Supplementary Materials: Urbanisation-induced Land Cover Temperature Dynamics for Sustainable Future Urban Heat Island Mitigation

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This supplementary material supports the main text as follows:

S1. Urban Heat Island concept

Contributing Urban Heat Island (UHI) factors are described in the energy balance equation:

$$Q^* + Q_A = Q_H + Q_E + Q_G \tag{1}$$

where Q^* is net radiation; the balance between incoming and outgoing energy at the top of the atmosphere. Q_A depicts anthropogenic heat emitting systems such as air-conditioning and automobiles. Q_H and Q_E are turbulent fluxes of sensible (energy heating the air) and latent heat (energy used for evaporation) respectively, while Q_G is the surface conductive heat flux (energy heating the ground). In relation to the UHI convection (Q_H) is representative of building thermal properties, evaporation (Q_E) is a function of vegetation coverage and ground storage (Q_G) is dependent on surface albedo [1].

S2. MODIS Land Surface Temperature data

The Moderate Resolution Imaging Spectroradiometer (MODIS) Land Surface Temperature (LST) data Version 5 (V5) implements a modified version of the Product Generation Executives (PGE16) code that entails three modules: PGE16A, PGE16B and PGE16C (new compared to version 4). PGE16A obtains LST (T_s) for each clear sky land pixel per five minutes of MODIS data using the generalised-split window algorithm:

$$T_s = C + \left(A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_{31}+T_{32}}{2} + \left(B_1 + B_2\frac{1-\varepsilon}{\varepsilon} + B_3\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_{31}+T_{32}}{2} \tag{2}$$

where ε=0.5$(\varepsilon_{31} + \varepsilon_{32})$ and $\Delta\varepsilon = \varepsilon_{31} - \varepsilon_{32}$ represent the mean and difference surface emissivity values from MODIS bands 31 and 32, based on results of estimated land cover types per pixel established using Thermal-Infrared (TIR) Bidirectional Reflectance Distribution Function (BRDF) and emissivity modelling [2,3]. T_{31} and T_{32} are the brightness temperatures in these split-window bands. Coefficients: C, A_i and B_i (i=1,2,3) are provided from interpolation on multi-dimensional look up tables derived using linear regression of simulated MODIS data from radiative transfer calculations [3,4]. Obtained radiance values are converted to either LST day 1 km^2 or LST night 1 km^2 pixels. PGE16B computes LST and emissivity using bands: 20, 22, 23, 29 and 31-32 through the day/night LST algorithm to scale atmospheric parameters for optimal LST and emissivity retrieval. PGE16C removes cloud contamination from LST products [5].

Owing to the large spatial extent of MODIS LST (1 km^2) difficulties ensue when attempting validation from point ground based measurements such as weather stations [5]. Therefore validation is achieved through Temperature (T) or Radiance (R) based methods. T validation directly compares ground measurements with satellite LST distributed over the MODIS pixel, whilst the R method estimates in situ temperature from MODIS Top Of Atmosphere (TOA) radiance with surface emissivity, atmospheric temperature and water vapour profiles in a radiative transfer code [6]. In order to globally validate MODIS LST the R methodology is implemented due to the limited spatial coverage of the T methodology [6]. Across 32 global sites (the most extensive study to date) accuracy was assessed through differencing R derived LST and MODIS LST with an average of -0.34 K and standard deviation of 0.61 K, agreeing with the pre-launch statement that accuracy is better than 1 K and in most cases 0.5 K [5].

S3. Seasonal land cover temperature variation

Seasonal land cover temperature variation was computed using the complete time series (2000, 2003, 2005, 2007, 2013 and 2015) of classified Landsat imagery from MacLachlan et al. (2017) [7,8] and MODIS Terra LST data (MOD11A1, collection 5; [9]) for daytime (Figure S1) and nighttime (Figure S2). Temperature was assigned to a land cover class where it represented more than 50% of a MODIS pixel area of either the coincident year of classified image or future classified image where no coincident land cover data existed.

