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Simple statistical models of surface/atmosphere energy fluxes and their hysteresis in a desertic Mexican city (Mexicali)

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RESUMEN

Se proponen modelos estadísticos para componentes del balance de energía superficie-atmósfera (radiación neta, calor sensible y calor almacenado en el suelo) como funciones de la radiación global. El presente estudio se llevó a cabo a lo largo de tres estaciones del año (invierno, primavera y verano) en Mexicali, una ciudad árida del noroeste de México, mediante campañas representativas de medición en tres tipos de uso del suelo en el área de estudio: urbano, rural (desértico) y suburbano cultivado. El patrón de histéresis en los modelos propuestos, entre la radiación global y la neta se encontró en verano en sitios urbanos y suburbanos, lo que al parecer se debe a la humedad atmosférica ocasionada por la irrigación artificial y la inercia térmica de la cubierta vegetal. Para evaluar la calidad de los modelos se utilizaron el coeficiente de determinación (R^2) y el error cuadrático medio.

ABSTRACT

Statistical models for surface-atmosphere energy balance components (net radiation, sensible heat, and soil-stored heat) as functions of global radiation are proposed. This study was carried out during three seasons (winter, spring, and summer) in Mexicali, an arid city of northwest México, by means of representative measurement campaigns of three types of land use in the study zone: urban, rural (desert), and farmed suburban. The hysteresis pattern in the proposed models between the global radiation and net radiation was found during summer at suburban and urban sites, which seems to be originated by atmospheric moisture introduced by artificial irrigation and the thermal inertia of land cover. The coefficient of determination (R^2) and the mean square error are used as indicators of the quality of models.

Keywords: Statistical models, energy balance components, hysteresis.

1. Introduction

Urbanization produces important changes in the surface and atmospheric local conditions because transformations of the radiative, thermal, hydrologic, and aerodynamic characteristics affect the natural hydrologic and solar energy balances (Oke, 1987). The radiation budget at the surface/atmosphere interface can be expressed in the following way:

$$Q^* = (Q_s\downarrow + Q_l\downarrow) - (Q_s\uparrow + Q_l\uparrow) = Q_g - (Q_s\uparrow + Q_l\uparrow) \quad (1)$$

where Q^* is the net all-wave radiation resulting from the incoming solar radiation (short and long-wave, $Q_s\downarrow + Q_l\downarrow$) or global radiation, minus the outgoing short and long-wave radiation ($Q_s\uparrow + Q_l\uparrow$).

The net all-wave radiation flux is not only the end result of the radiation budget but also the basic input to the surface energy balance (Oke, 1987), which is expressed as:

$$Q^* = Q_H + Q_E + Q_s \quad (2)$$

where Q_H and Q_E are convective fluxes to or from the atmosphere, called sensible and latent, respectively; and Q_S is referred as the conduction to or from the underlying soil.

The turbulent fluxes of sensible and latent heat of evaporation are responsible for the warming and moistening, respectively, of the atmosphere from the surface up to a height of approximately 100 meters during the day, except in situations of deep convection when the effect extends to greater altitudes. The flux in the soil penetrates only a few centimeters deep (Focken, 2008).

Energy balance measurements in the surface atmospheric boundary layer are scarce in arid environments, as featured by Chow *et al.* (2014) for Phoenix, Arizona, 330 km east-northeast of Mexicali, and by Offerle *et al.* (2005), who evaluated the balance at city and building levels for Ouagadougou, Burkina Faso, in west Sahel. In the later site, the net all-wave radiation increased with urbanization because of the higher albedo, lower heat capacity, and thermal conductivity of the bare soil compared to the urbanized surface in residential zones, despite the decrease in albedo in the urban center caused by the materials and geometry of the buildings. As a result, the surface temperatures of bare undisturbed soil could exceed the surface temperatures in the residential area and urban center by 15-20 ºC. The turbulent heat exchange measured over a residential area was dominated by sensible heat flux.

For both cities, Ouagadougou (Offerle *et al.*, 2005) and Phoenix (Chow *et al.*, 2014), latent heat fluxes were greater than expected from vegetated areas, which in accordance with water use were primarily irrigated.

Similar to the studies of Mexico City (Tejeda and Jáuregui, 2005, for example), the present work follows the hypothesis that vertical fluxes of sensible and latent heat are turbulent in nature and that the global radiation is distributed uniformly in the study area, which is true for homogenous sky conditions such as a desertic environment (Mexicali and its surroundings). In Mexico City, Velasco *et al.* (2011) also made observations of the energy balance components in a residential and commercial neighborhood to evaluate the parameterizations and understand the energy balance partitions in tropical urban environments. They found that the largest differences between the modeled and observed fluxes corresponded to incoming long-wave radiation because of errors in cloudiness data, which are inputs to the models.

The objective of this paper is the empirical modeling of the energy balance components (Q^*, Q_H, and Q_S) as functions of the global radiation for three different types of land use in the city of Mexicali and its surroundings (32.6º N, 115.5º W, 10 masl): urban (Engineering Institute of the Autonomous University of Baja California), farmed suburban (Campestre), and rural (Villa Zapata).

Some estimation models presented hysteresis, i.e., the dependent variables (energy balance components) exhibited one behavior when the independent variable (global radiation) was increasing and a different behavior when it was decreasing, thus completing a sort of ellipse between explained and explanatory variables. The presence of hysteresis was detected in the data from the Campestre zone during the summer, when it was found that in the time from daybreak until midday, the relationship between global radiation and net radiation and the other components of the energy-balance behaved differently than from midday to daybreak (see section 4). For this reason, it was necessary to divide the model into two parts to describe the behavior of the phenomenon, as presented