Modeling CAP-LTER Flux Tower Measurements using an Advanced Urban Canopy Model

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1. Introduction

According to the United Nations, more than 50% of the world's populations are currently living in cities. Being humanity's engine of creativity, wealth production and economic growth, rapid urbanization has emerged as the source of many adverse urban environmental problems due to rapidly growing anthropogenic stresses such as the heat island effect, emissions of greenhouse gases, production of pollutants, etc.

Last decade has seen increasing research efforts devoted to parameterize urban surface energy exchange processes that hold a key to solving the environmental problems. Among these models, the Arizona Single Layer Urban Model (ASLUM) we developed here is capable of predicting surface energy budget partitioning, facet and soil temperatures, and volumetric soil moisture profiles for a variety of urban land cover types.

ASLUM is a "state-of-the-art" urban canopy model that features: (1) an improved resolution of urban facet (roofs, walls, or roads) heterogeneity; (2) an analytically-tractable algorithm for heat conduction in building envelops and soils; and (3) a built-in urban hydrological model for realistic prediction of evapotranspiration process.

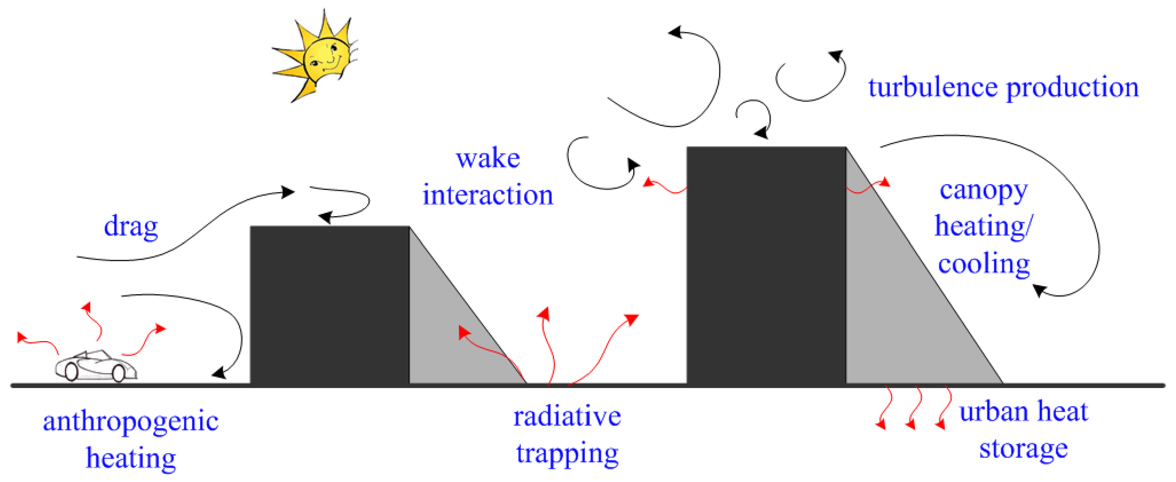
2. Arizona Single Layer Urban Model (ASLUM)

2.1 Urban Energy module in ASLUM

The energy balance equation for the whole atmospheric layer is given by:

$$R_n + H_F = H + LE + G$$

Here, R_n is the net radiation, H_F is the anthropogenic heat flux, H, LE and G are the sensible, latent and conductive heat fluxes respectively.



