Supplementary Material for *On the statistics of urban heat island intensity*

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4. Largest city cluster, Flemish Diamond

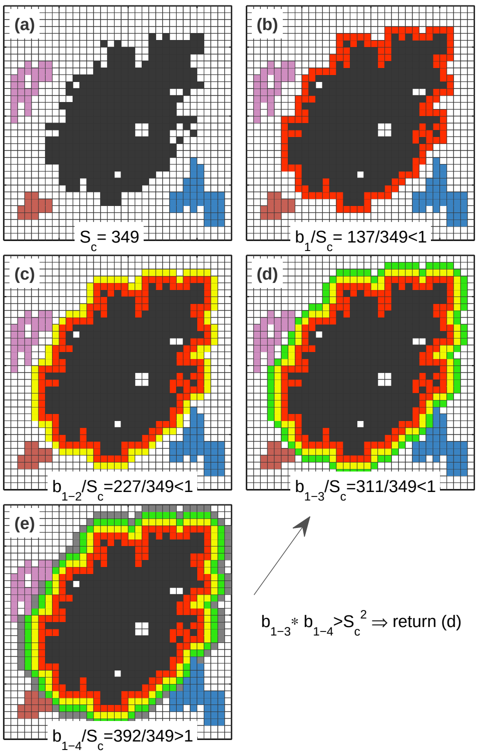

Figure 1. Illustration of the boundary generation algorithm. (a) The various clusters have been identified, as indicated with colors. The considered cluster in the center (grey) has 349 grid cells. (b)-(e) The boundary is built by consequently forming layers around the considered city cluster, devoid of urban cells of other clusters. Closed inner non-urban pixels are not taken into account. The boundary stops growing when the boundary is larger than the cluster. To decide whether the last generated layer should remain as the boundary, the criterion in Eq. (1) is applied, resulting finally in a boundary consisting of three layers in this example.

1. Boundary Generation Algorithm

The boundary of a cluster refers to the area surrounding it. The area of the boundary is specified to be of approximately equal size as the cluster area, i.e. $S_B^{(i)} \simeq S_C^{(i)}$. After each city cluster has been identified, the boundaries are constructed under the following constraints:

- Every cluster must have at least one boundary layer.
- A non-urban cell can serve as boundary cell for more than one cluster.

The boundary of a considered city cluster is then built layer by layer as follows:

1. An arbitrary non-urban grid cell adjacent to the considered city cluster is the first cell marked as belonging to the layer.
2. Iteratively, for a non-urban cell, if any of its 4-connected cells is a confirmed layer cell, and any of its 8-connected cells is an urban cell of the same cluster, then the cell is attributed to the layer.
3. The procedure is continued until no more cells can be attributed to this layer.
4. The next layer is built by iteratively adding a non-urban cell, if any of its 4-connected cells is a confirmed cell of the previous layer.
5. Successively, further layers are added and the procedure is stopped if the total number of boundary cells (i.e. the sum of layer cells) is lager than the number of cluster cells. The boundary stops growing when $S_B^{(i)} \geq S_C^{(i)}$.

After finishing the iterative generation of layers which together form the boundary, it has to be decided whether the area including the last layer is closest to the area of the cluster or if the area excluding the last layer is closer. If b_j is the number of boundary cells created in the jth layer, the total size of the boundary with n layers is $S_B^{(i)} = \sum_{j=1}^{n} b_j$. To decide whether the nth layer should remain in the boundary, the following criterion must be fulfilled:

$$\ln \sum_{j=1}^{n} b_j - \ln S_C \leq \ln S_C - \ln \sum_{j=1}^{n-1} b_j \ ,$$

$$\Rightarrow \sum_{j=1}^{n-1} b_j \sum_{j=1}^{n} b_j \leq S_C^2, \qquad (1)$$

i.e. the geometric mean of boundary sizes with $n-1$ and n layers must be less than the cluster size. Otherwise, the nth boundary layer is omitted, and only $n-1$ layers are used to represent the boundary, as illustrated in Fig. 1(d) and (e). The algorithm is illustrated in Fig. 1 for a cluster with 349 cells and the procedure stops with 4 layers, whereas a boundary consisting of 3 layers is chosen with 311 cells.

