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A new urban soil model for SOLENE-microclimat: Review, sensitivity analysis and validation on a car park

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ABSTRACT

The main purpose of this study is to evaluate an urban soil model that will accurately reproduce the heat flux into urban soil, which has an influence on the urban heat island effect, for typical urban land use such as a car park. After a complete literature review, a sensitivity study is carried out on a large number of parameters: material properties, layer size, deep boundary condition, and convective heat transfer coefficient. The model's ability to reproduce heat conduction transfer is validated via a measurement campaign performed on an asphalt car park during hot days. The mean daily RMSE between estimated and observed surface temperature is 0.86°C, and 0.72°C, 0.58°C, 0.26°C and 0.13°C respectively at 5 cm-, 10 cm-, 34 cm- and 50 cm-depths. Performances obtained using different node distributions are discussed and compared with results from the literature. The model is more efficient than most of the other models applied under similar conditions. Finally, application of the proposed model on a yearly basis demonstrates that the accuracy loss caused by the decrease in the number of nodes is higher for clear and sunny days.

1. Introduction

In conditions of global warming, the development of cities must be carried out considering the urban heat island (UHI) phenomenon (Oke, 2002) as a serious environmental issue. This phenomenon has several consequences on outside comfort and on building energy needs. In order to mitigate the UHI, it is necessary to identify its causes and to quantify the impact of mitigation solutions. Measurements campaigns are useful to evaluate the UHI, but linking it to the influence of modifications in urban form or urban planning choices is quite tricky.

For this purpose, numerical simulation is a powerful tool. Several models under development simulate the UHI phenomenon and its consequences. Different scales are considered, depending on the application intended: for example TEB (Masson, 2000) or ARPS-VUC (Tavares et al., 2015) are more suitable for city-scale applications while models like SOLENE-microclimat (Bouyer, 2009), Envi-met (Yang et al., 2013) and EnviBatE (Gros, 2013) are more appropriate for the district scale.

For a given scale, each tool may have one specific feature among many others: EnviBatE (Gros, 2013) is designed to study the energy demand of a group of buildings, SOLENE-microclimat (Bouyer, 2009) focuses on outdoor comfort and on the impact of urban

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climate on indoor comfort, and ENVImet (Yang et al., 2013) is dedicated to outdoor comfort.

All those models have in common the fact that they represent several physical mechanisms: radiative fluxes, thermal fluxes and fluid dynamics. Furthermore, the representation of these phenomena is essential to accurately calculate the soil surface temperature, which is the key to the interaction between the soil and the urban environment (radiative and sensible fluxes). The heat flux stored and released by urban material respectively during day- and night-time is one of the main causes of UHI development. This heat flux is greater in urban than in rural areas due to the high inertia of the materials used. The simulation of heat transfer in facades and in the soil are therefore of the highest importance.

Consequently, there is a need to enhance the ability of urban soil models to simulate heat fluxes in complex heterogeneous urban contexts. The SOLENE-microclimat model (whose efficiency has already been proven) is being developed and validated to answer this need. It is a complex model made up of several modules (Musy et al., 2015), implying that validation should be performed on each module individually. This article presents one of these validation steps.

The main purpose of this article is to modify and validate the existing SOLENE-microclimat soil model. The modifications are based on a review of the literature and on a sensitivity analysis. Validation is performed using temperature and flux measurement carried out on an open car park.

The open space is chosen to get away from the constraints of an urban environment: diffuse and reflected solar radiation depending on masks, the albedo of the surrounding surfaces, long-wave radiation exchanges with surrounding surfaces, etc.

As the accuracy of the model is often linked to its numerical cost, the additional aim of this study is to develop optimized discretization in order to reach a compromise between accuracy loss and computational efficiency.

The results of the study are divided into three parts:

- Sensitivity study on model parameters,
- Model validation using a centimetric grid in order to evaluate the model's ability to reproduce conductive heat transfer into the soil,
- Calculation of the accuracy loss caused by different node distributions.

The model's performance is then compared to that of models identified in the literature. Finally, performance is analysed for a whole year of simulation.

This exhaustive study provides accurate information about the reliability of the SOLENE-microclimat soil model.

2. State of the art

2.1. Existing models

In the literature on microclimate models, soil representation is rarely fully described. However, soil models are also used in other fields such as:

- Geothermal energy applications,
- Road applications: pavement sustainability or frost forecasts,
- Hydrology and interaction between soil, vegetation, and atmosphere.

Those other domains have the advantage of proposing a different point of view on the way to model heat transfer in the ground. In Table 1 the articles used for the following literature review are shown together with the characteristics of the soil models.

Even though the field of application is different, all the articles presented have the common objective of predicting surface temperature or ground heat flux. Depending on the application, the physical mechanisms modelled are not the same. In addition to conductive heat flux, moisture flow is often modelled. This is the case for several applications that use bare-soil and vegetation covers (Qin et al., 2002; Saito and Simunek, 2009; Herb et al., 2008; Asaeda and Ca, 1993). This is useful to estimate the water availability for vegetation or to adjust the thermal properties of the soil depending on humidity content. Nevertheless, for impervious surfaces, moisture flux is mostly neglected (Herb et al., 2008).

The soil model presented in this paper is designed for an impervious surface in an urban environment. Urban grounds are heterogeneous and made up of different layers characterized by large differences in their physical properties. The model must therefore be able to take several layers into account. In the literature, soil is modelled by either a homogeneous or a heterogeneous column. But for a given area, the size of each layer and its physical properties are not accurately known. By simplification, half of the soil models presented here consider a homogeneous column of soil (Table 1). Nevertheless, in order to accurately simulate the conduction flux all along the vertical axis, the soil profile should be consistent with reality, which implies considering a heterogeneous soil.

Thermal properties are either set to experimental data (i.e.: to better represent measurements the albedo is defined as the ratio between incident and reflected solar radiation), or calibrated.

However, the impact of thermal properties has rarely been investigated. Best (1998) and Herb et al. (2008) studied the influence of material characteristics (diffusivity, specific heat, etc.) on surface temperature. According to Best (1998) and Herb et al. (2008), the emissivity and the thermal conductivity of the pavement have the most influence on surface temperature, while the characteristics of the soil underneath have little influence.