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Experimental scale and dimensionality requirements for reproducing and studying coupled land-atmosphere-vegetative processes in the intermediate scale laboratory settings

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Past investigations of coupled land-atmosphere-vegetative processes have been constrained to two extremes, small laboratory bench-scale and field scale testing. In recognition of the limitations of studying the scale-dependency of these fundamental processes at either extreme, researchers have recently begun to promote the use of experimentation at intermediary scales between the bench and field scales. A requirement for employing intermediate scale testing to refine heat and mass transport theory regarding land-atmosphere-vegetative processes is high spatial-temporal resolution datasets generated under carefully controlled experimental conditions in which both small and field scale phenomena can be observed. Field experimentation often fails these criteria as a result of sensor network limitations as well as the natural complexities and uncertainties introduced by heterogeneity and constantly changing atmospheric conditions. Laboratory experimentation, which is used to study three-dimensional (3-D) processes, is often conducted in 2-D test systems as a result of space, instrumentation, and cost constraints. In most flow and transport problems, 2-D testing is not considered a serious limitation because the bypassing of flow and transport due to geo-biochemical heterogeneities can still be studied. Constraining the study of atmosphere-soil-vegetation interactions to 2-D systems introduces a new challenge given that the soil moisture dynamics associated with these interactions occurs in three dimensions. This is an important issue that needs to be addressed as evermore intricate and specialized experimental apparatuses like the climate-controlled wind tunnel-porous media test system at CESEP are being constructed and used for these types of studies.
The purpose of this study is to therefore investigate the effects of laboratory experimental dimensionality on observed soil moisture dynamics in the context of bare-soil evaporation and evapotranspiration. Experimentation is conducted in test tanks ranging from small 1-D soil columns to intermediate scale 2 and 3-D tanks exposed to both static and controlled airflow. The individual experiments are analyzed and compared with each other based on differences in observed soil moisture dynamics. Results demonstrate that the measurement capabilities improve significantly with increasing scale and dimensionality as would be expected. Under static conditions, the vegetated and bare-soil cases yielded very similar results in the intermediate-scale 2 and 3-D tanks; there was not significant data fidelity losses when the additional dimension was neglected. Sensor installation within the 3-D tank was more difficult than in the 2-D tank. When exposed to continuous, constant, unidirectional airflow however, the importance of the third dimension becomes visible. Elongated plumes of elevated soil moisture form in the vicinity of plants in the 3-D tank as a result of the feedbacks that occur between the subsurface, atmosphere, and plant. In the 2-D tank, the plume width could not be determined.