USING REMOTELY SENSED DATA TO ESTIMATE THE SURFACE HEAT FLUXES OVER TAIWAN'S CHAIYI PLAIN

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ABSTRACT Traditionally, surface energy fluxes are obtained by model simulations or empirical equations with auxiliary meteorological data. These methods may not effectively represent the surface heat fluxes in a regional scale due to scene variability. On the other hand, remote sensing has the advantage to acquire data of a large area in an instantaneous view. The remotely sensed data can be further used to retrieve surface radiation and heat fluxes over a large area. In this study, the airborne and satellite images in conjunction with meteorological data and ground observations were used to estimate the surface heat fluxes over Taiwan's Chaiyi Plain. The results indicate that surface heat fluxes can be properly determined from both airborne and satellite images. The correlation coefficient of surface heat fluxes with *in situ* corresponding observations is over 0.60. We also observe that the remotely sensed data can efficiently provide a long term monitoring of surface heat fluxes over Taiwan's Chaiyi Plain.

KEY WORDS: Surface Heat Fluxes, Remote Sensing, Taiwan's Chaiyi Plain

1. INTRODUCTION

The geothermal/surface energy process is one of the important factors that affect the climate, hydrosphere cycle, land cover formation, as well as human activities. In recent years, the human-induced global climate change further demands the understanding of the geothermal/ surface energy process in effect on the environment and the method that can effectively monitor the states of geothermal/surface energy process.

Several methods can be used to determine or estimate the surface energy/heat fluxes, such as eddy covariance system, Bowen ration system, and empirical methods like Penman-Monteith equation. However, these methods can not effectively address the spatial variability of the surface energy, as these methods rely on point observations. With the advance of remote sensing technology, varied data is now available for determining or estimating spatially-distributed surface heat/energy fluxes, such as high resolution airborne thermal images and high temporal satellite images.

In this paper, the study of using high resolution airborne thermal image and multi sensor/resolution satellite images in conjunction with meteorological data and ground observations to estimate the surface heat fluxes over Taiwan's Chaiyi Plain is presented. This study is part of the long-term research on the heat island effect over Taiwan's Chaiyi Plain.

2. PROCEDURE DESCRIPTION

2.1 Methodology

The methodology used in this study to retrieve the surface heat fluxes from remotely sensed data is based on the theory of surface energy and radiation balance. Under steady atmospheric condition, the net radiation can be considered as a balance between incident and outgoing radiation:

$$R_n = (1-\alpha)R_s^{\downarrow} + R_L^{\downarrow} - \varepsilon_0 \sigma T_0^{\ 4} \qquad (1)$$

where R_n = the net radiation (W/m^2)
$R_s^{\downarrow}$ = the incident short-wave radiation (W/m^2)
$R_L^{\downarrow}$ = the incident long-wave radiation (W/m^2)
α = the surface albedo
ε_0 = the surface emissivity of TIR band
σ = the Stefan-Boltzmann constant (W/m^2K^4)
T_0 = the surface temperature (K)

Furthermore, the surface energy balance at the land-air interface can be written as:

$$R_n = G_0 + H + \lambda E \qquad (2)$$

where R_n = the net radiation (W/m^2)
G_0 = the soil heat flux (W/m^2)
H = the sensible heat flux (W/m^2)
λ E = the latent heat flux (W/m^2).

The soil heat flux (G_0) can be derived from the method developed by Kustas and Daughtry (1990) and

Bastiaanssen et al. (1998) as a function of surface albedo, surface temperature, and normalized difference vegetation index (NDVI):

$$G_0 = \Gamma \times R_n$$
$$\Gamma = T_0(0.0032 + 0.0062\alpha)(1 - 0.987NDVI^4) \quad (3)$$

Hence, the sensible heat flux and the latent heat flux then can be determined by using surface radiation and energy balance in conjunction with short/long-wave radiations, and soil heat flux that are derived from remote sensing data.

2.2 Data Collection

Data collected for this study include *in situ* ground truth, high resolution airborne thermal images, high resolution FORMOSAT-2 images, and MODIS images. The reason to gather these data is that three basic surface parameters, surface albedo (α), NDVI, and surface kinetic temperature (T_0), are required to retrieve the surface heat fluxes from remotely sensed data. Because the airborne data does not supply enough information to derive NDVI and surface albedo, the high resolution multispectral FORMOSAT-2 (8 m) image are needed to obtain these parameters.

