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Quantifying the impact of human activity on temperatures in Germany

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Human activity directly influences ambient air, surface and groundwater temperatures. Alterations of surface cover and land use influence the ambient thermal regime causing spatial temperature anomalies, most commonly heat islands. These local temperature anomalies are primarily described within the bounds of large and densely populated urban settlements, where they form so-called urban heat islands (UHI). This study explores the anthropogenic impact not only for selected cities, but for the thermal regime on a countrywide scale, by analyzing mean annual temperature datasets in Germany in three different compartments: measured surface air temperature (SAT), measured groundwater temperature (GWT), and satellite-derived land surface temperature (LST).
As a universal parameter to quantify anthropogenic heat anomalies, the anthropogenic heat intensity (AHI) is introduced. It is closely related to the urban heat island intensity, but determined for each pixel (for satellite-derived LST) or measurement point (for SAT and GWT) of a large, even global, dataset individually, regardless of land use and location. Hence, it provides the unique opportunity to a) compare the anthropogenic impact on temperatures in air, surface and subsurface, b) to find main instances of anthropogenic temperature anomalies within the study area, in this case Germany, and c) to study the impact of smaller settlements or industrial sites on temperatures.
For all three analyzed temperature datasets, anthropogenic heat intensity grows with increasing nighttime lights and declines with increasing vegetation, whereas population density has only minor effects. While surface anthropogenic heat intensity cannot be linked to specific land cover types in the studied resolution (1 km $\times$ 1 km) and classification system, both air and groundwater show increased heat intensities for artificial surfaces. Overall, groundwater temperature appears most vulnerable to human activity; unlike land surface temperature and surface air temperature, groundwater temperatures are elevated in cultivated areas as well. At the surface of Germany, the highest anthropogenic heat intensity with 4.5 K is found at an open-pit lignite mine near Jülich, followed by three large cities (Munich, Düsseldorf and Nuremberg) with annual mean anthropogenic heat intensities > 4 K. Overall, surface anthropogenic heat intensities > 0 K and therefore urban heat islands are observed in communities down to a population of 5,000.