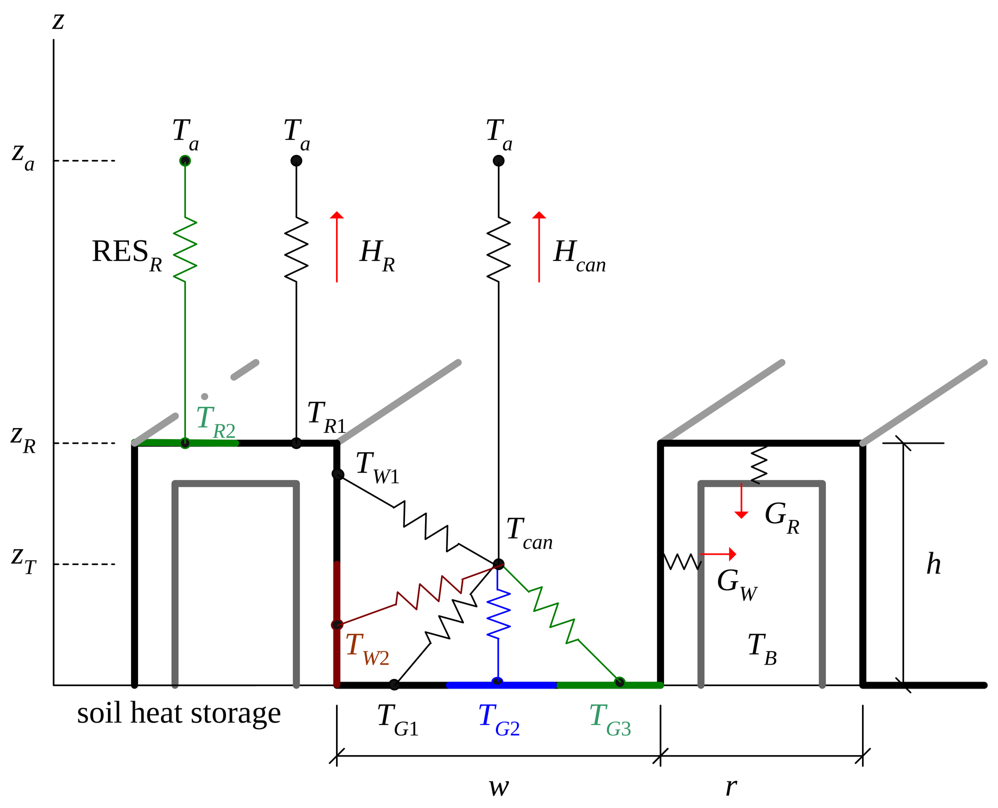


Fig.1 Schematic energy module in ASLUM

ASLUM adopts the most common single-layer "canyon" representation for urban areas and further divides each urban facet into different material types to incorporate the surface heterogeneity, as shown in Fig.1. For instance, ground surfaces may contain asphalt, concrete pavement and lawns or green turfs; wall materials can be a mixture of brick and glass; roofs include conventional, white or green covers.

Driven by atmospheric forcing including air temperature, pressure, humidity, wind speed and downwelling shortwave / longwave radiation, the ASLUM can provide us radiation budgets, predict turbulent heat fluxes (H and LE), and reproduce surface temperatures and conductive heat fluxes (G).

