CENSUS of Cities: LCZ Classification of Cities (Level 0) – Workflow and Initial Results from Various Cities

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1. Introduction

Knowledge about the footprint and internal structure of urban areas is relevant for various applications in urban climatology as well as related fields. The World Urban Database and Portal Tool (WUDAPT) has been conceived as an international collaborative project for the acquisition, storage and dissemination of climate relevant data on the physical geographies of cities worldwide (Mills et al. 2015); the result will be a physical census of cities. The acquired data represent information that describe the form (surface cover, the construction materials and geometry) and function (metabolism, i.e. exchange of energy, water and materials) of cities. To capture these data at a useful spatial scale, WUDAPT categorizes data gathering into different levels of detail using distinct methodologies (See et al. 2015). The Level 0 data collection, which is the subject of this extended abstract, describes a city in terms of its constituent neighborhood types using the Local Climate Zone (LCZ) scheme (Stewart and Oke 2012); this represents a generic and culturally neutral description of urban landscapes based on their effect on the local air temperature. The level 1 data collection provides refined estimates of the specific characteristics and their probability distribution of an individual neighborhood by crowd sourcing but it is still an approximation. The most comprehensive or wall-to-wall estimate of LCZ parameters is referred to as level 2 data collection, as it could be derived from ancillary databases (e.g. building footprint files) if available.

Due to the different spectral characteristics of the LCZ in different parts of the world, a semi-automated workflow needs to be established to conduct the initial level 0 mapping. Despite recent progress in the delimitation of global high resolution urban land cover masks from multispectral optical (Pesaresi et al. 2013) and SAR (Esch et al. 2013) imagery, the internal differentiation of urban structures and morphologies from the same data is still a challenging task. Furthermore, the required level of detail and the boundaries between the classes depend on the application. In the urban climatology community, the LCZ scheme (Stewart and Oke 2012) has recently gained acceptance as a standard typology for the classification of local scale urban landscapes. The method was originally developed for meta-data communication of observational urban heat island (UHI) studies, but since then has been successfully applied to mapping studies as well (Bechtel and Daneke 2012; Lelovics et al. 2014). An especially promising approach is based on multi-temporal multi-spectral and thermal remote sensing data and modern machine learning methods. Therefore, a universal, simple and objective LCZ mapping method based on free data and free software was designed (Bechtel et al. 2015). The method allows local experts to conduct and validate LCZ-classifications for their respective cities and thus contribute to the generation of the Level 0 product for the worldwide database on urban form and materials, WUDAPT.

In this extended abstract we present conceptual considerations for the development of a common methodology to derive LCZ from remote sensing data which has been outlined by Bechtel et al. (2015). Section 2 gives a summary of this paper discussing the appropriateness of LCZ mapping, the requirements, and the limitations. Additionally, selected results from an expert workshop in Dublin are presented in section 3. In total, 18 cities in Africa, Asia, Europe, as well as North and South America were classified by local experts according to the proposed method. The resulting LCZ atlas of 18 cities is seen as a proof-of-concept as well as a major contribution to WUDAPT.

2. A universal LCZ mapping scheme based on free data and software

LCZs were originally introduced to standardize the classification of urban and rural field sites for observational UHI studies (Stewart and Oke 2012). Previously, the UHI had been defined as an urban-rural air temperature difference at screen height ($\Delta T_{U\text{-}R}$), but UHI studies revealed considerable variety in the labeling of landscapes, i.e. which ones are 'rural' or 'urban' (e.g., airports could be considered as either type) (Stewart 2011). LCZs, which aim to provide a more appropriate, universally understood, and climate-based classification of urban and natural landscapes, are defined as "regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale. Each LCZ has a characteristic screen height temperature regime that is most apparent over dry surfaces, on calm, clear nights, and in areas of simple relief" (Stewart and Oke 2012, p. 1884). In addition to their utility in providing standardized measurements of the UHI intensity, LCZs are associated with extensive information on their physical and functional properties including the urban structure, the urban cover, the urban fabric and the urban metabolism, and hence also provide a useful discretization of the landscape with respect to its surface layer climate.

The origin of the scheme implies some restrictions for mapping purposes, i.e. identifying a representative station location indicates concentration on landscape prototypes rather than mixed or indistinct settings. Nevertheless, the classes deliver a disjoint and largely complementary discretization of the (urban) landscape universe, cover the majority of existing urban forms, and are therefore suitable for mapping purposes (Bechtel et al. 2015). Furthermore, the scheme is generally well balanced between accuracy and universality, while allowing for the use of subclasses when required.