2. Summer mean land surface temperature (LST) of Greater London and surroundings

Figure 2 shows the summertime (June-August) mean land surface temperature averaged over 6 years (2006-2011), as obtained from MODIS MYD11A2 data (see data Section in the main article). Similar to the results shown in the main article (Fig. 1(b)), the urban cluster identified by City Clustering Algorithm (CCA) *Rozenfeld et al.* [2008, 2011] agrees well with the heat pattern and vice versa. Due to the cooling effect of vegetation, parks within the city and around can be seen due to their lower temperatures.

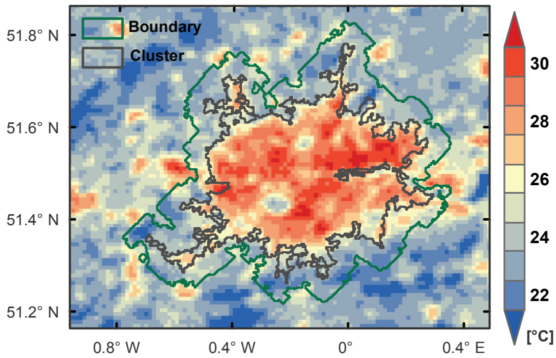

Figure 2. 6-year (2006-2011) summer (June-August) mean LST for the Greater London area derived from MYD11A2 datasets, i.e. LST at ∼13:30 local time. The city cluster and the urban heat distribution are in agreement. The blue pixels within the cluster are zones with relatively low temperatures, where the land cover is characterized by a large share of green areas.

3. Exemplary comparison of LST and 2 m air temperature as well as the corresponding UHI intensities

The comparison of UHI intensities is based on

- MODIS LST as detailed in the data Section of the main article and
- 2 m air temperature records from the German Weather Service (DWD).

Berlin is chosen as an example to conduct the comparison. The air temperature records from the weather stations in Berlin and vicinity are in hourly resolution, covering 2006 to 2010. The data from 12:30 CET to 14:30 CET, about the overpass time of Aqua satellite, are averaged and then aggregated into 8-day resolution which are in accordance with the temporal resolution of the MODIS data. Figure 3 shows the stations used for this comparison, among which Alexanderplatz, Tegel, Dahlem, Buch, Tempelhof, Schönefeld are within the city cluster of Berlin. The remaining three stations – Potsdam, Köpenick, and Lindenberg – are used to represent the boundary, since they are located in non-urban space. Analogous to the definition of LST-based UHI intensity, the UHI intensity obtained from the 2 m air temperature is defined as the mean temperature difference between urban stations and non-urban stations ("boundary"). Figure 4(a), (c) and (e) shows the time series of cluster temperatures (T_C), boundary temperatures (T_B), and the difference between them (ΔT), respectively, retrieved from LST and 2 m air temperatures. Strong correlations are found between the different temperature measurements (Fig. 4(b) and (d)), as suggested earlier by *Prihodko and Goward* [1997]. However, the UHI intensity derived from these two methods shows no correlations (Fig. 4(f)). The LST based UHI intensity shows apparent seasonal cycles, whereas the same seasonality can hardly be seen for the UHI intensity derived from air temperature data (Fig. 4(e)). By contrast, the air temperature based "midday" UHI intensity fluctuates around 0 °C.