2.2.1 *In situ* data: Three micro-meteorological stations were constructed over Chaiyi Plain since late 2005. They include an eddy covariance system (Chaiyi Girl's Senior High School, 23°28'23.72"N, 120°26'58.99"E) and two Bowen ratio systems (Niaoxiu Station, 23°29'27.78"N, 120°24'26.20"E, and Guogou Station, 23°29'58.33"N, 120°20'06.02"E). The eddy covariance system is located in urban area with concrete surface, and the two Bowen ratio systems are set up on the crop fields. These stations acquire surface meteorological data and incoming/outgoing radiance in minute interval, which are used as a reference for data analysis. Figure 1 shows the locations of the three stations.

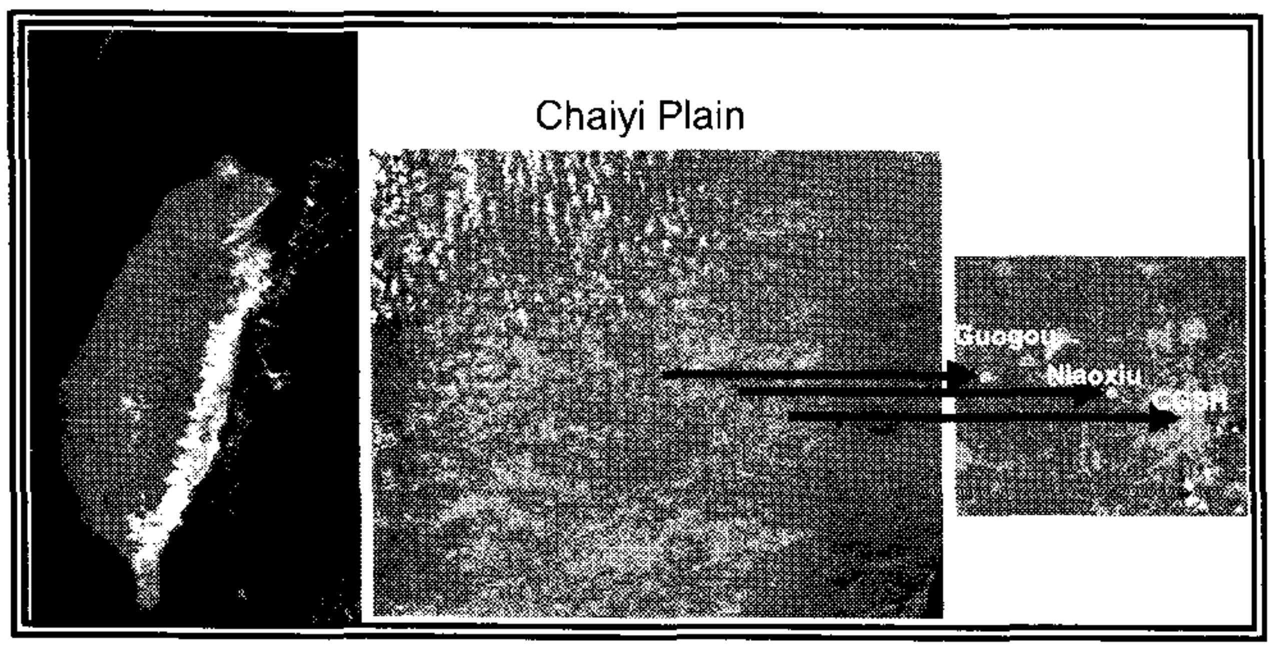

Figure 1.Geographical locations of three micro-meteorological stations

2.2.2 Airborne data: The airborne thermal infrared data was acquired by FLIR system's ThermoVision® A40M thermal infrared camera on Dec 27, 2006. This camera was hosted on a helicopter, and acquired thermal infrared spectrum from 7.5 to 11 μm. For this particular mission, the data were collected at several altitudes, and resulted in a varied spatial resolution range from 0.8 m to 1 m.

2.2.3 Satellite data: Eleven MODIS images acquired in 2006 were used to estimate the surface heat fluxes over Taiwan's Chaiyi Plain. Four MODIS bands were used in this study. Band 1 and band 2 were used to estimate the surface albedo and NDVI, and band 31 and band 32 were used to retrieve surface temperature. In addition, the FORMOSAT-2 image taken on Jan. 1, 2007 was used to estimate the surface heat fluxes from high resolution airborne thermal image. Table 1 shows the FORMOSAT-2 and MODIS bands used in this study.