2.2 Urban hydrological module in ASLUM

(1) For natural surfaces

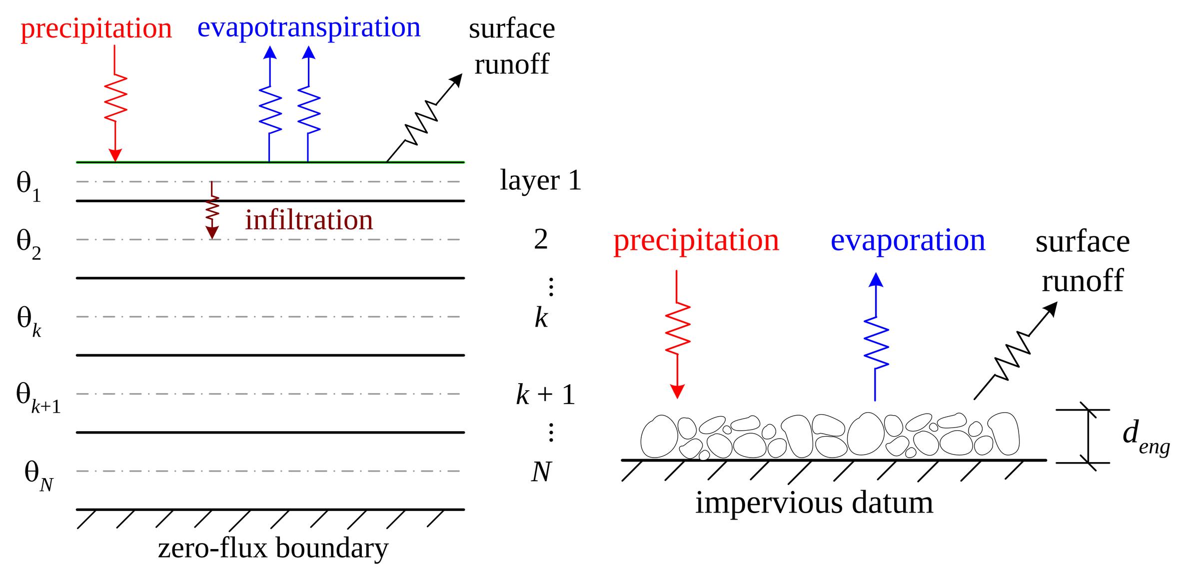
The soil depth has been divided into discrete layers as shown in Fig. 2(a). The prognostic equation for the volumetric soil-moisture content θ_{nat} is given by the one-dimensional vertical diffusive form of the Richards equation, derived from Darcy's law:

$$\frac{\partial \theta_{nat}}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\partial \theta_{nat}}{\partial z} + K + F_\theta\right)$$

(2) For engineered pavements

It is assumed that there exists a water-holding layer above the impervious datum, as shown in Fig. 2(b). The prognostic equation for the actual depth of retention δ_w can be written as:

$$\phi_{eng}\frac{\partial \delta_w}{\partial t} = \begin{cases} P - E_p, & \text{if } \delta_w < d_w \\ 0, & \text{if } \delta_w \ge d_w \end{cases}$$



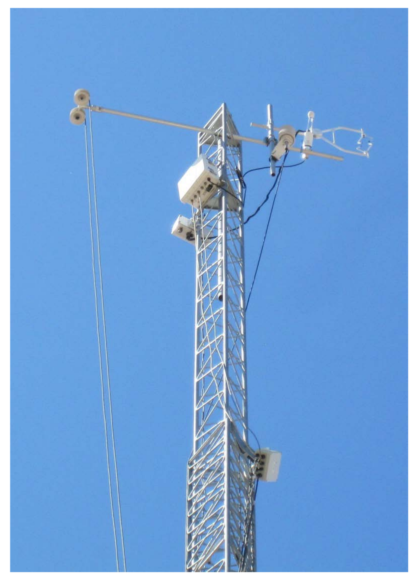
a. Natural surfaces b. Engineered pavements

Fig.2 Schematic hydrological module in ASLUM

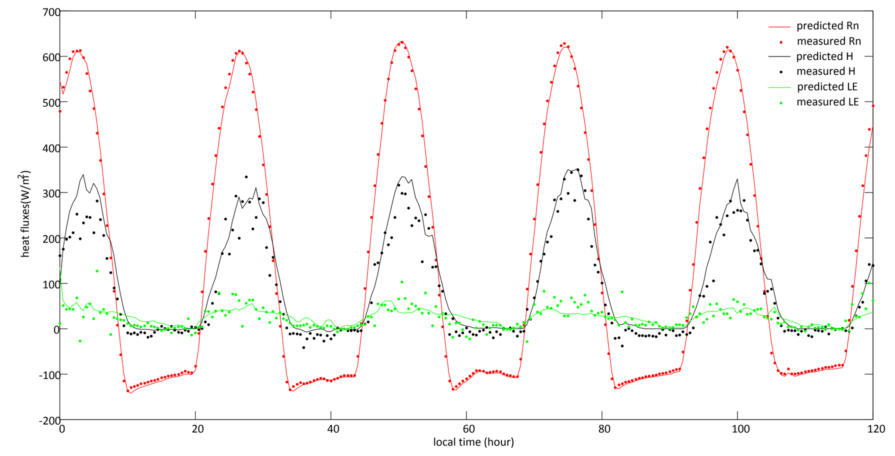
Here, ϕ_{eng} is the surface porosity of engineered materials; E_p is the potential evaporation rate; and d_w is the maximum water-holding depth of an engineered sub-facet.

