THE WATERSHED SEGMENTATION APPROACH FOR VIIRS NIGHT-TIME DATA

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ABSTRACT

The remote sensing of night-time lights (NTL) has been growing since the last decade. Recently, the watershed-based partition (WBP) approach was presented as a useful method for identifying patterns of human settlements based on NTL in a novel scale of analysis. In this paper we tested several methodological procedures and then presented the pre-processing techniques needed for implementing the WBP. We submitted the original VIIRS-Day/Night Band data to a series of operations to emulate a topography entry for the segmentation algorithm for detection of watersheds. The processed data were submitted through a gradual exponentiation until the parameters of the segments were stabilized. From the third power on, the changes of the parameters remain above 10%. From the fifth to the sixth power, the changes represent less than 0.6%. The results of the segmentation indicate that the exponentiation can enhance the segmentation process of NTL through the WBP approach.

Key words — Night-time lights, VIIRS, human settlement, watershed-based partition.

1. INTRODUCTION

Night-time lights (NTL) are probably one of the main footprints of anthropogenic artifacts on the surface of the Earth. Although the light sources at night can be associated with many natural phenomena, like auroras, volcano activities and lighting, the most evident ones emerge from the human activities [1]. When compared to the traditional data of visible and infrared images and infrared sensors from remote sensors, an interesting advantage of remote sensing of NTL is the information provided about socioeconomic dynamics with detailed spatial characteristics, representing a variety of information about human activities [2].

Many studies have found straight relations between night-time data and socioeconomic and demographic factors, such as Gross Domestic Product (GDP), road density, energy consumption, house vacancy and population [3]. More recently, seasonal variables have been also related to variations in the brightness of NTL, but there is no key factor controlling these dynamics [4]. Although different approaches have been used to explore NTL, none of them have established an optimal unity of analysis for identifying and characterizing urban form and patterns. Previous researches involving these variables often focused on setting out units that stem from the socioeconomic or demographic variables itself [4].

Dou et al. [5] reviewed the existing methods in the literature and selected three of the most common methods to extract the urban area by using NTL: local optimized threshold (LOT); urban vegetation adjusted night light index (VANUI); and classification of the Earth Surface Temperature Supporting Vector Machine (INNL-SVM). The performance of those methods for extracting urban area based on the VIIRS-NTL data was evaluated in seven assessment sites with different natural and socioeconomic conditions in China. All those approaches have their pros and cons. However, in terms of associating the NTL with socioeconomics factors, they are restricted by the contiguity of the patches and, therefore, are not able to assist at the studies involving inner city socioeconomic patterns.

The watershed approach based on NTL data [2] has been proved as an efficient method for partitioning the different patches of sources of lights in a more detailed scale and, hence, it provides a new unit of analysis that is more suitable for inner city researches. This method considers the image as a topographic surface, were the local peak of light represents the watershed bottom, the decay of the radiance value ranging off the hotspot represents the watershed slope, and the local minimum radiance levels represents the watershed divide. Each unit of analysis (watershed) should represent a light source or, most commonly, a group of light sources that has a certain pattern of decay until the radiance values start to rise again, meaning that another peak of light has a greater influence over the radiance values of that particular area. Finally, the parameters of those watersheds based on NTL can be used to delineate human settlements.

Despite being a useful method, Ma et al. [2] did not present a meaningful way to target a satisfactory result, i.e., which pre-processing and processing methods were necessary to obtain the shown result. Thus, our goal is to search and apply a segmentation in order to define a feasible unit of analysis from NTL from VIIRS Day/Night Band (DNB). We present all the methodological procedures and details necessary for the segmentation, and focus our discussion on the consistency of the results by comparing how the different processing methods affect the general performance of the segmentation based on the analysis of its parameters.

2. MATERIAL AND METHODS

2.1 Study Area

The macro-region of the Paraíba Valley and the North Coast presented great economic growth in the period of the coffee culture, in the 19th century. With its decline, the region only regained importance from the 1970s onwards: industries of the Metropolitan Region of São Paulo (RMSP) moved to municipalities in the Paraíba Valley, especially those located closer to the capital in the municipality of São José dos Campos. This area presented strong economic growth mainly from industry and technology sectors, especially along the axis of the Eurico Gaspar Dutra (BR-116) highway, a development axis that links RMSP to the Metropolitan Region of Rio de Janeiro. The potential of geographical interconnection due to its privileged location is a relevant aspect in the process of occupation, settlement, and regional urbanization, that intensified the urbanization along BR-116 [6,7].