To derive a LCZ map as a level zero description of the urban landscape in the WUDAPT context, a simple workflow in the form of a protocol is needed, enabling local operators with different backgrounds to derive a LCZ map. The following criteria were used to find a suitable method: the procedure should be universal, as objective as possible, computationally efficient (less than 10 minutes on a standard desktop computer), and fiscally inexpensive (based on free and widely available data and software). Several previously suggested LCZ mapping schemes have been evaluated regarding this criteria, including a manual sampling of individual grid cells using Geo-Wiki, digitisation of homogenous LCZs, a GIS-based approach using building data (Lelovics et al. 2014), object based image analysis (Gamba et al. 2012; Weng 2014) and supervised pixel-based classification (Bechtel 2011; Bechtel and Daneke 2012).

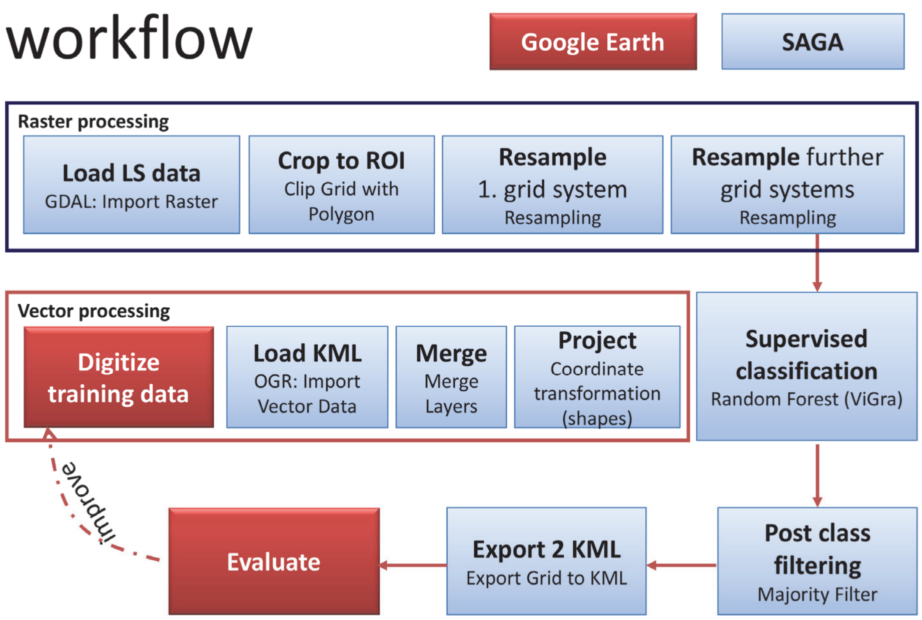

Fig. 1: Workflow for the WUDAPT level 0 LCZ mapping procedure based on free data and software (Bechtel et al. 2015).

The latter was found to be comparably robust and largely objective but the workflow had to be modified and simplified to achieve the aims of universality and a straightforward approach. In particular, random forest was chosen as the classifier since it combines high accuracy and computational performance, is non-parametric (which is important since classes often have different appearances), and provides an unbiased error estimate without additional testing data. However, the individual classes have inherently different spectral properties in different parts of the world due to the generic and culturally neutral nature of the LCZ scheme (Schneider et al. 2009; Bechtel et al. 2015). Therefore, examples of each class for each city are needed to train the classifier with the respective spectral signatures. This makes local training knowledge of the local urban structures a critical component of the mapping process. Different data sources have been considered and eventually multi-spectral and thermal Landsat data from different seasons were chosen, which implies that the discrimination is based on urban cover and fabric rather than structure and metabolism.

The most appropriate scale for the classification was chosen according to a) the concept of LCZs (*hundreds of meters to several kilometers in horizontal scale*), b) pattern recognition restrictions (each pixel must consist of representative fractions of surface covers like roofs, street, grass, and trees, which means that the sampling distance should be larger than the building block size and smaller than the average size of the LCZ) and c) user requirements. Since the scales of interest will likely span several orders of magnitude and the use cases are not previously known, an aggregation scheme should be part of the portal tool. Further, since the LCZs are not arranged on a regular grid, the classification should be conducted on finer scale (approx. 100 m) and subsequent post classification filtering should be applied to decrease the granularity, erase small discontinuous areas, and bring contextual knowledge to the mapped product (Bechtel et al. 2015; Gál et al. 2015). The final workflow, as displayed in Fig. 1, was implemented using the free software Google Earth and the free and open GIS package called SAGA (Conrad et al. 2015).

