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# Towards typologies of urban climate and global environmental change

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## Abstract

The beauty of cities is that every city is different. From the homogenizing perspective of global environmental change that speaks trouble. We need an understanding of which kind of cities can contribute what kind of measures to mitigate and adapt to global environmental change. Typologies of cities offer a bridge between the idiosyncratic and the global. Bounoua *et al* (2015 *Environ. Res. Lett.* **10** 084010) analyse the impact of urbanization on surface climate. We discuss their results and suggest avenues for further systematic analysis.

Urbanization represents a comparably small land-use take globally, but the change in land use intensifies, with infrastructures built to stay. This raises decisive questions on the change in urban climate, the modulation of global warming at local scale, and the change in vegetation at different spatial scales. Bounoua *et al* (2015) contribute important insights to this blooming research field by investigating the surface urban heat island (SUHI) effect in urban regions in the United States. The authors use two different data sets with different spatial resolution: one covers urban land cover at 30 m resolution (Landsat-based ISA), and the other biophysical products at 500 m resolution at 8 day-intervals (MODIS). Relying on metereological data as well as heat absorption functions Bounoua, Zhang *et al* model surface temperature of ten US cities, representing different ecoregions. By calculating the difference between impervious surface area and the vegetated land surrounding them, they calculate the SUHI of these cities.

The study contains insights that are of interest to the wider scientific community. The paper demonstrates the specific influence of vegetation class—which determines to large degree the temperature differences between built environment and surrounding area. As a result, the SUHI varies between 3.3 °C (broadleaf deciduous forest, Washington, DC) and 2.2 °C–2.3 °C (temperature grassland, Chicago), and a negative SUHI of −2.5 °C (desert, Phoenix). This makes intuitive sense, as broadleaf trees offer more cooling by transpiration, in contrast to arid desert areas. The SUHI is also more pronounced where absolute temperatures are lower (e.g. comparing Washington DC with Atlanta). The reason is that higher temperatures lead to shutdown of plant transpiration (or more formally: stomatal closure), by this ceasing their cooling function.

These data are valuable for further research aiming to identify appropriate mitigation and adaptation strategies for different classes of cities. The aim is to build action-oriented typologies of cities.

Hence, it is valuable to reflect the results of Bounoua *et al* in the context of mitigating urban heat islands. In a study on urban adaptation in the US, (Georgescu *et al* 2014) report that cool highly reflective white roofs are a more effective cooling strategy than adding vegetation to roofs. But the difference between cool roofing and green roofing is more accentuated in arid states like California (1.2 °C additional cooling) than in humid states like Florida (0.2 °C additional cooling). Together these studies suggest tentative mitigation portfolios (Georgescu *et al* 2015) for different types of urban climates:

- especially but not only in arid environments: increase the reflectivity of the built environment;
- if space and water is available: plant urban trees, possibly heat resistant types. Reduce impervious surface where possible, e.g. modify parking spaces;
- especially if space is limited: Include green roofs as part of portfolios.

Such a typology would also need to systematically include a number of confounding factors (Georgescu *et al* 2015). For example, reflectivity increases would be compromised by seasonal sandstorms; reflectivity increases might also impact hydrological cycles by reducing precipitation at regional scale. In addition, water scarcity might induce detrimental trade-offs on urban scale or beyond. A total weighting of mitigation typologies will not only depend on the expected change in extreme heat events for cities, but also demographic change, and hence total exposure (Jones *et al* 2015).

Clearly, these strategies also influence climate mitigation strategies. For example, cool roofs or increased urban vegetation reduce cooling energy demand, but in the case of reflectivity modifications also can increase urban heating demand in winter. In turn, adding green spaces is likely to induce higher health perception and significantly less cardio-metabolic conditions (Kardan *et al* 2015). Hence, the wider goal is the integration of urban mitigation and adaptation strategies, and possibly even urban quality of life, into comprehensive typologies, as called for by Solecki *et al* (2015). Such an comprehensive endeavor would have energy-use and GHG emission typologies of cities as its second pillar, in addition to the pillar of an urban climate typology, In fact, our own typologies, relying on hierarchical tree regression, clearly demonstrate that local climate (heating degree days and cooling degree days) is an important discriminator of cities on global level (Creutzig *et al* 2015) and on local human settlement level (e.g., in England: Baiocchi *et al* 2015). In these city typologies, other discriminators include urban form, economic well-being, and fuel prices.

A second interesting result of Bounoua *et al* addresses the issue of land carbon storage in urban areas and could also become element of the suggested comprehensive typologies. Bounoua *et al* calculate the counterfactual stored in urban areas by extrapolating the carbon content of the surrounding vegetation. They find that impervious surface—representing 1.1% of the total continental US land—replaces 0.9%–1.8% of the total US land carbon uptake, in line with (Imhoff *et al* 2004). This is a surprisingly high effect, given that agricultural land displays a much lower relative change in carbon (plus 5.0% representing 32.1% of total continental US land).

Such results are important as global model of net primary productivity remain ignorant of the urban contribution, and model urban carbon uptake with fixed parameters, a situation that modellers are eager to change (Haberl *et al* 2007). But of course, the result is also significant in its own right: reducing the impervious surface in cities is likely to make a measurable contribution to increasing total land carbon uptake.

There are two other but related concerns that point into fruitful further research directions: geographical scope, and integration with theory. First, the systematic analysis of urban heat islands is currently US centric. As other world regions display different climates, and often very different urban forms, analysis of other world regions would likely enrich any typology of urban climate and global environmental change. Second, urban economics provides a rich potential to relate urban dynamics to empirical insights on environmental and climate change outcomes (e.g., Viguié and Hallegatte 2012, Creutzig 2014). It would be particularly interesting to scrutinize the role of urban form and population density and to elucidate what how different mitigation and adaptation constraints interact to produce ‚sustainability windows of urban form’ (Lohrey and Creutzig 2015).

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