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Supplementary Materials

Modelling daily mean surface air temperature calculated from different methods and its impact on urban-related warming evaluations over Guangzhou and Shenzhen using the WRF model

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S1. Experimental design

The simulated domain covers the majority areas of East Asia with 30 km resolution, for which the central latitude and longitude of the simulated domain were 35°N and 108.5°E, respectively. The coarse horizontal mesh consisted of 259/199 grid points in the longitudinal and latitudinal directions, including a 15-grid-point buffer zone that was not used in the analysis. In order to more concisely to describe the urban surface distributions and its expansion, the nested modeling two-way feedback was adopted. The first nested domain covered the majority of eastern China with 10 km resolution, including 222 longitudinal grids and 312 latitudinal grids, respectively. The second nested domains covered three city clusters (BTH: Beijing-Tianjin-Hebei; YRD: Yangtze River Delta; PRD: Pearl River Delta) within eastern China with 3.3 km resolution, including 150 longitudinal grids and 120 latitudinal grids, respectively. The air pressure at the top of the model was 10 hPa with 51 levels in the vertical direction.

Two numerical experiments (1980-2016), which differed only in the land use data over China (including the coarse domain over China, the eastern China, and the three nested domains), were performed using the WRF3.4 model. The International Geosphere Biosphere Programme (IGBP)-modified 20-category land-use categories were adopted in the model. The first experiment (EX1) was integrated using the fixed-in-time land-use data (urban data in U1980), whereas the second experiment (EX2) was integrated based on reconstructed annual land-use data for the years 1980 and 2016. A series of restarts for individual years starting from July 1 in the previous year were performed, for which the first six months were regarded as 'spin-up' time and only the simulated results for the present year were to be analyzed.

In order to include urban surface effects in computing energy and water exchanges between the atmosphere and the land, the unified Noah land-surface model (including a four-layer soil model and urban canopy model with the default urban-related parameters) [1], was adopted in the integrations. Other physical parameterization schemes adopted in the experiments included the WRF single-moment 6 class graupel microphysics scheme, the Community Atmosphere Model shortwave and longwave radiation schemes, the Yonsei University boundary-layer scheme, and the Grell 3D ensemble cumulus scheme (for 30 and 10 km-resolution simulations only).

S2. Reconstruction of annual urban gridded data

The trends of the urban surface expansion and the corresponding spatial patterns over China were determined using on the integrated data from population information, multiple-source satellite images, and National Land Cover Datasets obtained from the Chinese Data Sharing Infrastructure of Earth System Science [2]. Meanwhile, the nighttime light datasets from the Defense Meteorological

Satellite Program-Operational Linescan System, which can display socioeconomic activities under urbanization and population growth, were also included. The datasets showing the most 'accurate' results in representing urban fractions were then selected and combined to construct five urban surface fraction images over China (U1980, U1990, U2000, U2010, and U2016) [2-3] at the model resolutions of 30, 10 and 3.3 km, respectively, using 1-km urban surface data.

Based on the five fractional images on each model grid point, the fractional urban surface data in the individual year for the years 1980 and 2016 were then reconstructed. The increase in fractional urban surface areas was assumed to increase linearly during each time period (1980-1989, 1990-1999, 2000-2009, 2010-2016), for which the annual fractional urban surface areas adopted in the model could avoid unrealistic discontinuity-induced spurious values for the energy and water cycles during long-term integrations.

Annual land-use data for the coarse and two nested domains, instead of the default land-use data in the WRF model, were then obtained using the reconstructed annual fractional urban data and other land-use categories from the default land-use data. For the WRF model before version 3.6 (version 3.4 here), only one dominant land-use category was assigned to each grid points during the integrations according to the methods by [4].

S3. Driving data

The initial conditions and time-varying boundary conditions were provided by the National Centers for Environmental Prediction (NCEP) - the Department of Energy (DOE) Atmospheric Model Intercomparison Project (AMIP-II) reanalysis dataset during 1979 and 2016 (R-2) [5]. During the integrations, the identical driving data, including sea surface temperatures and atmospheric data were used, for which the forcing was only applied at the boundaries. The reanalysis data with a resolution of 2.5° × 2.5° were interpolated into the WRF model domains with the bilinear method and updated every 6 hours.

