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Impact of 3-D Structures and Their Radiation on Thermal Infrared Measurements in Urban Areas

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***Abstract*— Land surface temperature (LST) is a key parameter for many fields of study. Currently, LST retrieved from satellite thermal infrared (TIR) measurements is attainable with an accuracy of about 1 K for most natural flat surfaces. However, over urban areas, TIR measurements are influenced by 3-D structures and their radiation that could degrade the performance of existing LST retrieval algorithms. Therefore, quantitative models are needed to investigate such impact. Current 3-D radiative transfer models are generally based on time-consuming numerical integrations whose solutions are not analytical, and are therefore difficult to exploit in the methods of physical retrieval of LST in urban areas. This article proposes an analytical TIR radiative transfer model over urban (ATIMOU) areas that considers the impact of 3-D structures and their radiation. The magnitude of this impact on TIR measurements is investigated in detail, using ATIMOU, under various conditions. Simulations show that failure to acknowledge this impact can potentially introduce a 1.87-K bias to the ground brightness temperature for street canyon whose ratio "wall height/road width" is 2, wall and road temperature is 300 K, wall emissivity is 0.906, and road emissivity is 0.950. This bias reaches 4.60 K if road emissivity decreases to 0.921, and road temperature decreases to 260 K. ATIMOU is also compared to the discrete anisotropic radiative transfer (DART) model. Small mean absolute error of 0.10 K was found between the models regarding the simulated ground brightness temperatures, indicating that ATIMOU is in good agreement with DART.**

***Index Terms*— 3-D, land surface temperature (LST), radiative transfer, thermal infrared (TIR), urban areas.**

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I. Introduction

LAND surface temperature (LST) is one of the most important Earth surface parameters, as it is the key factor affecting the energy balance of the Earth and is required by studies of global warming, evaporation, and urban heat islands [1]–[5]. Thermal infrared (TIR) remote sensing provides a suitable and efficient way to obtain accurate LST information from the Earth's surface. Regional and global LST may be obtained, based on TIR measurements, using existing LST retrieval algorithms. After decades of improvement, various types of LST retrieval algorithms have been developed [5]–[8] and have achieved great success for natural flat surfaces [9]–[15]. However, in urban areas, 3-D structures and their radiation affect satellite TIR measurements, especially in high spatial resolution images [16], [17], because the observed radiance would increase due to the radiation of the surroundings and reflections inside 3-D structures; the observed signal would be anisotropic through various viewing angles. Consequently, the performance of existing LST retrieval algorithms may deteriorate significantly if this impact is not well addressed in observed signals. Therefore, quantitative models are needed to investigate the impact of 3-D structures and their radiation on TIR measurements in urban areas.

To understand the anisotropic thermal behavior of urban areas, a number of previous researches have studied the 3-D surface modeling. Johnson *et al*. [18] proposed the surface heat island model (SHIM) to address the effects of building 3-D geometries. Voogt [19] developed a model to estimate the observed radiance in urban areas by considering five components: roof, sunlit and shadowed ground, sunlit and shadowed walls. Later, Krayenhoff and Voogt [20] proposed a more detailed model—temperatures of urban facets in 3-D (TUF-3D)—to study urban surface temperatures for a variety of surface geometries and properties. In their model, buildings were divided into cubic cells and internal building temperature was also considered. These three models are excellent thermal tools with which to estimate energy balance and study urban climate [21]; however, they do not allow for analysis of the dominating factors that impact satellite-observed TIR signals at the sensor level in detail [16]. Gastellu-Etchegorry *et al*. [22], [23] and Guillevic and Gastellu-Etchegorry [24] extended the discrete anisotropic radiative transfer (DART) model to the TIR region, providing a modified model capable of simulating the sensor-observed TIR spectral radiance of 3-D scenes. Although the current version of DART