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Characteristic lengths for evaporation suppression from patchy porous surfaces

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For non-uniformly wet porous surfaces, evaporation rates vary nonlinearly with mean surface water content and with the areal fraction of wet patches. The nonlinearity stems from the complex vapor field forming over individual pores and patches that could enhance vapor fluxes from pores surrounded by dry area (relative to fluxes from the same area of free water surface). The resulting evaporation rates from such a surface are similar to free water surface evaporation despite considerably lower evaporating area (low surface water content). Theoretically, such flux compensation could be suppressed by lumping isolated pores into clusters with equal mean water content. The resulting arrangement in wet patches ensures nearly 1D conditions within the patch and some flux enhancement at the periphery. The interplay between patch water content, patch size, and mean surface water content within a prescribed air flow boundary layer was modeled analytically using single pore diffusion as a building block. Results show existence of a characteristic cluster size that yields the largest evaporation suppression for a given boundary layer thickness and spacing between patches. For patches larger than this size, the relative evaporation rate from patchy surface (relative to free water surface evaporation) reaches a predictable rate equal to the fractional area of clusters. Model predictions for the relation between pore cluster size and evaporation suppression were evaluated numerically and in a series of wind tunnel experiments using porous surfaces with different pore clusters. The findings could be used for the design of optimal porous covers for suppressing evaporation losses from water reservoirs, or for controlling evaporative drying from engineered porous surfaces.