Table 1. The Bands of FORMOSAT-2 and MODIS are used in this study

FORMOSAT-2		
Spatial Resolution: 8 m		
Band	Bandwidth (μm)	Spectral Region
1	0.45-0.52	Blue
2	0.52-0.60	Green
3	0.63-0.69	Red
4	0.76-0.90	Near Infrared (NIR)
MODIS		
Spatial Resolution: 1km		
Band	Bandwidth (μm)	Spectral Region
1	0.620-0.670	Red
2	0.841-0.876	Near Infrared (NIR)
31	10.78-11.28	Thermal Infrared (TIR)
32	11.77-12.27	Thermal Infrared (TIR)

3. RESULTS

The data collected for this study include ground truth, airborne image, and satellite images. Each dataset has in its own coordinate system. Therefore, it is a priority to convert all data into a standard coordinate system. Despite the airborne image, both ground truth data and satellite images have been assigned with coordinate system. Hence, coordinate conversions that converted the data coordinate system to Taiwan 97 projection system were applied to those data.

For the airborne thermal infrared images, a georectification procedure was necessary, because these images do not associate with any coordinate system and the flight engineering data were insufficient to be precisely registered onto the images. As a result, the image-to-image registration that uses 0.5 m digital orthophotos from Council of Agriculture, Executive Yuan as reference was used to georectify the airborne images. The first order polynomial function and the Nearest Neighbour resampling method was used to resample the image to FORMOSAT-2 resolution (8 m), and the total RMS for these registrations was less than 0.3 m. Figure 2 shows the georectification process.

