddy field and water body to different residential conditions.

		Effective range (m)			
Date		2005/06/05	2007/08/30	2008/04/26	2010/02/11
Paddy surface condition		Pounding water	Transplant seedling	Active growth	After harvested
	Low-density residential	90	90	135	90
	High-density residential	75	90	90	120
	Low-density residential	180	120	105	120
	High-density residential	120	75	135	105

Table 2. Average range of cooling effects of various paddy field conditions to residential area.

Paddy field condition	To	Range of cooling effect (m)
Active grow	Residential	110

Transplant seedling	Residential	90
After harvest	Residential	80
Pounding water	Residential	105

4. CONCLUSIONS

1. The conceptions of fractional vegetation cover and fractional water cover were used to determine the surface emissivity on each pixel and then the land surface temperature can be calculated accordingly. The results showed good agreement while compared the surface temperature with ground records at weather stations.

2. The ranges of cooling effect were determined by the distance of the boundary of paddy field and residential area to the inflection points on the surface temperature plot. This is due to the effective cooling potential, cool air current may be effective to a distance and gradually reduce its influence and resulted in an inflection point on the surface temperature curve.

3. The average range of cooling effects were 110, 90, 105and 80 meters for active growth, transplant seedling, and after harvested periods, respectively. It indicated that the lands covered with water are more effective to cool the temperature in residential areas.

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