5.10 REMOTE SENSING AND MODELLING OF URBAN HEAT ISLANDS

James A. Voogt*[1] and T.R. Oke [2]
[1]University of Western Ontario, London ON CANADA [2]University of British Columbia, Vancouver BC CANADA

1. INTRODUCTION

The addition of thermal remote sensors to the suite of measurement approaches for studying urban heat islands has provided new avenues for the observation of urban heat islands and the study of their causation. It has also proved problematic in complicating definitions of urban heat islands and in correctly interpreting remote observations. Here we present a review of remote sensing of urban heat islands and use a case study of the urban heat island of Vancouver BC to illustrate our points. Our review is prompted in part by the appearance of new satellite-based sensors and the more widespread application of infrared sensors in studies of surface climate that increase opportunities for using thermal remote sensing for studying the urban heat island.

2. CASE STUDY OVERVIEW

A detailed study of the urban heat island of Vancouver, BC, Canada was conducted on 24-25 August 1992 using a combination of ground, aircraft and satellite-based sensors. The study incorporated traverses of air and surface temperature over a rural to urban transect at times critical to heat island development. Three fixed sites in rural, urban residential, and light industrial land-use areas provided general surface layer characteristics and surface energy balance data. An additional site in downtown Vancouver provided within-canyon data. The prevailing weather was characterized by cloudless skies and a daytime sea-breeze circulation under a stationary high pressure system.(Figure 1).

Figure 2 presents a spatial depiction of the heat island cross-section as derived from aircraft and vehicle traverses of directional brightness and air temperature, respectively. These results will be used to illustrate differences between surface and atmospheric heat islands and difficulties inherent in using thermal remote sensors to observe urban heat islands.

3. PROGRESS ON URBAN THERMAL REMOTE SENSING

3.1 The urban surface.

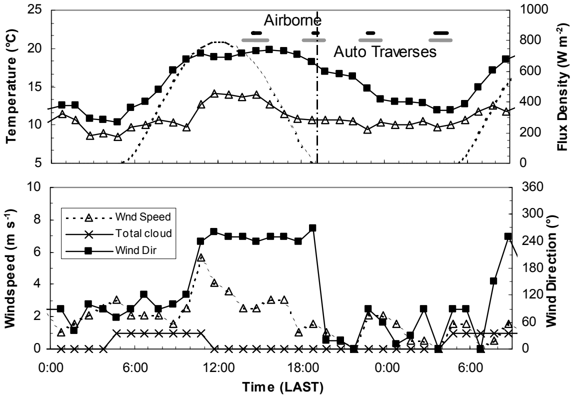

Figure 1. General meteorological conditions during the study period.

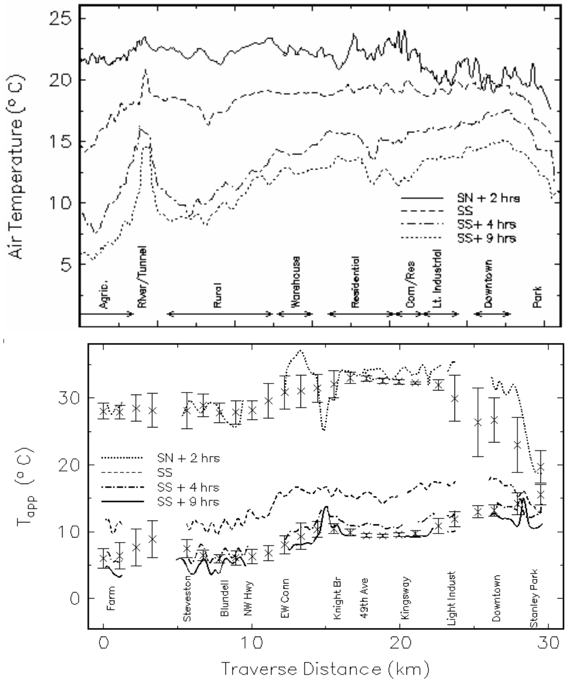

Figure 2. Cross-section of the Vancouver urban heat island derived from vehicle traverses of air temperature (top) and surface brightness temperature (bottom).

