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8.5 THERMAL CHARACTERISTICS OF URBAN LANDSCAPES

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1. INTRODUCTION

Although satellite data are very useful for analysis of the urban heat island effect at a coarse scale, they do not lend themselves to developing a better understanding of which surfaces across the city contribute or drive the development of the urban heat island effect. Analysis of thermal energy responses for specific or discrete surfaces typical of the urban landscape (e.g., asphalt, building rooftops, vegetation) requires measurements at a very fine spatial scale (i.e., < 15m) to adequately resolve these surfaces and their attendant thermal energy regimes. Additionally, very fine scale spatial resolution thermal infrared data, such as that obtained from aircraft, are very useful for demonstrating to planning officials, policy makers, and the general populace the benefits of the urban forest. These benefits include mitigating the urban heat island effect, making cities more aesthetically pleasing and more habitable environments, and aid in overall cooling of the community.

High spatial resolution thermal data are required to quantify how artificial surfaces within the city contribute to an increase in urban heating and the benefit of cool surfaces (e.g., surface coatings that reflect much of the incoming solar radiation as opposed to absorbing it thereby lowering urban temperatures). The TRN (thermal response number)(Luvall and Holbo 1989) is a technique using aircraft remotely sensed surface temperatures to quantify the thermal response of urban surfaces. The TRN was used to quantify the thermal response of various urban surface types ranging from completely vegetated surfaces to asphalt and concrete parking lots for Huntsville, AL.

2. ATLAS Sensor

Data were obtained from the Airborne Thermal/Visible Land Application Sensor (ATLAS). The ATLAS sensor, because of its spectral bandwidth combinations, offers the capability for acquiring multispectral data, including thermal data, at various spatial resolution levels depending upon aircraft altitude. The ATLAS is operated by the NASA Stennis Space Center and is flown on-board a Lear 23 jet aircraft.

The ATLAS is a 15-channel sensor that incorporates the bandwidth range of the Landsat Thematic Mapper (TM) with additional bands in the middle reflective infrared and thermal IR range. System specifications for the ATLAS are provided in Table 1. These offer the potential to make accurate measurements of thermal responses for different landscape characteristics and their corresponding land-atmosphere interactions over small wavelength regions. Data of this type would be very useful in understanding how thermal responses for typical urban surfaces are partitioned in the thermal region of the electromagnetic spectrum, as well as within the visible and reflective infrared regions.

ATLAS data were collected at a 10 m pixel spatial resolution on September 7, 1994 over Huntsville, AL during the daytime, between approximately 11:00 a.m. and 3:00 p.m. local time (CDT) to capture the highest incidence of solar radiation across the city landscape around solar noon. Each flight line was repeated with approximately 2 hour time difference between repetitions.

3. Atmospheric Corrections

Atmospheric radiance must be accounted for in order to obtain calibrated forest canopy temperatures. Although the ATLAS channels fall within the atmospheric window for atmospheric long wave transmittance (8.0-13.0 μm), the maximum transmittance is only about 80%. The amount of atmospheric radiance in the atmospheric window is

TABLE 1

ATLAS SPECIFICATIONS

Channel #	Band Width Limits (m)
1	0.45-0.52
2	0.52-0.60
3	0.60-0.63
4	0.63-0.69
5	0.69-0.76
6	0.76-0.90
7	1.55-1.75
8	2.08-2.35
9	3.35-4.20
10	8.20-8.60
11	8.60-9.00
12	9.00-9.40
13	9.60-10.2
14	10.2-11.2
15	11.2-12.2

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air. Resistance is low for small leaves in windy conditions and their temperatures are closely coupled with air temperatures (Oke, 1987). Larger leaves with increased r_b rely more on λE to maintain leaf temperature and stomatal resistance becomes more important. If the canopy/leaf is under moisture stress, less water is available for evaporation and the leaf/canopy becomes warmer. In urban areas, building height, size, and organization generate complex surfaces which makes it extremely difficult to estimate r_b.