3. Classifications from various cities

The results presented in this section are an outcome of the expert workshop in Dublin and were further processed and enhanced by Foley (2015). An example classification for Chicago is shown in Fig. 2 as a separate map and as an overlay on Google Earth.

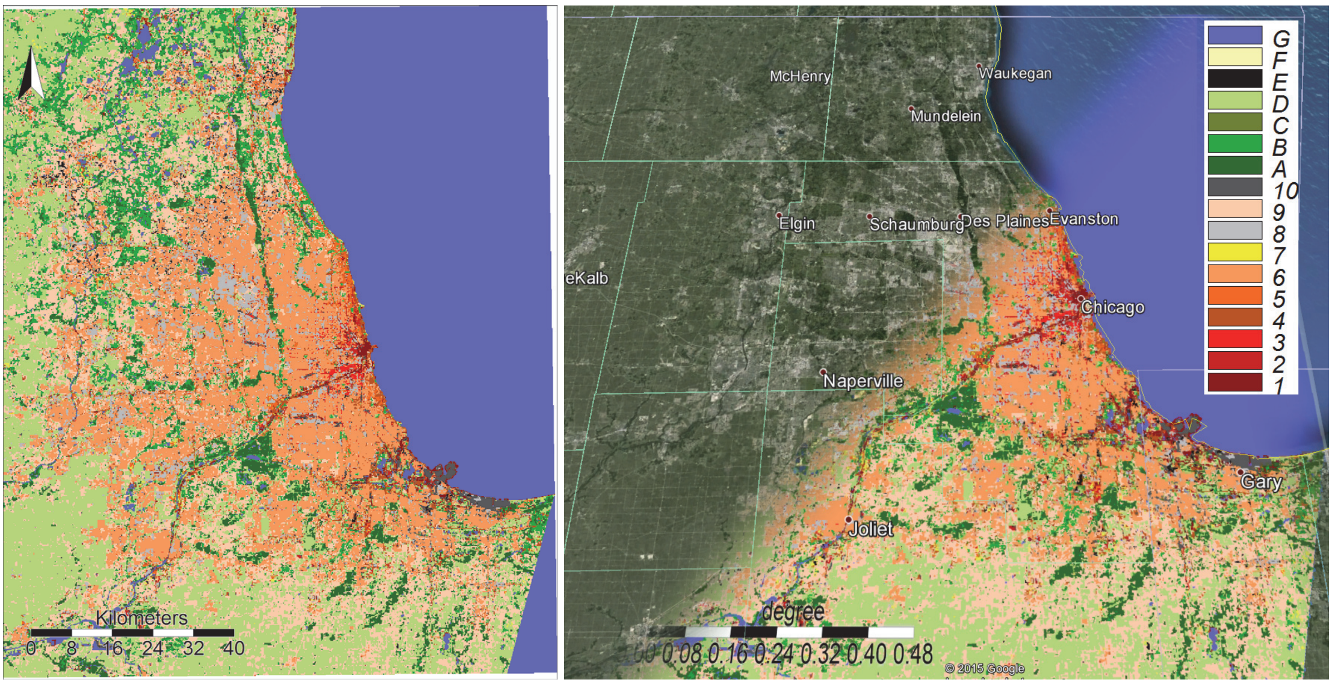

Fig. 2: Classification results (left) and overlay on Google Earth (right) for Chicago (1 – Compact high-rise, 2 – Compact mid-rise, 3 – Compact low-rise, 4 – Open high-rise, 5 – Open mid-rise, 6 – Open low-rise, 7 – Lightweight low-rise, 8 – Large low-rise, 9 – Sparsely built, 10 – Heavy industry, A – Dense trees, B – Scattered trees, C – Bush, scrub, D – Low plants, E – Bare rock / paved, F – Bare soil / sand, G – Water).

