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Quantifying warming effect due to urbanization based on comparative measurements of the surface energy budget

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Land use changes from natural ecosystems to urban built-up have strong influence on local climates. The urban heat island has received much attention as an important environmental problem. However, detailed mechanisms have not be clear enough. In this study, we conducted comparative measurements of the surface energy balance at an urban built-up and a forest, and evaluated factors contributing surface warming due to the land use change based on a methodology called temperature decomposition.

We measured the energy balance at the urban built-up in Sakai,Osaka and at a cypress plantation (Kiryu Experimental Watershed) in Shiga. Sensible and latent heat fluxes were measured using the eddy covariance method. The ground heat flux for the urban area was estimated using the objective hysteresis model with relevant plot-scale experiments. In this study, we evaluated the urbanization effect from the forest plantation to the urban in terms of changes in surface temperatures associated with surface albedo, aerodynamic resistance, Bowen ratio, and ground heat flux.

In daytime, the urbanization increased net surface temperatures by 5.5 K in the summer (June to August 2014) and 3.8 K in the winter (January, February, and December 2014). The daytime warming was mostly contributed by increased surface resistance due to the urbanization in the summer (4.4 K) and the winter (3.7 K). In the urban built-up, the decreased surface roughness due to a high building density restricted the heat transfer redistribution into the atmosphere. Consequently, we found that the decreased surface resistance was the most effective factor to warm the urban surface temperatures in daytime. In nighttime, the urban surface temperature was higher than those in the forest in the summer (1.9 K) and the winter (2.5 K). Change in ground heat flux most strongly contributed to the nighttime warming in the summer (4.2 K) and the winter (5.2 K). In the urban built-up, a lot of incoming energy was stored in buildings and impervious roads in daytime. This energy was radiated and warmed up the urban surface in nighttime. The estimated net increases in the surface temperature were lower than those estimated using the bulk model in daytime and nighttime. The discrepancy could be caused by uncertainties associated with estimated radiative fluxes, energy imbalance of turbulent fluxes, and no consideration of anthropogenic heat in the urban built-up.