

URBAN CLIMATE ZONE DETECTION AND DISCRIMINATION USING OBJECT-BASED ANALYSIS OF VHR SCENES

P. Gamba^a, G. Lisini^a, P. Liu^b, P. J. Du^b, H. Lin^c

^aDipartimento. di Elettronica, Univ. di Pavia, 27100 Pavia, Italy

^bChina Univ of Mining and Technology, 221116 Xuzhou Jiangsu, P. R. China

^cSchool of Geodesy and Geomatics, Xuzhou Normal University of China, P.R. China

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ABSTRACT: Studies on the relationship between urban land use classes and the urban heat island effect have gradually become more important, due to the increasing awareness of this environmental problem. Remote sensed data has been an effective measure for monitoring and analyzing urban temperature, but they are less effective in discriminating among areas affected by different micro-meteorological behaviours. This paper introduces a methodology to discriminate among zones with different urban climate starting from panchromatic VHR data. An automated framework assists in characterizing the spatial distribution of the urban elements (buildings, roads, urban green) which affect the climatic conditions in urban blocks. The proposed methodology combines: automated recognition of building concentrations at different spatial scales and automated information fusion framework in order to discriminate among typologies. The methodology is validated by showing results in two different case studies.

1. INTRODUCTION

The traditional description of an urban landscape is based on urban land use and land cover classes. Although this is a good solution for cartographic mapping applications, it is not always the case for environmental mapping applications. For instance, the traditional land use classes do not match those needed for urban climate and meteorological studies. To solve this issue, a first comprehensive classification system for characterizing the urban environment with respect to urban meteorology was developed (Stewart and Oke, 2009, Stewart, 2009), and the same classification scheme was applied in a different environment by Nduka and Abdulhamed (2011). These works introduced the so called “thermal climate zones” or “local climate zones”, defined as regions of relatively uniform surface-air temperature distribution across different horizontal scales (Stewart and Oke, 2009). These climate zones can be differentiated by means of multiple characteristics of the urban 2D and 3D landscape, such as the built surface fraction, the building height-to-width ratio, the sky view factor (percentage of sky visible from the ground), the height of roughness elements, the anthropogenic heat flux, and the surface thermal admittance. Most of these characteristics, being connected to physical characteristics of the urban objects, can be tracked by remote sensing data. Until now, however, there are only very limited attempts to use remotely sensed images to obtain a (semi)automatic mapping of urban areas in terms of this taxonomy. Specifically, the latest example is Bechtel (2011), where coarse resolution (Landsat) data have been used to map these zones and to find their temporal behaviour along more years. It is therefore interesting to understand whether VHR imagery widely available for various parts of the globe may be exploited to map urban area according to this peculiar environmental land use legend. Specifically, as the urban climate zones are defined by various patterns of buildings and values of the radiance (together to the mean value of their height), it makes sense to see whether pattern recognition algorithms applied to VHR data for urban area discrimination from its surroundings may be also used for this task.

Accordingly, the aim of this paper is to design a methodology to discriminate among different urban climate zones starting from panchromatic VHR data, and including a variety of spatial

indices computed with respect to the test scene. In section 2 the complete methodology will be introduced, describing the different processing steps implemented. Experimental results for the town of Xuzhou (P.R. of China) and Atlanta (Georgia, USA) will be provided in Section 3. Finally, conclusions will be drawn in Section 4.

2. THE PROPOSED METHODOLOGY

The proposed methodology is based on two different sub-chains. The first one is devoted to the extraction of spatially homogeneous urban areas within the scene, which may be labelled as “block”. The idea is that these blocks may be then assigned, using the second part of the procedure, to one of the urban climate zone classes by considering a suitable combination of spatial and spectral indexes.

The first sub-chain can be subdivided into two subsequent steps. The first one is the identification of the human settlement as opposite to all the other land use classes in the area. To this aim, we use the PanTEX index proposed by Pesaresi *et al.* (2008), which proved to be extremely effective on panchromatic images at 2.5 m spatial resolution. The area identified as human settlement is further segmented into homogeneous zones using a Spanning Tree Reduction scheme (Marpu *et al.*, 2007) or a more complex approach based on combination of geometrical features into closed boundaries (Lisini *et al.* 2005).

The following sub-chain, aiming at classifying each homogeneous area into a urban climate zone class, is based on the joint analysis of a few indexes which we feel may capture most of the features listed in the introduction. To this aim, we assume that a multi-scale version of the same index used for urban area detection may be useful, as it helps in enhancing spatial patterns at multiple geographical scales. To obtain a multi-scale PanTex, the same textural feature (contrast) used to build the original index is computed with different lag distances (which is equivalent to assume a different spatial resolution of the data). Additionally, the original image and the results of an edge extraction by means of a Sobel filter are included, to insert spectral and edge density information, respectively.