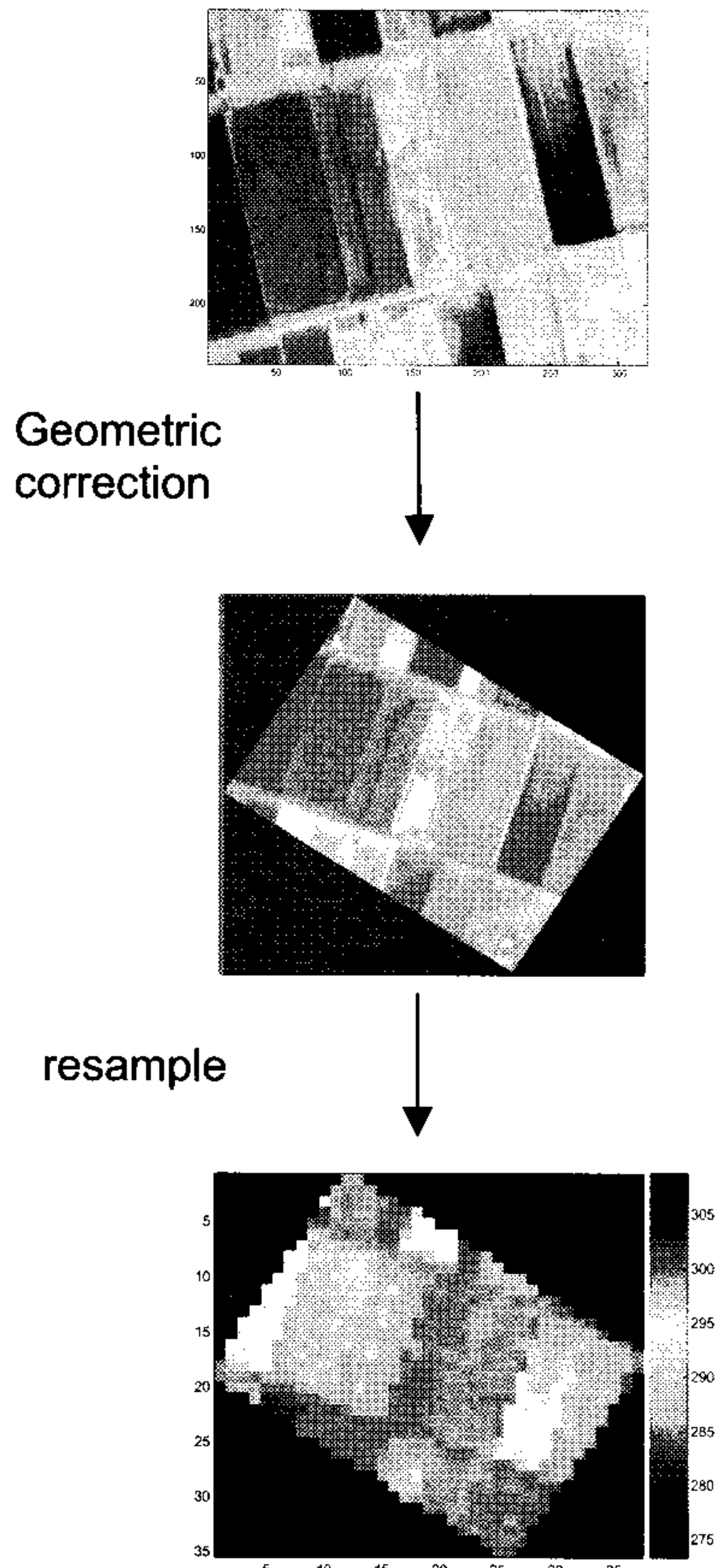

Figure 2. Flow chart of airborne image processing

Due to a miscommunication, only the Guogou station was in the flight path of Dec 27, 2006 mission, and no other airborne image was taken exactly over the other two stations. As a result, the result and discussion of this study were based on the Guogou station.

Table 2 shows the comparison of surface energy fluxes retrieved from airborne image and *in situ* data. The heat fluxes retrieved from airborne image were closed to the *in situ* measurements, which indicated that using remote sensing data to retrieve surface heat fluxes is feasible.

Table 2. Comparison of the heat fluxes retrieved from airborne image with the *in situ* measurements

	R_n (W/m^2)	G_0 (W/m^2)	SH (W/m^2)	λE (W/m^2)
Retrieved data	343.96	39.55	10.56	289.52
Guogou Station	424.45	13.33	24.66	386.48

Figure 3 presents the surface heat fluxes, the net radiation (R_n), soil heat flux (G), sensible heat flux (SH), and latent heat flux (LH), retrieved from the airborne image. The land covers in this area are mainly crop fields. Figure 3 shows that the surface heat fluxes can be used to distinguish the crop types easily. It was found that the rice paddy (350W/m^2) has higher latent heat flux than the corn field (250W/m^2), but the sensible heat flux is in opposite. Furthermore, the net radiation over corn is higher than over rice paddy and soil heat flux of corn is lower. These characteristics are resulted from different environmental path radiances and plant structures,