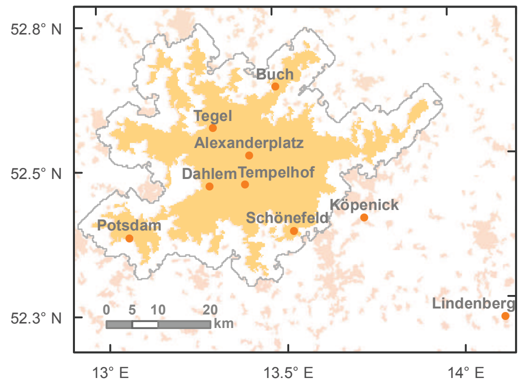

Figure 3. Locations of weather stations in Berlin and vicinity, where 2 m air temperature are measured. The orange area represents the cluster for Berlin, while its boundary is outlined with grey line. The pink areas are other clusters near Berlin. To obtain the UHI intensity, we calculate the urban temperature through averaging the data from Alexanderplatz, Tegel, Dahlem, Buch, Tempelhof, Schönefeld, whereas the rural temperature is calculated form the records measured at Potsdam, Köpenick, and Lindenberg.

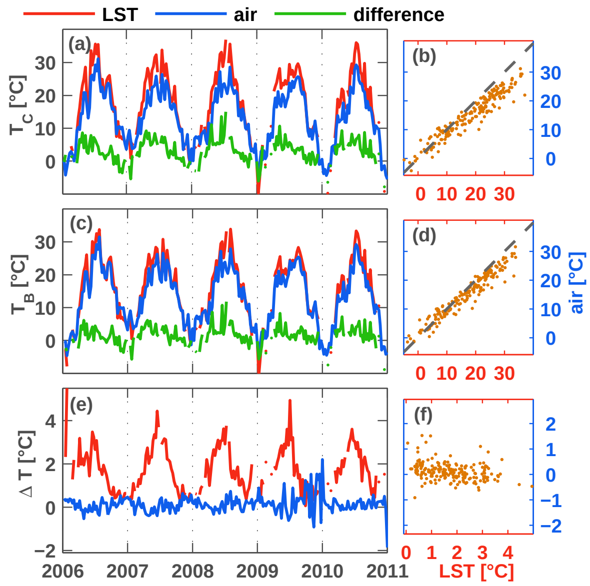

Figure 4. Comparison of LST and 2 m air temperature as well as the resulting UHI intensities. The cluster records are shown in panel (a) calculated from LST (red) and air temperature (blue). The difference of both is green. Panel (b) is the scatter plot of air temperatures with LST. The analogous for the boundary is depicted in panel (c) and (d). Panel (e) shows the resulting UHI intensities. There is an apparent seasonal variability for the LST based UHI intensity, whereas the air temperature based UHI is relatively stable throughout the year. No significant correlations can be found between them, as seen in panel (f).

4. Largest city cluster, Flemish Diamond

Figure 5 depicts the largest city cluster as identified in this study for comparison with Greater London in Fig. 1(a) in the main article.

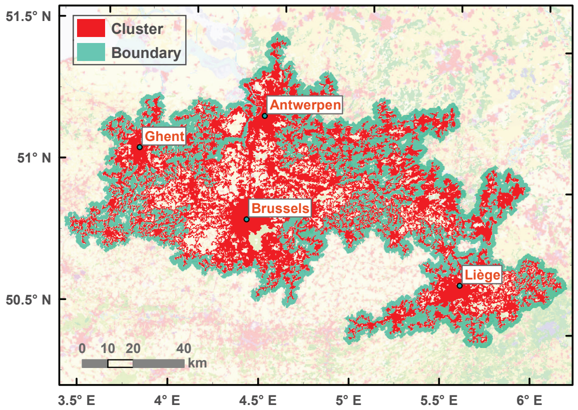

Figure 5. Urban cluster (red) and boundary (green) identified by CCA for the largest cluster in the scope of this study. The cluster contains mainly the Flemish Diamond (a multi-centered urban agglomeration of Brussels, Ghent, Antwerp and Leuven) and Liège, characterized by scattered urban areas. Cluster and boundary are to some extent interwoven, which should not harm the analysis, since the temperature corresponds well with the land cover as seen in Supplementary Material Fig. 2.

Acknowledgments

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