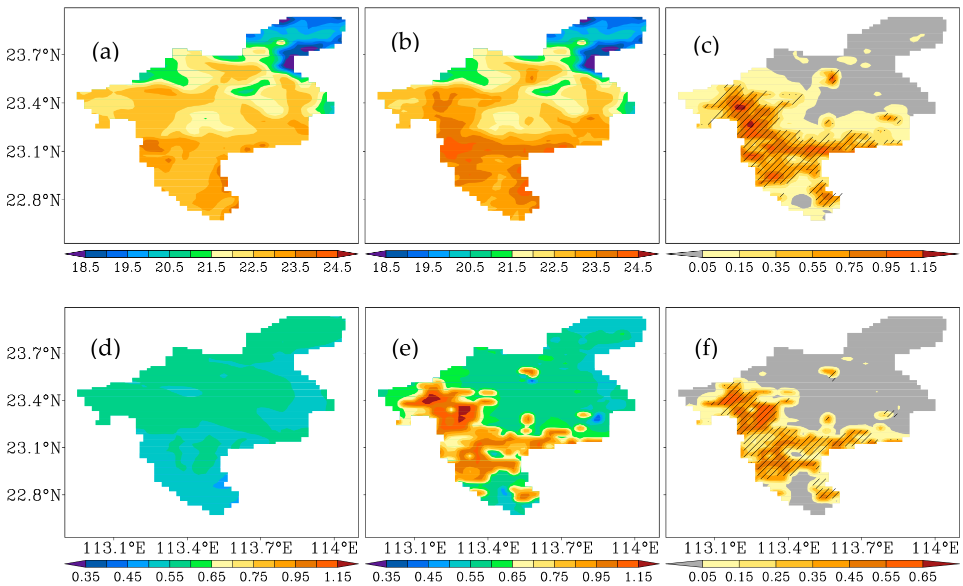

Figure S1. Spatial distributions of (a-c) annual mean SAT (units: °C) and (d-f) the changing trends (units: °C/decade) calculated using T_c under (a, d) EX1 and (b, e) EX2, and (c, f) the corresponding differences (EX2 minus EX1) over Guangzhou. (Oblique line denotes passing the 90% confidence level significance t-tests)