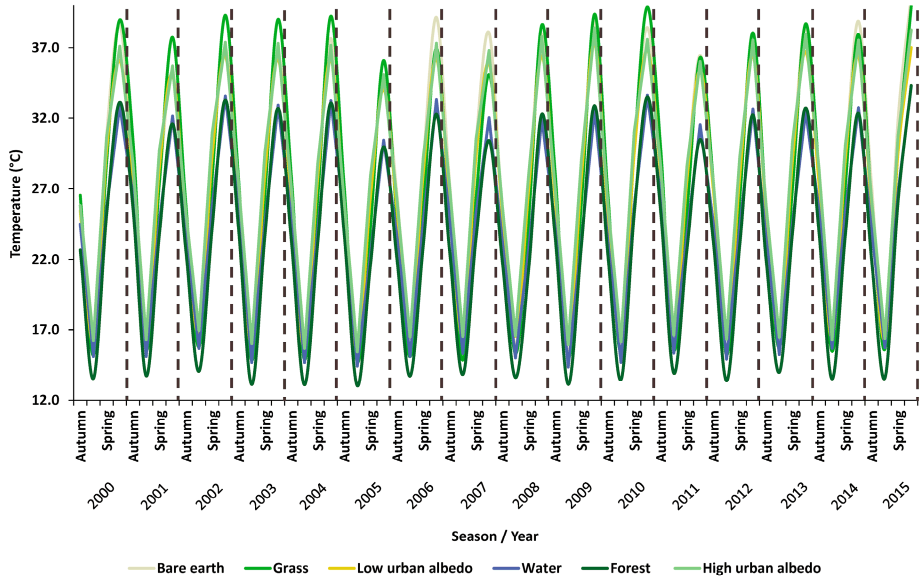

Figure S1. Seasonal daytime land cover temperature average between 2000 and 2015 from MODIS LST, using coincident or future Landsat land cover classes aggregated to MODIS resolution where it represented more than 50% of a MODIS pixel area.

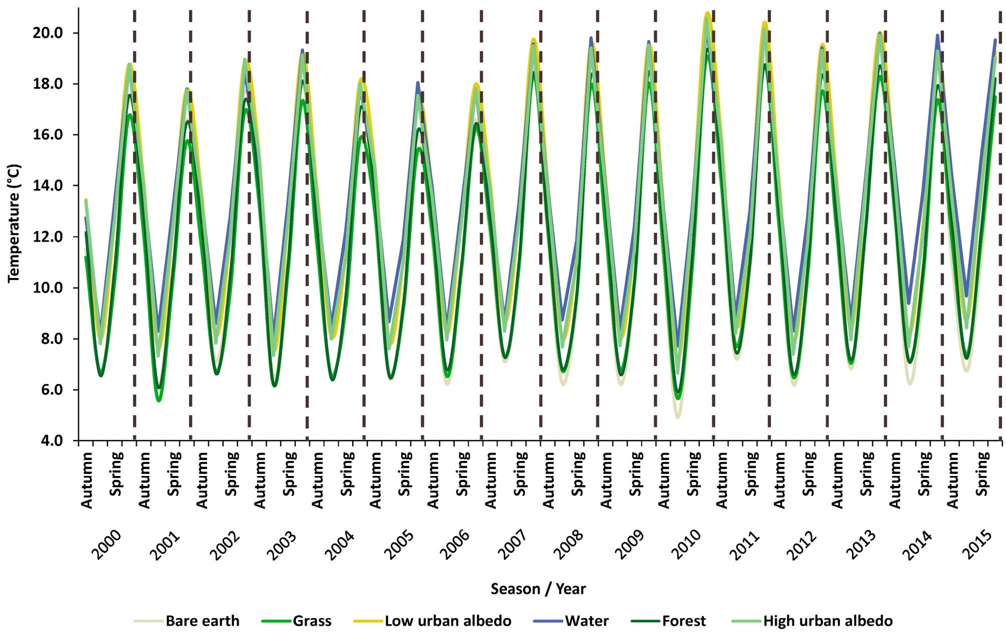

Figure S2. Seasonal nighttime land cover temperature average between 2000 and 2015 from MODIS LST, using coincident or future Landsat land cover classes aggregated to MODIS resolution where it represented more than 50% of a MODIS pixel area.

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