Given this context, the intra-regional economic diversity is ample, and the region stands out nationally for intense and diversified economic activity. Industrial production is highly developed, with the automotive, aeronautic, aerospace and military sectors predominating in the municipalities located along the axis of BR-116. Port and oil activities are intense in the North Coast, and tourism sector dominates the economy in Serra da Mantiqueira, shoreline and historical cities [8].

2.2 VIIRS night-time data

Compared with its predecessor, the Operational Linescan System (OLS), the DNB has dramatic improvements to spatial, spectral and radiometric resolution. The DNB has a radiometric quantization of 14-bits and a swath width of 3,000 km. In order to achieve spatial consistency, a software on board of the instrument aggregates the sub-pixels cells represented by the detectors in 32 different modes, varying along track and scan direction. The result is a Ground Sample Distance of approximately 740 ± 43 meters at scan direction and 755 ± 22 meters at track direction. The VIIRS data used in this study is the most recent annual composite of the DNB data (2015) provided by the National Oceanic and Atmospheric Administration (NOAA). This composite is an average of the radiance values from all the daily night-time data that have been already undergone a removing process of the temporal lights and non-light values, such as fires, boats, stray lightning and lunar illumination. For the cloud free composite, the DNB data is reprojected into 15-arc second grids using terrain-corrected position information (approx. 450 m at the equator).

2.3 Watershed segmentation method

The focus of this paper is to implement and optimize the response of the segmentation method first approached by Ma et al [2]. We have tested out several algorithms available in different Geographic Information Systems and have found that the watershed detection method, implemented on the software SPRING 5.5.3 [9] was best suited to the task. Besides the image itself, this method does not require any ancillary data to proceed with the segmentation, such as flow grid, contributing area or drainage extraction. Those arguments are inherent to the original watershed concept, but meaningless in the NTL case.

The watershed method applies the Sobel filter (a high-pass filter for detection of borders) to the image to identify and pursue the borders based on its texture. Once the borders are highlighted, it is possible to specify a flooding threshold that will progressively expand the regions and eventually dissolve segments above the established threshold [9]. In this approach, we did not specify a flooding threshold, so none of the segments would be eventually merged. Hence, there is no other input parameter that must be specified apart from the night-time data itself. Because the method presupposes a topographic entry, we first submitted the night-time VIIRS data to different transformations that allowed the algorithm to properly identify the light segments and explore the optimal segmentation.

Firstly, we inverted the values of the VIIRS night-time annual composite by subtracting the maximum value of the sample and then extracted its negative product (Equation 1). The peaks of lights would then be interpreted as valleys by the algorithm. Secondly, we set the maximum values of the resultant matrix to dummy values, since they correspond to non-lighted pixels. We also set the maximum values to zero and tested both segmentations forms from there. Thirdly, the values were progressively raised, in order to maximize the borders identification and compare the different factors of power (Equation 2). Finally, each one of the segmented matrices was assigned to the original dataset and we compared their total area, number of segments and mean area of lighted pixels.

$$INTL_n = -(NTL_n - NTL_{max}) \quad (1)$$

$$RNTL_n = f(INTL_n)\begin{cases} {INTL_n}^k, & INTL_n \neq INTL_{max} \\ 0, & INTL_n = INTL_{max} \end{cases} \quad (2)$$

where NTL is the original radiance value of a pixel; NTL_{max} is the maximum radiance value from the sample; INTL is the inversed radiance pixel value; $INTL_{max}$ is the maximum inversed radiance value from the sample; RNTL is the raised radiance value of a pixel; n is a specific pixel and k is the exponent that was progressively raised.