3. Results

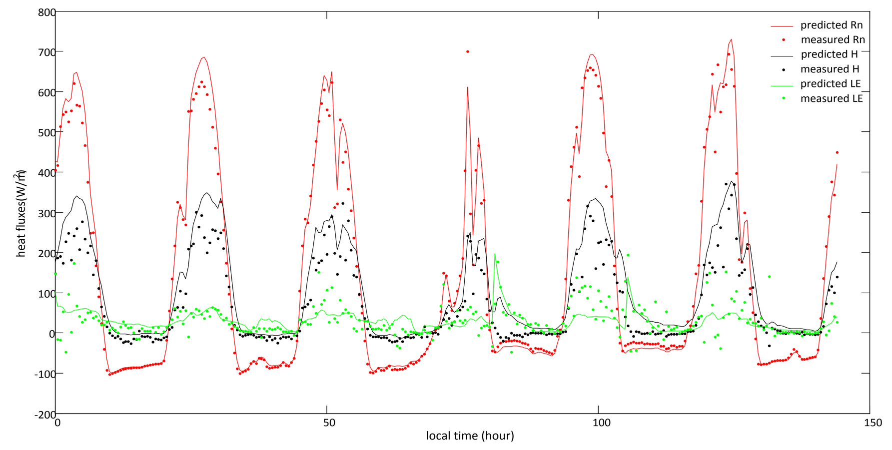
(1) Net radiation and turbulent heat fluxes predictions at CAP-LTER flux tower site in West Phoenix