Using these indexes, a decision tree classifier is designed using training data and eventually applied to the whole data sets, as presented here below.



Figure 1. The overall framework of the proposed procedure.

2.1 Segmentation approach

The two segmentation approaches tested in this work correspond to two very different methodologies aiming at subdividing a urban area into texturally homogenous blocks. Correspondingly, their results are very different on different scenes, and the availability of both of them allows choosing the best solution for the subsequent analysis and classification of these blocks into climate zones. The main idea is in any case to avoid under-segmentation (i.e., the subdivision into large blocks) and aim at over-segmentation, although this may require additional efforts and computational power to analyse more blocks than the actual number of them in the scene.

The Spanning Tree Reduction scheme (Marpu *et al.*, 2007) adopts an approach, aiming at a spanning tree minimization inspired by Duda *et al.* (2001), together with a region growing technique where the graph is used to guide the merging process. The algorithm is based on building a graph over the image connecting all the objects, using the Standard Deviation to Mean Ratio (SMR) as the homogeneity criterion while merging the objects (higher value of this ratio will yield bigger objects and vice-versa). This approach was designed for multispectral data, and cannot be directly applied to panchromatic data, as it is based on a pixel by pixel analysis and aggregation. As such, it would result into either a hugely under-segmented or a vastly over-segmented scene in most of the cases. Better results can be obtained by considering as additional band(s) the spatial index(es) computed to extract the urban extents. By this way the segmentation, although performed at the pixel level, include information about the pixel neighbourhood, possibly at multiple scales.

An alternative approach is based on the tools available in the Built-up area RECOgnition tool – BREC (Gamba *et al.*, 2007), a software developed by the TLC &RS Lab of the University of Pavia. The idea is that building blocks in urban areas are usually surrounded by rings of roads, and thus any area surrounded by a closed road loop can be considered as an excellent proxy to an urban block. The segmentation approach is therefore made by two steps:

- a) the extraction of the road network in urban areas following the approach in Negri *et al.* (2006) applied to the original VHR panchromatic scene of the area. The approach extracts road candidates, recognizes road junctions and improves the road network by minimizing a functional quantifying the plausibility of new connections, removals of small or isolated segments, or addition of missing roads or road segments;
- b) a further regularization of the extracted network to characterized closed road loops by considering perceptual grouping rules, as suggested for instance in Lisini *et al.* (2005) for urban road extraction in VHR images.

As a result, the urban blocks are recognized and made available for the following labelling step, performed by means of a decision tree.

2.2 Decision Tree definition

The Decision Tree structure used to label the segmented blocks and assign them to the different climate zones has been obtained by a detailed analysis of a small sample of the blocks in the first test case described in next section. Despite this approach is apparently biased by a specific city structure and location, the same rules apparently works in different locations, as also discussed in the following paragraphs. The main rationale is that these rules refer to spatial indexes that, in turn, describe quantitatively the spatial structure of the different parts of a town.

The Decision Tree, tuned with empirical tests as explained in next section, accepts as inputs three images:

- a) the original image (labelled as OR)
- b) the PanTex filter output with a kernel of 5 x 5 pixels applied at the full scale data (P1);
- c) the PanTex filter output applied to a subsampled data set at 5 m/pixel.

The extracted rules are as follows:

- areas with a pixel value in P5 ≥ 400 will be labelled as "Open set mid rise";
- areas showing a pixel value in OR < 120 and in P1 < 2000 and P5 < 200 will be labelled as "Compact low rise";
- areas showing a pixel value in OR ≥ 125 and P5 ≥ 210 will be labelled as "Extensive low rise";
- areas showing a pixel value in P1 < 2000 will be labelled as "Open set low rise";
- the rest of the pixels will be labelled as "Dispersed low rise".

Please note that different "range" of pixel values in Pesaresi results depend on the specific kernel size used.

3. EXPERIMENTAL RESULTS

The experimental results of this research come from two different datasets. The first test corresponds to the analysis of a scene by ALOS PRISM, with a spatial resolution of 2.5 m, acquired on August 12, 2008 and depicting a portion of the town of Xuzhou, in the Jiangsu province, P.R. of China. The second test is small subset of a panchromatic Worldview-2 image (0.5 m/pixel) covering a portion of the town of Atlanta (USA), kindly provided by Digitalglobe.