3. RESULTS AND DISCUSSION

3.1 Selection of segmented data

We used the variables of total identified area, mean area and number of the identified segments to explore whether the exponentiation of the processed data modified the segmentation performance (Figure 1). From the original RNTL data to the second exponent, there was an increase of circa 100 km² on the total segmented area, while the mean area of the segments decreased from 7.8 to 7 km² and 62 new segments were identified. From the third power on, the changes are subtler, remaining above 10% for all three metrics. From the fifth to the sixth power, the changes represent less than 0.6% for all three metrics.

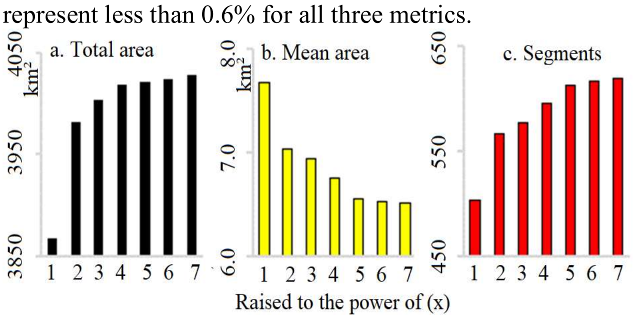

Figure 1. Total area, mean area and total number of segments from the distinct exponent power, ranging from one to seven.

The stability of the metrics from the fifth power on indicates that the detection of new segments due the exponentiation is not strongly affected by the over-segmentation. Instead, as the exponentiation power grows, new identified segments might not be neither big or small enough to lead into major changes in the mean area. Therefore, we decided to adopt the fifth power to proceed with the assignment of the segments to the NTL original dataset. It is important to underline that the evaluation of these metrics does not provide enough information to comprehend if the changes are associated with new segments being identified or already identified segments being split.

3.2 Characteristics of night-time segments

The final product obtained by the implemented method is presented at Figure 3, along with the profiles of both original and transformed data. Many small units of NTL data have not been identified by the segmentation method. Borders from middle to strong light sources have also not been properly identified. Both these problems might have been caused by the main purpose of the watershed method.

Since the delimitation of borders occurs through the application of a high-pass filter, it was expected that patches with nearly homogeneous values would be less efficiently highlighted by the filter. Despite the transformations, it is likely that those pixels have so similar values that even the exponentiation was unable to distance these values. Single pixels were also not identified by the method (Figure 2).

Small patches scattered away from the BR-116, here represented by the profile line, are mainly associated with districts from the larger cities or small towns across the Serra do Mar and Serra da Mantiqueira highlands, northern and southern from the BR-116, respectively. Many of them are delineated by only a single segment and therefore the method would not present a better result than a simple binary mask of lighted pixels. Larger patches from major cities have been successfully disaggregated into small patches with single peaks of lights for each one. The microregion of São José dos Campos has numerous standalone centers of development and has contingent urbanized areas that are shared with its neighbor cities. The presence of geographic features, like high sloped areas, and BR-116 that crosses the city might contributed for these multi-nuclei of lights configuration.

There are also peaks of lights with near borders, that is, hotspots with high values and small area then its neighbors. Those can be more easily associated with specific urban structure that contributes to the concentration of source of lights, like the region of the São José dos Campos Airport and the gas flare associated with the facilities of an oil refinery (Refinaria Henrique Lage Revap).

Although it is hard to determine the main sources of lights in these areas, given the still relatively coarse spatial resolution of the VIIRS sensor [2], previous studies have found that the lighted area and the intensity of lights can be associated with many socioeconomic variables [2, 3, 4]. However, it is important to highlight that the night-time sources of lights might not always be treated as an explanatory variable, at least not without a fine investigation of the factors controlling the radiance sensed by the VIIRS-DNB. These influences can come from different nature, such as socioeconomic, infrastructural and physical [4]. Hence, this unity partition method can assist the design of experiments involving the night-time data.

