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A pavement-watering thermal model for SOLENE-microclimat: Development and evaluation

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ABSTRACT

In a dense urban area, pavement watering could be a solution to mitigate the Urban Heat Island. So far, mainly experimental studies have been used to evaluate watering techniques. In this study, a soil model dedicated to pavement watering has been developed within the urban climate model SOLENE-microclimat. This watering model is presented and evaluated via a measurement campaign performed on an asphalt car park during warm days. The measurement campaign reveals that the surface cooling is mainly due to evaporation (80%). However, under warm conditions, the heat flux exchanged between the runoff water and the surface should also be modelled. Indeed, watering events are modelled through a runoff convective heat flux and a latent heat flux. The mean daily RMSE between estimated and observed surface temperature is 1.04°C, 0.86°C, 0.66°C, 0.35°C and 0.21°C respectively at the surface, 5 cm-, 10 cm-, 34 cm- and 50 cm-depths.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) assessed that heatwaves will be more frequent and more intense during the 21*st* century than during the 20*th* century. The last major European heatwaves led to approximately 70,000 excess deaths across the continent (Robine et al., 2008). The urban heat island (UHI) effect exacerbates the consequences of such climatic event on human health, as confirmed by Laaidi et al. (2012) and Conti et al. (2005) who showed a clear relationship between UHI and mortality in Paris and in Italian cities respectively. Reducing the UHI is then a major challenge addressed to the scientific community. Several countermeasures are currently investigated in all regions of the world and under different climates. Santamouris et al. (2017) reviewed the performances of the most common UHI mitigation technologies: building material albedo, vegetation, water. He concludes that UHI may be partly or fully annihilated using a combination of all technologies but that there is a need to improve the performances of each of them. The present article focuses on the pavement watering solutions. Regardless of the technique used to spread the water (cleaning trucks - Hendel et al., 2015b - or sprinklers set in the street structure - Himeno et al., 2010), the correct modelling of the physical phenomenon induced by this technique and their interaction with local climate will help to improve its performances.

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1.1. Watering techniques

In very dense urban areas, the UHI may be mitigated by spreading water over pavements. The evaporation of the water in the air and the heat flux exchanged between the water and the ground contribute to cool both the surface and the air temperature. It also induces an increase of the air humidity. Yang and Zhao (2015) investigated the effect of different surfaces (water ponds, low vegetation, asphalt) on the air temperature and humidity through an experimental work realised under hot climate conditions. They measured humidity and air temperature gradients over the different studied surfaces. If they can measure high differences over the specific humidity variable close to the ground, these differences strongly decrease with the height. At 1.2 m high, the profiles are similar, even with low air velocities. As a result, impact of watering on air humidity should not alter the effect obtained thanks to the lower surface temperature.

Daniel et al. (2018) confirmed that watering mainly limits the warming of the urban surface, reducing their infrared emissions. They found that watering techniques have a positive impact on human comfort. The used index comfort (UTCI) may be increased by the humidity but it is also decreased by the air temperature and mainly by the surface temperature. Finally Broadbent et al. (2017) showed that the average increase of vapour pressure did not have a negative influence on comfort under very hot and dry climate (South Australia during summer).

Under warm conditions, these processes offer a quick response while the water is spread over the surface. However, evaporation is constrained by the pavement water-holding capacity (which depends on the surface roughness). Below a certain volume of water spread, all the water is stored in the surface porosity and can evapourate. Above a threshold proper to the surface characteristics, the holding capacity of the surface is over-passed and the water excess runs off toward sewers.

Watering techniques have been mainly studied through experimental works (Hendel et al., 2015b; Himeno et al., 2010) which confirm the positive impact of watering techniques. Himeno et al. (2010) found that in the case of hot weather (above 30°C), pavement watering can reduce the air temperature by 2°C in the morning and 4°C in the afternoon. Hendel et al. (2015a) worked on the optimisation of those waterings, minimising the total amount of water spread, maximising the evaporation. With a watering rate of 0.31 to $0.41 L/m^2/h$ every 30 min, the surface temperature could be reduced by 4°C in the morning and 13°C in the afternoon. According to Broadbent et al. (2017), the performance assessment of watering techniques during heatwave conditions at the micro-scale has rarely been modelled. Daniel et al. (2018), Grossman-Clarke et al. (2010) and Broadbent et al. (2017) evaluated the mitigation potential of these techniques at the meso-scale.

1.2. Pavement watering in microclimatic models

In the literature, most of the models used to simulate the urban surface energy balance, calculate the latent heat flux induced by the vegetation (Grimmond et al., 2010). However, these models are not appropriate for pavement watering application since they do not consider the heat flux exchanged between the surface and the runoff water.

The Town Energy Balance (TEB) model (Masson, 2000) is one of the few urban climate models that is able to simulate pavement watering events (Daniel et al., 2018; Broadbent et al., 2017) at meso-scale. It distinguishes the evapotranspiration from the evaporation over impervious surfaces. In the case of impervious surface, the following processes are modelled: interception, evaporation of the available water and surface runoff. For each surface, a water reservoir is set according to the water holding capacity of the pavement and its content is updated at each time step. It is filled during a watering event and emptied by the evaporation. When the maximum capacity of the reservoir is reached, the excess is transferred to the sewer. By default, the pavement considered in the model is a road and its storage capacity is set at 1 mm (Daniel et al., 2018). However, this parameter is a variable of the model and then may be set to a different value (see Section 3.2.1).

The main purpose of this article is to present and evaluate a watering model that has been developed within the SOLENE-microclimat model. This microclimatic model is a research tool dedicated to urban climate modelling at the neighbourhood scale. It consists of several model pieces including a radiative model SOLENE, and several urban surfaces models (buildings, soils, vegetation...) which have been described and assessed in Malys (2012), Musy et al. (2015), Bouyer (2009). In this tool as in most of the microclimate tools (Grimmond et al., 2010), waterings over impervious surface could not be modelled.

The watering model is elaborated based on a review of the literature and evaluated on an open asphalt parking lot, chosen to avoid interference with other surfaces thermal behaviour, like solar radiation diffusion and reflection as well as long-wave emission from the surrounding vertical surfaces (building facades). In these conditions, we can isolate the watering model from the other SOLENE-microclimat model pieces and assess it properly. This article is the second step of a complete evaluation of SOLENE-microclimat soil model. Indeed in a previous article (Azam et al., 2017), the soil model has been assessed under same conditions.

The model is presented in Section 2. After a review of the different methods used to calculate each heat flux, the model equations are developed and the algorithm is sum-up in a flow-chart (Section 2.2.4). Section 3 deals with the model evaluation. The case study is first presented (Section 3.1). Based on those results assumptions previously made are verified. Results of the model are compared to the observed temperature and heat flux (Section 3.2). The model is evaluated on surface temperature and latent heat flux. Finally, the sensitivity of the model to the soil model node distribution is studied.

2. Method

The proposed watering pavement model will be an additional model piece to the soil model used in SOLENE-microclimat. The SOLENE-microclimat original soil model is briefly presented in Section 2.1 but further details are available in Azam et al. (2017).