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Urban Heat Island-Induced Circulation and Convection

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Urban heat island-induced circulation and convection are investigated theoretically and numerically in the context of the response of a stably stratified flow to specified low-level heating that represents an urban heat island. In a theoretical approach, analytical solutions in physical space for the equations governing small-amplitude perturbations in a three-dimensional, time-dependent, hydrostatic, nonrotating, inviscid, and Boussinesq airflow system are obtained. The solutions reveal typical internal gravity-wave fields in response to the thermal forcing, including low-level upward motion downwind of the urban heat island. The flow response pattern in three dimensions is similar to that in two dimensions, but the intensity of quasi-steady flow is weaker in three dimensions because of the dispersion of gravity-wave energy into an additional dimension. The transient flow response to steady heating is compared with that to unsteady heating to get some insight of the time evolution of urban heat island-induced circulation. In a numerical approach using a cloud-resolving model (ARPS), extensive dry and moist simulations with various heating amplitudes and basic-state wind speeds are performed. To isolate urban heat island effects on urban-induced precipitation changes, other potential factors such as urban surface roughness are not considered. It is demonstrated that a downwind updraft cell induced by the urban heat island can initiate moist convection and result in downwind precipitation under favorable thermodynamic conditions. Results in three dimensions are compared with our previous results in two dimensions and the effects of the horizontal structure of the urban heat island are examined. Our numerical modeling results highlight a universal role that the urban heat island plays in downwind precipitation enhancement.