5. Thermal Response Number (TRN)

Luvall and Holbo (1989, 1991) present a technique, the primarily through remote sensing (Thermal Response Number, TRN), for describing the surface energy budget within a forested landscape. This procedure treats changes in surface temperature as an aggregate response of the dissipate thermal energy fluxes (latent heat and sensible heat exchange; and conduction heat exchange with biomass and soil). The TRN is therefor directly dependent on of surface properties (canopy structure, amount and condition of biomass, heat capacity, and moisture). A time interval of 15-30 minutes between remote sensing over flights of the same area using the Thermal Infrared Multispectral Scanner (TIMS) for selected forested landscapes, has revealed a measurable change in forest canopy temperature due to the change in incoming solar radiation (K). Surface net radiation integrates the effects of the non-radiative fluxes, and the rate of change in forest canopy temperature presents insight on how non-radiative fluxes are reacting to radiant energy inputs. The ratio of net radiation to change in temperature can be used to define a surface property referred to as the Thermal Response Number (TRN). The TRN in units $Jm^{-2}\ K^{-1}$ is given as:

$$\text{TRN} = \sum_{t_1}^{t_2} R_n^* \,\Delta t/\Delta T \qquad (7)$$

where

$$\sum_{t_1}^{t_2} R_n \Delta t \qquad (8)$$

represents the total amount of net radiation (R_n) for that surface over the time period between flights ($\Delta t = t_2 - t_1$) and ΔT is the change in mean temperature of that surface. The mean spatially averaged temperature for the surface elements at the times of imaging is estimated by using

$$T = 1/n \sum T_p \qquad (9)$$

where each T_p is a pixel temperature (smallest area resolvable in the thermal image), and n is the number of pixels in the surface type.

6. Results and Discussion

A total of 21 different urban surface types were extracted from the data. Urban surface types ranged from those completely covered by man-made materials, ie asphalt parking lots and concrete parking garage to completely vegetated surfaces, ie golf course, bottom land hardwood forest (Table 2).

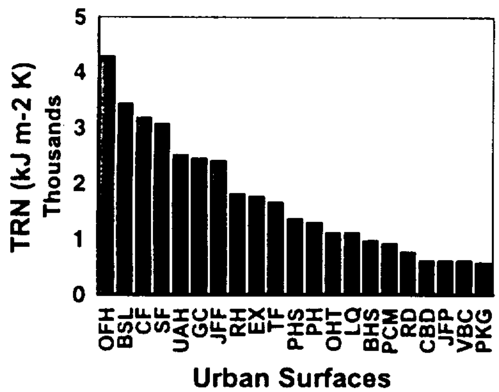
TABLE 2

Site Code	Urban Surface
OFH	Army Officers' Housing Area
BSL	Big Springs Lake
CF	Cotton Field
SF	Bottomland Hardwoods
UAH	University of Alabama Campus
GC	Golf Course
JFF	Pine forest
RH	Rual Housing
EX	Executive Lodge Motel
TF	Turf Farm
PHS	Public Housing-Single Story
PH	Public Housing-2 Story
OHT	Old Industral/Mill/Housing
LQ	Limestone Quarry
BHS	Bulter High School Roof
PCM	Parkway City Mall
RD	Road-I565
CBD	Central Business District
JFP	Asphalt Parking Lot
VBC	Roof Van Braun Center
PKG	Parking Garage (CBD)

It is apparent that the TRN separates out the various site types extremely well (Figure 1). Urban surfaces which are mostly composed of manmade materials, such as a parking garage and an asphalt parking lot had the lowest TRN. These surfaces partitioned the net radiation mostly into sensible heat and storage. As the vegetation component of the surface increased, the TRN also increased. The effect of irrigation on changing the partitioning of the net radiation was evident at the site which had the greatest TRN, the officers housing area (OFH). Usage of sprinklers in this housing area was encouraged by the fact that residents do not have to pay for water usage. With adequate soil moisture, most of the net radiation would be partitioned into latent heat.

It is important to point out that traditional image classification techniques use only structural

FIGURE 1



differentiation of surfaces in the visible wave lengths and not functional differentiation. Urban areas are composed of a very heterogeneous mixture of man-made materials and vegetation. The vegetation component responds to soil moisture availability by controlling its water loss through the stomata. This in turn changes how the energy is partitioned in the vegetation canopy and hence its temperature. Using the TRN for classification of urban surfaces results in a functional classification based on how the surface energy is partitioned into sensible heat, latent heat or into storage.

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The following record has updated.

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