The use of the Airborne Thermal/Visible Land Application Sensor (ATLAS) to Determine the Thermal Response Numbers for Urban Areas.

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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 several cities in the United States.

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:

$$\text{TRN} = \sum_{t_1}^{t_2} tR_n^* \, \Delta t / \Delta T \qquad (1)$$

where

$$\sum_{t_1}^{t_2*} R_n \Delta t \qquad (2)$$

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

$$T = 1/n \, \Sigma \, T_p \qquad (3)$$

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.

A range of 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 .

It was apparent that the TRN separates out the various site types extremely well. 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.

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

References

Luvall, J. C., and H. R. Holbo, 1989: Measurements of short-term thermal responses of coniferous forest canopies using thermal scanner data. *Remote Sensing of Environment,* **27**, 1-10.

Luvall, J. C., and H. R. Holbo, 1991: Thermal remote sensing methods in landscape ecology. In M. G. Turner and R. H. Gardner (eds.), *Quantitative Methods in Landscape Ecology*, Springer-Verlag, New York, 127-152.