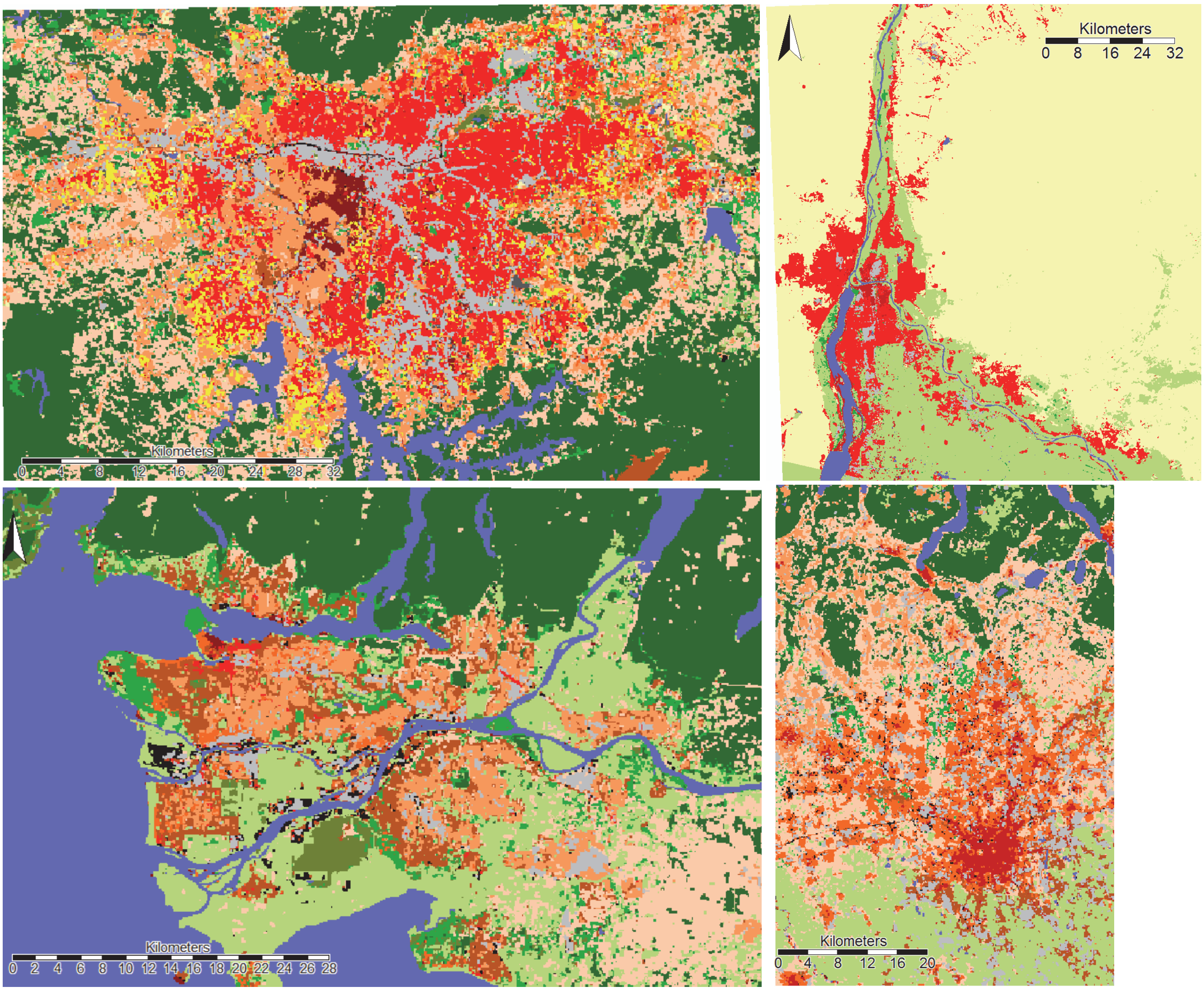

Fig. 3: Classification results for Sao Paulo (upper left), Khartoum (upper right), Vancouver (lower left), and Milan (lower right) using the same methodology (colormap as in Fig. 2).

The classification results for Sao Paulo, Khartoum, Vancouver, and Milan, which are based on the same methodology, are displayed in Fig. 3. The common visualization and landscape description immediately allows for a visual comparison of settlement patterns on different continents. For instance, Sao Paulo shows a large percentage of compact built areas while Vancouver has a distinct business district surrounded by massive open developments and industrial and commercial types along the Fraser River. The pattern of Milan reveals urban sprawl between existing village cores in the north and a much more planned development in the south with dense structures along certain axis and green spaces in between. The pattern of Khartoum is ultimately dominated by water availability, with an urban core where the White Nile and Blue Nile Rivers converge. However, this city was also especially difficult to classify using the multi-spectral remote sensing data since the spectral signatures of the city and the surrounding arid areas are rather similar (see Fig. 4).

