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Parameterization of net radiation in an arid city of northwestern Mexico

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RESUMEN

La urbanización, al cambiar las propiedades de la superficie, modifica de manera sensible el balance de radiación y con ello el clima citadino, por lo que se propuso cuantificar ese balance en diferentes coberturas superficiales para varios días del mes de agosto de 2011 en una ciudad árida del noroeste de México. Se estimó el albedo de cada superficie y algunas otras propiedades de la atmósfera local, como el índice de claridad atmosférica (K_0) y la emisividad atmosférica (ε_{atm}). Las superficies en las que se realizaron las mediciones fueron asfalto, concreto, poliestireno con pintura elastomérica blanca (PPEB), arcilla y césped. Se encontró que para un ciclo de 24 h de medición, el mayor valor promedio de radiación neta fue para el asfalto (146.1 Wm^{-2}), y el menor valor promedio para el PPEB (33.6 Wm^{-2}). Los valores estimados de albedo varían de acuerdo con la superficie, mientras que los de K_0 y ε_{atm} dependen de las condiciones atmosféricas prevalentes. A partir de las mediciones se propusieron modelos estadísticos preliminares de la radiación neta en función de la radiación solar entrante y la radiación neta de onda corta, encontrándose en todos los casos coeficientes de determinación superiores a 0.97. Se analizan las probables implicaciones de los resultados encontrados en el medio urbanizado.

ABSTRACT

During the process of urbanization, different surface properties significantly alter the radiation balance. This paper attempts to quantify this balance over different surface types in an arid city of northwest Mexico over several days in August 2011. The albedo of each surface type, as well as local atmospheric properties such as the atmospheric clearness index (K_0) and atmospheric emissivity (ε_{atm}), were estimated. The surfaces on which measurements were performed were asphalt, concrete, polystyrene painted with white elastomeric paint (PWEP), clay, and grass. It was found that, for a 24-h cycle of measurement, the highest average value of net radiation was for asphalt (146.1 Wm^{-2}), and the lowest average value was for PWEP (33.6 Wm^{-2}). Estimates of albedo values vary depending on the surface, whereas K_0 and ε_{atm} are dependent on prevailing atmospheric conditions. From these measurements, preliminary statistical models of net radiation as a function of incoming solar radiation and net shortwave radiation were proposed. For each model, the coefficients of determination were higher than 0.97. We discuss the likely implications of the results found for the urban planning of the city.

Keywords: Radiation balance, net radiation, shortwave radiation, longwave radiation, albedo, atmospheric emissivity, atmospheric clearness index.

1. Introduction

Net radiation is a fundamental driver of climate in the lower layers of the atmosphere, and its effects depend on both the structure and composition of the atmosphere and the presence of clouds, in addition to surface characteristics such as albedo, emissivity, temperature, moisture and the thermal properties of underlying soil (Kessler and Jaeger, 1999). It is also the driving force for many physical, dynamic, and biological processes, including warming of the soil and air, photosynthesis, and evapotranspiration, the latter being important for the quality and yield of crops and the planning of water resources (Bennie *et al.*, 2008; Ji *et al.*, 2009; Li *et al.*, 2009; Geraldo-Ferreira *et al.*, 2011; Ayoola, 2014).

Net radiation is also important in studies of surface energy balance, where its magnitude is mainly related to sensible and latent heat flux (Kalthoff *et al.*, 2006). The relationship between radiation and surface energy balance is important for understanding urban climates (or microclimates) caused by varying surface types (Arnfield, 2003). The spatial heterogeneity of urban landscapes leads to a non-uniform transmission and distribution of energy radiation. Because the urban area is a complex physical interface, the thermodynamic and kinetic properties of the underlying surface may be substantially changed by modifying the physical characteristics of that surface (Wang and Gong, 2010; Cui *et al.*, 2012). These factors result in cities that have unique climatic characteristics.

Many previous studies have examined rural-urban radiation differences using climate models, models of terrestrial ecosystems, or computational fluid dynamics models. However, these studies have combined the radiation differences produced by the heterogeneity of the urban landscape, making it difficult to explain the energy transformation from different surfaces and to accurately simulate micro-climatic characteristics within a city (Groleau and Mestayer, 2013). In addition, due to the variety of factors involved, observations from weather stations cannot effectively distinguish the effects of underlying surfaces on components of the radiation balance (White *et al.*, 1978; Christen and Vogt, 2004). Despite its importance, net radiation is measured at a limited number of standard meteorological stations because net radiometers are expensive instruments and require constant care in the field. Therefore, to gain a better understanding of the effects that different horizontal surfaces have on radiation balance and the subsequent effect on the surrounding environment, an experimental campaign was conducted in Mexicali, an arid city in northwest Mexico, on five different surface materials. Using measurements gathered from this study, we postulated preliminary statistical models of net radiation as a function of incoming solar radiation and net shortwave radiation, as well as estimates of biophysical characteristics such as albedo, atmospheric clearness index, and atmospheric emissivity. The implications of the results on urban planning are discussed.

2. Methodology

In the following section, we discuss the procedures and materials used during this study, including the experiment site and its construction, mathematical models used to estimate biophysical properties, and the theoretical background regarding net radiation models.

2.1 Experimental campaign

The experiments were conducted at the Engineering Institute of the Autonomous University of Baja California, located on a campus in Mexicali, Mexico (32.6º N, 115.5º W, 12 masl). Mexicali has a dry, arid climate with extremely hot summers and cold winters and is one of the hottest cities in Mexico, with average maximum temperatures in August of 42 ºC. Mexicali receives 90% of the maximum potential hours of daylight each year and a mean annual rainfall of approximately 75 mm (García-Cueto and Santillán-Soto, 2012).

Radiation balance data and weather information were collected by the staff of Applied Climatology. Observation equipment was installed on the roof of the Engineering Institute. The study area contained mixed-use land, but the experimental design allowed us to measure the relevance of each surface. A wooden drawer with dimensions of 1 × 1 × 0.55 m was placed on a platform 1.5 m away from the roof of the building. The drawer was pre-filled with native soil and overlaid with the following surfaces: asphalt, concrete, polystyrene with white elastomeric paint (PWEP), clay, and grass. At a height of 0.20 m from each surface, an NR01 radiometer (Hukseflux Thermal Sensors), which measures four components