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Conjugate soil-vegetation-air-radiation model for studying the environmental impact of porous media such as vegetation

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In this paper, a conjugate model is presented to evaluate the effect of vegetation on the surrounding environment. Vegetation intercepts solar radiation, providing shading to the ground, and offers natural cooling through evapotranspiration, cooling the air flowing through the vegetation. However, vegetation also slows down the air flow and its transpirative cooling potential is strongly dependent on the water availability in the soil. In order to accurately account for all these phenomena, the vegetation model should include airflow including momentum, heat, moisture, radiation and the water cycle in an integrated approach.

Vegetation, in this study a tree, is modeled as porous medium, including source/sink terms for heat, mass and momentum fluxes. A radiation model is developed to model the short-wave and long-wave radiative heat fluxes between the leaf surfaces and the surrounding environment as well as the extinction of radiation passing through the porous medium. The radiation model enables to model in detail the impact of the diurnal variations of solar intensity and direction, and the long-wave radiative fluxes between vegetation and nearby surfaces. A finite volume approach is applied to the discretization of the vegetation foliage where the leaves of the tree are aggregated into finite volumes. The heat and mass exchanges are determined from a leaf energy balance model applied foreach leave in the discrete volume. This enables a description of the heat and mass fluxes from vegetation with a realistic geometry and leaf density distribution. Furthermore, the transpiration process at the leaf surfaces is coupled to the water availability at the roots of the plants. For this, a full water cycle model for vegetation or conjugate soil-vegetation-air-radiation model is developed. The vegetation-air model is coupled with a soil model to capture the full water cycle. The vegetation is characterized in the soil using a root area density (RAD) distribution function, which provides sink terms of water uptake by the roots in the soil. The soil water transport model is coupled with the evapotranspiration at the leaves, taking into account the water transport within the tree.

In the present study, the influence of trees on the local climate in cities is studied using the developed vegetation model implemented in OpenFOAM. As an example, we quantify the influence of shading and transpirative cooling due to vegetation on pedestrian thermal comfort inside a street canyon. The influence of various tree features such as size, shape, location and quantity is studied. The transpirative cooling effect of a tree is found to be highest at lower wind speed and diminishes in humid and low temperature conditions, where the vapor pressure of air is near saturation and the transpiration from vegetation diminishes. The transpirative cooling effect of vegetation depends primarily on its leaf area density due to the coupled effect on both wind speed and air temperature. If vegetation does not transpire, increasing the number of trees results in an increase in air temperature downstream of the vegetation.

References

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