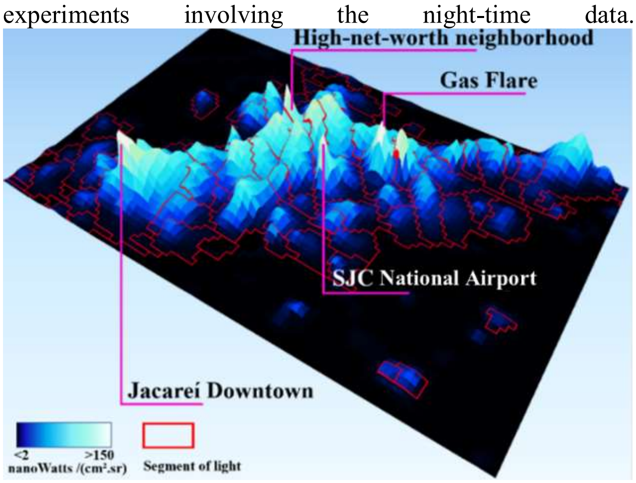

Figure 2. Perspective of the main sources of lights from the São José dos Campos microregion.

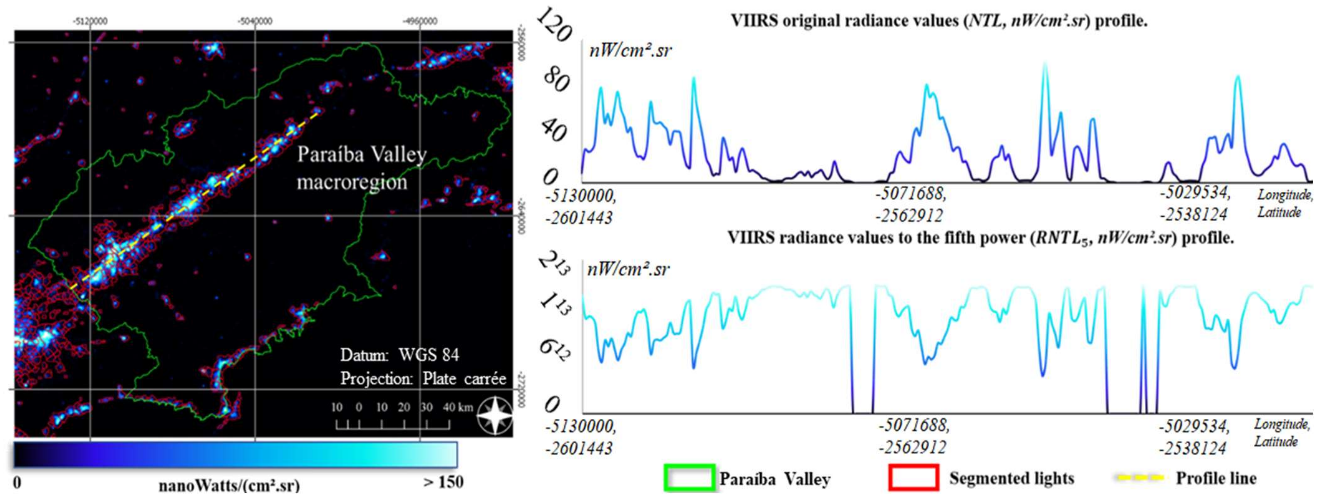

Figure 3. Segments and profiles of the nighttime data (NTL) and the product used for the segmentation process (RNTL).

It is also reasonable to consider the overgloom effects over the segmentation. The overgloom effect is the stray light surrounding light sources that are detected by the sensor, where actually there are no light sources. It occurs basically due to the atmospheric scattering of the light and the surface albedo influence and, in this case, can lead to the misidentification of the borders.

5. CONCLUSIONS

We tested a segmentation algorithm based on the concept of a watershed associated with adaptations of the original night-time data. The technique allowed us to successfully create partitions of NTL, considering all the premises of local hotspots and borders detections previously proposed by Ma et al. [2]. Areas with a slow decay of values from the center to the borders and small areas with single lighted pixels or homogeneous values were not detected by the segmentation method, but since they comprehend less than 1% of the total successfully detected and segmented area, and are mainly associated with overglooms effects, these downsides are not significant. Finally, we point out a few issues that should be addressed by future projects. Although the main goal of our work was to implement a segmentation method that can be useful for the composition of an inner-city scale of analysis, the availability of data that can be associated with this unit of analysis might be rare or not reliable in many places. Therefore, the usage of this method for composing the base of a research involving NTL relies on the decisions of how to specify more general data into a finer scale.

6. ACKNOWLEDGEMENTS

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