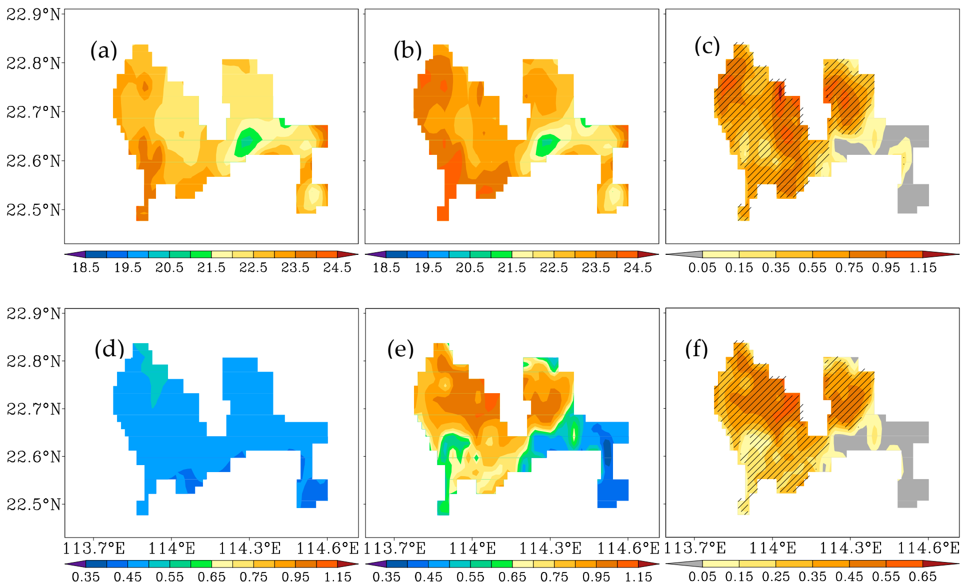

Figure S2. Spatial distributions of (a-c) annual mean SAT (units: °C) and (d-f) the changing trends (units: °C/decade) calculated using T_c under (a, d) EX1 and (b, e) EX2, and (c, f) the corresponding differences (EX2 minus EX1) over Shenzhen. (Oblique line denotes passing the 90% confidence level significance t-tests)

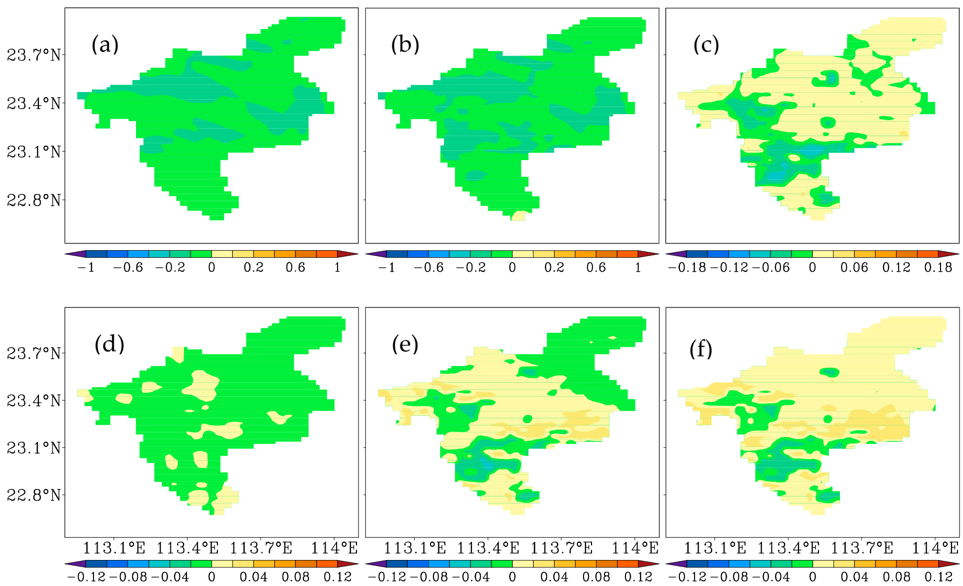

Figure S3. Spatial distributions of the differences for (a-c) annual mean SAT (units: °C) and (d, f) urban-related warming contributions (units: °C/decade) calculated using T_c and T_4 (T_4 minus T_c) under (a, d) EX1, (b, e) EX2, and (c, f) the corresponding differences (EX2 minus EX1) over Guangzhou. (Oblique line denotes passing the 90% confidence level significance t-tests)