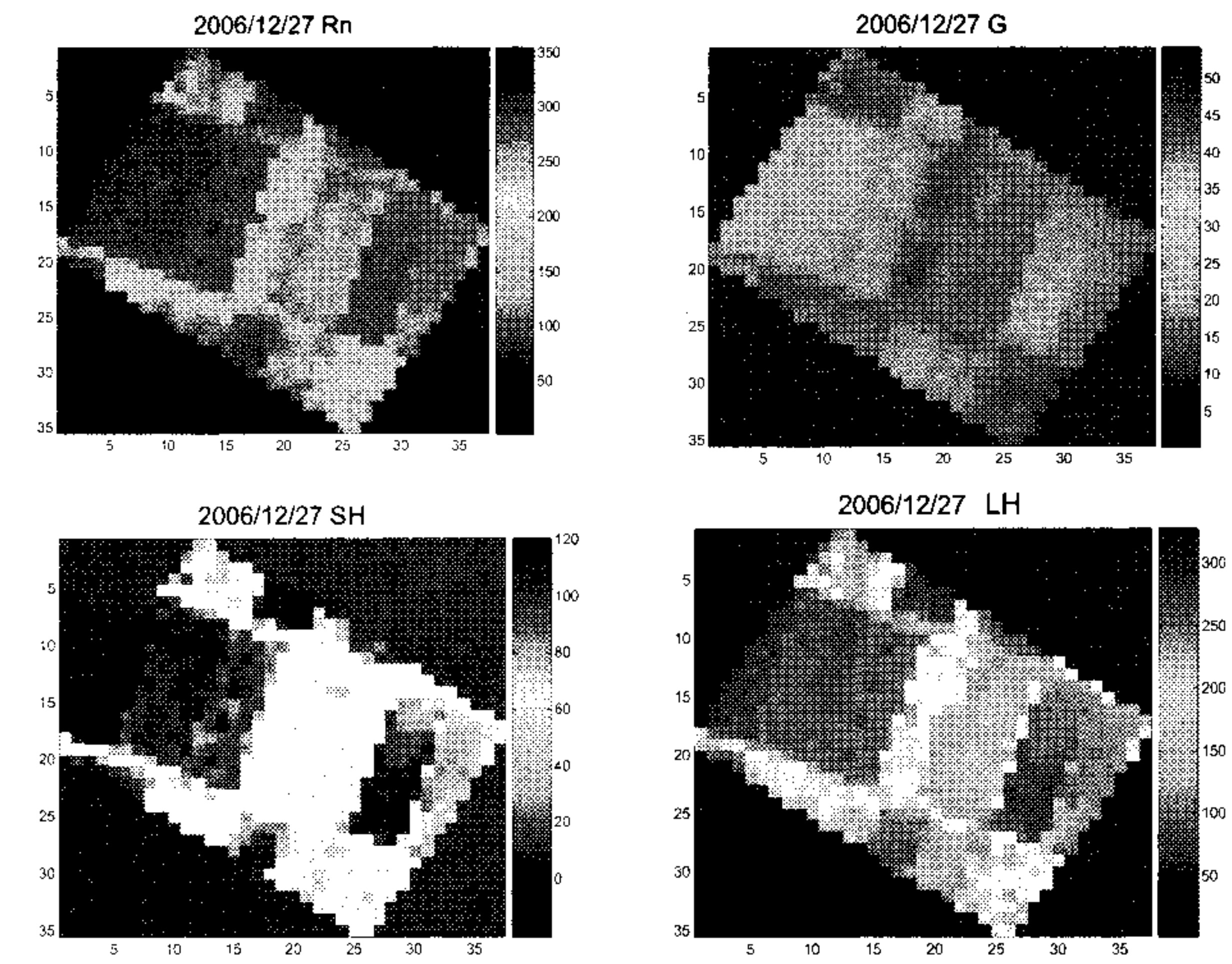

Figure 3. Surface heat fluxes are estimated from airborne data on Dec 27, 2006

Satellite image has the advantage of frequently revisit schedule and low image cost, unlike airborne system that subjects to weather condition, air space restriction, and high operational cost. However, satellite image does have its disadvantage in terms of spatial resolution.

In this study, four MODIS images were selected to study the performance of coarse resolution image in estimating surface heat fluxes. Table 3 shows the comparison of the surface heat fluxes retrieved from MODIS image and the *in situ* measurement. From the table, the biases of the sensible heat flux and latent heat flux were 61.10 W/m^2 and 57.97 W/m^2, respectively, and the correlation coefficient of surface heat fluxes with *in situ* measurement was over 0.60.

Table 3. Comparison of the MODIS results with *in situ* measurements

2006/01/19	R_n (W/m^2)	G_0 (W/m^2)	SH (W/m^2)	λE (W/m^2)
MODIS	406.66	62.80	76.04	267.81
In situ	379.22	83.79	105.34	187.73
2006/02/11				
MODIS	439.43	68.53	69.85	301.06
In situ	490.44	90.63	139.32	260.49

2006/11/10				
MODIS	386.71	57.48	58.78	270.44
In situ	377.67	55.73	117.50	204.44
2006/12/05				
MODIS	404.44	50.05	64.62	289.78
In situ	403.59	32.57	138.99	232.03

4. CONCLUSIONS

This study compares three different methods including traditional ground measurement, high-resolution airborne thermal sensing, and satellite based remote sensing to estimate/retrieve surface heat fluxes. The result indicates that using the remote sensing technique to evaluate surface hear/energy has achieved a level of practical use. Although airborne image can reveal detailed energy flux information, it is difficult to obtain high-quality and -quantity airborne images, because it subjects to weather, labor, cost, and restriction from regulations. On the other hand, satellite based thermal sensing can provide quantity data. For example, the combination of Aqua and Terra satellites can provide up to four images per day, and the correlation coefficient of surface heat fluxes retrieved from MODIS data with *in situ* measurements is above 0.60 in this study. However, there still exists space to improve by using the MODIS data to retrieve surface energy such as the problems associated with geometry and radiometry. The problems can be resolved and further improved by careful calculation or implementation of proper geospatial techniques, and will be the task of our future work.

ACKNOWLEDGEMENT

The authors acknowledge the funding support by Academia Sinica of Taiwan.

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