For both areas the challenge, as highlighted in the previous section, was to use 2D data, without spectral information, to obtain spatial indexes allowing an analysis of different zones and their classification into thermal climate zones. Results depend on both segmentation and decision tree accuracy. An incorrect segmentation may result into less precise classification of the urban blocks, as the spatial indexes used

by the decision tree are averaged for each block. The rules defined for the decision tree are however more important, as they allow to assign each block to a climate zone, once its spatial boundaries have been individuated by the segmentation step. For this reason, and since the segmented urban image can be obtained by various means – not least the possibility to use available GIS layer for a town, the evaluation will focus in the following paragraph mostly on the second step of the procedure, without paying much attention to the approach used to achieve a correct segmentation.

3.1 1st test area: Xuzhou

For the first test area five urban climate zones were considered, those which are present in the scene settlements: “open set mid rise”, “compact low rise”, “open set low rise”, “dispersed low rise”, “extensive low rise”. By applying the procedure introduced in Section 2 to a first set of urban blocks, roughly extracted from the original data and taken as a sample set, good results are expected, as this set was used to design the rule set described above. Indeed, encouraging results are achieved, as shown in fig. 2 together with the corresponding colour legend. Misclassifications are of course present, but the overall accuracy of the map at the object level is quite high, 81%.

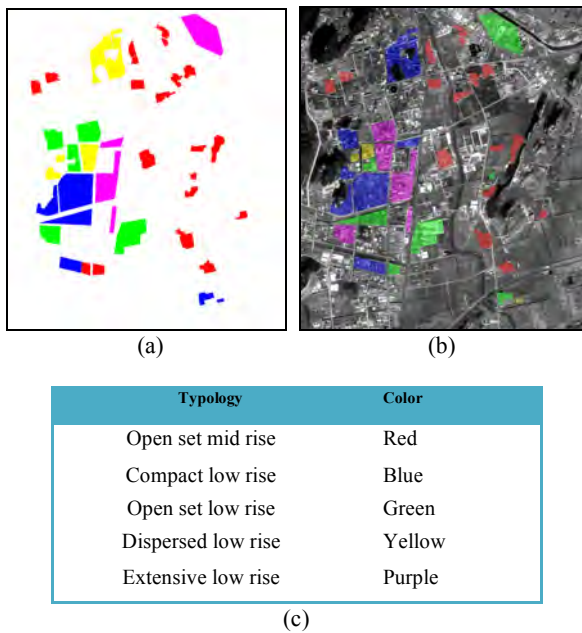


Figure 2. Experimental results: (a) the obtained urban climate zone map, to be compared with (b) a ground truth obtained by visual classification and superimposed to the original data set. Classes are identified by colours according to the legend displayed in (c).

In the previous example, the blocks were obtained manually, as the focus was on the definition of the decision rules to be applied for block labelling. The same approach was however applied to the whole urban area, after performing a segmentation by means of the two algorithms introduced in the previous section. The results are depicted in fig. 3.

Since the best result is obtained by the second approach, this set (including 301 blocks) was used as input to the labelling procedure. The final results are shown in fig. 4(a), and should be compared with the detailed ground truth in fig. 4(b).

Although the colour patterns appear visually similar, the overall accuracy at the block level is about 51% if computed regardless of the block size. Overall accuracy at the pixel level instead reaches 63%. The worst discrimination is achieved between the “open set low rise” and “dispersed low rise” classes and this may be due to the fact that the two typologies are very similar considering only two texture scales. In the future, the possibility to consider multiple scales and possibly (differential) attribute profiles (Della mura *et al*, 2011) will be considered.

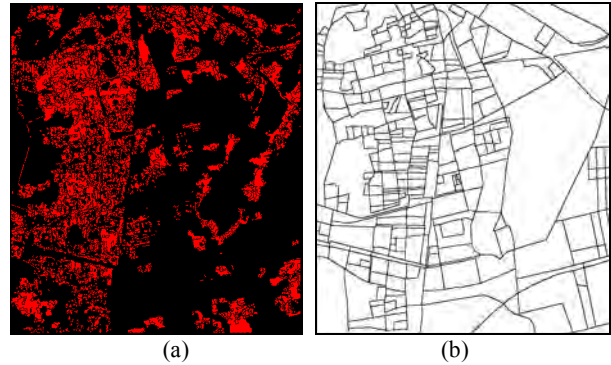


Figure 3. Segmentation of the PRISM image of Xuzhou, P.R. of China: (a) results by using the STM approach, (b) results by delineating blocks using the road network.

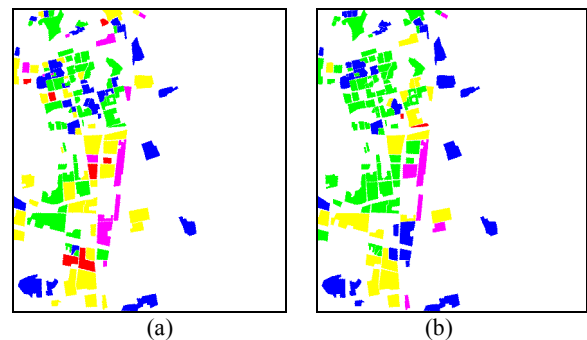


Figure 4. Climate zone extraction for the town of Xuzhou, P.R. of China: (a) final results of the proposed segmentation and classification procedure (b) detailed ground truth obtained by manually delineating and labelling individual blocks.