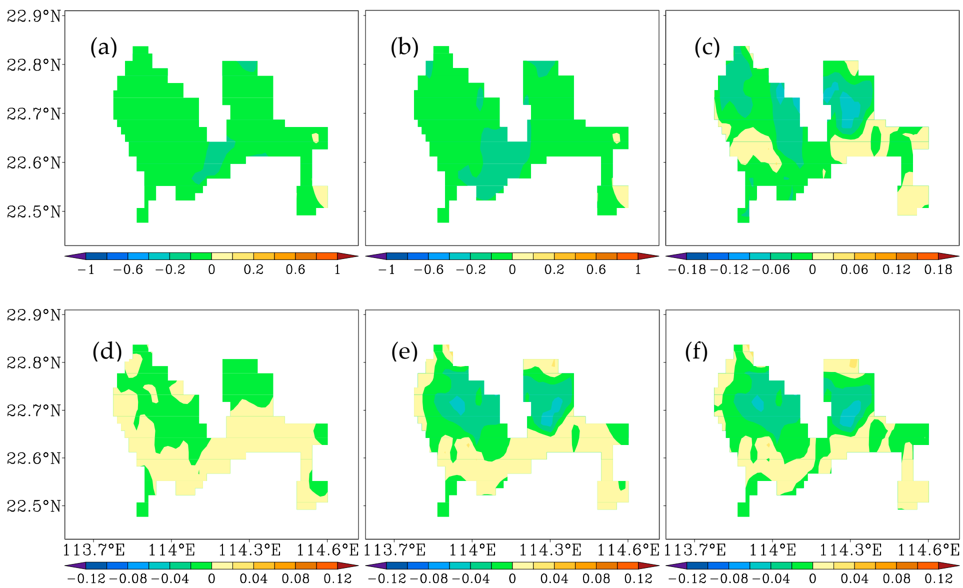

Figure S4. Spatial distributions of the differences for (a-c) annual mean SAT (units: °C) and (d, f) urban-related warming contributions (units: °C/decade) calculated using T_c and T_4 (T_4 minus T_c) under (a, d) EX1, (b, e) EX2, and (c, f) the corresponding differences (EX2 minus EX1) over Shenzhen. (Oblique line denotes passing the 90% confidence level significance t-tests)