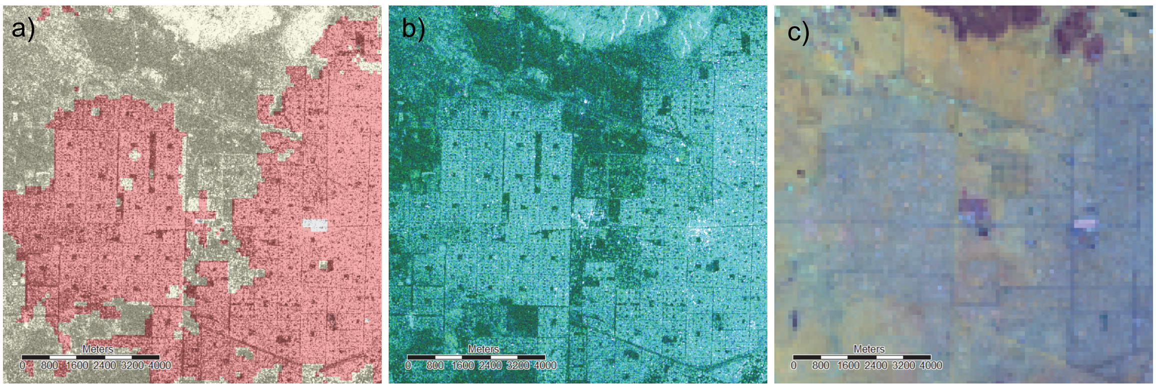

Fig. 4: Example from Khartoum. a) LCZ classification overlaid on Sentinel 1 SAR data; b) SAR color composit; c) multi-spectra color composite from Landsat bands 7-4-2.

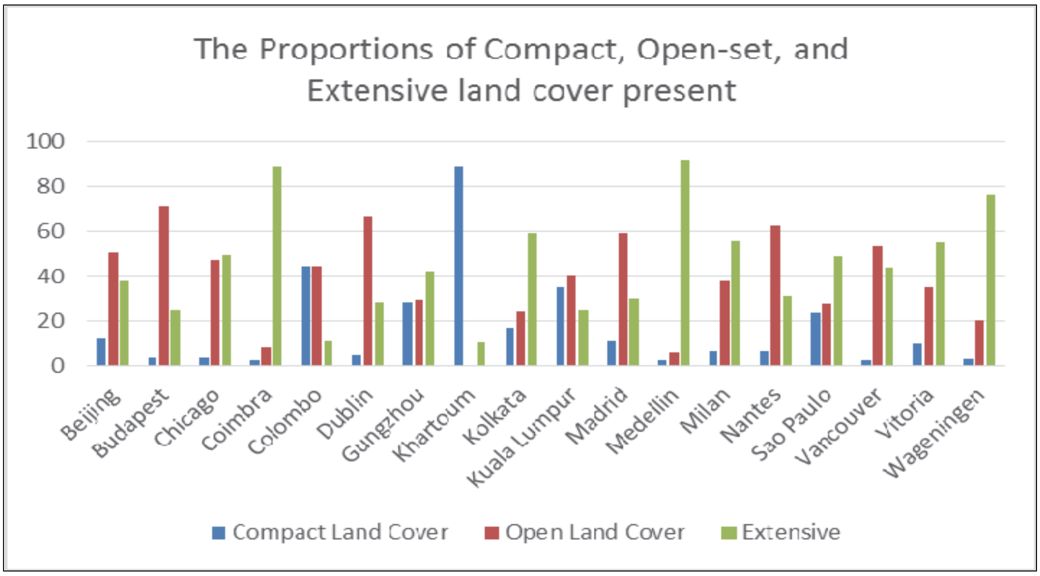

Fig. 5: Fractions of compact, open-set, and extensive land cover present within each study area (Foley 2015).

In addition to interpretation, the LCZ classification also allows for quantitative analysis of the settlement structure across different continents. Fig. 5 shows the fractions of compact (LCZs 1 – 3), open (LCZs 4 – 6), and extensive structures (LCZs 7 – 10) for the 18 cities, which show remarkable differences. While Colombo, Khartoum, Kuala Lumpur, and Sao Paulo have the largest portions of compact types, Budapest, Dublin, and Nantes, have greater than 60% open-set land cover while Coimbra and Medellin are dominated by extensive natural land cover.