One important comment on these numbers is that the ground truth maps was not obtained by a meteorologist, but by a remote sensing specialist, and using the panchromatic band only. Accordingly, we do not expect a 100% accuracy of the ground truth, and a better validation procedure, including in the loop local experts, is definitely required. As such, the level of accuracy shown above should be considered as matching the level of uncertainty in the validation set. Just to further prove this fact, in fig. 5 a panchromatic and the corresponding pansharpened image of a small portion of the area are depicted. The two additional images in this figure correspond to two different visual assessments of the urban climate zones, made by two different experts and using the same colour legend as in fig. 2. It is clear that the panchromatic image do not allow an easy discrimination of the classes, “open set mid rise” and “open set low rise”. The colour image may provide hints for discrimination, but these are connected to a priori knowledge of building typologies and thus not easily generalizable.

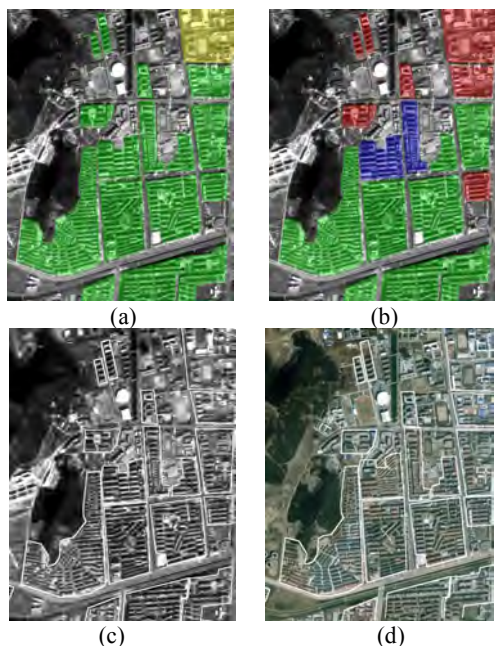


Figure 5. Example of problematic assignment of urban blocks to urban climate zones: (a), (b) two different visual interpretations by remote sensing experts, to be compared with the block borders superimposed to (c) the panchromatic and (d) the colour image of the same area.

3.2 2nd test area: Atlanta

For the second test site, a panchromatic image covering a portion of the town of Atlanta was used. The corresponding multispectral data set is depicted in fig. 6.



Figure 4. Second test set used for validation: a portion of the town of Atlanta (USA).

For this area, the same methodology was applied, with the only difference that only 4 urban climate zones were used; “Open set mid rise”, “Open set low rise”, “Dispersed low rise”, “Extensive low rise”. Indeed, visual inspection of the area cannot discriminate more than 4 different urban patterns. As for segmentation results, the two methodologies proposed above were tested, but didn’t provide a fine enough delineation of the city blocks. Thus, confusing demarcation would have decreased accuracy results in the next step. Therefore, while further research is ongoing on this first step, and in order to focus on testing the decision rules, a manual block delineation using multispectral data was performed. Accordingly, the scene was subdivided into 17 blocks as shown in fig. 7(a).

The final mapping results using the same rules described in section 2 for the Xuzhou test are proposed in the same figure. A comparison with a manually extracted ground truth (fig 7c)

show that only three blocks (highlighted in red) are misclassified, an excellent result, especially because it was obtained by using the same parameters considered on a different location, with very different data.

As a matter of fact, the overall accuracy value for this second test site was computed as 82.5%, higher than in the previous test case, mostly because of the reduced number of classes and the smaller number of blocks considered in this image.



Figure 7. Experimental results second test set: (a) the extracted urban climate zone map (color legend is the same as in fig. 2), to be compared with (b) the ground truth obtained by visual classification of the segmented blocks into climate zones.

4. CONCLUSIONS

The preliminary results reported in this work show that it is feasible to use VHR optical data for urban climate zone discrimination. The proposed approach is based on spatial indexes, able to model building patterns and this recognize dense versus sparse area. The information about the third dimension may be inferred from the availability of shadows, and thus again by spatial patterns in the original image, but the results in this work show that this is not an easy task, and that it is very difficult to use this kind of information in an efficient manner. The straightforward extension of this approach would be the use of VHR data including both 2D and 3D information, such as the multi-views data sets available by Worldview-2, from which a complete Digital Surface Model can be extracted to complement the bi-dimensional image data.

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