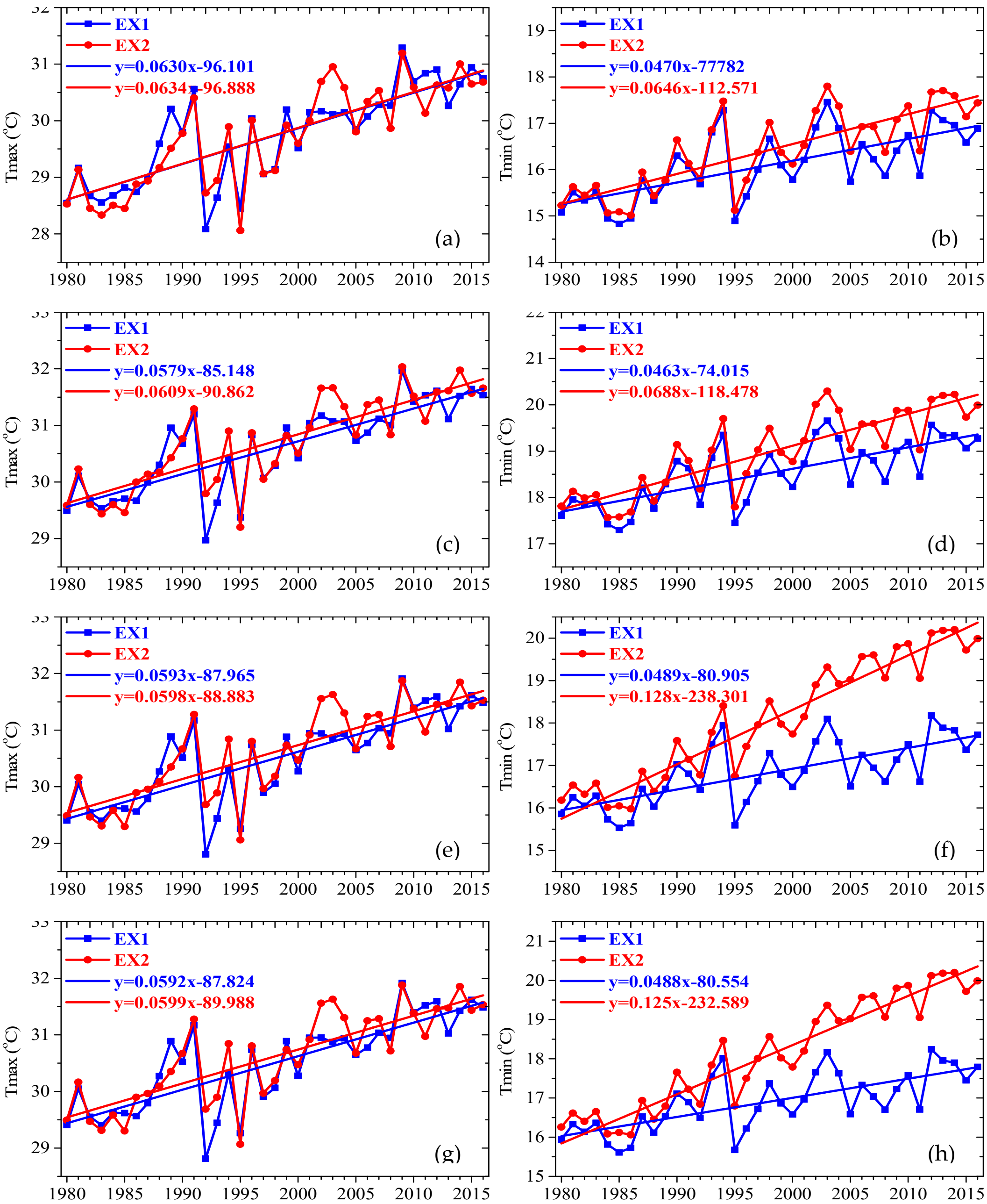

Figure S5. Time series of annual mean (a, c, e, g) T_{max} and T_{min}, and the changing trends over the subregions of Guangzhou (a, b: the entire areas; c, d: U2U areas; e, f: N2U areas; g, h: urban areas) for EX1 and EX2.

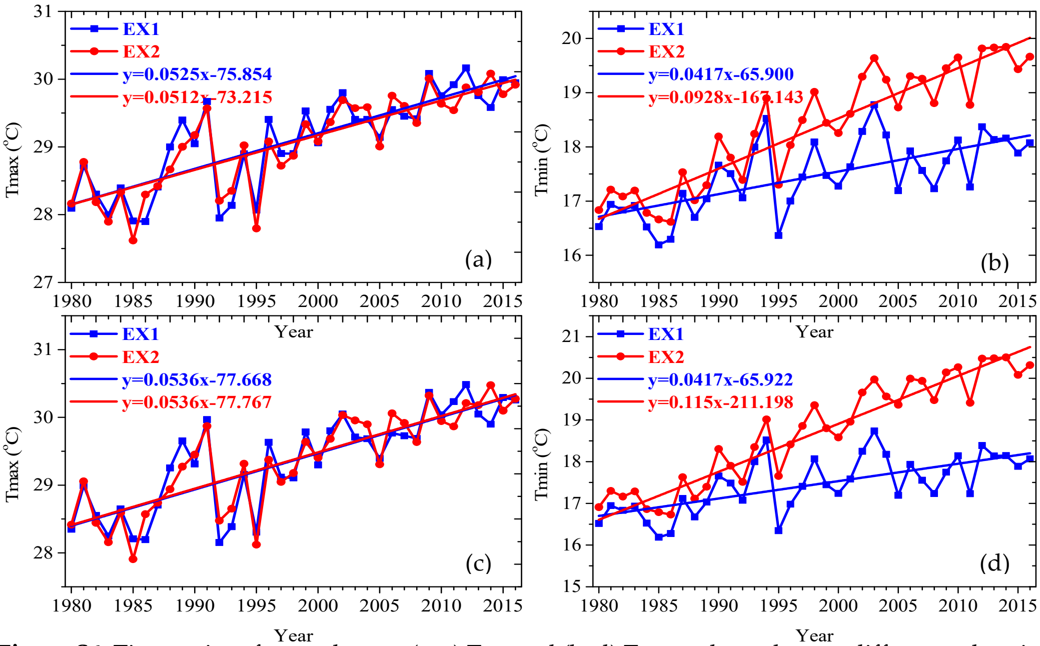

Figure S6. Time series of annual mean (a, c) T_{max} and (b, d) T_{min}, and trends over different subregions of Shenzhen (a-b: the entire areas, c-d: urban areas) for EX1 and EX2.

References

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