4. Conclusions and outlook

In this extended abstract a methodology for LCZ mapping was outlined, which is used as a level 0 description of urban landscapes in the WUDAPT framework. Following a brief discussion of conceptual considerations (such as appropriateness, requirements, and limitations of LCZ mapping), selected results from an expert workshop in Dublin were presented. It was demonstrated that the established workflow based on semi-automated classification of multi-temporal, multi-spectral and thermal remote sensing data and local expert knowledge can deliver a basic patially extensive climatic description of entirely different urban areas around the world. Moreover, the common methodology, that has been proposed in Bechtel et al. (2015) allows for statistical analysis of the fractions of different urban types, which has not been possible previously due to the non-standardized descriptions of these landscapes. Limitations include the prerequisite for high quality training data, in particular, and the limited spectral separability of certain materials. The latter could possibly be eased by the incorporation of free SAR data, which is the subject of ongoing research. Furthermore, the extracted patterns should be analysed using more sophisticated measures such as landscape metrics. Finally, the utility of this basic landscape description in urban energy balance models (Alexander et al. 2015) is currently being investigated but still requires more detailed inspection.

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References

Alexander, P. J., G. Mills, and R. Fealy, 2015: Using LCZ data to run an urban energy balance model. *Urban Clim.*, **13**, 14–37, doi:10.1016/j.uclim.2015.05.001.

Bechtel, B., 2011: Multitemporal Landsat data for urban heat island assessment and classification of local climate zones. *Urban Remote Sensing Event (JURSE), 2011 Joint*, Urban Remote Sensing Event (JURSE), 2011 Joint, IEEE, 129–132.

——, and C. Daneke, 2012: Classification of Local Climate Zones Based on Multiple Earth Observation Data. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, **5**, 1191–1202, doi:10.1109/JSTARS.2012.2189873.

Bechtel, B., and Coauthors, 2015: Mapping Local Climate Zones for a Worldwide Database of the Form and Function of Cities. *ISPRS Int. J. Geo-Inf.*, **4**, 199–219, doi:10.3390/ijgi4010199.

Conrad, O., and Coauthors, 2015: System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. *Geosci Model Dev Discuss*, **8**, 2271–2312, doi:10.5194/gmdd-8-2271-2015.

Esch, T., and Coauthors, 2013: Urban footprint processor—Fully automated processing chain generating settlement masks from global data of the TanDEM-X mission. *IEEE Geosci. Remote Sens. Lett.*, **10**, 1617–1621, doi:10.1109/LGRS.2013.2272953.

Foley, M., 2015: DERIVING LOCAL CLIMATE ZONES USING LANDSAT SATELLITE IMAGERY. University College Dublin, 188 pp.

Gál, T., B. Bechtel, and E. Lelovics, 2015: Comparison of two different Local Climate Zone mapping methods. 9th International Conference on Urban Climate, Toulouse.

Gamba, P., G. Lisini, P. Liu, P. Du, and H. Lin, 2012: Urban climate zone detection and discrimination using object-based analysis of VHR scenes. *Proc. 4th GEOBIA*, 7–9.

Lelovics, E., J. Unger, T. Gál, and C. V. Gál, 2014: Design of an urban monitoring network based on Local Climate Zone mapping and temperature pattern modelling. *Clim. Res.*, **60**, 51–62, doi:10.3354/cr01220.

Mills, G., J. Ching, L. See, B. Bechtel, and M. Foley, 2015: An Introduction to the WUDAPT project. 9th International Conference on Urban Climate, Toulouse.

Pesaresi, M., and Coauthors, 2013: A Global Human Settlement Layer from optical HR/VHR RS data: concept and first results. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6578177 (Accessed January 12, 2015).

Schneider, A., M. A. Friedl, and D. Potere, 2009: A new map of global urban extent from MODIS satellite data. *Environ. Res. Lett.*, **4**, 044003, doi:10.1088/1748-9326/4/4/044003.

See, L., and Coauthors, 2015: Developing a community-based worldwide urban morphology and materials database (WUDAPT) using remote sensing and crowdsourcing for improved urban climate modelling. *Urban Remote Sensing Event (JURSE), 2015 Joint*, Urban Remote Sensing Event (JURSE), 2015 Joint, 1–4.

Stewart, I. D., 2011: A systematic review and scientific critique of methodology in modern urban heat island literature. *Int. J. Climatol.*, **31**, 200–217, doi:10.1002/joc.2141.

——, and T. R. Oke, 2012: Local Climate Zones for Urban Temperature Studies. *Bull. Am. Meteorol. Soc.*, **93**, 1879–1900, doi:10.1175/BAMS-D-11-00019.1.

Weng, Q., 2014: *Global Urban Monitoring and Assessment through Earth Observation*. CRC Press, 420 pp.