Our ability to describe in detail the physical structure of urban surfaces has advanced slowly. The canopy architecture of vegetated surfaces has received detailed attention and techniques have been developed to extract surface structural parameters using remote sensing. In contrast, urban surface morphology, while subject to detailed inventories of land cover has only

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* Corresponding author address: James A. Voogt, Dept. of Geography, University of Western Ontario, London ON N6A 5C2 Canada; e-mail: javoogt@uwo.ca

recently been assessed quantitatively, largely through morphometric analysis related to studies of wind flow intend to characterize the aerodynamic roughness of urban surfaces. Particularly lacking is an ability to describe the combination of built and vegetative elements that make up the urban surface. Urban surfaces are typically represented at small scales as regular combinations of rectangular bluff-body elements. These ignore significant small scale complexity such as pitched roofs, and variable building height and often completely ignore urban vegetation. Plane-parallel vegetation canopies and regular geometric urban surfaces form the end-members of a spectrum of surface types; more realistic urban surface representations need to include elements of both.

Advances in these areas are likely to draw from significant increases in capability afforded by digital hemispherical photography for assessing the view factors of urban surfaces and the combined use of remote sensing and GIS techniques to better characterize the structure of the urban surface.

Some progress has been made on the assessment of urban surfaces as viewed by a remote sensor through the use of sensor view models (e.g. Soux *et al.*, 2000) that advance our understanding beyond the basic conceptual description given by Roth *et al.* (1989). Even so such models typically represent the buildings as block-like elements on a plane surface and therefore constitute a rather crude approximation to the actual complexity of urban surfaces. Development and application of sensor view models is more advanced for agricultural and forested surfaces where better information on the structural attributes of vegetation canopies is available.

4.2 Sensor-derived vs actual surface temperatures.

The three-dimensional nature of the urban surface combined with solar and sensor geometry implies that: a) the urban surface will contain strong microscale temperature patterns influenced by the relative orientation of the urban surface facet to the sun (or, at night to the sky) as well as by the thermal properties of urban surfaces that may also vary with urban surface position and orientation; b) a biased view of the urban surface is ensured when remote sensors are used to view a three-dimensionally rough surface. Together, these properties lead to an effective anisotropy of the upwelling longwave radiation from the urban surface.

The few available observations indicate that urban areas are characterized by significant effective thermal anisotropy that ranks them high relative to other surfaces. Nadir remote views of the urban surface may yield temperatures that are warmer or cooler than off-nadir views, depending on the view direction relative to solar geometry. Observations indicate that anisotropy remains surprisingly strong in residential areas characterized by relatively low building height and large amounts of vegetation. In these areas, the microscale structure of some urban surfaces, especially peaked roofs and the anisotropy created due to shading patterns by a fairly sparse canopy of trees may be influencing factors. Confirmation awaits studies that examine a greater range of urban surfaces that incorporate a range of vegetative canopy structures, and/or modelling studies.

Directional effects of urban effective thermal anisotropy are complicated by uncertainty in urban surface emissivities. Advances in the separation of land surface temperature and emissivity effects using multi-channel approaches may generate improved urban surface emissivity estimates, although the assumptions inherent in the methods may be restrictive over urban areas where small scale heterogeneity is strong.

Models of thermal anisotropy have been applied to a range of vegetated surface covers. A model intended to simulate simple, non-vegetated urban surfaces has recently been proposed (Soux *et al.*, 2000); sample results for the time of the afternoon heat island traverse are shown in Figure 3. Such models may contribute to the assessment of effective urban thermal anisotropy and in developing our ability to normalize directional temperature observations, to predict directional behaviour of a variety of urbanized surfaces and to calculate integrated hemispherical values for a surface to supplement the limited angular sampling of remote sensors (e.g. Otterman *et al.*, 1995).

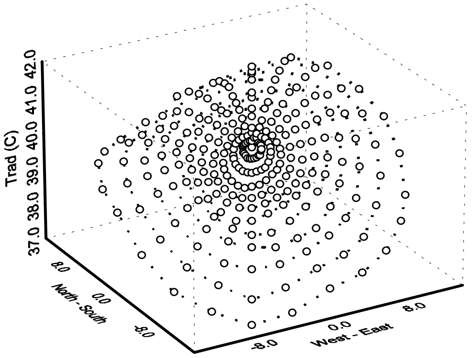

Figure 3. Modelled directional brightness temperatures illustrating the effective thermal anisotropy over a light industrial area in Vancouver during the time of the afternoon heat island transect. Plotting coordinates converted from the sensor viewing direction and angle.

5. REFERENCES

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