CAP-LTER tower



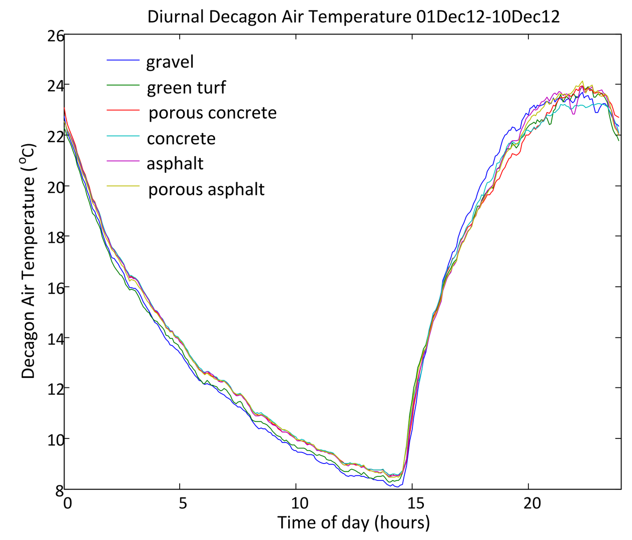
Pre-monsoon season

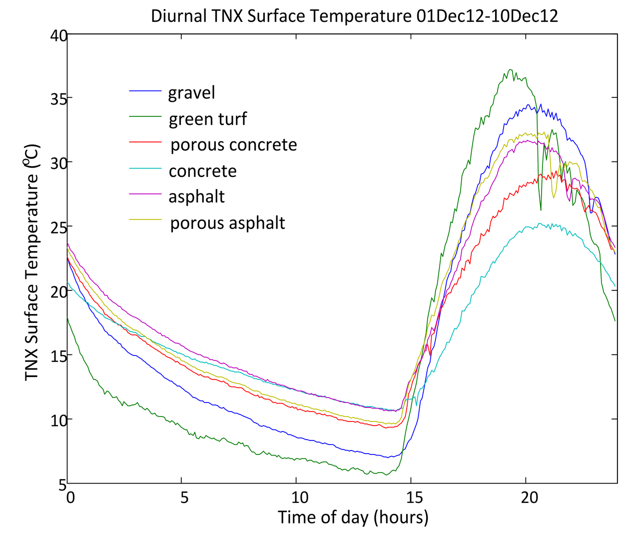


Monsoon season

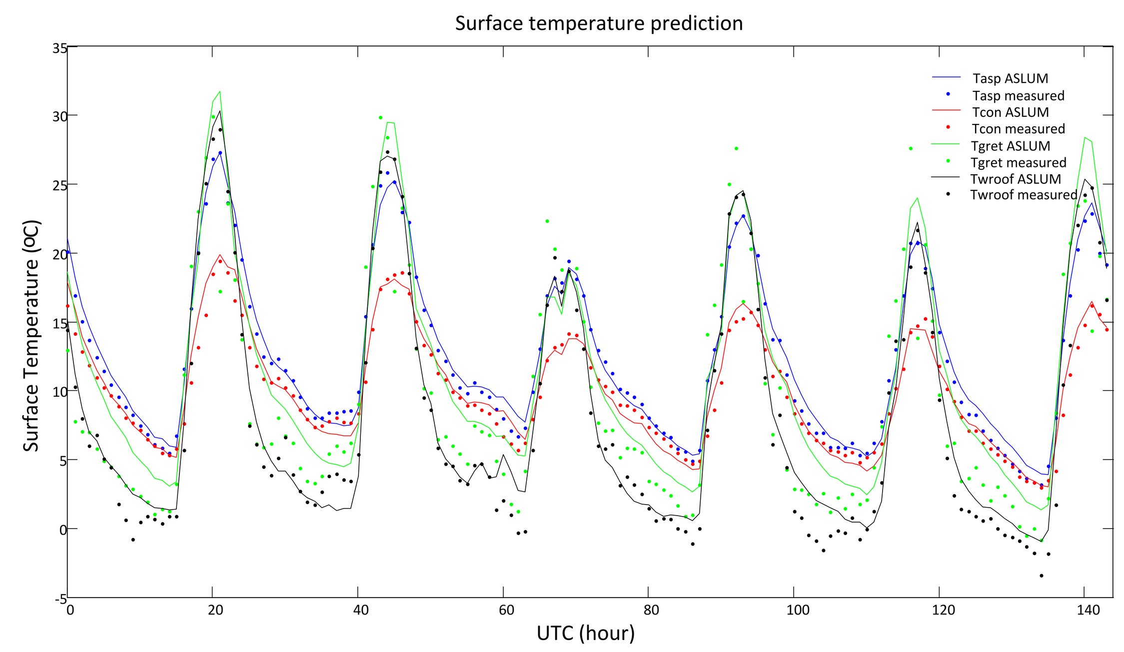
(2) Heterogeneous ground surface temperature predictions at experiment sites near ASU in Tempe

Experiment site near ASU





ASU's CSB roof (white roof)



4. Summary & Perspective

- In this study, we applied ASLUM to simulate the field measurements of surface energy budgets obtained by the CAP-LTER eddy covariance tower at the Maryvale site in West Phoenix for both pre-monsoon and monsoon seasons. In addition, model predictions are compared with a wireless sensor network measurement of surface temperature for different pavement types (concrete, asphalt, and green turf). Results of comparison show a good agreement between the model predictions and the field measurements, indicating that ASLUM is a useful numerical tool for capturing surface energy and water exchange in urban areas.
- The framework of urban structure in this work is regarded as a "street canyon" which considers a single road bordered by facing buildings. For further study, ASLUM based on canyon concept will be coupled into WRF to predict regional scale urban climatology. In that way, the radiation budgets and turbulent heat fluxes for the metropolitan Phoenix could be predicted, which will provide significant guidance for urban meteorological and ecohydrological services under future climate challenges.

References:

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