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Linking anthropogenic heat input and growing heat storage in subsurface urban heat islands

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Groundwater temperatures within cities are rising due to the ongoing heat input from anthropogenic heat sources such as buildings and paved surfaces. While heat input and the heat already stored in the aquifer have each been analysed previously, there is currently a lack of studies directly comparing increase in existing heat storage with the prevailing anthropogenic heat input. Here the main objective is to compare the heat input predicted from a one-dimensional (1-D) conduction model to the observed heat storage increase in order to validate our model and to identify site-specific factors relevant for the thermal evolution around the analysed wells. Anthropogenic heat input is quantified for 12 locations in Osaka, Japan with an analytical, statistical heat flux model. Annual mean anthropogenic fluxes into the subsurface are determined for each year between 2003 and 2011. Within the model, fluxes from buildings and from different land cover types such as paved surfaces and green spaces are analysed separately in order to better differentiate their influence on the prevailing subsurface urban heat island.
We reveal for our study site that mean fluxes from asphalt covered areas (0.14 ± 0.04 W/m^2) and from buildings (0.17 ± 0.10 W/m^2) are about five times as high as mean fluxes from unpaved land (0.03 ± 0.03 W/m^2). Mean fluxes from grass covered areas are negative (-0.02 ± 0.03 W/m^2) indicating that the atmospheric urban heat island is fuelled by the subsurface urban heat island. Furthermore, our results show that the temporal variation of mean fluxes from buildings is very stable over all analysed years while fluxes from asphalt, grass and unpaved areas vary as much as 0.04 W/m^2 between individual years.
The determined cumulative heat input (2003 to 2011) of the individual wells ranges from 2 MJ/m^2 to 37 MJ/m^2. Overall, the root means square error (RMSE) between cumulative heat input and observed increase in heat storage is 12.8 MJ/m^2. However, for four wells heat input was severely underestimated due to additional heat sources such as construction work that were not considered within our model. If these wells are not considered, then the RMSE between heat input and increase of heat storage decreases to 6.8 MJ/m^2 and heat input and storage satisfactorily correlate (correlation coefficient of 0.7).